

REMOTE SENSING FOR NATURAL HAZARD STUDIES

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Lec 14b: Introduction to Floods - II Part B

Hello everyone, welcome back to Lecture 14 of Module 5. So, we will continue Lecture 14 here. So, before I continue with the flood, let us talk about the water balance equation because this is one of the very important aspects and fundamentals that you need to know when you are working with the flood.

Water Balance Equation



Water Balance Equation:

A fundamental concept that shows the relationship between precipitation (inputs) and outputs, such as runoff, evapotranspiration, as well as the change in storage within the system.

$$P = Q + ET + \Delta S$$

Where,

P = Precipitation,
Q = Runoff / Streamflow,
ET = Evapotranspiration,
 ΔS = Change in storage.

$$\text{Change in storage } (\Delta S) = \text{Inflow} - \text{Outflow}$$

So, the water balance equation is a fundamental concept that shows the relationship between the precipitation, which is your input, and the output, such as runoff, evapotranspiration, and the change in storage within the system. So, here you see this particular equation. So, the P that is your input, that is your precipitation; then comes the Q, which is your runoff or stream flow. ET is evapotranspiration, and delta S is your change in storage. Now, just consider this as a particular area; this is a cross-section, and here the inflow can be your stream flow, which is coming from upstream, or it can be precipitation. So, that is the input for this particular region or area. So, this is the inflow.

And then comes the output. What is the output here? So, it can run off, which is going down, and we measure it as Q; then evapotranspiration; and then, because of these two, there will be a change in the storage. So, whether the level was here before the inflow started and after the inflow, maybe it will reach this or maybe that. So, this will be your delta S. The change in the storage is equal to inflow minus outflow. It can be negative, or it can be positive. If the inflow is more than the outflow, then you will have a positive change in the storage. If your inflow is less than the outflow, then it will be negative. So, to understand this water balance equation, I have used some numericals here to explain its application; I will be using two different problems that we will solve here to understand the application of this water balance equation. So, the first problem statement is to estimate the average annual evapotranspiration for a given watershed using the following data.

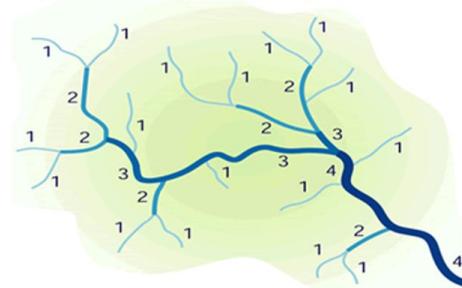
Water Balance Equation



Problem Statement: For a given watershed, estimate average annual evapotranspiration (ET) using the following data.

Knowns are:

- Surface Area (A) = 11,839 km²
- Mean annual runoff (Q) = 144.4 m³/s
- Average Annual Precipitation (P) = 1.08m
- $\Delta T = 1\text{yr}$
- $\Delta S = \text{insignificant}$



So, here the knowns are the surface area that is given, the mean annual runoff (Q) that is also given, and the average annual precipitation that is also given. The time that we are going to use here is 1 year, and the delta S, which is the change in storage, is insignificant. So, what do we have to calculate?

We must calculate the evapotranspiration. So, how will we do that? We will try to learn today. So, here you can see this is the stream that we are talking about, and here the surface area is given for this whole thing. Then the mean annual runoff, Q', which is measured here, is also given, as well as the precipitation in this particular area.

Water Balance Equation

Change in storage (ΔS) = Inflow - Outflow

$$\Delta S = P - (ET + Q)$$

$$ET = P - Q$$

$$Q = \frac{144 \frac{m^3}{s} \times \frac{86400 \text{ sec}}{\text{day}} \times \frac{365 \text{ day}}{\text{year}}}{11839 \text{ km}^2 \times 10^6 \frac{m^2}{\text{km}^2}} = 0.38 \text{ m/yr}$$

$$ET = (1.08 - 0.38) \text{ m} = 0.7 \text{ m}$$

Analysis!!!

