REMOTE SENSING FOR NATURAL HAZARD STUDIES

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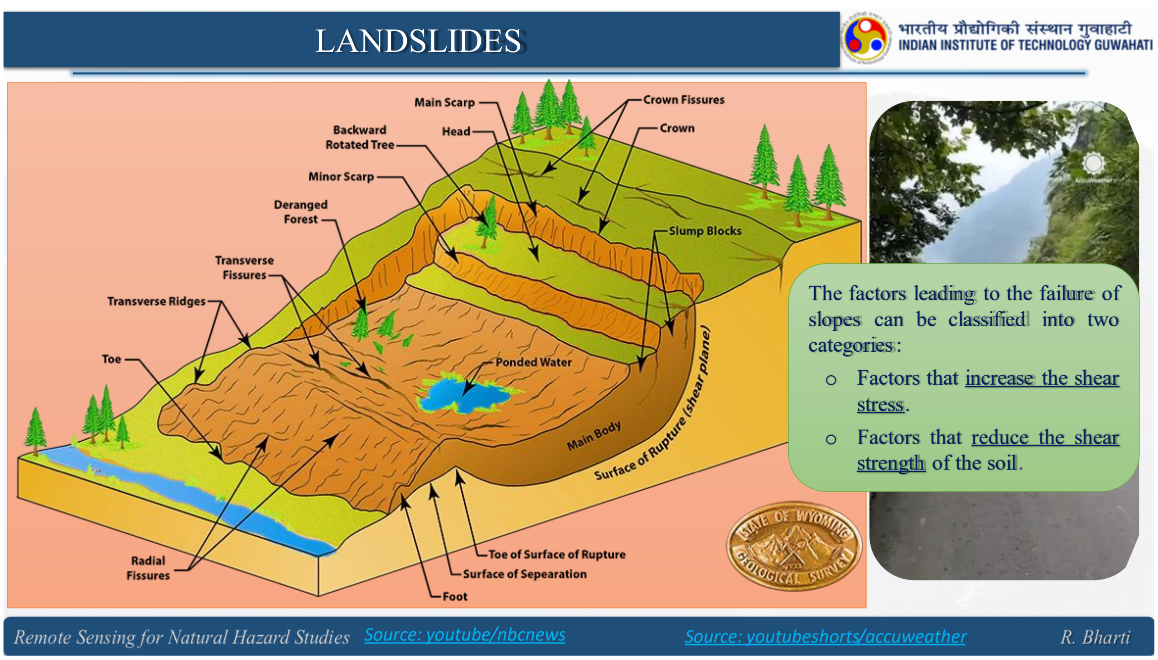
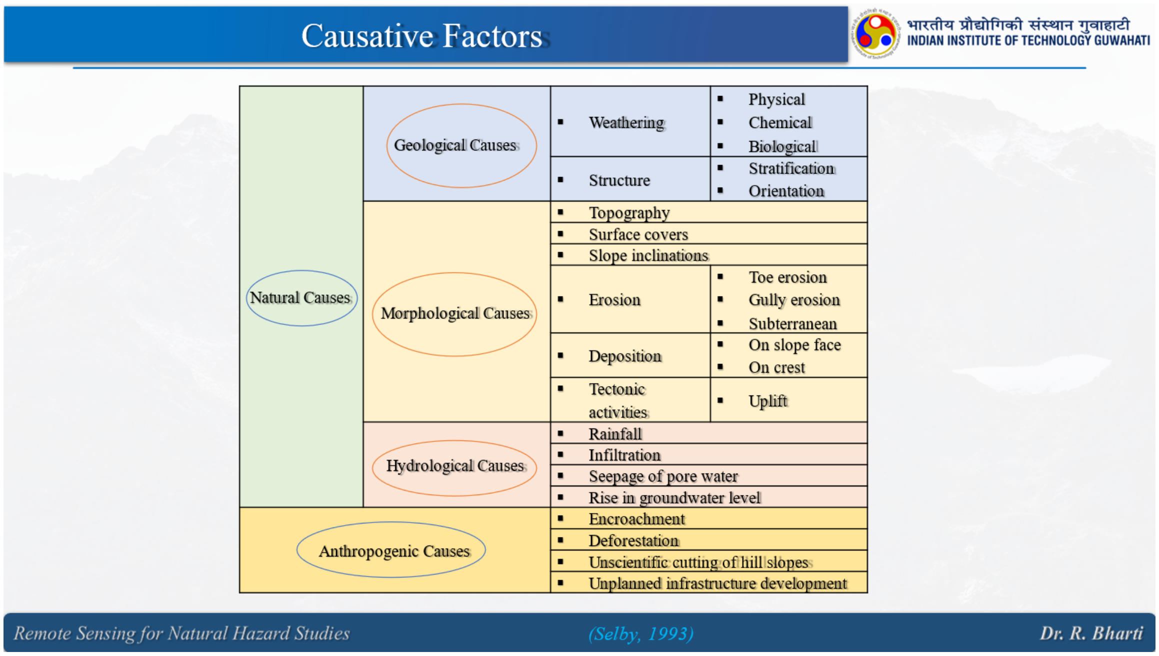
Lec 29a: Remote Sensing for Landslide Studies-I Part A

