

## REMOTE SENSING FOR NATURAL HAZARD STUDIES

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### **Lec 29b: Remote Sensing for Landslide Studies-I Part B**

Hello everyone, welcome back to Lecture 29. This is Part 2. So, in the previous lecture, we continued the discussion of landslides. In part 2, we will mainly talk about the mitigation as well as the early warning system that has been implemented by different agencies, universities, and researchers. So, I hope you have understood the basics of landslides, and now we will continue with the mitigation. So, the simplest means of dealing with landslide hazards is to avoid construction on steep slopes and existing landslides, which is not practical. Why is it not practical? Because of the increase in the population, we are experiencing a shortage of space. Especially in the cities. So, we are trying to build houses or construct buildings everywhere, and avoiding a particular area is not practical. So, what happens when we are looking for the mitigation measures? So that we can start building our houses, offices, or different buildings.

So, the construction policy related to slope stability is very, very important. So, each state government is responsible for producing this construction policy related to slope stability for their areas. Monitoring an early warning system can help residents evacuate temporarily when the probability of landslide activity is very high. So, suppose this is the area that has a history of landslides. So, what happens first is to avoid constructing in those areas where we have a history of landslides.

Which is not practical. Now the second one is the construction policy. There should be some norms given by the government that outline the precautions you have to follow; only then can you build your buildings here, or you can utilize this area for other purposes. Then the next one is, if we know that some of the areas are prone to landslides, then we should have an early warning system. So, this is how we can help the people residing in those regions save their lives and property.

So, there are three major topics here. So when we talk about these mitigation methods, the first one is soil slope stabilization, because whenever we talk about landslides, it is basically the failure of this slope, right? Here, the top layer is always or commonly soil. So, if we have the soil slope stabilization method, then we will probably save our lives and property. Then comes the rockfall hazard mitigation. I hope you remember the rockfall,

which consists of rock pieces that are falling from the elevated areas to the downslope, and they are toppling or rolling. Then comes the debris flow hazard mitigation. Then, landslide dam mitigation is necessary because many of the high-altitude areas are experiencing breaches in the dams due to landslides. So, we also talk about landslide dam mitigation. Then comes the biotechnical landslide mitigation. These are different from this one because here we will talk about the biotechnical.

So, with the help of plants and vegetation, how can we reduce the intensity or the frequency of landslides? So, the first one is soil slope stabilization. So, here, soil slope stability can be increased through drainage control. To install a surface and subsurface drainage system to reduce water infiltration. Then comes the slope reinforcement using retaining walls, soil nailing, rock bolts, and geotextiles to strengthen the slope. So, many of you might have seen this retaining wall, or maybe rock bolts or geotextiles, which are used.

To prevent the landslide. Then comes the vegetation and bioengineering: plant deep-rooted vegetation to enhance soil cohesion and reduce erosion. So, what happens when this is the slope and we select a particular plant that has roots going down in it? So, if this is the slip circle, if this is the surface of the rupture, and if the roots are long, they are holding the underlying soil or the rocks, then this will give strength to this material. So, that is why deep-rooted vegetation is used to enhance soil cohesion and reduce erosion. Surface protection: apply erosion control mats, shotcrete, or riprap to prevent surface erosion. Because this surface erosion prevention is also important. Then load management restricts heavy loads and construction activities on unstable slopes because if this is in, let us say, a metastable slope. So, then we will restrict the movement of heavy vehicles or even the construction activities on this particular slope; that way, we can ensure the stability of the soil slope. So, this table gives you the combination of slope stabilization techniques; it is from Howell 1999. So, this geotechnical engineering technique, then bioengineering aspects, and then combinations of both.

So, here when we talk about the geotechnical aspects, the first topics are reinforced soil, soil nailing, soil anchors, and retaining walls. And here you have densely rooted grasses, shrubs, and trees; then comes the most complex vegetation structure. Then deeply rooted trees, large trees, and large bamboo clumps. So, these are used in bioengineering methods. Then we can also have a combination of both.

So, wire bolster cylinders and planted shrubs or trees, jute netting with planted grasses, soil anchors, and deeply-rooted trees. Retaining wall with a line of large bamboo clumps planted above it. So, here you can see how we are utilizing the information or expertise from the different domains to prevent the landslide. So, that is why I call it a multidisciplinary problem; it has to be solved by all the people from the relevant areas coming together to solve this problem. Then comes the rockfall hazard mitigation; rockfalls

cause an extraordinary amount of monetary damage and death because they come with velocity, and their size can range from very small to very large.

