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Predicting Landslide Using Machine Learning Algorithm

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Abstract: This survey takes a close look at how machine learning is changing the way we predict landslides. Landslides can be really dangerous, so it's crucial to have effective ways to predict when they might happen. The survey compares machine learning to more traditional methods and puts the different machine learning models into three groups: supervised, unsupervised, and ensemble methods. The survey also explores where we get the data from, how we pick out the important parts, and which case studies show that machine learning is good at predicting landslides. It talks about how we measure if the predictions are accurate, the problems we still need to solve, and the things we need to be careful about, like ethical issues. In the end, the survey looks ahead to what's next and says that machine learning is making a big difference in making landslide predictions more accurate. This helps us manage the risks better and handle disasters more effectively

IndexTerms - Landslide prediction, Machine learning, Decision Tree, Random Forests, Deep Learning, SVM .

I. INTRODUCTION

Predicting landslides is really important for keeping people safe and protecting buildings and nature from the serious effects of these big movements of land. If we can predict landslides early and accurately, we can take actions to lower the risks and prevent a lot of damage. The usual methods we use for this are good, but they struggle with the complicated factors like the Earth's makeup and the environment that affect landslides. Machine learning, a type of technology that learns from data, looks like it could be a great solution to deal with these challenges. It has the potential to make our predictions about landslides stronger and more precise. This survey looks into how machine learning can be a game-changer in predicting landslides, especially when compared to the limits of the traditional methods we usually use.

1. **Challenges in Traditional Methods** : The usual ways we predict landslides use simple models that have a hard time understanding all the different things that can cause a landslide. These methods might not be very flexible in dealing with the always-changing conditions in areas where landslides are likely to happen. Also, they often depend a lot on old information, which can be a problem because it doesn't include the latest and most complete data we need to make predictions that are right on target [1].
2. **The Potential of Machine Learning** : Machine learning, which is really good at finding patterns in big sets of data, changes how we predict landslides. Models in machine learning, like neural networks and ensemble methods, can look at a bunch of different types of data about the land and the environment all at once [2]. This helps us get a full picture of what might cause a landslide. With machine learning, we can make models that do a better job than the usual methods because they can understand complicated connections between things and adjust to the changing conditions over time [3].
3. **Definition of Landslides**: Landslides are when rocks, dirt, and other stuff slide down a slope. They happen because of things like heavy rain and human activities. Landslides can take different forms, like rocks falling or debris flowing. Figuring out how they work is really important to reduce the risks and lessen the impact on the environment. Landslides usually happen because of a mix of natural factors like the Earth's makeup, water, and things people do [4]. Being able to predict when they might happen and managing them well is crucial to dealing with the problems these events can cause [4].

Types of Landslides:

1. **Rockfalls**: Rock Falls happen when individual pieces of rock quickly move downhill. This can be because of things like weathering and earthquakes. Since these events are caused by gravity, they're hard to predict and can be really dangerous [5]. The speed and path of the falling rocks can be harmful, affecting both the natural surroundings and buildings [5].

2. **Debris Flows**: Debris flows are quick movements of wet mud, rocks, and debris, usually set off by things like heavy rain. Because they move fast and can be really destructive, they're dangerous. It's important to grasp how debris flows work so we can figure out and reduce the risks linked to these events [6].
3. **Landslide Avalanches**: Landslide avalanches are when rocks, snow, or ice quickly slide down a slope, and they can cause a lot of damage. Things like earthquakes or weathering can set them off, leading to severe impacts on the land and buildings. It's really important to understand how these landslide avalanches work so we can figure out and lessen the risks involved. [7].
4. **Landslide Slumps**: Landslide slumps happen when soil or rock rotates along a curved surface. They move more slowly compared to other landslides but can still be quite destructive, especially if they're influenced by factors like too much water. Experts have defined these slumps as a specific kind of slope movement [8]. It's crucial to understand how they work so we can figure out and lessen the risks linked to these geological hazards.
5. **Earthflows**: Earthflows are slow to moderately quick movements downhill of fine-grained materials, often set off by things like too much water. They're kind of like a mix between slow landslides and faster debris flows [9]. Experts have sorted them into a specific category of slope movement, highlighting their significance in figuring out and lessening the risks linked to geological hazards.

