THE ROLE OF AN AUTOMATED DIGITAL MONITORING SYSTEM IN ASSESSING THE RISK OF MUDFLOWS

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Abstract. This extensive article analyzes the increasing importance of automated digital monitoring systems in assessing and managing flood risks. It describes how advanced technologies in remote sensing, the Internet of Things (IoT), geoinformation systems (GIS), and artificial intelligence (AI) have transformed the mudflow hazard monitoring process from a reactive approach to a predictive model. The article examines existing scientific literature, methods, and technologies, presents analytical results of global experience, and provides practical recommendations for the effective implementation of automated monitoring systems in mudflow-prone areas.

Keywords: Flood hazard assessment, automated monitoring systems, IoT, remote sensing, GIS, early warning systems, digital sensors, real-time data, emergency risk management, hydrological forecasting.

Introduction. Mudflows are one of the most frequent and devastating natural disasters in the world, causing human casualties, property damage, and disruption of socio-economic activity. Traditional mudflow monitoring systems are often based on periodic manual data collection, which leads to delayed warning and reduced effectiveness of preparatory measures.

Thanks to the rapid development of digitalization technologies, automated monitoring systems offer real-time, accurate, and comprehensive solutions for mudflow risk assessment.

The automated digital monitoring system tracks rain intensity, river levels, soil moisture, and other relevant hydrological indicators by integrating real-time sensors, satellite imagery, data transmission networks, and analytical software. These systems support early warning mechanisms, help to take timely measures, and thereby significantly reduce the risk of disasters caused by mudflows [4].

Literature review. In recent years, significant progress has been made worldwide in the field of monitoring and forecasting mudflow risks, especially due to the introduction of automated digital monitoring systems. The scientific works of foreign researchers demonstrate effective approaches in this area.

Among previous researchers, Alsdorf and Lettenmaier (2003) developed monitoring systems through satellite imagery in river basins and areas with high risk of mudflows. They proved the possibility of detecting changes in water levels through high-resolution images obtained from satellites such as Sentinel and MODIS[2].

Horritt and Bates (2002) proposed a methodology for simulating river floods and mudflow risks through hydraulic modeling based on point-based (raster) digital elevation models (DEM). Their research serves as an important tool in forecasting mudflows through digital monitoring.[1]

The model, developed by Di Baldassarre and the team of authors (2010), proposes to conduct a mudflow risk assessment by combining remote sensing and geoinformation systems (GIS). They analyzed affordable and effective monitoring solutions for regions of Africa and Asia with limited infrastructure[4].

Miller et al. (2015) used automated sensors and Internet of Things (IoT) technologies in hydrological monitoring in their research. The real-time mudflow warning system they developed has been shown to be particularly effective in mountainous areas with rapidly changing weather conditions[3].

Jain et al. (2018) created mudflow detection systems based on intelligent monitoring stations and cloud computing technologies in the northern regions of India. They conducted a flood probability assessment using algorithms based on artificial intelligence [5].

Tarpanelli et al. (2017) also proposed microwave satellite technologies for monitoring surface water flows. They developed methods for detecting the presence of water on the ground through changes in signal intensity [3].

Hapuarachchi et al. (2011) emphasized in their articles the need to integrate weather models with hydrological models. They showed that linking automated monitoring systems with real-time weather data significantly increases efficiency [1].

In general, foreign studies show that automated digital monitoring systems are one of the most promising tools for detecting, assessing, and preventing mudflow hazards. These systems achieve high efficiency when integrated with artificial intelligence, remote sensing, sensors, cloud technologies, GIS, and real-time data streams.

Methods. This study used a comprehensive methodology covering several areas:

Technological analysis: Assessment of sensor types (ultrasonic, radar, piezoelectric), telemetry systems, cloud platforms, and data analysis programs used in mudflow monitoring. The advantages of technological analysis are that through this analysis, the types and capabilities of sensors were accurately assessed. It has been practically shown that various natural indicators (rainfall, soil moisture, water level) can be accurately measured using ultrasonic, radar, and piezoelectric sensors. At the same time, the ability to transmit data over long distances through telemetry has significantly simplified the automation process. However, these sensors may not provide reliable information in certain conditions, especially in high-altitude or barrier areas. Moreover, the installation of equipment and its regular maintenance require significant expenses [3]. In my opinion, technological analysis is one of the important steps in assessing mudflow risk. However, when choosing sensors and equipment, it is necessary to consider the geographical conditions and economic possibilities of the locality. Any technology should not be viewed as "installed - done", but its technical support should be provided continuously [6].