So, mainly it blocks the highway, which is the major problem, and then your clearance of the highway takes so much time that by the time the financial aspects of the high-altitude areas change. Diverting highways around rockfall areas is not always practical because we are mainly talking about the high-altitude region, where alternate highways or alternate routes are not possible. Methods of rockfall hazard mitigation include trimming cable and mesh so that the rockfall coming from the top can be controlled. Shotcrete, anchor bolt dowels, and controlled blasting. Some of the places this is required because if that particular road is used by many people, then we have to save lives, right? So, in such cases, controlled blasting will give you better results.

So, possible measures to reduce the damage due to rockfall are from Pang 1987. So, the berms, rock shed, ditch, fill, and fence. So, this will help you reduce the damage caused by the rock falls. Now comes the debris-flow hazard mitigation. So, mitigation methods to contain and deflect debris flow include debris flow barriers.

It is very difficult to control the debris flow if the scale is large, but if the scale is small, then this debris flow barrier will work; construct check dams. Retention basins and deflection walls are used to control flow. If it is expected that a particular area may experience debris flow, then you can have check dams, retention basins, and deflection walls. Then, we can also work on drainage management. So, here we improve the surface and subsurface drainage to reduce water infiltration in such areas.

Then slope stabilization uses vegetation, retaining structures, and grading to minimize slope failure. Then we can also have very good land use planning or land use utilization. So, restrict development in high-risk zones and enforce hazard zoning regulations. So, it is up to the state government how it is implementing and how it is getting conveyed to the common people. So that the people are aware that this particular area should not be used.

So, here you can see that this is from Vagnon 2020. So, debris flow mitigation measures are needed. So, this is an example of a check dam. Here you can see that the open-type sabo structure comes next. So, this is from Japan; then comes the concrete slit barrier here; this is from Portugal. The flexible net barrier is here; it will hold the debris. This will not control the water, but it will hold the debris. You can see all of this. So, this is from Italy. So, this is the kind of mitigation we can have for the debris flow.

When we talk about landslide dam mitigation, it is very important to understand the hazard caused by this particular dam breaching because of the landslide. So, when we talk about the landslide dam, it is caused by two types of flooding: one is upstream or backwater flooding as the impoundment fills, and the second is downstream flooding resulting from the failure of the dam. So, these two are the different cases. So, when you have a high-

altitude dam here and here, you have a glacier or maybe some fluvial system. So, the water is coming here, and because of the flooding, there will be impoundment failures.

So, the backwater will cause the failure of this particular chunk, and because of that, waves will be generated, and this particular lake will fail, which will cause the landslide dam. Another case is where the downstream flooding results from the failure of the dam. So here there is another lake that has failed, and this water has come here because of that; this lake will fail, and here is the barrier, and this particular area will have the landslide dam scenario. Mitigation measures to prevent flooding from landslide dams are diverting the inflow of water. So, you can have the diversion of the inflow that is coming to this particular lake, or use the pumps and siphons to drain out the rising water.

So, you can pump it out. Construction of open channel spillways will ensure continuous discharge of the excess water. Provision of a drainage tunnel through the abutment. Provision of drainage conduit, culvert, and pipe of a line tunnel through the dam. So, these are some of the mitigation measures for the floods caused by landslide dams. When we talk about biotechnical landslide mitigations, as I said, if this is the slope that is unstable, then this is the failure surface.

We should have the vegetation here, right, which has roots going beneath this surface; then only will it give stability to this particular soil. So, in such a situation, we have to take the help of bioengineering or biotechnology experts, and then we have to find the grasses, plants, or trees that have longer roots. Used to reduce the consequences of landslides, mitigation measures. Biotechnical slope protection includes vegetated composite soil or structural bodies that are environmentally friendly. Vegetation is the best mitigation measure to stabilize slopes to prevent excessive erosion.