Hello everyone, today we will continue with module 8, which is on Landslide. So, this is the 29th lecture on remote sensing for natural hazard studies. Before we continue, let us quickly have a look at what we have covered in the last lecture, so that you will be comfortable while continuing this particular topic. So, when we talk about landslides, they are the downward and outward movements of slope-forming material composed of natural rock, soil, artificial fills, or combinations of these materials. So, you have seen these videos where you can easily see the impact of landslides and the scale of the landslides. So, a landslide can be of a smaller scale; it can be of a larger scale.



So, when we see the different components of a landslide, you can see this particular plane; it is the surface of the rupture, and we call it the main body. Now, here you have the crown of this particular line, and then you can see that this particular layer was basically in continuation of this, which has shifted because of the landslide. So, this is known as the head. And this is the minor scar; now this is the ponded water.

It can be present; it cannot be. This is just for the example, and here you have the toes. These are the toes, and this is the surface of the separation. I hope you are following this. All of these are highlighted, so it is very easy to understand, but you need to remember all of these: how to characterize a landslide, what the different features are, how we can identify them in the field, and how to convey our field investigation information. So, when we talk about the landslide, basically, there are two different factors that are triggering this landslide. So, one is shear stress and the other one is shear strength. So, if there is an increase in the shear stress, that will trigger this landslide. If there is a reduction in shear strength of the material, then a landslide will also occur.



So, let us see this in the next slide that we covered yesterday. So, when shear strength is high and shear stress is low, Then that particular slope is in a stable condition. When shear strength is slightly higher than shear stress, that particular slope is in a metastable condition. When shear strength is low and shear stress is high, then that slope is definitely unstable, and we can expect a landslide phenomenon. This particular slide gives you information about the causative factor.

Here, it has been divided into two major categories. The first one is natural causes, and the second one is anthropogenic. But in the field, you will be able to identify whether the natural processes are triggering this landslide or whether it is anthropogenic. But nowadays, human intervention is so high that it is very difficult to segregate or differentiate in the field, which one has played a more important role in triggering the landslide. But you need to understand what the different natural causes are and what the different manmade or anthropogenic causes are.

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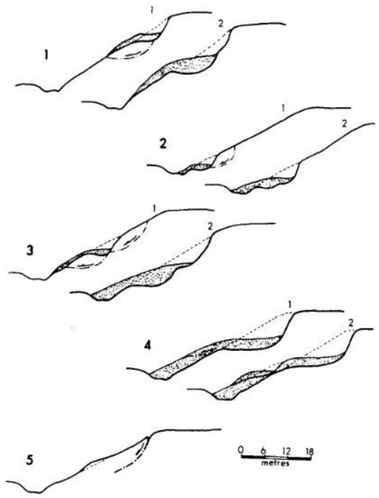
- ADVANCING
- RETROGRESSIVE
- ENLARGING
- DIMINISHING
- CONFINED
- MOVING
- WIDENING



1) Advancing
2) Retrogressing
3) Enlarging
4) Diminishing
5) Confined

So, these natural causes are divided into three categories: geological. And then morphological and hydrological. You can see here that geological causes have the weathering, structural-related errors; then physical, chemical, and biological weathering come under this. In the structure, you have stratification and orientation. Then, when we talk about these morphological causes, we have topography, surface cover, slope inclinations, as well as erosion, deposition, and tectonic activities.

