REMOTE SENSING FOR NATURAL HAZARD STUDIES

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Lec 30b: Remote Sensing for Landslide Studies-II Part B

Hello everyone, welcome back to Lecture 30; this is part 2. So, we will continue our discussion. So, here you can see these two images, and both are of the same area. So, this is an optical remote sensing image. So, here you can see we can identify that there is some deformation, but when we look at this LiDAR imagery, we notice it clearly. So, this is very evident that these areas are under a particular landslide, whereas here it is very hard to identify the boundary, but here you can easily demarcate their boundary.

So, once you do that, you can also identify this flow, which was not possible in the reflective domain of images. But when we talk about this LiDAR information, it can be done using a UAV, and here you can see this is a vegetated area, and because of the vegetated area, this information is covered in the normal satellite images. So, the rapid mapping of landslides in the Western Ghats of India triggered by the 2018 extreme monsoon rainfall using a deep learning approach.

Remote Sensing for Landslide Studies

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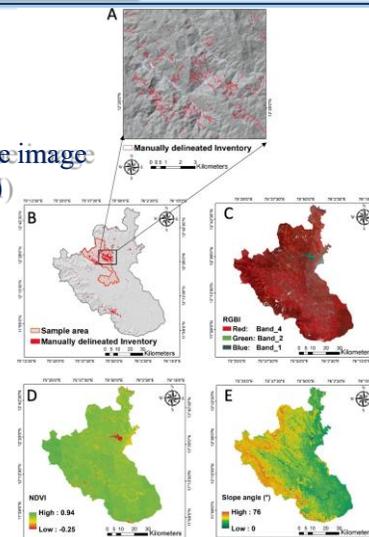
Input data used in the study:
- ✓ Manually delineated inventory
- ✓ False Color Composite (FCC) of the Planet scope image
- ✓ Normalized Difference Vegetation Index (NDVI)

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

Where,
NIR – Reflectance in Near Infrared band
Red – Reflectance in Red band
- ➤ Slope map generated from the DEM

Remote Sensing for Natural Hazard Studies   *Meena et al., 2021*   *R. Bharti*

So, this is done by Meena et al. 2021, and here you can see this is the study area and this

is the landslide we were talking about. So, this is from Karnataka, India; the convolutional neural network (CNN) is used to detect the landslide, and here they have used the 3M PlanetScope Dove optical image and 12.5-meter ALOS PALSAR. So, these were used in this particular study, where they manually delineated the landslide, the false color composite of the PlanetScope image was used, and then they used the normalized difference vegetation index (NDVI) that I have already discussed with you.

So, here you can see that this map shows the sample area. So, this is the sample area and the manually delineated inventory that is in red color. This is the RGB of that image, this is NDVI, and this is the slope map; here, the minimum is 0 and the high is 76. So, this slope map is used further. Now, based on the input and the CNN method, they have detected the landslide, and this is the automated one; this is the manual one.