## VETIVER



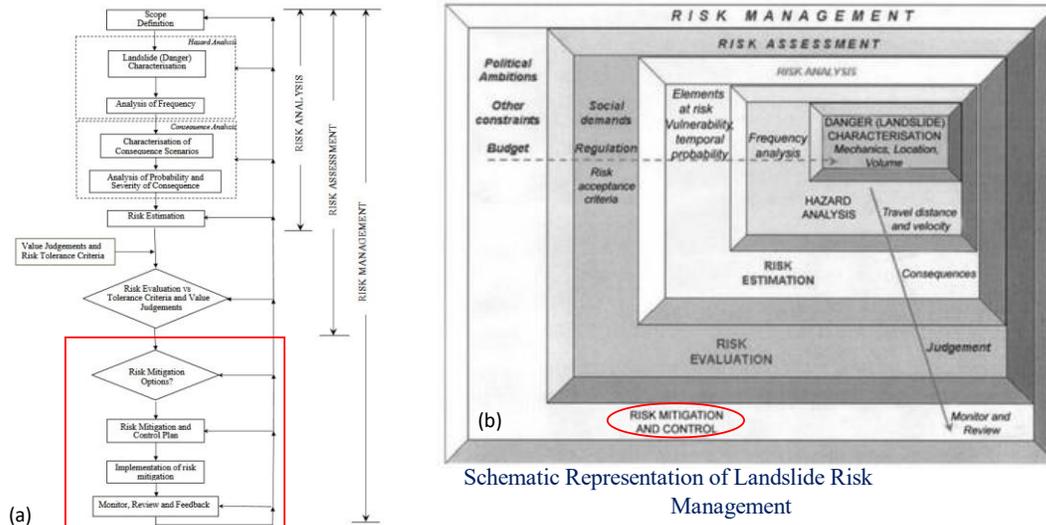
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*Source: Kumar and Kumari, 2023*

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One of the most promising types of the plant is vetiver, a type of grass that works very well to stabilize slopes against erosion in many different environments. So, that is very, very important. So, this particular plant is a type of grass. So, this grows in different environments because you might have used it in your area, but it may not work for another area because it will not grow. But this is one of the grasses that work well in different environments. So, here this is from Kumar and Kumari 2023. Here, they have given the example of a vetiver soil stabilization mechanism by vetiver grass. So, here you can see their roots, which are going beneath this ground. So, slipping zones on slopes are usually 0 to 2 meters in depth. And these are the vetiver roots. So, that is why this is very common and very famous when we are talking about biotechnical landslide mitigation. This is the vertebrate, so this is how it looks. So, now we understand the mitigation part. But another very important component is the landslide early warning system. We have understood the different components of the landslide.

We have also understood the various mitigation measures. Now we will talk about the early warning system. How can we establish or how can we develop an early warning system? What are the key elements of the early warning system that have been discussed here? So, it consists of 4 key components: the first one is risk knowledge, then comes monitoring and warning services, then comes dissemination and communication, and finally response capability. So, let us say that this particular area has the susceptibility to landslides. So now what we will do is have the risk knowledge that these particular areas have a history of landslides, then comes the monitoring and warning system.