Geospatial analysis: dynamic mudflow hazard maps were created by integrating real-time sensor data with GIS. Through this analysis, real-time mudflow hazard maps were created, integrating sensor data with GIS. This is a very important innovative approach that allows for quick decision-making in emergency situations. Geospatial analysis provides visual and local representation of data [5]. However, highly qualified specialists are needed to fully utilize GIS platforms. Moreover, the completeness and reliability of data are not always guaranteed, especially when there are interruptions in internet connection or sensor transmission. In my opinion, geospatial analysis is a "mirror" of digital monitoring. If sensors are "ears," then maps are "eyes." When both work together, they allow for quick and effective risk assessment. But this system needs to be constantly updated and monitored[2].

Comparative analysis of the situation: automated systems implemented in the Netherlands, Japan, and Bangladesh were analyzed and compared. Through this type of analysis, the experience of the above-mentioned countries was thoroughly studied. Monitoring systems adapted to the geographical, climatic, and technological conditions of each country were analyzed. For example, while dams and water level sensors are well-developed in the Netherlands, early warning systems based on artificial intelligence are widely used in Japan. According to the results of the analysis, it was found that in such a comparative analysis, it is not always possible to fully apply the experience of another country to our own conditions. Because the natural and climatic conditions, financial capabilities, and the level of preparedness of the population are different. Studying foreign experience is useful, but it requires critical and selective analysis. In Uzbekistan, similar systems can be implemented gradually, adapted to local conditions [6].

Expert interviews: Feedback from hydrologists, emergency managers, and information technology specialists. Through this, the effectiveness of the system and the possibilities of its widespread use were assessed. The opinions obtained through interviews help to identify approaches close to practice. In this process, hydrologists, emergency management managers, and information technology specialists provided specific examples in their respective fields. They provided important information about the conditions under which the system works effectively, which elements need to be strengthened or simplified. At the same time, such interviews may not always be objective and complete. The experience of some specialists depends on the local situation, and its generalization can lead to incorrect conclusions. Moreover, the data obtained from interviews can sometimes be subjective and based on personal experience, not scientific analysis [6]. Thanks to this, we have the opportunity to combine theoretical analysis with practice. However, caution is needed when using data collected during the interview - it is advisable to compare each opinion with a wide range of sources and facts.

Mathematical models and formulas integrated with GIS are widely used in automated digital monitoring systems used in the assessment of mudflow risk. One of the most common methods is the calculation of the Flood Hazard Index (FHI).

$$\mathrm{FHI} = \alpha \cdot \frac{Q}{A} + \beta \cdot S + \gamma \cdot L$$

Here:

Q - maximum water flow (m^3/s), A - basin area (km^2), S - surface slope (%), L - length of the flow path (km), α, β, γ - coefficients determined by specialists depending on the situation.

How is FHI applied? (Example)

Imagine that the following information exists for a mountainous basin:

Indicator	Value
Max flow (Q)	120 m^3/s
Area of the basin (A)	15 km^2
Surface slope (S)	25 %
Streamline (L)	5 km
Coefficients	α = 0.5, β = 0.3, γ = 0.2

Substituting into the FHI formula:

$$\mathrm{FHI} = 0.5 \cdot \frac{120}{15} + 0.3 \cdot 25 + 0.2 \cdot 5$$

$$\mathrm{FHI} = 0.5 \cdot 8 + 0.3 \cdot 25 + 0.2 \cdot 5 = 4 + 7.5 + 1 = 12.5$$

Interpretation of the FHI result:

FHI Value	Risk Level
0 – 5	Low risk
5 – 10	Moderate risk
10 – 15	High Risk
>15	Extremely high risk

Mathematical models and, in particular, the FHI (Flood Hazard Index) formula stand out as an important practical tool for assessing mudflow risk. This formula allows for the quantitative determination of mudflow risk: that is, the result is expressed in the form of specific figures and serves as a universal criterion for comparing risk levels in different geographical conditions. For example, if FHI = 12.5, this means that there is a high risk. This approach allows for a uniform approach to assessing hazardous areas.