Landslides have a big and often very damaging effect on nature and places where people live. The results can be instant destruction and also have lasting effects on the environment and communities, affecting things like ecology and people's lives for a long time.

Environmental Impact:

1. **Ecological Disruption**: Landslides change the way the land looks, leading to loss and separation of habitats, which has an impact on plants and animals. [10].
2. **Soil Erosion**: When landslides happen, the soil movement adds to erosion, which can harm soil fertility and the quality of water. [6].
3. **Altered Hydrology**: Landslides can change how water drains, possibly causing shifts in river paths and making areas more prone to floods. [3].

Impact on Human Settlements:

1. **Infrastructure Damage**: Landslides harm roads, bridges, and buildings, messing up transportation and communication systems [11].
2. **Loss of Lives and Livelihoods**: Landslides happen quickly and cause a lot of destruction, leading to injuries, loss of life, and people having to leave their homes. This affects communities and how people make a living [12].
3. **Economic Consequences**: The money spent on fixing the damage from landslides, rebuilding, and the loss of productivity can have a big impact on the economy of the areas that are affected [12].
4. **Social Disruption**: Landslides create a lot of social problems, like people having to leave their homes, dealing with emotional stress, and communities falling apart [13].

To manage the risks of landslides well, it's crucial to grasp how different things like the Earth's makeup, the environment, and human activities all interact. This means focusing on things like giving early warnings, planning how we use the land, and following practices that are good for the long-term well-being of the environment and communities.

In the past, when predicting landslides, people mainly used observations and rule-of-thumb methods. Although these approaches gave us useful information, they struggled to handle the intricate aspects of what causes landslides and how they work.

1. **Geomorphological Mapping**: Geomorphological mapping is a traditional method for predicting landslides. It includes going out into the field, observing the land, and making maps that show which areas are likely to have landslides. This technique is important because it helps us see how the shape of the land is connected to the risk of mass movements like landslides. The maps created through geomorphological mapping give us a good idea of where landslides might happen.

   To make these maps, researchers go to the actual sites and check things out. They look at the shape of the slopes, figure out the geological features, and study the soil and plants covering the area. They then sort the slopes into different groups based on how stable they are and how likely they are to have landslides. This helps in planning how to use the land and coming up with ways to lower the risks [14].

   Making maps of the land's shape is like the starting point for studying landslides. These maps give us important details that help create plans to manage the risks effectively. We can build on this foundation by using newer methods like remote sensing and GIS (Geographic Information Systems). These modern techniques help us get even more detailed and accurate information for better landslide studies and risk management plans.
2. **Rainfall Thresholds**: The Rainfall Thresholds method is an old but reliable way to predict landslides. It works by figuring out the amount of rain that could make slopes fail. This method understands that heavy rain is closely linked to the higher chance of landslides. When the rainfall goes beyond a certain limit, the soil gets really wet, loses its strength, and the slopes can become unstable, possibly leading to landslides.

   To figure out these rainfall thresholds, researchers study past landslides and the rainfall that happened around those times. By pinpointing the specific rainfall conditions before landslides, scientists create models based on real data. These models help predict when similar events might happen in the future [15].

   Even though rainfall thresholds are helpful for predicting landslides, their success depends on having precise and timely rainfall information. This emphasizes the possibility of combining this method with advanced

technologies such as weather monitoring systems and climate models. This combination can improve our ability to predict landslides more effectively [15].

