

## REMOTE SENSING FOR NATURAL HAZARD STUDIES

**Course Instructor:** Dr. Rishikesh Bharti  
Associate Professor  
Department of Civil Engineering  
Indian Institute of Technology Guwahati  
North Guwahati, Guwahati, Assam 781 039, India  
e-mail: rbharti@iitg.ac.in  
Website: <https://fac.iitg.ac.in/rbharti/>

---

### **Lec 16b: Remote Sensing for Floods- I Part B**

Hello everyone, welcome back to Lecture 16. So, we will continue discussing the important factors that are involved in flood studies. So, let us talk about the rainfall data. So, in general, automated weather station (AWS) and river gauge data are used in GIS to generate a spatial rainfall map. Because when we refer to remote sensing-based analysis, we are always involved in the spatial domain. We are not doing this for a point location; we are doing it for the entire watershed. So, in such cases, we also need this rainfall data for the whole area. So, we try to utilize the in situ measured or possibly remote sensing-based information, which is derived to generate the rainfall map for the entire study region. So, the estimation of the precipitation has different sources. So, one can have a network of rain gauges, then a ground-based radar system, then we have rain estimation from models, and then remote sensing datasets.

So, geomorphology and geohazard maps help to assess geological structure and infiltration rates influencing surface runoff. Drainage patterns reflect both surface and subsurface geological formations, particularly lithology. So, the lithology is very, very important as it will provide you with information about how a natural drainage system will be formed and what the percolation capacity of that particular region is. Drainage patterns also reveal geomorphic characteristics and landform evolution due to structural and morphological changes. This is very, very important to include.

Then comes the drainage density. So, you might remember that this kind of map can be generated using remote sensing and GIS. So, you can either go for the automated methods to extract the river channels or the streams, or you can also opt for manual delineation. So, once you have that, you can calculate the density. So, drainage density analysis performed using DEM data integrated into a GIS system supports the evaluation of runoff potential and terrain infiltration characteristics.

So, this kind of map can be generated, and remember, again, we are talking about the spatial domain. So, for the entire watershed, this information will be available. Now, the next factor is the land use and land cover. Influence infiltration, because based on the land use and land cover, how we are utilizing it and how we have divided the area will decide

whether that particular area will have the percolation capability or not. So, LULC influences infiltration, evapotranspiration, surface runoff, and water storage capacity.

Because if the area is getting urbanized, then it will be losing its percolation capability, as generally we opt for paved surfaces, And the evapotranspiration of the area is not having very good vegetation cover or is not exposed to sunlight, then the behavior will be different for this particular reason. And then, the drainage congestion caused by that surface runoff will generate waterlogged areas. So, water storage, water logging, surface runoff, evapotranspiration, and infiltration are all connected with land use and land cover. High priority is assigned to agricultural land and water bodies, and low priority to settlements and barren land that are in the flood studies. Changes in land use and land cover due to human activities or anthropogenic activities, the hydrological cycle, and increased flood risk are significant.

So, because of this, there will be an impact on the hydrological cycle, and the flood risk will be increasing. Urban expansion and population growth are key contributors to flood vulnerability, and so, LULC reflects natural characteristics and human activities affecting groundwater presence and development because it also defines what the population is in that particular area. So, this LULC is an indirect way of identifying, or it will give you an idea of how the surface and subsurface waters are being utilized in this particular region. So, this is one example; this is a land use land cover map generated for India. So, LULC categories include water bodies and mud land.

Vegetation, settlement, arid terrain, and shrub cover that are available in this category or this classification. So that you can assign the weightage to each of these while analyzing them. Then comes the soil map, which is one of the very important factors that are affecting the water infiltration and surface runoff. Because if you remember, we discussed that if you have different types of soil columns, you will have different amounts of percolation, or they have different capacities to hold water, So, in such cases, it will have direct impact on the flood. Soil supplies essential nutrients, water, oxygen, and root support for plant growth, and if your soil is fertile, then for that particular reason you will have more vegetation, and the vegetation has a positive impact on reducing flood events.

They act as a buffer protecting plants' roots from extreme temperature variations. So, in such cases, they will be supporting the vegetation to sustain itself in that particular region even during a non-monsoon period. Understanding soil characteristics is crucial for assessing water flow and flood potential. Now the elevation comes. So, we have already discussed the digital elevation model. So, I hope you will be able to easily understand this. Elevation influences flood risk by directing stream flow and altering soil and vegetation characteristics. Low-lying areas, especially near rivers and in the lower Gangetic plain, are more vulnerable to flooding, because you will have a high velocity. Water naturally flows from higher elevations and accumulates in lower regions, increasing flood potential.