The FHI formula can be automatically calculated by integrating data from sensors and digital altitude models (DEM). This minimizes the human factor and allows for real-time analysis and quick decision-making. Parameters such as Q (flow volume), A (waterway area), S (bedding gradient), and L (way length) in the formula are considered physical indicators of natural processes. They are transformed into a holistic system analysis and allow for a comprehensive representation of mudflow risk.

In addition, the FHI formula, when integrated with GIS (geoinformation systems) and AI (artificial intelligence) technologies, creates the possibility of creating dynamic risk maps, automatic recognition of hazardous areas, and early warning of the population. This will further increase the effectiveness of modern digital monitoring systems in combating mudflow hazards.

At the same time, the FHI formula also has some drawbacks. One of the main problems is the subjectivity of the coefficients. The coefficients α, β, and γ in the formula are conventionally determined by specialists and are not specific for each basin. This, depending on a person's subjectivity, creates a risk of either overestimating or underestimating the level of risk. Also, the formula does not cover all important factors: for example, factors such as atmospheric pressure, type of precipitation (rain or snow), soil structure are not taken into account. In this case, the accuracy of the analysis may decrease.

Another limitation of the formula is that it is suitable mainly for mountainous, small basins. In regions with large river systems or complex topography, it is advisable to apply this formula in conjunction with other models.

In our opinion, the FHI formula is one of the most useful and practical methods for assessing mudflow risk. Its simple structure, reliance on real data, and quick calculation capabilities make it a very convenient tool in practice. Especially for automated monitoring systems, FHI calculation is an effective way to obtain results with high accuracy with average technical resources.

However, each basin requires a unique and individual approach. Therefore, the FHI formula can be used as part of a comprehensive analysis, and not as a "one-stop shop solution." Meteorological, geological, and local characteristics must also be taken into account. Thus, the FHI formula should be considered as the main indicator in assessing mudflow risk, but also as an integral element of a comprehensive systematic analysis.

Results. The automated digital monitoring system is an advanced tool for assessing and managing the risk of mudflows. Mudflow is a rapidly moving, destructive flow of water, mud, and rock layers, often caused by heavy rainfall, snowmelt, or geological instability in mountainous areas. Such systems allow supporting real-time data, early warning, and decision-making using advanced technologies such as sensors, data analysis, communication networks, and predictive modeling.

Below is a detailed explanation of how these systems work in mudflow risk assessment, their components, functionality, advantages, and challenges. Components of the automated

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digital monitoring system. Automated digital monitoring systems aimed at assessing the risk of mudflows consist of several interconnected important components, each of which contributes to a complete understanding of the state of the environment and possible risks. Measuring equipment is used to measure mudflow velocity.

Sensors and measuring instruments:

Rain gauges. This equipment measures the amount of precipitation. They should be installed in a flat, open area. There are automatic types that transmit information to the center. This equipment operates without human intervention, consumes less energy, and can be used in any climate. They can provide real-time information and help collect long-term weather forecasts. The disadvantage is that measurements can be inaccurate due to snowfall or dust, leaf fall. However, it is a very necessary tool for predicting mudflow hazards (Figure 1).

Figure 1. Rain gauge.

Soil moisture sensors. These sensors are installed deep in the soil and measure the level of moisture in the ground. They can work in conjunction with drones or GPS devices. There is the possibility of remote control and information retrieval. They are used both in agriculture and to assess the risk of mudflows in mountainous areas. The disadvantage is that there may be differences in results for some soil types. If a malfunction occurs, it is necessary to install a new one. The advantage is that it greatly aids in the early detection of landslides (Figure 2).

Figure 2. Soil moisture sensor.

Inclinometer and tiltmeters. This equipment measures the angles of inclination and movement of the earth. They are installed underground or on walls. On the basis of auxiliary data, it is possible to assess the risk of landslides. The devices operate continuously and automatically record information. If incorrectly set, the results may be erroneous. By connecting them with other sensors, a unified monitoring system can be created (Figures 3, 4).

Figure 3. Inclinometer Figure 4. Tiltmeter

Piezometers. This equipment measures the groundwater level and pressure. They are placed inside the wells. It can be used for a long time and gives accurate results. It is used to analyze soil movement through groundwater pressure. The disadvantage is the complexity of installation and maintenance. However, they are very reliable in engineering and geological work (Figure 5).