3. **Historical Records**: The Historical Records method for predicting landslides is all about looking at what happened in the past. Researchers analyze old records of landslides to see if there are any patterns or trends. This method understands that by studying past landslides, we can learn a lot about what causes them. Scientists go through documented cases of landslides, paying attention to things like the kind of land, how it's used, and the weather events that happened before each landslide [16].
   Using the Historical Records method helps create maps that show where landslides are likely to happen, which is useful for figuring out the risks. But there are challenges, like making sure we have all the right information and that it's accurate. To get a full picture of how landslides work, researchers combine the old records with newer technologies like remote sensing and GIS. This gives us a better and more complete understanding of how landslides happen [16].
4. **Topographic Factors**: The Topographic Factors method for predicting landslides is about looking at the shape of the land, like how steep it is, which direction it faces, and its curvature. This method understands that these terrain features affect how stable a slope is. Slopes that are really steep, face a certain way, or have a particular shape are more likely to have landslides [17].
   Researchers use high-tech tools like Geographic Information Systems (GIS) and remote sensing to make really detailed maps of the land. This helps them find places that might be at risk of landslides. Although this method is helpful, it's even better when they add in more details like the kind of soil and what covers the land. By mixing the old way of looking at the land with these new technologies, we get a much better idea of where landslides might happen and how risky they could be.
5. **Hydrological Modeling**: The Hydrological Modeling method in landslide prediction is about figuring out how water affects the stability of slopes. This method understands that too much water can make the soil less stable by reducing its stickiness and increasing the pressure inside, which can lead to the slope collapsing [18].
   Researchers use computer models to pretend how water moves through the land. They think about things like how hard it's raining, what the soil is like, and what plants are there. These models help predict how water and the land interact, affecting how stable the slopes are.
   Even though Hydrological Modeling is really important for predicting landslides, how well it works depends on having really good data and considering other things that can affect it. By adding in new technologies like satellite data for rainfall and remote sensing, we can make these models more accurate. This helps us assess the risk of landslides in a better way [18].
   Although these methods give us useful information, they have some drawbacks. They depend a lot on old data, make things a bit too simple, and struggle to deal with different environmental situations. To make them better, we can combine them with machine learning techniques. This mix helps us predict things more accurately and overcome the problems these traditional methods have.

This paper compares various ML algorithms, methods, and solutions in mainstream literature to showcase their use in notable landslide applications for new solutions or services. The rest of the paper is organized as follows: Section II presents the literature review, Section III presents the machine learning models, Section IV presents key advantages, Section V presents Role of Machine Learning in Landslide Prediction, Section VI presents risks of using ML algorithms in IRNSS, Section VII presents conclusions and Section VIII presents future work.

II. LITERATURE STUDY

In this research paper [19], scientists compared three computer models Decision Trees, Support Vector Machines (SVM), and Random Forests to figure out which one is best at predicting where landslides might happen around the Three Gorges Reservoir in China. the models might struggle with capturing all the complex interactions between different factors. In this research study [24], scientists compare several algorithms, like Decision Trees, Support Vector Machines, Random Forests, and more. There's no one-size-fits-all model that works best in every situation. This research study [25] takes a close look at different computer techniques like Decision Trees, Support Vector Machines, and Random Forests used for predicting landslides. The goal is to figure out how well these techniques work and understand their pros and cons, contributing to making better methods for predicting landslides. They tested Decision Trees, Support Vector Machines, and Random Forests using datasets that include details about the ground, the shape of the land, and the weather [25]. The study [26] looks into whether combining several SVM models together, creating a kind of team, makes the predictions better than using just one model. They gather lots of information about the ground, the shape of the land, and the weather to build a complete dataset for predicting landslides. Additionally, this approach might work best in certain situations, and using it in different places needs careful consideration of local characteristics. This research [27] introduces a new way of making maps that show where landslides might happen. They combine two different computer models, the Extreme Learning Machine (ELM) and the Naive Bayes classifier, to create a hybrid model. To do this, they collect lots of information about the ground, the shape of the land, and the environment to create a diverse dataset. While hybrid models can be powerful, they might be a bit more complex to understand and may require more computing power. This research [28] takes a close look at different computer models to predict landslides in the Qazvin Plain. The study wraps up with a detailed comparison of how well these advanced computer models performed in predicting landslides in the Qazvin Plain. The success of these models might vary in different geological and environmental settings. The results of this study may be specific to the Qazvin Plain and might not apply universally to other regions without considering local conditions. This research [29] focuses on making maps to show where landslides might happen in Wushan County,