So, this is when we talk about the slope. So, let us take this example: you have the elevation, and once you have the elevation, you can easily calculate the slope because the slope is the first derivative of the elevation. And once you have the elevation, we have this kind of map that can be generated in GIS. And here you will have a different slope angle. Slope or gradient refers to the steepness and direction of a land surface. Steep slopes prompt faster overland flow, reducing water infiltration and increasing runoff. Maybe your soil is good at infiltrating the water, but because of the high slope, it will not have the time to percolate; it will act as surface runoff. Slope plays a critical role in flood risk and water distribution across landscapes. Then comes the plan curvature; plan curvature measures slope variation in a specific direction and indicates flow patterns. So, here you can see the plan's curvature.

It provides valuable geomorphic insight that helps understand terrain behavior and how it will behave during a flood event. Negative curvature indicates concave surfaces, 0 curvature indicates flat areas, and positive curvature indicates convex areas. So, this shape can give you an idea of whether it will hold the water temporarily or immediately release the extra water coming from upstream, which will help you decide or model this particular area correctly. So, this is what is written here: it helps to assess water flow tendency and the potential for water accumulation in this particular zone. Now comes the stream's density.

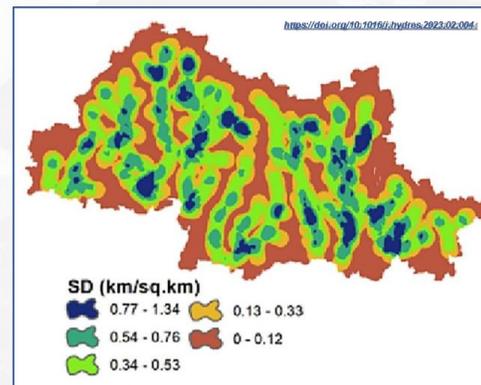
## FLOOD CONTROLLING FACTORS



भारतीय प्रौद्योगिकी संस्थान गुवाहाटी  
INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

### STREAM DENSITY

- Stream density is a key factor in assessing surface runoff and flood risk.
- It is defined as the total length of streams divided by the area of the catchment.
- Stream Density =  $S_{\text{length}} / C_{\text{area}}$
- Higher stream density indicates more drainage channels, leading to quicker runoff.
- It reflects terrain permeability and is a major flood-causing factor



So, we have also seen in the previous lecture that the stream density can be calculated using remote sensing data. Stream density is a key factor in assessing surface runoff and flood risks. It is defined as the total length of the streams divided by the area of the catchment. So, it is for the per unit area, so stream density can be calculated; higher stream density indicates more drainage channels leading to quicker runoff. If you have more channels available in that particular area immediately after a rainfall, it reaches that particular zone

and flows downward, it reflects terrain permeability and is a major factor causing floods. Then comes the flow direction. So, flow direction will help you determine the path and accumulation of water across a surface. So, here you can see that the flow direction is given, and these colors are used for different directions. So, it represents the direction in which water will flow out of each pixel based on the terrain elevation. The flow accumulation values at a pixel are the total of all upstream flow entering into this particular zone.

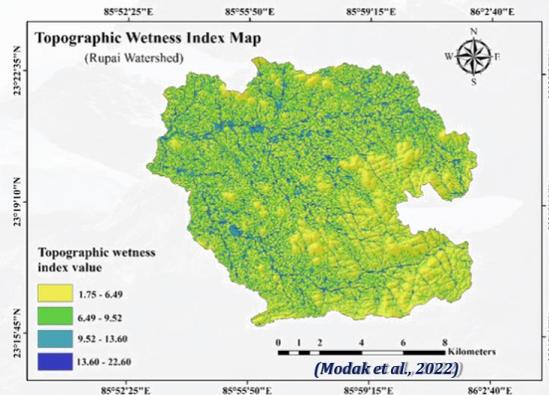
GIS tools are used to compute flow direction, which is crucial for modeling water movement and flood zones. Because once you use all these parameters, your prediction and modeling will be very, very accurate, and you will be able to save more lives and property. Then comes the distance from the river and road for a particular settlement. You can calculate how far it is from a particular river and how much time it will take if there is a flood event. Areas closer to rivers are at higher risk of flooding, especially during heavy rainfall and river overflow.