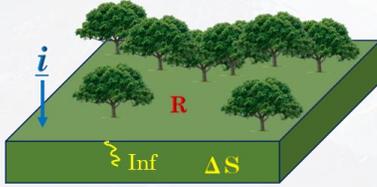
Surface Area (A)	= 11,839 km ²
Mean annual runoff (Q)	= 144.4 m ³ /s
Average Annual Precipitation (P)	= 1.08m
ΔT	= 1yr
ΔS	= insignificant

So, let us start with the basic form of this equation: the delta S, which is equal to inflow minus outflow, where the inflow is your precipitation that is given here, and the ET that we need to calculate. So, ET plus Q, both are outflows. So, here the ET is unknown, but Q is known. So, ET is equal to P minus Q because delta S is insignificant. Now, in this Q, we can change this form, and you can calculate the Q like this, and then ET will become 0.7 meters. Now here you see that delta S is insignificant, which means there is no change in the storage.

So, here the inflow is present, and evapotranspiration is also occurring. So, here 0.7 plus Q, that is here; if you add them together, that is the total discharge, total outflow of this particular system. Then you need to analyze what will happen if the situation continues to be like this, whether this water state will be dry after some time, or what the impact will be. So, the analysis is very, very important here.

Water Balance Equation

Problem Statement: In a gentle hill slope, find the change in storage of soil water (ΔS) using following data.



Knowns are:

Surface Area (A)	= 10000 km ²
Rainfall intensity (i)	= 30 mm/hr
Surface Runoff	= 15000 L for 40 min
ΔT	= 40 minutes
Percolation (Outflow)	= Insignificant
Evaporation (ET)	= Insignificant

Then the next problem statement is to find the change in storage, delta S, of soil water on a gentle hill slope using the following data. So, for this particular water set, the surface area is given, and the rainfall intensity is given. So, the intensity is 30 mm per hour, surface runoff is 15,000 liters for 40 minutes, delta T is 40 minutes, percolation outflow is insignificant, and evapotranspiration is insignificant.

Now you need to calculate the delta T. So, we will start with the same equation: the change in storage is equal to inflow minus outflow.

Water Balance Equation

Change in storage = Inflow - Outflow

$$\Delta S = \text{Infiltration} - 0 \text{ (no output)}$$

Infiltration = Precipitation (P) - Runoff (R)

Rainfall intensity (i) = 30mm/hr

$$\text{Therefore, } P = i \times \Delta t$$

$$P = \frac{30 \text{ mm}}{\text{hr}} \times 40 \text{ min} \times \frac{\text{hr}}{60} \times \frac{\text{m}}{1000 \text{ mm}} = 0.02 \text{ m}$$