part of the Three Gorges Reservoir in China. The study tries out a mix of different computer models, creating a combined approach to make more accurate predictions about areas prone to landslides. The study concludes that these combined computer models like Decision Trees, Support Vector Machines, and Random Forests perform better in making landslide susceptibility maps compared to using individual models alone. Also, the model might work better in Wushan County's specific terrain, and using it in other regions needs to consider the local geological and environmental conditions. This [30] research focuses on creating maps to predict where landslides might happen in the difficult terrain of the Himalayan region. The study systematically compares how well various computer models based on decision trees such as Random Forests and Gradient Boosting Machines perform for making landslide susceptibility maps in the Himalayan region. This [31] study is all about creating maps to predict where landslides might occur, and it takes a unique approach by combining several different computer models, such as Decision Trees, Support Vector Machines, and Random Forests, into one combined model. When applying this method to different places, local environmental conditions and characteristics need careful consideration [31]. This [32] research is about creating maps to predict landslides in the U Minh Thuong National Park in Vietnam. What makes it unique is the use of a system called Adaptive Neuro-Fuzzy Inference System (ANFIS) combined with Geographic Information System (GIS) techniques. The goal is to provide a more advanced and location-specific method for predicting where landslides might happen. They use ANFIS to understand the complex relationships between these different factors and adapt to the dataset. Additionally, GIS techniques are employed for spatial analysis and mapping. By combining adaptive modeling with spatial analysis, the research contributes to a better understanding of areas prone to landslides in the U Minh Thuong National Park.

III. METHODS OF DETECTION

Machine learning is a game-changer in predicting landslides because it can adapt and change to different situations. This means it gives us more detailed insights and helps us assess and manage risks better. There are different types of machine learning models used for predicting landslides, each with its own strengths and uses.

1. **Decision Trees**: Decision Trees are like versatile and understandable computer models used for figuring things out or making predictions. In predicting landslides, these trees help us find out the important factors by looking at what happened in the past. Imagine a tree-like map where each decision point is like a question about a certain thing, and each path gives the answer. We build this tree step by step, choosing the best questions to help us make the most informed decisions. One cool thing about decision trees is that they're easy to understand [20]. The tree structure that comes out of this process makes it simple for researchers and people working on the problem to grasp and explain how decisions are made. This clarity is especially crucial in fields like predicting landslides, where having practical insights is key for managing risks effectively.
   Application in Landslide Prediction: In predicting landslides, we can use decision trees to figure out which geological, topographic, and climatic factors matter the most. Imagine moving through this tree like taking a journey. Along the way, we can find out the important points and how these factors interact. This helps us create models that show where landslides are likely to happen based on these critical details [20].
   While Decision Trees can sometimes be thrown off by irrelevant information or unusual cases, we have a solution. We use something called Random Forests, which is like combining a bunch of these trees together. This teamwork helps us make predictions more accurately and deal better with tricky situations when mapping where landslides might happen.
2. **Random Forests**: Random Forests is like a team of decision trees working together. They learn from different parts of the information and then team up to make a decision. In predicting landslides, Random Forests are a strong and reliable way to handle the complexity in the data. What's cool about Random Forests is that they're made up of many individual trees, each trained on a random piece of the data. Their combined prediction is like taking a vote from all these trees, which helps prevent making decisions based on just a small part of the information [19]. This teamwork makes Random Forests good at avoiding mistakes and improving how accurately they predict landslides. Additionally, they also tell us which factors are most important, helping us figure out what really matters in predicting landslides.
   Application in Landslide Prediction: In mapping areas prone to landslides, Random Forests are really good at dealing with lots of different types of information like the shape of the land, soil details, and how much it rains. They stand out because they can understand complicated connections and how different things affect each other. This makes them perfect for figuring out the complex nature of predicting landslides [19].
3. **Support Vector Machines (SVM)**: Support Vector Machines (SVM) are like smart tools in computer learning that are really good at figuring out categories or making predictions. When it comes to predicting landslides, SVM helps draw lines on a map to show which areas might be at risk and which are probably safe. It works by finding the best line that separates different areas while keeping the most space between them. This space is like a safety zone. The goal is to find the best line that works well not just for what we already know but also for new information we haven't seen yet. SVM is clever at handling tricky relationships in the data, especially in predicting landslides where things might not follow a straight line [21]. It does this by using a trick that transforms the information into a more detailed space, helping it draw better lines and make more accurate predictions.
   Application in Landslide Prediction: When we're figuring out which areas might be prone to landslides on a map, Support Vector Machines (SVM) are really handy. They look at things like the shape of the land, what the ground is made of, and what covers the land to sort areas into different categories based on their risk of landslides. SVM is good at dealing with lots of details in the information and understanding how different factors interact. This is why it works well in predicting landslides [21].