So, you can see that manually it is going above this, so that means this is underestimating the landslide area. So, they have also identified true positives, false positives, and false negatives, and this kind of images will provide you with more accurate results, which will justify that whatever result you have produced is of use. In this particular map, the results of the CNN model are enlarged. Showing the detection of true positives, false positives, and false negatives in the testing area. So, this A is the forest area, B is the nearby road network and hilly terrain, and C is your nearby built-up area, and how these true positives, false positives, and false negatives are coming.
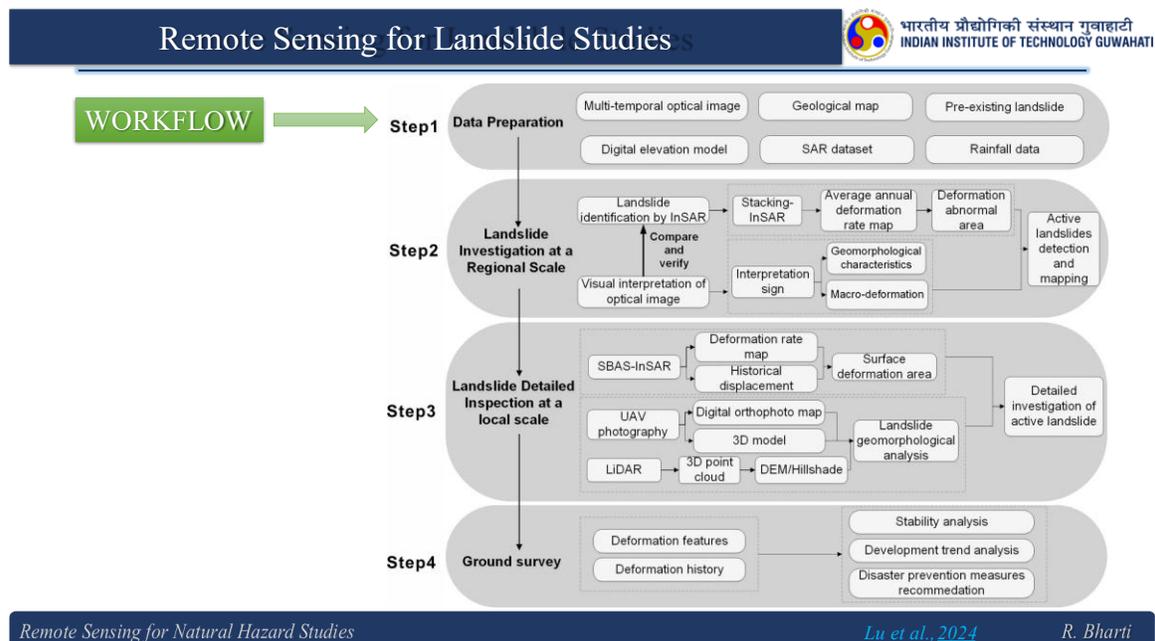

Then we will talk about another study: this is active landslide detection using integrated remote sensing technology for a wide region and multiple stages, a case study in southwestern China. So, here you can see that the elevation value is from 89 to 7416. And this shows the boundary of the study area. So, this is the boundary of the study area, and

the blue color indicates the key area. This is the key area, where the green color represents the river, and the major fault is represented by the black line.

So, this XSF, ANF, and YBF are the major faults present in this particular area and its history of earthquakes. So, earthquakes of different magnitudes greater than 7 are represented by this size, which is for 6 to 7, then 4.5 to 6, and then less than that. This map provides you with information about the seismic activity in the study area. So, situated in a rare topographic change gradient caused by these major faults, this area is also a highly seismically active area utilizes different remote sensing techniques in active landslide detection on a regional and local scale. So, this is the workflow that they have followed. So, first was the data preparation, then they had the landslide investigation at a regional scale, and then they did the detailed landslide inspection at the local scale. And then conduct a ground survey because you need to validate the information derived from your remotely sensed images regarding the landslide. So, if you go through this, you will be able to understand how they are following this methodology.

Then, the regional scale average annual deformation phase map along the LOS radiance. The figure provides a closer examination of seven deformation hotspot areas, highlighting numerous deformation anomalies within each area. So, you can see that I have marked it with different colors. So, you see, this circle will appear. So, this is A. Then you have B, then you have C, then you have D. So, these are the enlarged ones, and then you have E. So, these are listed here: A, B, C, D, E. The local scale LiDAR-based validation for active landslide mapping. So, here you can see that the A in this map is the LiDAR data and mapped active landslides along the highway from Lee County to Mao County. And B to D here, this B to D is the detailed result of the landslides. From left to right: optical remote sensing images, lidar-derived DEMs, stacking InSAR annual deformation phase results, and the SBAS-InSAR annual deformation rate result. So, these four are here. This is for the Tonghua landslide. So, this is the Pt 1, Pt 2, and Pt 3 time series deformation rate with precipitation. So, you can see the precipitation is here; this is the displacement, and this is the time or date. Here you can see this is Pt1, this is Pt2, and this is Pt3. So, how are they changing when you have a different amount of precipitation? The displacement is changing. So, this is in respect to time. Now, we will talk about landslide susceptibility mapping.