Figure 5. Piezometers

Seismic sensors. They measure ground vibrations and seismic movements. They are easy to install on the ground and can be placed at many points. They detect tremors during mudflows and provide real-time information. However, there is a possibility of giving an incorrect signal as a result of external influences. The advantage is that it is possible to monitor the state of the earth's surface and connect it to a warning system (Figure 6).

Figure 6. Seismic sensor

Weather stations. These automatic stations are designed to measure air temperature, wind speed, pressure, and humidity. They send information to the center and help prepare forecasts. Multiple parameters can be observed simultaneously. It is easy to integrate with AI or IoT technologies. The disadvantage is that service is required in case of damage. The advantage is that it provides comprehensive and accurate information (Figure 7).

Figure 7. Weather station

Water level measuring devices. They are used to monitor water levels in rivers and canals. Information is collected using automatic sensors. Helps in predicting flood or mudflow risks. You can monitor in real time and notify via SMS or alarm. However, a sharp change in the water level can lead to mechanical malfunction. The advantage is the possibility of early detection and automatic warning of mudflow hazards (Figure 8).

Figure 8. Water level gauge

All sensors are connected to data loggers, which record data at a certain time interval. Through wireless communication technologies (for example, IoT, satellite or mobile networks), data is transmitted to centralized servers in real time. This is especially important in remote and mountainous areas.

Data processing and analysis:

Cloud or local servers process real-time data using algorithms, statistical models, or machine learning to assess risk levels.

Geoinformation systems, integrating spatial data, allow mapping and visualizing mudflow-prone areas.

User Interface and Warning Systems:

Through the control panels, data is displayed in real-time in the form of graphs, heat maps, or risk scores and is available to emergency management teams. Automated warning systems (e.g., SMS, email, siren) warn the relevant agencies and the population when the established risk standards are exceeded [4].

2. Main functions in mudflow risk assessment. Automated digital monitoring systems perform several important functions in order to identify mudflow hazards and reduce their negative impact. Mudflows are a very dynamic process, depending on rapidly changing environmental conditions. Automated systems, unlike traditional (manual) monitoring, provide continuous, constant, and high-frequency data collection. This is important because manual monitoring often overlooks short-term changes that can cause mudflows.

As an example, rainfall data accumulates every few minutes, allowing for the timely detection of heavy rains that saturate mountain slopes. Sensors measuring soil moisture and capillary pressure reflect the underground state, which may not be visible to the naked eye. Such continuous monitoring is very important for identifying phenomena that can cause mudflows in a short time.

Real-time analysis and assessment of mudflow risk involves the continuous assessment of the level of risk and the establishment of priorities through the integration of several data sources and analytical methods. Below is a brief overview of the main parts of this process and their content:

Threshold-Based Analysis:

The system compares environmental indicators - for example, the amount of rain (for example, 50 mm in 24 hours) or the level of soil moisture - with predetermined risk norms. If these standards are exceeded, the warning system will automatically activate and send a warning signal about the risk of mudflows. For example, if the rainfall rate is 10 mm/hour or the soil moisture level is above 80%, a mudflow warning can be activated depending on local conditions.

Predictive Modeling:

Machine learning models - based on historical mudflow data - analyze real-time data. They take into account such data as rain intensity, soil type (e.g., clay or sandy clay), slope level (e.g., risk increases if it is >30°). These models determine the probability of mudflows in the region and the degree of their impact. For example, a Random Forest or neural network model, using cumulative rainfall, vegetation cover, and topographic data, can estimate the probability of a moderate mudflow in a designated area at 70%.

Calculating Dynamic Risk Scoring:

The system calculates risk levels for different geographical areas in real time and generates risk scores. These points are formed based on the results of predetermined norms (threshold) and prognostic models. Scores calculated for each region (e.g., 0 to 100) take into account the following factors:

- proximity to watercourses,
- population density,
- Level of infrastructure disadvantage.

High-risk areas (for example, if the score is above 80) are considered as a priority for strengthening monitoring or preparing an evacuation plan [5].