Surface Runoff = 15000 L for 40 min

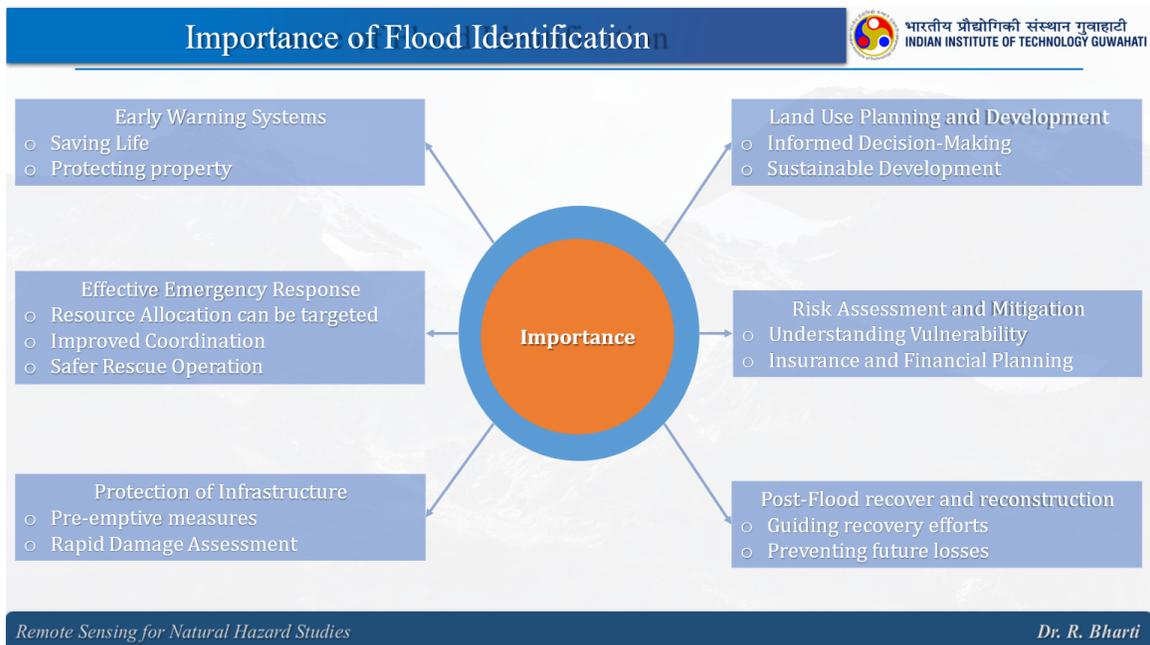
$$R = \frac{15000 \text{ L} \times \frac{0.001 \text{ m}^3}{\text{L}}}{10000 \text{ m}^2} = 0.015 \text{ m}$$

Infiltration = Precipitation (P) - Runoff (R) = (0.02-0.015)m = 0.005m

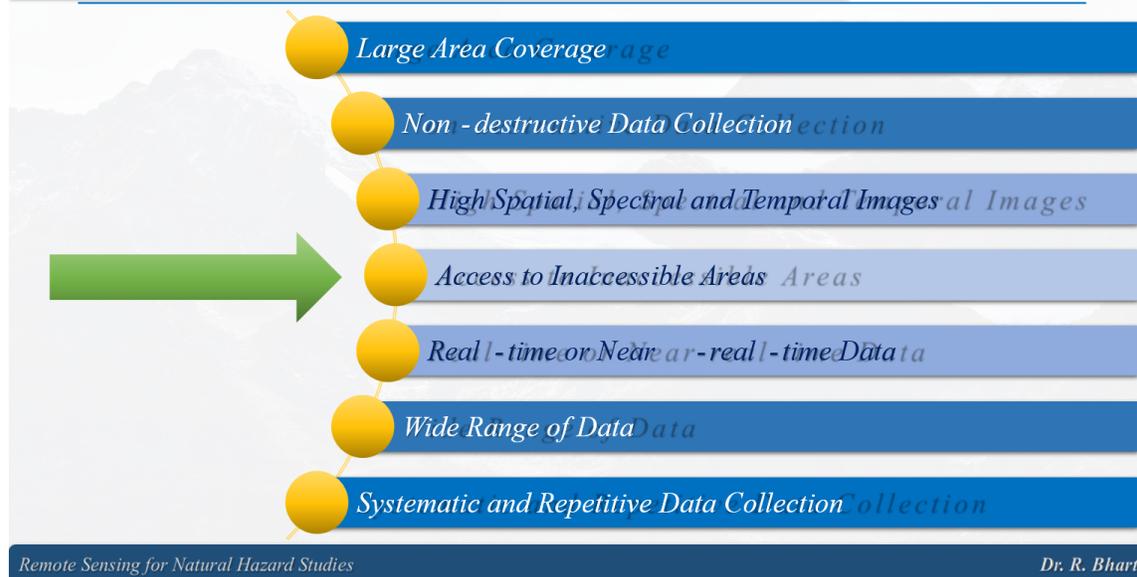
Surface Area (A)	=10000 km ²
Rainfall intensity (i)	=30 mm/hr
Surface Runoff	=15000 L for 40 min
ΔT	= 40 minutes
Percolation (Outflow)	= Insignificant
Evaporation (ET)	=Insignificant

So, Δs is equal to infiltration minus 0 because there is no output. So, infiltration will be equal to precipitation minus runoff. Here, the values are given, and the intensity is provided. So, you can calculate the precipitation. This will become 0.02 meters, and then surface runoff is given. So, you can also normalize these 40 minutes, and then you have infiltration equal to precipitation minus runoff, and this is 0.005 meters.