Water naturally flows from higher elevations to lower areas, accumulating near riverbeds, creating floodplains. Flooding usually starts in the river and spreads outward, affecting nearby low-lying areas first. So, because of that, the distance from the river and the road, and especially the topography, the slope, and the aspect—the aspect is the direction of the slope. So, the flood risk decreased with distance from the river. So, you can give low weight to the distant places from a river.

Roads are often built on elevated or stable terrain, making them less prone to flooding. So, that can be one key indicator of whether your area will have flooding or not. Areas near roads generally have lower flood risk compared to areas near rivers. In flood planning, both river proximity and road locations are used to identify safe and unsafe zones. Tools like GIS and Euclidean distance analysis help to map how far each area is from rivers and roads. This is very easy because we are talking about the spatial domain, and in the spatial domain, you have x, y, and z. This z can be your slope, z can be your satellite images, it can be a DN number, or it can be rainfall. So, everywhere you go, you have the location. So, if you know the latitude and longitude, you can easily calculate how far it is; distance is not a big issue here. Then comes the topographic wetness index.

### TOPOGRAPHIC WETNESS INDEX

- TWI is calculated using the formula:  $TWI = \ln(a / \tan \beta)$ , where  $a$  is the catchment area and  $\beta$  is the slope angle.
- The slope determines gravitational water movement, while the catchment area reflects potential accumulation.
- The selection of the flow direction algorithm significantly impacts the correlation between TWI and soil moisture.



Now, these are some of the indicators that we will be discussing. How are these used in flood studies? So, this topographic wetness index evaluates how topography influences runoff generation and water accumulation in a drainage basin. It reflects the balance between the slope and the upstream contributing areas, influencing soil moisture content. So, basically, we are talking about wetness; topographic wetness means the wetness of the surfaces. So, TWI is particularly important for flood risk assessment, especially in semi-arid regions prone to flash floods. And it is used to study spatial variability in soil properties like organic matter, texture, and nutrient levels because indirectly they will be feeding these plants, and that will act as one of the restrictions to this flood. TWI is calculated using the formula, which is given here and here.  $A$  is the catchment area, and  $\beta$  is the slope angle. The slope determines gravitational water movement while the catchment area reflects potential accumulation. So, here you can see one example of the topographic wetness index value, and here you can see that different values are classified into different groups, different zones.

### VEGETATION AND WATER INDICES

- Indices like NDWI and NDVI simplify flood detection.
- NDWI enhances water detection using green and NIR bands.
- NDVI identifies vegetation, which behaves differently from water spectrally.
- Combining indices improves flood map accuracy across land types.

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$$

$\rho_{NIR}$  : Reflectance in the Near-Infrared band.

$\rho_{RED}$  : Reflectance in the Red band.

$$NDWI = \frac{\rho_{GREEN} - \rho_{NIR}}{\rho_{GREEN} + \rho_{NIR}}$$

$\rho_{NIR}$  : Reflectance in the Near-Infrared band.

$\rho_{GREEN}$  : Reflectance in the Green band.

The selection of the flow direction algorithm significantly impacts the correlation between TWI and soil moisture. Now come the vegetation and water indices. So, here are indices, like NDWI and NDVI, that we have already discussed at the beginning of this course. So, those are used here. So, NDWI enhances water detection using green and IR bands and NDVI. It is used for vegetation, So, combining indices improves flood map accuracy across different land types. So, that is been used in different studies. There are several studies available you can refer some of the standard papers to understand how authors have used these indices to analyze the flood potential for their area. This is one example of NDVI. This is for NDWI, and here you can see that these values indicate the strength of the presence of water and vegetation. Now we have all the parameters, and we will be able to understand how the flood susceptibility mapping is being done. So, flood susceptibility mapping identifies areas prone to flooding based on historical data and environmental factors that we have discussed. It is a predictive spatial analysis tool used for disaster risk reduction and land use planning. The goal is to create a map showing the probability or likelihood of flooding across a region. It is a crucial step in preparing flood risk management and mitigation strategies.

So, this flood susceptibility mapping is very, very important to identify the area, whether it is in the high-risk zone or whether it is in the very low or moderate zone. So, this will help you to plan the mitigation measures. So, it requires the flood inventory map, which is one of the very important aspects. So, we need to have the historical data set so that we can identify and model the flood susceptibility of that particular region.