Early warning and dissemination:

Early warning is one of the most important functions of automated monitoring systems. By detecting the first signs of a mudflow (e.g., rapid soil moisture or minor slope movements), the system can:

automatic warning messages are sent to local authorities, emergency services, and the population via SMS, mobile applications, or sirens;

a temporary difference (signal time) is created - this allows for evacuation in hazardous areas, closing roads, or installing protective barriers.

As an example, in areas with a high risk of mudflows - for example, in the Alps or Himalayas - automated systems have managed to drastically reduce human casualties by warning people a few hours before the onset of a disaster.

Creation of risk maps for mudflow risk management through geoinformation systems.

How do GIS-based risk maps work?

Data integration (Figure 9):

relief data: Height data (for example, DEM - digital elevation model) is used to determine mudflow-prone slopes and steep plains. These areas are usually considered areas with a high probability of mudflow formation;

soil composition: Geotechnical data analyzes the underground composition and identifies areas with unstable soils (e.g., loose sedimentary layers). Such lands are considered areas with a high probability of mudflows;

Historical mudflow data: Information about past mudflow events serves as a basis for developing models for predicting potential future risks;

real-time sensor data: Sensors (such as soil moisture meters and rain gauges) provide continuously updated information about environmental conditions.

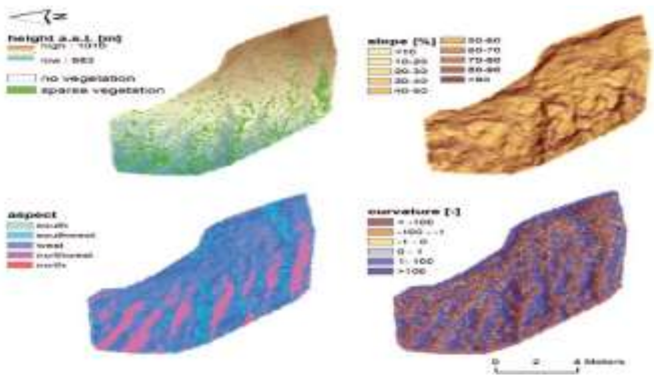

Figure 9. Data integration

Visualization: risk maps: on maps created through GIS, different information layers - relief, soil, and historical data - are combined, and hazardous areas are indicated in clear colors (for example, red - high risk, yellow - medium risk);

real-time layers: Data coming from sensors is constantly updated on maps. For example, if increased moisture is detected on a steep slope, the area will be automatically marked as hazardous on the map.

In support of urban planning, maps identify areas not suitable for construction and assist city and district administrations in making decisions on the allocation of zones and land use[2].

Access:

web/mobile interfaces - allowing stakeholders (e.g., planners, emergency service personnel) to view maps, analyze designated areas in close proximity, and view hazard information on demand;

interactive features (such as turning data layers on/off) increase usage efficiency.

Benefits:

proactive risk management: Disaster consequences are mitigated by early detection of hazardous areas;

Making informed decisions: Urban planners avoid construction in high-risk zones, which ensures safe development;

real-time action: Live data helps to carry out evacuation or risk mitigation measures in a timely manner;

Engaging parties: Accessible visualization tools make teams and official agencies active participants.

Long-term data analysis:

In addition to real-time monitoring, these systems also store data for long-term analysis. This is very important for:

Identification of directions: for example, tracking the trend of increasing the frequency of mudflows due to climate change;

Improvement of forecast models: increasing the accuracy of models by adding new data;

support for scientific research: development of research on the causes of mudflows and prevention strategies (Figure 10).