Different Methods Adopted in Landslide Susceptibility and Hazard Zonation
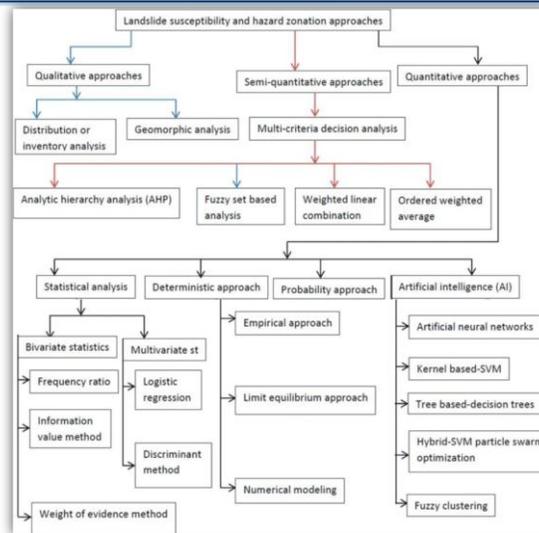
The process of identifying and spatially delineating areas prone to landslides based on terrain conditions, environmental factors, and historical landslide occurrences. So, here method that is used here. So, here the first one is the statistical method; you can go for logistic regression, discriminant analysis, etc. When we talk about the index-based method, weight of evidence, and frequency ratio, these methods can be used. Now, as I said, remotely sensed images have the option to be used in your machine learning algorithm.

So, you can use fuzzy logic, decision trees, support vector machines, neural networks, etc. Then comes the multi-criteria decision analysis, the AHP. So, here you need to have the field information; then this AHP will give you a very good result. This is the flow of different methods adopted in landslide susceptibility and hazard zonation; here, you can see the landslide susceptibility and hazard zonation approach. So, you start from the qualitative approach, then the quantitative approach, and there is the semi-quantitative approach.
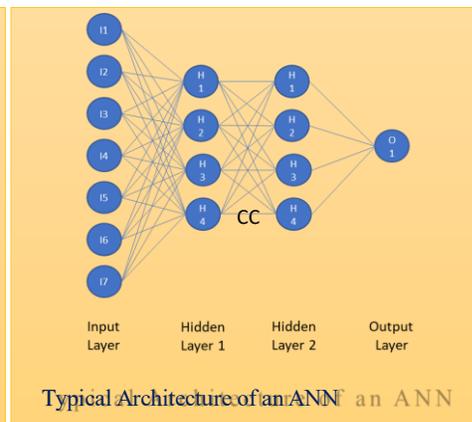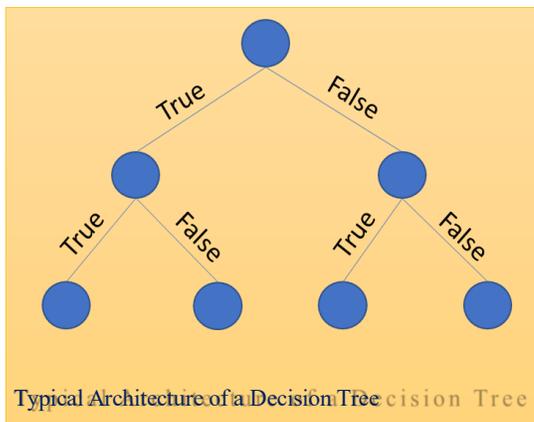
So, then we can have the qualitative, quantitative, and semi-quantitative. So, all these can be done with remote sensing images because you will be surprised to know that many of the parameters that are being used in landslide studies are generated with the help of remote sensing. So, that is why all this analysis can be done in the spatial domain. When you restrict yourself to the ground information and the conventional method, then those will be the point scale information. But when you incorporate remote sensing, it will cover a larger area, and we can call it spatial domain analysis.

When we talk about the machine learning method in LSM, the ML algorithms can learn the relationship between landslide occurrences and conditioning factors without requiring a predefined structural model in the dataset. So, what happened? Let us consider this as the study area. We know that all these points are the historical landslide events in this particular

region. Now, you want to analyze whether this x has the potential to fail. So, what we will do is generate all the parameters with the help of in-situ investigation or maybe from remote sensing that will be collected, and we will generate a database.