You might have heard about earthquakes. So, during the earthquakes, what happens is that the seismic waves are generated; those seismic waves produce vibrations at the surface, and because of that, uplift can take place, and that will change the slope of the area. When we talk about erosion, we have toe erosion, gully erosion, subterranean erosion, and then deposition on the slope face or on the crest. So, all these are playing a very critical role in landslides. When we say hydrological, we refer to rainfall, infiltration, seepage of pore water, and the rise in groundwater level.

All these will have an impact, which will change the stability of the slope, and subsequently, a landslide can occur. When we talk about anthropogenic activity, we have encroachment, deforestation, unscientific cutting of hill slopes, and unplanned infrastructure development; all these are due to human interventions. So, when we talk about the landslide, how do we classify them? So, there are different ways and different criteria based on which we can classify the landslides. So, here you can see the type of movement, the kind of material, the rate of movement, the geometry of the area of failure, and the resulting deposit. It causes the degree of disruption of the displaced mass, the relation or lack of relation of slide geometry to geologic structure, the degree of development, the geographic location of type examples, and the state of activity.

All these are playing a critical role. So, these are the different bases on which we can classify a landslide. So, we have also seen different types of mass movements. So, here when we have different movements, we have different names for them. So, starting with rotational landslide, then translational, then block slide, rock fault, topple, debris flow, debris avalanche, earth flow, creep, and lateral spread, all are different types of landslides that you may find in the field. So, here in this figure, we explain the rotational landslide, translational slide, block slide, rockfall, topple, debris flow, debris avalanche, earth flow, creep, lateral spread, and we have also discussed the velocity.

If you remember, based on the velocity, we have categorized different types of landslides. Here, these videos are meant to help understand this debris flow. Then you have rotational, translational, creep, rockfall, and topple; all are explained here. I hope you will be able to perceive how the material or the mass is moving, and based on the movement, we have different names for the landslide. And we also discuss the state of activity, whether it is active, suspended, reactivated, inactive, dormant, abandoned, stabilized, or relict.

So, here is the first phase. And this is where you will hardly notice that there were any landslide incidents because, due to natural processes, the slope is stabilized, and there is no relic of landslides on the surface. If you dig here, you will find information about the past landslides. Now, we will talk about the distribution of activities. So, here we have advancing, retrogressive, enlarging, diminishing, confined, moving, and widening.

So, this first one is for the advancing; here you can see the first one. For retrogression, you can refer to this. For enlarging, you have this; for diminishing, you have that. here you have, and the fifth one is confined, which is represented here. So, these are the different types of activities.

So, starting from advancing to widening, you can have different types of landslide activity. So, when we talk about the advancing, the ruptured surface extends in the direction of movement. So, if this is the slope and if this material is failing, then this slope is failing. So, it is extending in the direction of movement. So, it is extending in this direction; continuous triggers weaken the material at the toe.

This is the toe. So, at the toe, there will be a weakening of the material. So, you can see the video here, and you can see this is an example of advancing. So, this particular image will help you understand this advancing phenomenon. So, the rupture surface is extending in the direction of movement. So, this is in this direction, continuous trigger, this is continuously happening. So, it is changing, then weakening the material at the toe here. Now, the next one is retrogressive. So, the rupture surface is extending in the direction opposite to the movement of the displaced materials. I have a very nice video to explain this. Loss of support at the toe is due to erosion or excavation. A weak clay layer is triggering progressive failure. So, this is an example of your retrogressive, and here you can see how this retrogressive failure is taking place. This is the example. The field example here is the zone of the previous landslide, and this is the zone of the second landslide.

So, this was captured in 2013. This is the source of the photograph. When we talk about retrogressive landslides in soft clay. It can be modeled by the Material Point Method (MPM). So, if you want to know more about the MPM method, you can refer to the Wong et al. (2016) reference given at the end of this lecture.