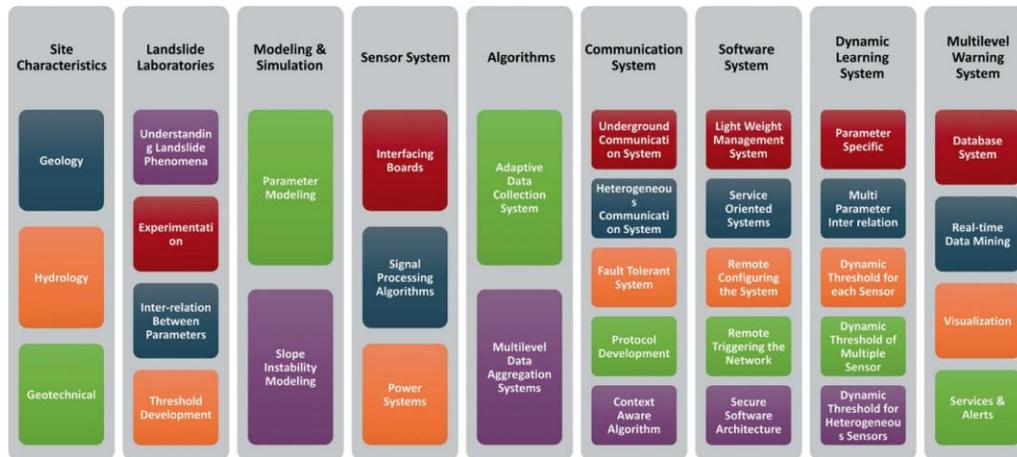


So, the monitoring and warning system will allow us to characterize these landslides, the soil, and the slope, and then we will have a complete understanding of this particular situation. We will also have knowledge from the forecasting that some of them may fail under certain critical conditions. So, in such a situation, what we will do is keep on monitoring those parameters that are responsible or that are the causative factors. So, such parameters will be monitored, and based on that, we will have the forecasting. Once we have the forecasting, we should disseminate the information, which means this should go to the common man that they should not visit this particular area or construct anything in these regions, as this is highly prone to landslides.

So, that is called the dissemination of information. Then, finally, response capability. So, once we have informed the local government and the local people that these areas are vulnerable to landslides, people should not visit this area, and the local government should be ready to respond when a landslide occurs. So, that is very important in the early warning system. And here it is very important to note that if any one element of this list fails, we will not call it an early warning system; it will be a study of landslide.

So, here we should have the risk knowledge, warning services, dissemination, and the response capability that are very, very important. When we start working on the landslide early warning system, we start with the risk analysis. Then we move to risk assessment, and then we move to risk management. Here you can see that this particular flowchart will give you the information on what we should do for the risk estimation, and then comes the risk assessment, and then comes the risk management. So, this is a very nice table that is given here, and this particular semantic representation of landslide risk management; here you see this particular block.

# Landslide Early Warning System (LEWS)



Components of a comprehensive LEWS (Ramesh et al., 2023)

So, it starts here with danger landslide characterization, then here you will have the hazard analysis, then we will move to risk estimation, then we will go to risk evaluation, and finally, we will have the risk mitigation and control. So, when the risk analysis, travel distance, velocity, and frequency analysis are done. When we talk about risk estimation, the consequences, elements at risk, vulnerability, and temporal probability are studied. When we talk about the risk evaluation, the judgment, risk acceptance criteria, social demand, and regulation that will be taking place here. Now, when we move to risk mitigation and control, we should have the monitoring and review; then political ambitions, other constraints, and the budget all come into play when we talk about risk mitigation and control.

So, this is a very nice flowchart given by Fell et al. (2005); again, the list of this paper is provided in the references. So, if any of you is interested, you can refer to his paper. So, this is a very nice representation of an IoT-based early warning system for landslides. So, here you can see there are some instruments or sensors that are installed in the field.

So, mainly these are 3. So, here is the tilt sensor, which will provide you with information about the slope if there is a change in the slope. This is the pore pressure and moisture sensor that measures the moisture content of the soil. Now, here is the third sensor that will provide information about the precipitation. So, once you have these 3 alarms installed in a given area, if there is a change in the slope, that means the landslide may occur. If there is a change in the moisture condition or pore water pressure of the soil, then the landslide may also occur.

If there is heavy precipitation, then there is a likelihood of a change in the pore water pressure and moisture conditions, and the slope can also be modified. So, this is a very nice

representation of the IoT-based early warning system. Now all this information is going back to the base station where it is input into the model, and the model is near real-time. These 3 sensors are providing you with near real-time information about the surface, and based on that, you can forecast that these areas are likely to fail or that these areas should be avoided for any kind of visit. So, this way we can generate or have a landslide early warning system where the people are in the central station or control station, and the data are transmitted with the help of Wi-Fi or the internet to the base station, and that is input into the model, and the model is generating the results.

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Here is the list of typical parameters monitored and the corresponding instruments used in the landslide early warning system. So, the first one is displacement. Then, cracking, strains, pore water pressure, groundwater level, soil water content, suction, and the seismicity and microseismicity of that particular area will be used in your model to provide the near real-time scenario of a particular location. So, you can refer to all these instruments that are listed here for monitoring these different parameters. So, the parameter monitored and the corresponding instrument used in LEWS are from Calvelo 2017.