So, these will be used as dependent variables. Influential factors include elevation, slope, topographic wetness index, distance to river, land use, land cover, etc. in this mapping. Input data is processed into a raster layer because all of these are in the spatial domain and

derived from satellite datasets. Values are extracted for flood and non-flood points. Now, let us say that these points are the flood points.

We have a history of floods in these regions. So, for these reasons, how these values are behaving. So, that will be for the flood. Then we also have a few points for the non-flood. And these together will be used to model and develop a relationship on how the area is prone to flooding, So, the flood inventory map is very important. So, these are essential tools in flood susceptibility modeling and disaster risk management.

These maps represent historical flood locations that are used as input for data-driven classification models. Generated by identifying past flood points and non-flood points in a GIS environment based on satellite data, field reports, and historical records to mark flood-affected areas. Because it is very important to include remote sensing satellite data, some floods are not being detected because we do not have in situ measurements everywhere. So, in such cases, remote sensing and the field report are very helpful here. It helps assess flood susceptibility by correlating flood points with environmental and topographical factors. So, when we talk about this flood susceptibility, we are trying to generate the early warning system. So, it will support the early warning system, urban development planning, and emergency preparedness. Once you have this flood susceptibility map with you, you can use it wherever you want; it can be used in early warning systems, in the planning of urban development, or in emergency preparedness. It also helps to prioritize high-risk areas for infrastructure investment and community protection. Because once you have the information, you will be very, very cautious about utilizing a flood-prone area for a permanent settlement.

Challenges for flood susceptibility mapping include the availability of data. Because this is one of the major factors that will reduce the accuracy of your model or your mapping, accurate flood event recording and the resolution limitation. Floods being aerial in nature pose representation issues when modeling as points. Because if we are talking about a river system, we are going with the one-point modeling. So, that does not make any sense, So, this is wrong.

So, you have to conduct the spatial analysis for the flood studies. So, conventional hydrological models have been widely used but often fall short in providing accurate flood forecasts. So, recent advancements in hydrological studies and geospatial techniques have led to the use of diverse and more reliable models. These models utilize satellite data, elevation models, rainfall runoff simulation, and machine learning to assess the spatial probability or likelihood of flooding based on the physical and environmental factors that we have discussed in the previous few slides. Now, let us talk about the different models that are available for flood susceptibility mapping.

### Frequency Ratio (FR) Model

- The Frequency Ratio (FR) model is widely used in hazard mapping, including floods, landslides, and forest fires.
- It estimates the probabilistic relationship between flood occurrences and flood conditioning factors (FCFs).
- The FR for each class of a conditioning factor is the ratio of the percentage of flood pixels in that class to the percentage of total area pixels in that class.

$$FR = \frac{(N_{ij}/P_{ij})}{(N/P)};$$

$N_{ij}$  : Number of flood locations.

$P_{ij}$  : Total number of flood locations in the study area.

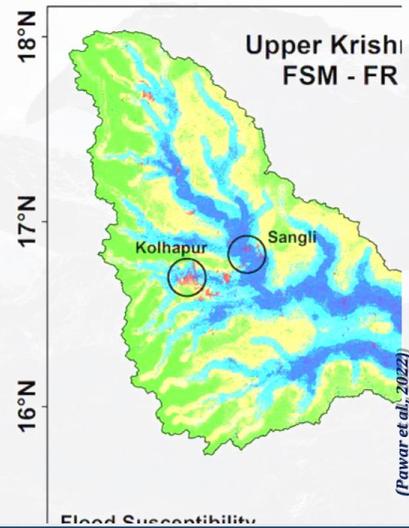
$N$ : Total number of pixels for each class of the factor.

$P$ : Total number of pixels in the study area.

So, the first one is the frequency ratio; this is the FR model, So, the frequency ratio (FR) model is widely used in hazard mapping, including floods, landslides, and forest fires. It estimates the probabilistic relationship between flood occurrences and flood conditioning factors. So, remember there are two terms: the flood occurrence and the conditioning factors. So, the FR for each class of a conditioning factor is the ratio of the percentage of flood pixels in that class to the percentage of total area pixels in that class, So, for the historical data set, we will plot on that map, and then we will try to identify whether the event has occurred or not. So here we will be using the number of flood locations, the total number of flood locations in the study area, the total number of pixels for each class of the factor, and the total number of pixels in the study area.