So, in the last slide, I will give you all the details of the references. So, here, Wong et al. have modeled the retrogressive landslide in soft clay. And this is from their paper. Now comes the enlarging of the ruptured surface of the landslide, which extends in two or more directions and grows over time due to new failures forming along its margins, increasing the area. Then the weak clay layer triggers progressive failure. So, here you can see how the enlarging is happening. So, here you can see in enlarging, you just try to look at this particular feature, and in the next image, what has happened is that this particular feature is missing. So, it is because of the enlargement. So, what happens when we enlarge? The ruptured surface of the landslide extends in two or more directions that are very clear here. It grows over time due to new failures forming along its margin, increasing the area. Weak clay layers trigger progressive failure. So, in this example, I hope it is very simple to understand. Then comes the diminishment. The volume of displaced material is decreasing.

So, slowly the volume of displaced material because of the landslide will decrease, losing energy and volume over time, reducing its impact and movement. So, you can see that with time it is losing its energy. And then comes the confined one. So, there is a scar, but no rupture surface is visible at the foot of the displaced mass. So, here in the confined space, you will not be able to see the foot of the landslide.

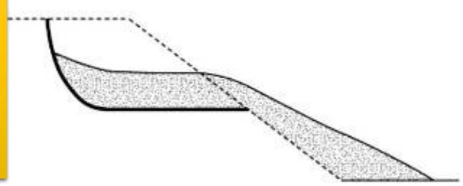
So, that is represented here in the confined line slide; I have photographs that will help you understand this diminishing. So, the volume of the displaced material is decreasing; you just need to try to understand this figure. Right now, it is slowly losing its energy. When we talk about the confined, there is no rupture surface, but a scarp is present. So, here you can see that this particular scarp is present. But there is no toe right at the rupture surface that is not visible here. Now, the moving displaced material continues to move without any visible change in the rupture surface or the volume of the displaced material. So, without any visible change, here you can see this is a case of a moving landslide. Then you have widening; the ruptured surface is extending into one or both flanks of the landslide. The weak side slope is collapsing due to continued movement; erosion at the flank increases instability.

STYLES OF ACTIVITY

- The styles of activity describe how different movements contribute to a landslide.
- Varnes (1978) classified landslides based on whether movement types occur in sequence, different areas, or as repeated events.

SINGLE LANDSLIDE:

- ✓ A landslide that occurs as a single movement without further reactivation or disruption.
- ✓ The displaced material moves as a single block without additional independent movements.



So, here you can refer to this widening slide line. So, these were the different types of distributions of activity. Now we will talk about the style of activity. So, when we talk about the styles of activity, the styles of activity describe how different movements contribute to a landslide. And since 1978, he classified the landslide based on whether the movement type occurs in sequence, in different areas, or as a repeated event.

So, this is very, very important. So, these are the styles of activity. So, when we talk about the first case, here we have a single landslide, a landslide that occurs as a single movement without further reactivation or disruption. So, this is one; then the displaced material moves as a single block without additional independent movement. Then comes the successive landslide multiple failures of the same type occurring at different times, but not sharing a failure surface or displaced material. The failures are independent events occurring in the same area, but without a direct physical connection.

For example, irregular successive rotational slips in clay slopes occur separately but contribute to overall slope instability. So, when we talk about this successive landslide, it is the multiple failures of the same type of landslide. So, when it is happening, we call it successive. So here is an example of a single and successive landslide. So here you can see there is only one. So this is single. Here you can see that there are two similar landslides happening in the same area. So this is successive. Then come the multiple landslides.

So here it is, the case: A landslide where the same type of movement is repeated over time, sharing a common rupture surface or displaced material, occurs. In the previous case, they were not sharing the same rupture surface; they were different. Here, sharing a common rupture surface that is important; if that is the case, we will call it multiple landslides. For example, a retrogressive rotational slide occurs where multiple rotational failures occur progressively upslope, each sliding along a deep common rupture surface. So, in such cases, we will call it multiple landslides.

Then we have the complex landslide, a landslide that involves at least two types of movement occurring subsequently, that is, one movement leading to another. Here you can see that when we are having this slump, the earth flow is also taking place. So, this is the slip surface, and both slump and earth flow are taking place here. So, for example, rock topple, rock slide, initial toppling of rock masses, followed by the sliding of part of the toppled material. So, here you can see this is the initial slump, and here you have the mudslide, and here you can call it a mud flow.