Then we will use machine learning, and in machine learning, the system will learn that if this particular location has failed in the past, what the different parameters are. So, based on that, it will generate a set of relationship for all these historical points. And on that basis, it will evaluate this particular location to determine whether it has the potential to fail or not. So, this machine learning algorithm can learn the relationship between landslide occurrences and conditioning factors without requiring a predefined structural model in the data, because you are defining the relationship now, and here we have some assumptions. So, the first one is that future landslides are more likely to occur in areas where past slope instabilities were triggered by similar conditions. Factors directly or indirectly associated with slope failure can be utilized to develop a predictive model for landslide spatial occurrences. This is what I discussed. So, here you will have factor analysis, then you will have model building, and then you will have the testing and validation step. What are the different advantages of machine learning? So, the ability to capture nonlinear relationships is important because when you use simpler models, they will not be able to correlate a number of parameters and their relationship with this slope failure, but when we go with machine learning. Here, you will have the opportunity to utilize all the historical data sets as well as different parameters, and then a new set of relationships will be generated.

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Typical illustration of some of the commonly used Machine Learning methods

Typical Architecture of a Decision Tree

Typical Architecture of an ANN

Higher accuracy and generalization in ML provide objective results with higher accuracy by learning from large datasets. So, here in the historical data set, the number of points should be large; then only will your machine learning help you. Better handling of large and high-dimensional data can efficiently manage and progress with higher-dimensional

data and identify important features. Because when you are talking about the parameter that is triggering the landslide. Here, the list is not limited to 5 or 6 parameters; it can be 10, 15, or 20, depending upon your area, and that can be used in machine learning, which will handle your high-dimensional datasets. Adaptivity and automation, the ML model can be updated and retrained for new data, making it adaptable. If you have generated an ML model for landslide studies for area X, a similar model can be used for area Y, depending on the retraining. You retrain your algorithm, and then your model will be able to predict. Integration with remote sensing and GIS can be integrated with a wide variety of remote sensing data and GIS, improving susceptibility mapping. So, when you have high-dimensional data in the spatial domain, you will have better predictions. This particular slide provides information about the landslide causative factors generally used in LSM studies. So, here you can see the slope, aspect, elevation, land use, land cover, distance from lineament, lineament density, distance from fault, distance from road, NDVI, relative relief, geomorphological map, drainage density, distance from drainage, TWI, SPI, and rainfall. The earthquake information includes the historical points. All of these can be generated from remote sensing, and your analysis can be done in the spatial domain. A typical illustration of some of the commonly used machine learning methods.

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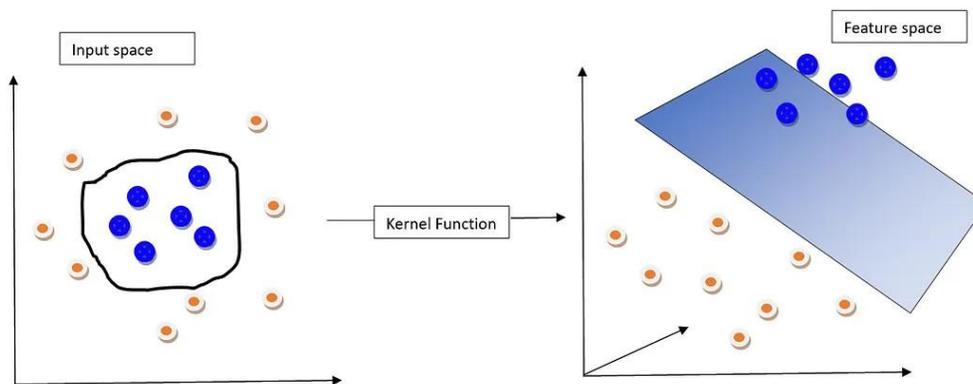INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

Illustration of Support Vector Machine:
Transforming non-linearly separable data in input space into a higher-dimensional feature space for linear separation