### Frequency Ratio (FR) Model

- FR values are calculated for each class of every conditioning factor.
- These values are combined to generate the Flood Susceptibility Index (FSI).
- The FSI is the sum of FR values across all contributing factors for each pixel.
- FSI formula:  $FSI_{FR} = \sum FR$
- A higher FR value (>1) indicates a strong correlation with flood presence; lower values (<1) suggest weak or no correlation.



All of these will be used here, and then we will be able to calculate the frequency ratio. So, this is one example of flood susceptibility mapping. So, the FR values are calculated for each class of every conditioning factor. So, now we have discussed the conditioning factors. Now, for each conditioning factor, we have the frequency ratio.

How important it is, and then these values are combined to generate the flood susceptibility index, which will be the sum of the FR values across all contributing factors for each pixel; again, it will be in a spatial domain, and using this, we will be able to sum all the FR values across all the conditioning factors. FR value greater than 1 indicates a strong correlation with the flood presence; lower values suggest weak or no correlation. So, this is how we will be able to analyze the results of the frequency ratio. Now, the next one is the statistical index. So, the statistical index model was initially developed for landslide susceptibility but is also used in flood mapping.

**Statistical Index (SI) Model**

- The Statistical Index (SI) model was initially developed for landslide susceptibility but is also used in flood mapping.
- It calculates weights based on the logarithmic ratio of flood density in a class to the total flood density.
- A positive SI value indicates a strong correlation; a negative value suggests low flood probability.
- Each class of a conditioning factor is assigned an SI weight through reclassification.

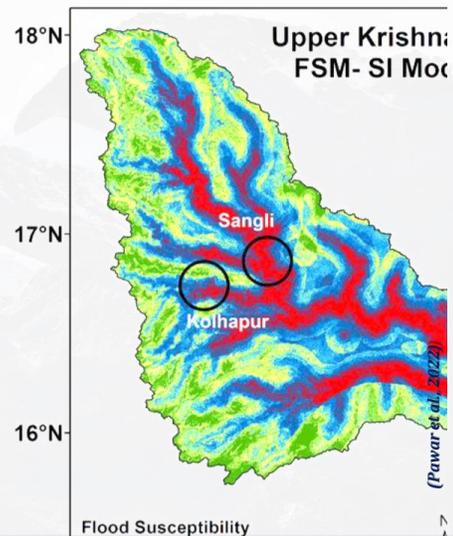
$$W_{ij} = \ln \left( \frac{N_{ij}/S_{ij}}{N/S} \right);$$

$N_{ij}$  : Flood pixels in the class i of factor j  
 $S_{ij}$  : The number of pixels in i class of j factor  
 $N$  : Total number of flood pixels of the study area  
 $S$  : Total number of pixels of the study area

It calculates weights based on the logarithmic ratio of flood density in a class to the total flood density. A positive SI value, the statistical index value, indicates a strong correlation, and the negative value suggests low correlation. Each class of a conditioning factor is assigned an SI value through reclassification, and then we will be able to use it together. So, here we are using the flood pixels in class i of factor j, the number of pixels in i of j factor.

**Statistical Index (SI) Model**

- Weights reflect how likely each class is to experience flooding based on past events.
- SI weights are summed using GIS tools to create the Flood Susceptibility Index (FSI).
- FSI formula:  $FSI_{FR} = \sum W_{ij}$
- SI model provides a more information by incorporating the strength of relationship logarithmically.

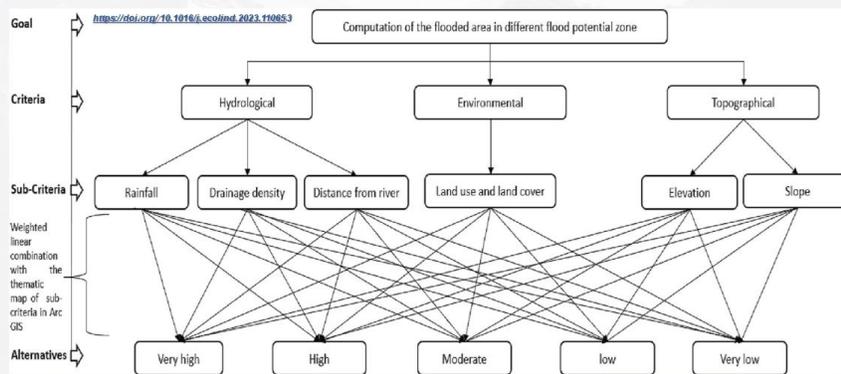


Total number of flood pixels in the study area. Total number of pixels in the study area. So, these parameters will be used to calculate this, So, weights reflect how likely each class is to experience flooding based on the positive event. Now, here are the weights that we

have calculated that will be utilized together again. We are going to sum them in GIS to create a flood susceptibility index. So, here, like the frequency ratio, you will have the statistical index value for each of the conditioning factors, and we are going to sum them together, and then we will be able to calculate or map the flood susceptibility. So, SI model provides some more information by incorporating the strength of relationship logarithmically.