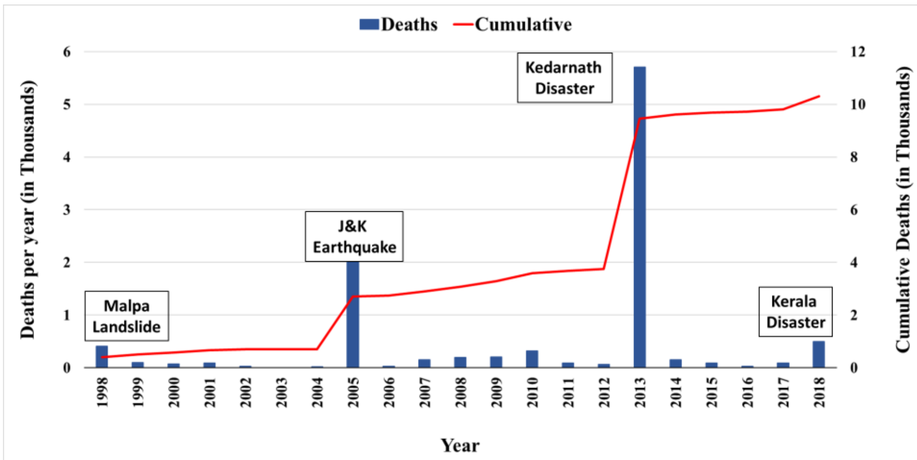
In this case, in the right-hand image, you can see the rotational rock slide; this is the earth flow that is taking place together. So, this kind of activity may take place in nature, and we have different names for it. Then comes the composite landslide, a landslide where two or more types of movement occur simultaneously in different areas of displaced mass, unlike complex landslides, which occur in sequence. For example, slide toe topples occur where part of the slope slides while the toe undergoes toppling.

So, this is a case of composite. So, it is important to note two or more types of movement occurring simultaneously. So, here is an example of a composite landslide. This particular figure is taken from the AGU website. So, this is the address, and here it is showing the multiple landslides from China that occurred in 2019 because of the heavy rainfall. So, you can see how many landslides are present in this particular area. So, this is one case that I wanted to show because you can easily see this kind of field traces in the surroundings. Now, let us see the elements of a composite landslide as observed in the case of the Arbaz landslide. So, here you can see that this is the composite landslide elements and Arbaz landslide. If you do not know, it is a composite landslide located in the mountain range in the eastern part of the Alps, northwest Slovenia. So, here you can see this is the rock face and the incised gully, which is active.

It is important to note that this particular area is the zone of rockfall. And here, this is the zone of sliding; this is the zone of debris flow. So, here, and finally, it is meeting this particular fluvial system, and here you can see the different boundaries. So, this is the typical structure of a composite landslide, and it is mainly from the Arbas Landslide. So, when we talk about the landslide, we also have environmental and other impacts. So, let us see the environmental impact of landslides. Forests, especially in the tropical regions, are destroyed by landslides. This is one of the major problems, and because of the landslide, we are experiencing deforestation. Debris flows are seen to fill and/or erode the stream channel for greater distances. Slumps and earth flows can cause partial to complete blockage of the channel, construct the channel locally, and even cause shifts in the channel configuration. So, there may be a modification in the channel pattern because of the blockage.

So, there may be a new channel formation, and that will change the topography of that particular area. Landslides can destroy fish habitats in the short term. The drinking water sources are also affected by the introduction of suspended sediments and organic materials. So, if there is a landslide here, the people downstream are mainly using this surface water. So, what happened because of the landslide is that there will be more suspended sediment and organic material in this surface water, and that will affect the health of the people.

Impact of Landslides



Deaths caused by landslides in India (1998-2018) *(Data Source: Martha et al., 2021)*

We also have the ecological impact of landslides; landslides change the topography and create erosional and depositional landforms. Landslides create open, exposed sites with more extreme microclimates than the surrounding terrain. The soil properties and texture are changed by the exposure of parent material, the removal of organic matter in the topsoil, and its deposition elsewhere. So, by altering both site and soil, landslides significantly contribute to the evolution of the landscape. So, slowly, things will change here, and this particular topography will be filled with vegetation, and the new topography will take its place.