4. **Neural Networks (Deep Learning)**: Neural Networks, especially the deep learning ones, are like super-smart computer programs inspired by how our brains work. When it comes to predicting landslides, these deep learning methods are like really fancy detectives. They're excellent at finding complicated patterns and connections in a bunch of information. Think of them as having layers of detectives. The first layer gets the basic information, then there are more layers that figure out more complex details. What makes them special is that they automatically learn from all the information, which is super helpful in predicting landslides where lots of different factors come into play.
   Application in Landslide Prediction: Fancy computer models like convolutional neural networks (CNNs) and recurrent neural networks (RNNs) are doing a great job in figuring out where landslides might happen. They're really good at dealing with how things relate to each other in both space and time. This makes them perfect for understanding the complicated connections between the Earth's makeup, the shape of the land, and the weather patterns all of which are crucial in predicting landslides. [22].
5. **Naive Bayes:** Naive Bayes is a computer program that's good at guessing things based on probabilities. People often use it to sort things into categories, like organizing text or even predicting where landslides might happen. Even though it seems simple, Naive Bayes can be surprisingly accurate and doesn't take too much time for the computer to figure things out. The trick behind it is a math concept called Bayes' theorem, which helps calculate the chance of something happening given the information we have. In predicting landslides, Naive Bayes looks at the available data and estimates how likely it is that a certain area might be prone to landslides [23]. The "naive" part comes from assuming that the details we use to describe a place are all independent of each other, which makes the calculations easy and the program quick to learn.
   Application in Landslide Prediction: Imagine using Naive Bayes as a tool to predict landslides. It looks at different details like the shape of the land, what the soil is like, and the weather. Then, it figures out the likelihood of a certain place having a landslide based on these details. While it might not understand really complicated connections as well as some other tools, its simplicity makes it a good choice in certain situations, especially when we don't have a lot of computing power [23].

These computer models for predicting landslides come in different styles, and how well they work depends on things like the kind of information available and the unique features of the area being studied. Researchers pick these models based on how complicated the problem is and how easy it needs to be for people to understand and use in real-life situations.

Table 1. Comparison of literature survey

Title	Focus	Methodology	Conclusion	Limitations
[19]	Comparative study of ML models for landslide susceptibility mapping in Three Gorges Reservoir, China	Decision Trees, SVM, Random Forests; Comprehensive dataset; Comparative analysis	Identifying the most effective model for landslide susceptibility mapping	Data quality dependency, Regional specificity
[24]	Landslide susceptibility mapping using ML algorithms: Overview and comparison	Review and comparison of ML algorithms; Diverse datasets; Evaluation metrics	Understanding strengths and weaknesses of ML approaches	Data quality impact, Context-specific performance
[25]	ML techniques for landslide susceptibility modeling: Comparative overview	Review and comparison of ML techniques; Diverse datasets; Performance metrics	Assessing performance of various ML techniques	Data quality impact, Regional variability
[26]	Landslide susceptibility mapping using ensemble SVM model	Ensemble SVM model; Comprehensive dataset; Training and validation; Performance metrics	Improving predictive accuracy with ensemble SVM	Data quality dependency, Computational complexity
[27]	Hybrid model integrating ELM with Naive Bayes for landslide susceptibility mapping	ELM and Naive Bayes hybrid model; Comprehensive dataset; Training and testing	Combining ELM and Naive Bayes for accurate predictions	Data quality impact, Model interpretability
[28]	Comparative assessment of ML models in Qazvin Plain landslides	Advanced ML models; Diverse datasets; Training and validation; Performance metrics	Evaluating prediction performances of advanced ML models	Data quality impact, Region-specific findings
[29]	Landslide susceptibility mapping in U Minh Thuong	ANFIS and spatial statistics integration; Comprehensive	Enhancing landslide susceptibility mapping	Data quality dependency, Context-

	National Park using ANFIS and spatial statistics	dataset; Training and validation	with ANFIS and spatial statistics	specific findings
[30]	Comparative assessment of decision tree-based ML models in the Himalayan region	Decision tree-based models; Comprehensive dataset; Training and validation; Performance metrics	Identifying effective decision tree-based models for landslide prediction	Data quality impact, Region-specific performance
[31]	Landslide susceptibility mapping using ML algorithms: Ensemble approach	Ensemble approach with various ML algorithms; Comprehensive dataset; Training and validation; Performance metrics	Improving accuracy with ensemble modeling	Data quality impact, Computational complexity
[32]	Landslide susceptibility mapping in U Minh Thuong National Park using ANFIS and GIS	ANFIS and GIS integration; Comprehensive dataset; Training and validation	Advancing accuracy with ANFIS-GIS integration	Data quality dependency, Context-specific findings