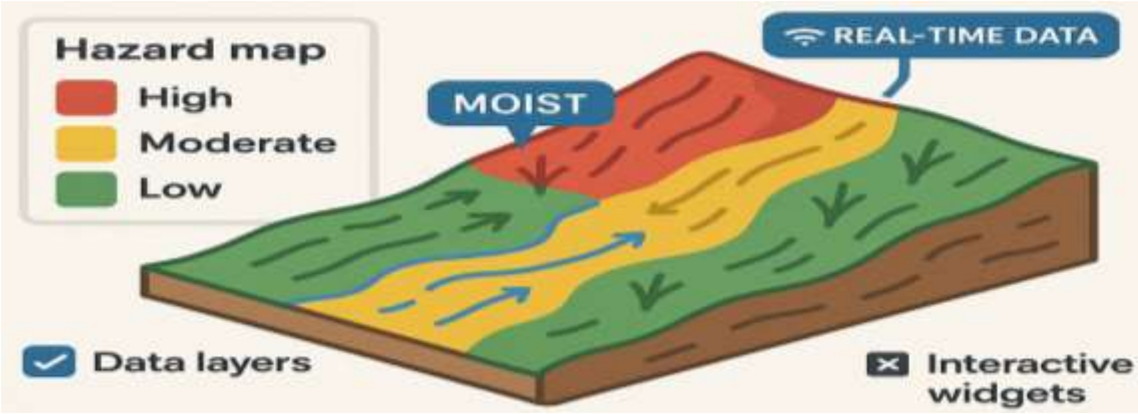

Figure 10. Risk map

3. Advantages of automated digital monitoring systems. Automated systems have a number of advantages over traditional manual monitoring methods:

accuracy and reproducibility: sensors provide high-precision data, which reduces errors made by humans and increases the reliability of risk assessment;

wide coverage (scalability): these systems have the ability to monitor remote and hard-to-reach areas via satellite or IoT networks[1];

timely response: real-time data processing and alert function enables prompt response to emergencies. This serves to save human lives and reduce material damage;

economic efficiency: initial installation costs may be high, but automation reduces the need for constant manual labor and on-site inspections;

integration with other systems: these monitoring systems can be linked to weather forecast models, seismic monitoring networks, and emergency response platforms. This ensures a holistic approach to disaster management;

community activation: communities can take timely and proactive action by delivering alerts directly to the population through mobile applications or local alarm systems.

4. Difficulties and limitations. Although automated digital monitoring systems have many advantages, they also face a number of practical difficulties and limitations:

high initial costs: Installation of sensors, communication infrastructure and data processing systems requires large investments, especially for developing countries;

maintenance: In severe weather conditions (such as heavy rain or very high/low temperatures), sensors may require frequent repairs or replacements;

Excessive data: Due to the large volume of real-time data, if not properly managed, it can overload the system or decision-makers;

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false positive/negative signals: Incorrect determination of risk standards or incorrect assumptions in the model can lead to failure to issue necessary warnings or unjustified evacuation;

coverage issues: In remote or underdeveloped areas, the system may not be fully operational due to insufficient infrastructure (such as internet or power supply);

team engagement challenges: An effective early warning system requires team awareness and trust. Regular advocacy and educational activities are necessary so that the population believes the warnings and acts in accordance with them [6].

5. Specific examples and practical application. Automated digital monitoring systems for mudflow risk assessment have been successfully implemented in a number of regions of the world:

Italy (Alpine region): A system for monitoring the risk of landslides and mudflows through a network of rain gauges, soil sensors, and radars operates in the Italian Alps (Fig. 11). In 2020, such a system in the Aosta Valley made it possible to timely warn the population about a major mudflow and laid the foundation for the implementation of evacuation measures.

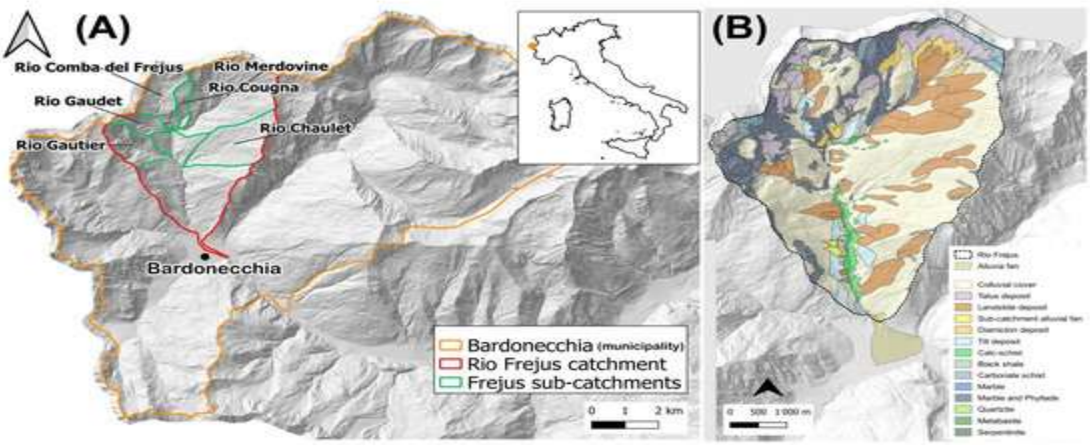

Figure 11. Avalanche and mudflow risk monitoring system in the Italian Alps

California, USA: After the devastating mudflows in Montesito in 2018, California implemented automated monitoring systems that provide real-time information about rainfall and soil moisture. These systems proved to be effective in predicting possible flash floods after a fire.