So, here you can see the monitored parameters: displacement, strain, cracking, microseismicity, rockfall event frequency, mass balance, pore water pressure, suction, soil humidity, water quality, weather, earthquakes, volcanic activity, atmospheric tides, and stream flow. All these are measured, and they have different methods of measurement. So, here you have geotechnical, hydrologic, geophysical, geodetic, remote sensing, and then meteorological. So, here you will be able to characterize the deformation activity, groundwater parameters, triggering parameters, and predisposing factors.

So, you can refer to this table, and here is the legend. So, you can use this information to read the names of this instrument. So, the component of a comprehensive landslide early warning system is given by Ramesh et al. 2023. So, for site characteristics, you have to have the geological information, hydrological information, and the geotechnical information about the surface or the soil. Then, landslide laboratories help you understand landslide phenomena.

Experimentation, interrelation between parameters, threshold development, modeling, and simulation; here, the parameter modeling and slope instability modeling. Then we have the sensor system, interfacing boards, signal processing algorithm, and power system right because you need to have the power. Then comes the algorithm, adaptive data collection system, and multilevel data aggregation system, because subsequently you have to keep updating your database. Then communication system because we are talking about the early warning system. So, underground communication system, heterogeneous communication system, fault tolerance system, protocol development, context-aware algorithm, then you have different software.

For the dynamic learning system, you have parameter-specific, multi-parameter interrelations, a dynamic threshold for each sensor, dynamic thresholds for multiple sensors, and a dynamic threshold for heterogeneous sensors. Then comes the multi-level warning system, along with the database system, near real-time data mining, visualization, services, and alerts. So this particular paper is explaining the different aspects of a landslide early warning system. And I have a few more details about this paper. Let us have some examples from the local scale and regional scale landslide early warning systems from around the world.

So, on a local scale, we have ACNES, which is from Norway. And here you have Elgarbin; it is from Switzerland. Then, the Three Gorges Reservoir it is from China. From the regional scale, you have Hong Kong from China, then Rio de Janeiro from Brazil, and then Norway. So, all of these are published in different years.

So, if you want to know about them, you have to refer to these papers. So, these are some of the local and regional-scale LEWS. In India, we have LEWS, and that is by different agencies, different universities, and different researchers. So, let us take a quick look. So, the National Landslide Forecasting Center (NLFC) by the Geological Survey of India is responsible for doing this landslide forecasting.

It was inaugurated on 19 July 2024. The web portal is here, and the mobile app is Bhooskhalan. So, you can look into the Google Play or Apple website; you will get more details about this. So, as the name indicates in Hindi, we call it Bhooskhalan. So, a landslide is called Bhooskhalan in Hindi. So, the input data used in these early warning systems

comes from the Indian Meteorological Department (IMD) and the National Center for Medium Range Weather Forecasting.

This is from the Ministry of Earth Sciences and then the National Remote Sensing Center of the Department of Space. National Disaster Management Authority, DMA, all the concerned State Disaster Management Authorities, and the District Disaster Management Authorities. So, these inputs are going into this particular Bhooskhalan app or maybe this particular website. You can just try Googling it, and then you can refer to this website. Some examples of local-scale and regional-scale LEWS in India that I am going to show are here.

So, this is from GSI. So here you can see, in Darjeeling, we installed it in 2018, and in Kalimpong, West Bengal, we installed it in 2021. Then we have the Nilgiris in Tamil Nadu, and it is in the year 2018. Local scale LEWS by a few institutions. So Munnar, Kerala, is the site where Amrita University, or Amrita Vishwa Vidyapeetham, is located. So, the first one is installed in 2023 by Amrita Viswa Vidyapeetham. That is in Munnar, Kerala. Then we have the Chanmari landslide in Gangtok that was again installed by Amrita Viswavidya Peetham. Then we have the Padar landslide in Mandi, which was installed by IIT Mandi, Himachal Pradesh. Please provide a sentence for correction.

This is the website of the National Landslide Forecasting Center. So, here you can see that all this information is needed, and then it will show you the Bhuskalan map or maybe the landslide maps. This is the Nilgiri Tamil Nadu map, which will be accessed on 14th January 2025. And here you can see that these maps have low, moderate, and high information; you can refer to this website for more details. Some of the references I have used in my presentation are listed here; you can refer to them if you want more detail about a particular topic or LEWS. This is the list again; here are all the papers I have used, and those are listed here. Right, this is the end of the references. So, with this, I will end Lecture 29.

Thank you very much.