So, I hope you have seen this kind of diagram many times. This is the typical architecture of a decision tree; this is the typical architecture of an ANN. And this is for the support vector machine. So, what happens when you have 2 groups of information and want to segregate them? So, in that case, the support vector machine will help. So, it will try to generate a plane that will separate this dataset from that dataset, which is possible with the support vector machine. Transforming non-linearly separable data in the input space into a higher-dimensional feature space for linear separation. So, this is very good for separating

2 pieces of information with respect to the landslide studies into 2 different groups, and that will be able to classify your data set. And in machine learning, different matrices are being used. So, various performance metrics are derived from the confusion matrix. Including overall accuracy, specificity, sensitivity, F score, and many other methods is used.

Area under the ROC curve, known as AUC, then you have the objective function OF, then you have the kappa coefficient, and then you have the reliability diagram. So, all of these are used to test your information or to validate your results that are being generated from the ML methods. Now let us talk about the landslide hazard assessment using the analytical hierarchy process (AHP), a case study from National Highway 5 in India. Here it is, from Calcutta to Simla. This highway faces frequent landslide events in the monsoon season.

Landslide hazard assessment is performed using the Analytic Hierarchy Process. So, this is from a particular publication. So, you can see the methodology they have used: the ASTR DEM, Google Earth maps, field information, soil map, and the ASTR DEM can provide you with the slope, aspect, curvature, relative relief, and TWI. Whereas this Google Earth and field data are used together for the landslide inventory. Then we have the validation of the landslide hazard map, and here the soil map will provide you with the geology, lithology, fault density, drainage density, and distance from the road; all of these are used together. And then it goes to the AHP. So, all of them are going to AHP; they have derived the landslide hazard map, and they have validated it. This slide provides you with the input slope, aspect, curvature, fault density, drainage density, relative relief, geology map, lithology, distance from the road, and TWI, all of which are in the spatial domain. And then they have used this together in the AHP, and they have derived this landslide hazard map. So, this green color is low, this light green is moderate, orange is high, and red is very high. So, along this highway, you can see how the distribution has come, and then they have used the AOC training and testing that will help you justify your results.

In the next study, it is ensemble random forest with SVM, ANN, NBT, and LMT for landslide susceptibility mapping in the Rangit River watershed of India. So, this is the study area. This is the flowchart that they adopted. So, here you can see these are the landslide conditioning factors. So, that is your input: slope, elevation, aspect, profile curvature, solar radiation, hillside, relative relief, drainage density, NDVI, LULC, lithology, and rainfall. Then, the distance to the road and the distance to the river that is being used. Then, the landslide inventory and these are used together for the selection of landslide conditioning factors, and this is going into the further model. So, finally, they have used the support vector machine, artificial neural network, Naive Bayes, and logistic model tree. They derived the landslide susceptibility map, validated the results, and used the ROC and other statistical metrics for validation. In their study, they used the DEM from USGS, which is the scale, and this is the output type.

An ensemble random forest tree with SVM, ANN, NBT, and LMT for landslide susceptibility mapping in the Rangit River watershed, India

✓ Rangit River watershed, Sikkim, India

✓ Ensemble Random forest tree with popular ML algorithms to generate LSM for the area
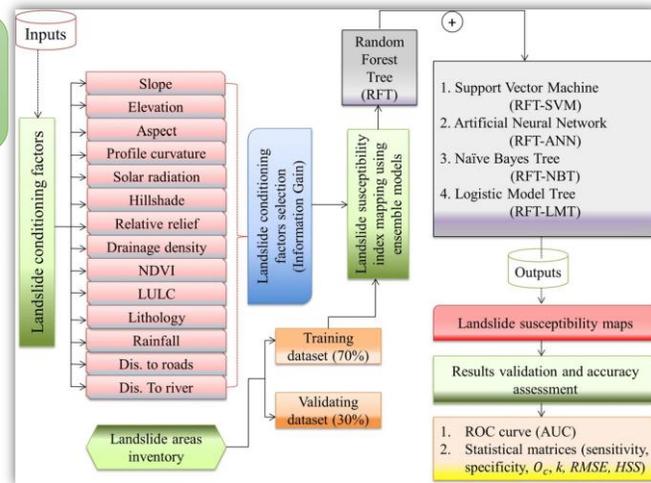
So, here you can see the complete details of where they have collected the different parameters or from where they have generated these parameters for the landslide studies. And this is the landslide inventory map. Here you have a landslide training data set and a landslide validating data set, and the altitude varies in this region between 313 and 3044 meters. Here are the results corresponding to the support vector machine and artificial neural network. And then you have the naive Bayes tree and the logistic model tree that is given here.