Nepal: Systems based on IoT technology and satellite communications in the Himalayas track remote, hard-to-reach slopes. This information serves as an important resource for local authorities and NGOs in emergency preparedness.

6. Future directions. Advances in technology are expanding the capabilities of automated monitoring systems:

Artificial intelligence and machine learning: Updated algorithms provide more accurate and reliable results in determining the causes of complex mudflows by analyzing multi-parameter data;

Drones and remote sensing: Drones with LiDAR or infrared (thermal) images are used as a supplement to ground sensors by mapping real-time terrain changes (Fig. 12);

Figure 12. Drone

adaptation to climate change: systems are being developed that also take into account risks associated with factors that increase the risk of mudflows - for example, heavy rains or rapid melting of glaciers;

collective integration: Work is being carried out to warn and inform the population through mobile applications and social networks.

The rapid development of modern technologies increases the efficiency of automated mudflow monitoring systems, making them more accurate, reliable, and timely. In particular, artificial intelligence and machine learning algorithms allow predicting complex mudflow processes by analyzing multi-parameter data, such indicators as rainfall, soil moisture, and changes in relief. This not only increases the accuracy of forecasts, but also ensures decision-making without human intervention.

At the same time, drones and remote sensing technologies (especially LiDAR and infrared imaging systems) allow real-time mapping of terrain changes. These technologies complement the data of ground sensors and play an important role in monitoring hazards in hard-to-reach mountainous areas.

On the other hand, flexible systems are being developed that take into account global climate change. Such systems analyze data on factors that increase the risk of mudflows - such as heavy rains or rapid melting of glaciers - and form long-term risk models. Through this, effective management decisions are made based on seasonal forecasts and prospective scenarios.

Collective integration is also of great importance. Through mobile applications and social networks, it is possible to warn the population in real time, inform about dangers, and ensure community participation. Based on photographs and information sent by the population, it became possible to constantly update monitoring systems.

Modern technologies, such as artificial intelligence, drones, climate models, and collective communication, are fundamentally changing the possibilities of detecting and preventing mudflows. They serve to ensure prompt, reliable, and comprehensive monitoring.

Automated digital monitoring systems are a unique tool for assessing mudflow risk. These systems enable continuous data collection, real-time analysis, early warning, and practical data provision. The integration of sensors, prognostic models, and communication technologies significantly strengthens preparation and action measures. This will help reduce human casualties and economic damage caused by mudflows.

However, to maximize the effectiveness of such systems, it is necessary to solve the problems of costs, maintenance, and public relations.

Discussion. Automated systems represent a fundamentally different paradigm in mudflow risk management. Unlike traditional models, they provide the possibility of flexible monitoring, real-time alerts, and the integration of multi-parameter data. At the same time, some difficulties remain:

Infrastructure costs: Initial installation requires significant investment in elements such as sensors, data transmission devices, and server centers; The introduction of an automated mudflow monitoring system will require significant initial infrastructure costs - sensors, data transmission equipment (GSM, satellites, radio), solar panels, server centers, drones, remote control terminals, and spare parts. These costs can be especially high for mountainous and hard-to-reach areas. In such cases, an approximate economic formula is used to assess economic efficiency (formula 1):

$$\text{IS} = \frac{(P \times V) - C}{C} \times 100\% \quad \textbf{(1)}$$

Where: IS - Economic efficiency (%), P - the share of population or facilities saved from a possible disaster (%),

V - the total value of the saved material assets ($),

C - costs of infrastructure implementation ($).