So, this is how we are utilizing the water balance equation to analyze the situation in our watershed. Now comes the identification and mapping of floods. So, this is one of the aspects which are very, very important. So, when we talk about this flood identification, it has a role in the early warning system. Then, it has a role in effective emergency response, protection of infrastructure, land use planning and development, risk assessment and mitigation, and post-flood recovery and reconstruction.

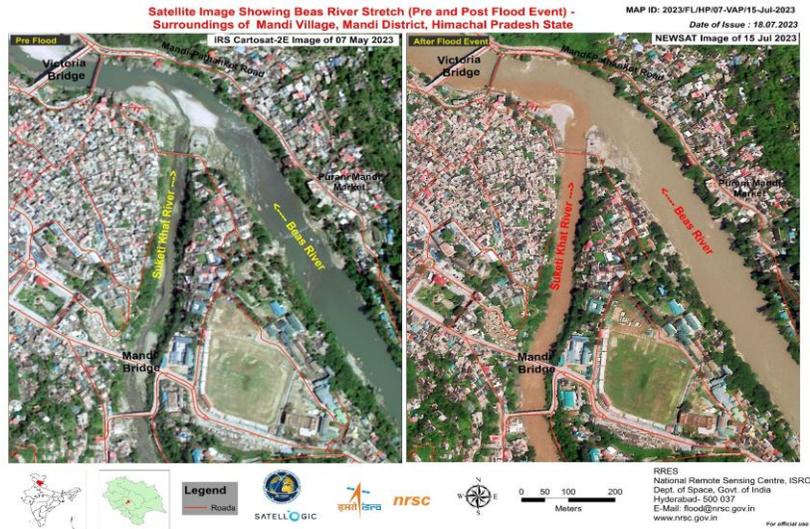


So, this identification is very important. So, here we will talk about the application of remote sensing and why we are using it in flood studies.



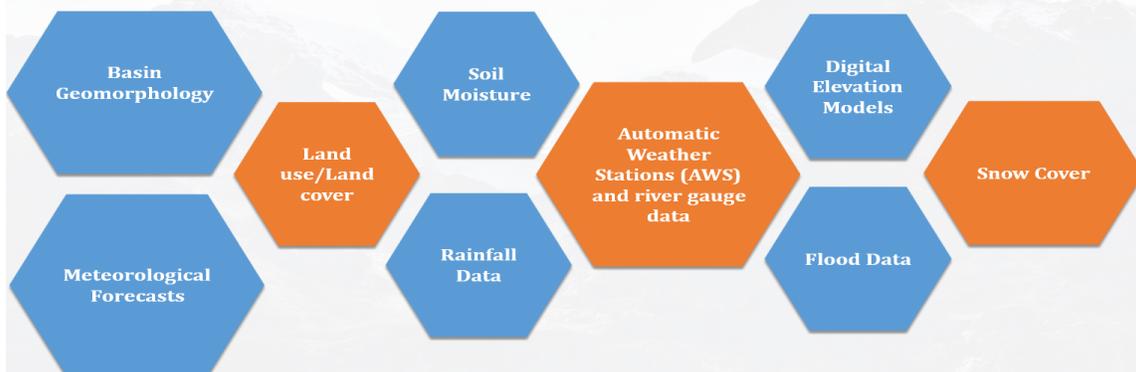
So, as we know, remote sensing has advantages, and the first one is large aerial coverage. The second is the non-destructive data collection; here we do not destruct anything, do not disturb the natural setting, we just try to capture the images, and then we try to analyze them. The high spatial, spectral, and temporal images are the advantages. Because when we have high spatial, spectral, and temporal images, we have more information about the area or the target, and this is also used for the inaccessible areas, because sometimes, after a disaster, we cannot visit the area. So, in such a situation, remote sensing can be our eyes.