So, this is a modification of the topography because of the landslide. So, this is the geomorphological change. When we talk about the social and economic impacts of landslides. So, we have direct losses and damage to infrastructure. So, like roads, bridges, buildings, agriculture, and property, that is very common. And we all know that because of the landslide, there may be a closure of roads, there may be problems with bridges, and there may be destruction of buildings.

So, these will be the direct impacts of the landslide. What are the indirect losses? So, we have revenue losses because of the closure of the road and the agriculture-related problems. Then we have revenue losses in the industrial, agriculture, and tourism sectors. If the area is very popular for tourism and if there are certain landslides that frequently occur, people will avoid going into those regions. So, tourism also gets affected because of the landslide. Then, property devaluation, a decline in real estate values, tax revenue losses, reduced property tax collection, and economic costs, such as debris removal and mitigation expenses, will be additional costs to the government.

Then productivity impacts human and animal losses due to injury, death, and trauma. Because of that, there will be direct and indirect impacts of landslides on our lives. When we talk about the landslide risk impact and economic consequences, rainfall-induced landslides are very common and are responsible for 89.6 percent of the total landslide fatalities 14 percent of the monetary losses and 0.53 percent of all natural hazard fatalities are reported by Hidalgo and Vega in 2021. 3.7 million square kilometers of Earth's landmass is highly susceptible to landslides, affecting 300 million people, as reported by Hidalgo. Mondell et al. (2021). Annual landslide-related losses increase from about 50 billion dollars in the 1980s to 200 billion dollars in the last decade. About 914 death per year due to rainfall-induced landslide. Here, you can see this is from this particular report. why am I showing you all this information that landslide is a major problem of any country, and we have to be very careful, and we have to start studying the landslide very systematically.

So, there are very good literatures which are available for our references. So, that is why I am referring some of them here to provide you more information about the landslide, starting from basic to the advanced level. Now, slowly we will go into the different risk assessment and also the real-time early warning system how we can establish them. So, when we talk about the population affected by landslide in different region between 1903 and America, Asia, Europe, Oceania, here you can see the total affected number of homeless, number of affected number of injured total deaths. So, the number is huge that means we have to be very, very cautious, and we have to start looking at this particular problem the landslide hazard, as a multidisciplinary approach. So, one particular field cannot solve and cannot provide all the information. So, we have to join together, and then we have to start looking at the landslide hazard as a multidisciplinary problem. 4.2 lakh kilometer square area is part of 19 states or UTs are vulnerable to varied landslide hazard.

This is published by the Geological Survey of India. This affects parts of 179 districts, 8 percent of the global landslide fatalities that is in India that is by Ram and Gupta 2022. Average annual landslide deaths are 847. and average annual financial losses are around 0.3 billion dollars for India. So, here you can see some of the examples of landslide how it is affecting, and these are from India.

This is from Dima Hassan Assam, this is in the north eastern part of India. Then here you have rainfall induced landslide from Munnar, Kerala, and here early warning system has been installed, and I will be showing you some of the examples. Impacts of landslides, so here you have the number of deaths in India, so 1998 to 2018, it is from Martha et al, 2021. So, when we say this Malpa landslide, it is one of the major landslide. So, here in the x-axis, you have years. y-axis, you have deaths per year in 1000, and here in this axis you have cumulative deaths in 1000s.

So, this Malpa, then you have J and K earthquake, then you have the Kedarnath disaster. So, how the numbers are increasing day by day. So, we have to be very very careful while analyzing and when we are talking about the early warning system for landslide hazard. So, here you can see this is the map from the Geological Survey of India. So, it says the susceptibility map, the landslide susceptibility map, and here there are three colors which have been used, the yellow is used for low, green is moderate, and orange or red is for high. So, all the pixels which are here in red colour that is showing the high susceptibility zone.

The green color says the moderate susceptibility zone, and the yellow is the lowest susceptibility zone. So, we can also call it the lowest or maybe the safer compared to the other 2 categories. This is from one paper, which is Sharma et al, 2024. So, here you can see the landslide susceptibility map for India, and here. it is divided into very high, high, medium, low, very low, and this red one is the highest class, the highest probability zone, and the blue one is the very low probability zone.

So, with this, I will end the part 1 of lecture 29, and I will be continuing this lecture in part 2. Thank you, thank you very much.