So, all of them are having similar results, but these are not the same. So, how do you define or justify which one is better? So, for that, you have to perform the accuracy assessment, and based on that, you will be able to comment that a particular model is performing well for my study area. In this condition, you see the AUC is almost comparable to 0.970, 0.977, 0.976, 0.978. So, in this case, it is very difficult to say that this particular model is better. When we go for the landslide monitoring, continuous observation, measurement, and analysis of slope movement to detect potential failure, assess risk, and develop an early warning system are necessary. Types of landslide monitoring include surface monitoring, where we conduct field surveys, use GPS, total stations, and remote sensing to track surface deformation. Then comes the subsurface monitoring, installing sensors like inclinometers, piezometers, and borehole extensometers to measure internal slope movement and groundwater pressure changes. Then, remote sensing-based monitoring, satellite-based, SAR-based, optical remote sensing, and LiDAR data sets are all used.

An aerial or UAV-based measurement drone with thermal, multispectral, or LiDAR sensors for high-resolution monitoring. Then comes the geotechnical and hydrological monitoring, which uses instruments to measure soil moisture, pore water pressure, and seismic activity. Real-time monitoring and early warning system, automated network

integrating sensors, IoT-based or AI-based for continuous data collection. So, this slide will provide you with information about how a satellite image looks at a particular landslide, whereas ground-based interferometry, or GB INSAR, is used, along with ground-based LiDAR and Doppler radar; all of these are utilized. So, here it is toppling. So, in this case, Doppler radar will help. So, how different types of remote sensing are being used for different types of landslide studies? So this is concise information about the remote sensing techniques. and the sensor type, platform, and key application. So, here you can see the interferometric SAR. So, this is basically radar interferometry; there are different sensors available from space, and it is good for detecting slow-moving landslides and measuring millimeter-scale ground deformation. When we talk about the GB-InSAR, it is a real-time monitoring system for unstable slope early warning of critical deformation. Then GNSS or GPS monitoring continuously tracks ground displacement, providing an early warning system. Then, light detection and ranging, this is LiDAR, high-resolution surface change detection tracking pre- and post-landslide deformation; then comes the UAV-based or drone-based. So, rapid response for landslide monitoring, detection of surface cracking, and movement trends.

Then, thermal remote sensing is used, so here there are a few thermal remote sensing datasets available in the public domain, and they are used for identifying temperature anomalies related to groundwater flow and potential slope failure. So, there are different types of remote sensing for different types of applications. When we combine different approaches, it will provide you with a better opportunity to study a landslide event. So, here it says the combination of GNSS, satellite INSAR, and GB-InSAR remote sensing monitoring improves the understanding of large landslides in high alpine environments. So, here is one study from Carla et al. (2019) and the deformation field of the Bosmatto landslide, Italy, that was generated. Geomorphological observations were combined with monitoring data from the following remote sensing system. So, I have been reading for 3.5 years at 2 permanent GNSS stations, 13 years of reading manually operated GNSS stations, 3.5 years of INSAR data from Sentinel-1, and 8 months of measurements from a GB INSAR. So, you can see how dedicated the researchers were to collect the data, and then they studied the landslide. The time series of displacement is measured by GNSS. So, here you can see that from October 2002 to April 2015, this horizontal displacement is a millimeter, which is around 900 or 900 something. When we talk about the vertical displacement, we refer to the same timeframe, which is approximately in the order of 500 millimeter.
 So, here this is what they have generated: deformation by satellite SAR, and this is the cumulative deformation by GBInSAR. Please provide a sentence for correction. So, how beautifully they have integrated all the information to study landslides. So, this is what is needed: you have to have the dedication to study a particular landslide event.