### Analytical Hierarchy Process (AHP)

The AHP is a qualitative multi-criteria decision analysis (MCDA) method that helps determine the weights of flood-contributing factors through structured pairwise comparisons.



Now, the next is the AHP, the Analytical Hierarchy Process. So, here, the AHP is a qualitative multi-criteria decision analysis, which is also known as MCDA, that helps determine the weights of flood contributing factors through structured pairwise comparison. So, here is one of the flows that nicely gives you an idea of how AHP is being used in flood studies. So, here you have three different categories: hydrological, environmental, and topographical parameters. So, in hydrology, you have rainfall, drainage density, and distance from the river. In environmental studies, you have land use and land cover; in topography, you have elevation and slope. And these are used together to identify whether an area is very high, high, moderate, low, or very low, and this uses AHP. So, a point-based rating scale ranging from 1 to 9 is employed to assess each contributing factor. So, again, we will be using all the parameters here, and the intensity of importance can be referred to in this table, and this is the definition, and this is the explanation.

So, this was given by Satie in 1977, and here you see the 1, 3, 5, 7, and 9 are given, but here I have mentioned it is from 1 to 9. So, here 2, 4, 6, and 8 are used for intermediate values between two adjacent judgments when compromise is required. So, it is not always 1 and 3; sometimes we are confused between 1 and 3, so we will be using this 2. So the AHP methodology contains 4 key steps: the first one is establishing a decision hierarchy, and the second one is determining the relative importance of the main factors and their sub-

factors. Then the third one is assessing the alternatives and calculating the overall weights corresponding to each criterion, and the fourth one is verifying the consistency of expert judgment.

## FLOOD SUSCEPTIBILITY MAPPING



भारतीय प्रौद्योगिकी संस्थान गुवाहाटी  
INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

### Analytical Hierarchy Process (AHP)

Mathematically, the process is defined as follows:

- Let  $C = \{C_j \mid j = 1, 2, \dots, n\}$  represent the set of criteria. The results of the pairwise comparison among  $n$  criteria are expressed in an  $[n \times n]$  evaluation matrix  $A$ , where each element  $a_{ij}$  (for  $i, j = 1, 2, \dots, n$ ) is the quotient of the weights of the criteria.

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \dots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \dots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \dots & a_{3n} \\ \dots & \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & a_{n3} & \dots & a_{nn} \end{bmatrix}, \quad a_{ii} = 1, \quad a_{ji} = \frac{1}{a_{ij}}, \quad a_{ij} \neq 0$$

- The principal eigenvector ( $v$ ) corresponding to the largest eigenvalue ( $\lambda_{\max}$ ) is to normalize the matrix and derive the relative weights through the Equation:  $A v = \lambda_{\max} v$

So, this is very, very important. So, your judgment will have the major impact on the AHP. So, mathematically, the process is defined using this. So, let us represent the set of criteria. The result of the pairwise comparison among  $n$  criteria is expressed in an evaluation matrix  $A$ , where each element  $a_{ij}$  is the quotient of the weights of the criteria. So, here you can see that this is one matrix, So, the principal eigenvector ( $v$ ) corresponding to the large eigenvalue  $\lambda_{\max}$  is obtained by normalizing the matrix and deriving the relative weights through this equation.

**Analytical Hierarchy Process (AHP)**

- The Consistency Index (CI) and Consistency Ratio (CR) ensures the consistency of the pairwise comparisons in the AHP process.
- Consistency Index (CI) is defined as,  $CI = \frac{(\lambda_{max}-n)}{(n-1)}$
- The CR, representing the final step in the AHP process, is expressed as the ratio between CI and the Random Consistency Index (RI):  $CR = \frac{CI}{RI}$
- The RI values is derived based on the number of criteria utilized.