For example, if the cost of implementing infrastructure is $500,000 (C), and the system protects public property, infrastructure, and hazardous areas worth $2,000,000 (V), and this protection is effective in 80% of cases (P), then:

$$IS = \frac{(0.8 \times 2,000,000) - 500,000}{500,000} \times 100 = \frac{1,600,000 - 500,000}{500,000} \times 100 = 220\%$$

This means that the system yields an effect of about $2.2 per $1 investment. This is considered a great economic benefit. Although the system's initial costs may seem large, its long-term benefits - protecting the population, reducing damage, reducing government spending, and the ability to make quick decisions - prove that this investment is justified. With the help of estimated economic formulas, it is possible to accurately assess the effectiveness of investments.

technical potential: Automated mudflow risk monitoring systems are based on high technologies, and their installation alone is not enough. For the effective use of such systems, it is necessary to correctly understand their structure, operating principle, software, and maintenance procedures. Working with sensors, drones, GIS platforms, and artificial intelligence algorithms requires certain skills and knowledge. In my opinion, the reliable and uninterrupted functioning of the systems depends primarily on qualified specialists. Such personnel are not trained by chance - it is necessary to constantly establish a system of their special training, retraining, and practical application. In this area, the shortage of personnel is one of the main problems.

Data integration: Information from only one agency is insufficient for mudflow risk assessment and early warning. The exchange of information between the fields of meteorology, hydrology, urban planning, ecology, and information technology, the harmonization of approaches, and interaction through a unified electronic platform will increase efficiency. In my opinion, the biggest obstacle in this direction is the segmentation of data and insufficient interaction between agencies. If meteorological data are not related to mudflow topography, the accuracy of the forecast decreases. Therefore, I believe that data integration should be approached at the level of state policy.

sustainability: Natural disasters like mudflows often disrupt infrastructure such as power supply, communications, or internet. Therefore, monitoring systems must be stable - that is, "resistant" - in order to function in any extreme situations. This means they must have an autonomous power source, offline operation mode, and secondary data storage channels. I think that in many projects, such a mistake is observed: systems are tested only under normal conditions. But during a real disaster, the main pressure falls precisely on these infrastructures. Therefore, supporting them with diesel generators, solar panels, or satellite communications should be the main requirement.

future developments: To make systems more efficient and sustainable, development in several directions is necessary. Firstly, open-source technologies can reduce costs and attract the scientific community. Secondly, with the development of public-private partnerships, financial resources will expand and new solutions will be introduced. Thirdly, involving the population in the monitoring process will ensure public participation and allow for the prompt collection of information. I expect that in the future these systems will operate not only centrally, but also on the principle of "bottom-up." That is, the population itself sends information through the mobile application, entrepreneurs introduce technology, and the state coordinates it. Such an approach guarantees the speed, inclusiveness, and stability of the system.

Conclusion. Automated digital monitoring systems are a revolutionary solution in mudflow risk assessment. Through accurate, timely, and practical data, they allow stakeholders to minimize damage and save human lives. The integration of IoT, remote sensing, and artificial intelligence technologies into emergency management systems is an important step towards smart and safe societies. Based on all stages of the conducted research, the following strategic recommendations are introduced:

political integration: governments must officially incorporate automated monitoring systems into national strategies to ensure national security and mitigate the consequences of natural disasters. This, in turn, will serve to strengthen their legal basis and coordinate the activities of all structures.

capacity building: for the effective use of automated systems, it is necessary to organize regular training sessions between local authorities and the population. For example, knowing how to act in the event of a mudflow threat directly allows saving human lives.

Financing models: attracting international grants, investments, and public-private partnership projects is of great importance in infrastructure expansion. With these funds, it will be possible to create sensors, drones, data centers, and on-site technical support systems.

standards of flexibility: to facilitate data exchange between different organizations, it is necessary to introduce a single data format and exchange protocols. For example, integrating hydrometeorological data with GIS platforms significantly increases forecast accuracy.

public involvement: information should be disseminated through mobile applications, SMS messages, and social media platforms to promptly warn the population about mudslide risks and develop safety skills. Through this, not only government agencies, but also citizens themselves will participate in the monitoring process.

pilot programs: special pilot projects should be implemented, taking into account the natural and geographical features of each region. For example, in mountainous areas prone to flooding, the most optimal solution is selected by checking automated radar sensors.

support for scientific research: simplification of engineering work, rapid integration of data analysis is achieved by increasing and effectively applying research work in this area. For example, the creation of analytical models based on artificial intelligence can expand the possibilities of predicting mudflows in the future.

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