In Hong Kong, the landslip warning system has seen 40 years of progress. So, here you can see it was established in 1977; this is the world's first territory-wide LWS. Warnings were delivered for about 90 percent of the time there was a fatal landslide. Widespread rain gauge network with 122 rain gauges at a density of 10 kilometers squared per gauge. So, here you can see how beautifully they have distributed this, and all this information is available in their paper. This is Kong et al. 2020. And here is the rainfall forecast made using short-range warnings of intense rainstorms in a localized system. So, here this is at 1 hour. So, this is from 3 to 4 pm, this is from 3 to 6 pm, and here they have also generated the correlation between landslide frequency and rolling 24-hour rainfall data. An example of forecasted landslide occurrences alongside cumulative rainfall curves used for issuing landslip warnings.

So, here you have the cumulative rainfall, the predicted number of landslides, and the date and time. This study is from India; it is the Amrita LEWS site in Munnar, Kerala, and it has been established in 2009. The key landslide types where the debris comes are earth slide, complex landslide with retrogressive movement, creep landslide, and debris flow. And the triggers were long-duration medium to heavy rainfall, changes in LULC, and anthropogenic activities in this area. A deep earth probe was used at this site to monitor the parameters in the field. The Deep, integrated with the IoT system for edge analytics, real-time communication, and powering the whole system, is known as the Intelligent Wireless Probe. The DEP is integrated with sensors such as rain gauges, moisture sensors, pore pressure transducers, strain gauges, and tiltmeters, etc. So, these are some of the photographs available in their paper. They have used the support vector machine, which is an adaptive learning methodology that integrates historical and near real-time data for slope condition forecasting 24 hours in advance. The algorithm is designed to function even in the absence of real-time field data due to unforeseen circumstances. In such cases, it utilizes rainfall forecast data from the IMD to maintain prediction reliability. So, they are also taking the input from IMD in parallel. The forecasted slope conditions are used for risk evaluation and risk control, enhancing the early warning capabilities of that system. So, this is their website.
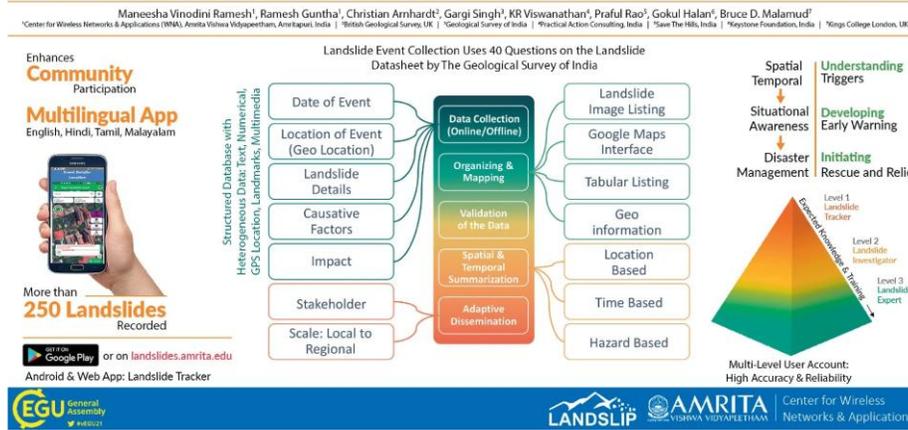
So, you can refer to that, and this app is also available on Google Play. So you can try that. So, when we talk about the early warning system, basically, it has a few components that are very critical: risk knowledge, monitoring and prediction, dissemination of information, and responses. and all of them play a significant role in reducing the loss of life and movable property. And remember, as we discussed earlier, if the failure of any part of the system implies the failure of the whole system. So, an early warning system should have all these components; only then does it qualify to be called an early warning system.

So, with this, I will end my lecture here. Module 8 is over now. We will continue the course with different hazards, and these are some of the references that have been used in this lecture. So, you can see that if you are interested, you can use these for reference.

Thank you. Thank you very much.