Saaty's ratio index for different values of N.										
N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

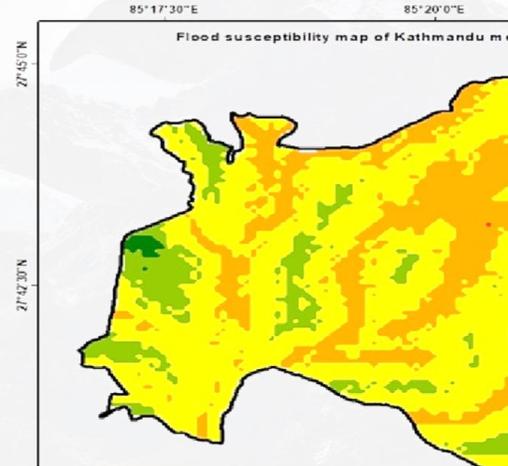
So,  $\lambda_{max}$  is equal to  $\lambda_{max}$ . So, the consistency index (CI) and the consistency ratio (CR) ensure the consistency of the pairwise comparison in the AHP process. So, this is very, very important. So, this consistency index is defined as the CI. And the CR is defined as this. So, here it represents the final steps in the AHP process expressed as the ratio between CI and the random consistency index RI. The RI value is derived based on the number of criteria utilized. So, Saaty's ratio index can be referred to here. So, you know the N; then you can refer to the RI value from this table. The weighted linear combination (WLC) method is a multi-criterion decision-making method used in flood susceptibility mapping. It evaluates the degree of influence of each flood conditioning factor (FCF). The WLC model aggregates thematic layers in GIS by combining them with their respective weights.

### Analytical Hierarchy Process (AHP) (Chaulagain et al., 2023)

Rainfall, LULC, Elevation, Drainage density, Slope, and Distance from river are the flood controlling factors utilized. Hence  $n = 6$ , & for the  $6 \times 6$  matrix,  $RI = 1.24$  is selected from the Random Index (RI) table.

The weights computed utilizing AHP are incorporated in Weighted Linear Combination method through the following equation to determine the Flood Susceptibility Index.

$$FSI = 0.07 \times [slope] + 0.05 \times [elevation] + 0.06 \times [drainage\ density] + 0.32 \times [distance\ from\ river] + 0.22 \times [land\ use\ and\ cover] + 0.28 \times [rainfall]$$



It allows for flexible integration of both qualitative and quantitative data sources. So, this is a weighted linear combination method. So, rainfall, LULC, elevation, drainage density, slope, and distance from the river are the flood-controlling factors that are utilized here. Hence,  $n$  is equal to 6, and for this 6 by 6 matrix,  $R_i$  is 1.24, referring to Saaty's table selected from the random index table. The weights computed utilizing AHP are incorporated into the weighted linear combination method through the following equation to determine the flood susceptibility index, and this is how you can generate the hazard classes. So, very low, low, moderate, high, and very high. Now comes the Information Value Method. So, the IV method is a bivariate statistical method based on information theory developed for an objective flood susceptibility analysis. So, it assesses the spatial relationship between flood occurrences and the conditioning factors of the CF classes.



### Information Value (IV) Model

- The IV model is a bivariate statistical method based on information theory developed for objective flood susceptibility analysis
- It assesses the spatial relationship between flood occurrence and conditioning factor (CF) classes.
- Interpretation of IV values:
  - ✓  $IV > 0$ : Strong correlation with flood occurrence
  - ✓  $IV = 0$ : Average correlation
  - ✓  $IV < 0$ : Weak or negative correlation
- The flood susceptibility map (FSM) is derived by summing IV values of relevant CF classes.

So, the interpretation will be that if the IV value is greater than 0, there is a strong correlation with flood occurrence; if it is equal to 0, there is an average correlation; and if it is less than 0, there is a weak or negative correlation. So, the flood susceptibility map is derived by summing the IV value of each CF, and then we will be able to generate the flood susceptibility map. So, here you can see the number of flood pixels in a class, total pixels in that class, total flood pixels in the study area, and total pixels in the study area that were used in this IV. And then these IVs will be used in this flood susceptibility mapping, and here N is the number of factors used in this analysis. This model enables a quantitative evaluation of each controlling factor influencing the flooding pattern correctly.