Then, real-time and near-real-time data can be acquired, and if the sensor is active, it is continuously capturing and putting them into the archives. And the wide range of data we have here, optical, microwave, lidar, UAVs, everything is involved in this particular thing, and the systematic and repetitive data collection. So, if we refer to a particular area, how a particular river channel is evolving, maybe we can use the Landsat data because, for the past 30-40 years, we have had continuous data. So, if you want to dedicate yourself to studying a particular channel or a stream that you can do or perform using these satellite images. This is one of the examples of inundation layers from 1998 to 2015 for Assam. This is from ISRO. It is available on the Bhuvan website.



The satellite image shows a stretch of the Beas River. So, here you can see how this is changing, these are some examples of applications of remote sensing you can see. So, it shows waterlogged areas. This is for Mumbai, when we talk about flood modeling, monitoring, identification, or forecasting, there are different parameters that we need to study or collect. So, the basin geomorphology is one of the important parameters, along with the meteorological forecast or the meteorological parameters. Then land use, land cover, soil moisture, the incident condition, rainfall data, precipitation, and if we have automated weather station data and the river gauge data that is required. Then, a digital elevation model is needed because we need to know the slope and aspect, and historical flood data is also required here. And if that area has the snow cover, and the input is from the snow cover, then we need to include this snow cover in this analysis. So, here you can see the different parameters observed in a study by Halдар to find the flood susceptibility mapping.

Parameters required for Flood Monitoring and Forecasting



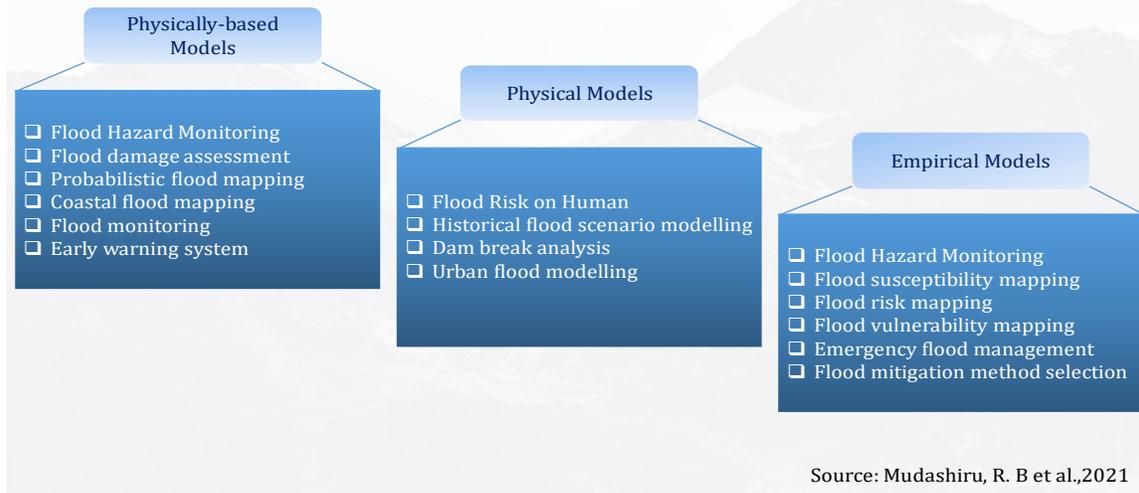
So, here you can see the elevation information, slope, TPI, TRI, TWI, relief amplitude, drainage density, distance to river, annual rainfall, LULC, SPI, MFI, NDVI, STI, geomorphology, and then MDWI, clay content, and lithology; all these maps were derived from the remote sensing data, and then he used them together to derive or to map the flood susceptibility of this particular area. So, here is another example from indiawaris.gov.in. So, here you can see that this is the annual average rainfall across the Brahmaputra Basin.