IV. Key Advantages:

The way we predict landslides is changing a lot because of machine learning. It's like moving towards smarter, data-focused, and proactive ways to manage the risks. Machine learning has a bunch of advantages over the old methods, shaking things up by being really good at understanding complicated connections in data and making our predictions more accurate. The key advantages include:

a. **Handling Nonlinear Relationships**: Machine learning models are great at understanding complex connections in data, which helps us get a more realistic picture of all the factors that play a role in landslides [2].
b. **Data-Driven Approach**: Machine learning uses big sets of data to find patterns and trends. This helps us take a data-focused approach that works well, especially when dealing with the varied and always-changing information related to landslides [3].
c. **Adaptability and Generalization**: Machine learning models, especially the smart ones like deep learning algorithms, are really good at adjusting to different situations and working well in various places and conditions [19].
d. **Integration of Multiple Data Sources**: Machine learning easily brings together information from different places, like pictures from satellites, details about the land's shape, and records of the climate. This helps us get a complete understanding of what causes landslides [19].
e. **Enhanced Prediction Accuracy**: Machine learning's talent for handling lots of different and complex data helps us make predictions more accurately. It becomes a powerful tool for creating models that reliably show where landslides are likely to happen [19].

V. Role of Machine Learning in Landslide Prediction:

The way we predict landslides has changed a lot by bringing in Machine Learning (ML) techniques. These techniques use smart algorithms that learn from data patterns, making them really good at handling the complicated factors that cause landslides and how they work. This makes our risk assessments more accurate and helps us be ready before something happens.

a. **Role of Machine Learning**: Machine Learning (ML) models are crucial in predicting landslides because they look at a ton of data, figure out patterns, and connect the dots between different things that contribute to landslides.
b. **Data Sources and Feature Extraction**: Machine Learning (ML) algorithms handle all sorts of data like pictures from satellites, details about the shape of the land, records of rainfall, and information about the soil. There are techniques that help pick out the important stuff from all this data, making sure we focus on the key things needed for predicting landslides.
c. **Types of Machine Learning Models**: Different types of Machine Learning (ML) models are used for predicting landslides like Supervised Learning involves using labeled data to train models to make predictions. It's like teaching the system by showing it examples. Think of it like decision-making trees or random forests. Unsupervised Learning, the models find patterns in data that don't have labels. It helps group things together or spot unusual patterns, kind of like sorting and finding things without being told what to look for. Deep Learning involves using neural networks, which are like computer brains, to handle really complicated relationships in a lot of data. It's great for dealing with complex information.
d. **Integration with Remote Sensing**: Machine Learning (ML) works hand-in-hand with technologies like remote sensing, making it better at studying pictures from satellites. This combo helps analyze the images more effectively and gives us up-to-the-minute information about how the landscape is changing.
e. **Improving Accuracy and Early Warning Systems**: Machine Learning (ML) is really good at dealing with complicated connections between things and handling huge amounts of data. This makes it much better at predicting things accurately. This is super important when it comes to making early warning systems that we can trust. These systems help us evacuate on time and lower the risks before something happens.
f. **Challenges and Future Directions**: There are some challenges with using Machine Learning (ML) for landslide prediction. We need really good data to teach the models well, and sometimes it's hard to understand why the models

make certain predictions. Ongoing research is working on solving these challenges and coming up with new and clever ways to make ML even better for predicting landslides.

VI. Conclusion

In conclusion, exploring landslide prediction through machine learning has uncovered a range of methods and models. These include popular algorithms like Decision Trees, SVM, and Random Forests, as well as inventive combinations like ELM-Naive Bayes. Although advancements in ensemble techniques and adaptive models, such as ANFIS, enhance accuracy, it's crucial to choose models that fit the specific context. Challenges still exist, like relying on data quality, dealing with regional differences, and handling computational complexities. The ever-changing nature of this field emphasizes the ongoing need for exploration, ensuring robust and context-aware mapping of landslide susceptibility in various geological and environmental conditions.

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