### Information Value Model

$$IV = \log \left( \frac{N_{stpix}/N_{cpix}}{N_{tspix}/N_{tapix}} \right);$$

$N_{slpix}$  : Number of flood pixels in a class;  
 $N_{cpix}$  : Total pixels in that class;  
 $N_{tspix}$  : Total flood pixels in the study area;  
 $N_{tapix}$  : Total pixels in the study area;

- **Flood susceptibility map (FSM) =  $\sum_{i=1}^n IV_i$ ;**

Where  $IV_i$  is the information value of each class,

$n$  is the number of factors.

- This model enables quantitative evaluation of each Control factors influence on flooding patterns.

Then, this one is very very important again. So, this is the Shannon Entropy Index. The SEI is a bivariate statistical method used in flood susceptibility mapping. It helps in measuring the degree of disorder or uncertainty associated with each flood conditioning factor. SEI is based on the probability distribution of flood occurrences across different factor classes. It provides a systematic and objective way to assign weights to conditioning factors. Now we will be using all the conditioning factors for my study, and that will be used here.

The method has been widely used in natural hazard studies, including flood, landslide, and drought assessments. So, this is one of the very popular methods, the Shannon Entropy Index. The probability of flood occurrence for each class of a conditioning factor is calculated. Subsequently, entropy  $E_j$  is computed using the formula that is given here. A higher entropy value indicates a more uniform distribution and less influence on flood occurrences, The weights of each factor are derived using this formula.

### Shannon Entropy Index

- The probability of flood occurrence for each class of a conditioning factor is calculated.
- Subsequently, entropy ( $E_j$ ) is computed using the formula:  $E_j = -(\sum P_{ij})(\log P_{ij})$
- A higher entropy value indicates a more uniform distribution and less influence on flood occurrence.
- The weight of each factor is derived using:  $W_j = \frac{(1 - E_j)}{(n - \sum E_j)}$
- These weights are then multiplied with the respective factor layers to create the flood susceptibility map.

These weights are then multiplied by the respective factor layers to create the flood susceptibility map. So, we are deriving the flood susceptibility map everywhere. So, SEIE helps to reduce subjectivity in assigning weights to the control factor or the controlling factor. It reflects the contributions of each factor based on observed flood patterns. It is easy to integrate into GIS platforms for spatial analysis because all the datasets will be in the spatial domain.

### PRECIPITATION ESTIMATION

Rainfall at the surface is related to cloud top properties observed from satellites:

- ❑ VIS Reflectivity: **Brighter (thicker clouds) → Heavier rainfall**

**Dark → No rain**

- ❑ IR Brightness Temperature: **Colder → Heavier rainfall**

**Warm → No rain**

- ❑ NIR Brightness Temperature:

**$|T_{NIR} - T_{IR}| \sim 0$  (large drops/ice) → Rain more likely**

**$|T_{NIR} - T_{IR}| > 0$  (small water drops) → No rain**

Its adaptability makes it useful for multi-hazard assessments. So, you can use it for other hazards as well. Then, precipitation information. So, here is one of the very important pieces of information that are required for the flood studies. So, it is the true measurement

of the rainfall, with no coverage over the ocean or remote regions, because we need to have the automated weather station. Point measurements are not representative of the whole area; different designs of rain gauges introduce errors in the measurement because ultimately you are going to interpolate the values.

So then comes the ground-based radar system. So, these are excellent space and time resolutions, observations in real time, limited coverage over oceans and remote regions, and it requires signal calibration and correlation, which is the requirement of this ground-based radar system. Then comes the last point, which is One major point that restricts us from using this ground-based radar system is that it is costly. So, we have this alternative remote sensing. So, a rain gauge can provide direct rainfall data, but the spatial density of the rain gauge network is too low to be used to study the spatial variability of rainfall. And the ground-based radar provides an indirect measurement of rainfall, but beams get blocked by mountains, buildings, and forests, etc.

Large aerial coverage over land and oceans is necessary. Then remote sensing images become one of the important sources of information in generating rainfall or precipitation. So, it has high temporal and spatial resolution, no interferences, complete coverage over oceans, mountainous regions, and sparsely populated areas where other sources of rainfall data are not available, and supplements ground-based radar and rain gauge estimates. Estimates of the rainfall from satellite data are less direct and less accurate than either gauges or radar; that is one of the limitations. So, somewhere you have to make the trade-off.

So, there are different techniques by which we generate precipitation. So, with this, I will end this lecture, and we will continue this application of remote sensing in floods. So, thank you very much, and keep watching the next videos so that you will be able to understand the complete application of remote sensing in flood studies.

Thank you.