These are some of the examples that I wanted to show because they are very, very important elevation information of the Brahmaputra Basin derived from SRTM-DEM. So, the SRTM-DEM. Earlier, it was only 90 meters, but nowadays we also have 30-meter data, So, this is available freely on their website. So, you can visit the USGS website, the Earth Explorer, and then you can register and download these datasets. This is the land use and land cover distribution of the basin for the years 2005 to 2006, derived from IRS resources at one satellite data using the LISS 3 sensor.

So, you can download it from Bhuvan. The Brahmaputra basin predominantly features forests, agricultural fields, grazing land, tea plantations, and waterlogged swampy areas or wetlands. So, you can download this. Download from IndiaWRIS, or you can also go to Bhuvan and download them. So, when we have all this data set, then we can go for the flood monitoring and forecasting methods. So, here we have a snowmelt runoff model. Hydrodynamic model, rainfall runoff model, or flow routing models, So, these are different approaches that we are using to model the flood and forecast the events correctly. When we talk about the snowmelt runoff model, it is a hydrological model that helps to determine the runoff from the melting of the snow.

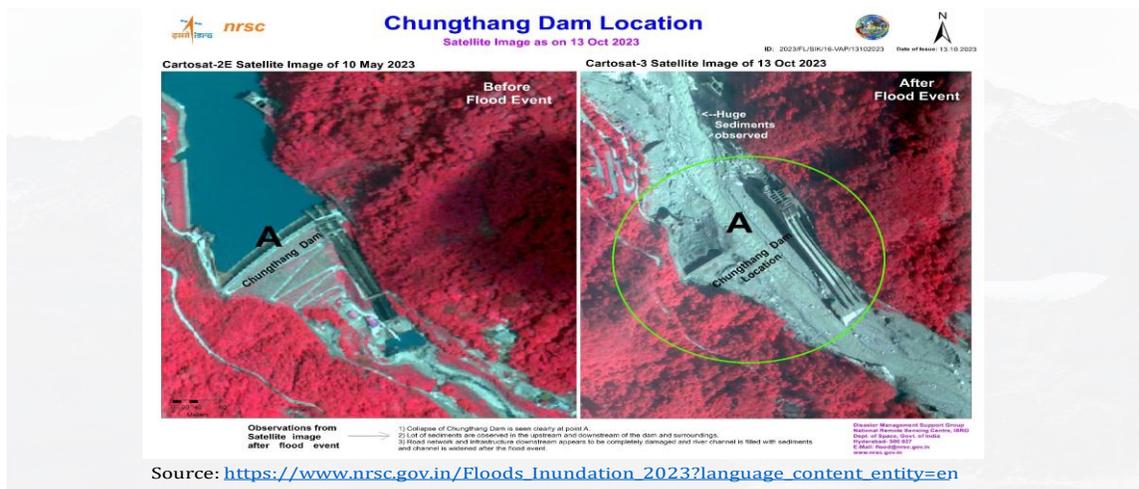
Then comes the hydrodynamic modeling; it identifies the flood-prone zone and improves the resilience of mitigation plans. The rainfall runoff model helps to understand the processes in the water system due to changes in weather conditions, vegetation, and impervious regions. Then we have a flow routing model that helps to track the flood waves in a river channel and measure discharge, flow depth, volume, etc. So, this is a flow routing model. So, there are different models in flood hazard monitoring and their suitability. In this slide, different models of flood hazard monitoring and their suitability are explained. So, when we use the physically based model, it works for flood hazard monitoring. Flood damage assessment, probabilistic flood modeling, coastal flood mapping, flood monitoring, and early warning system.

Different Methods in Flood Hazard Monitoring and their suitability



Then we have physical models, which are for assessing the flood risk based on historical human flood scenarios and modeling. Dam break analysis, urban flood modeling, then we have empirical models, which include flood hazard monitoring, flood susceptibility mapping, flood risk mapping, flood vulnerability mapping, emergency flood management, and flood mitigation method selection. So, these are different approaches or different models that have been used in flood studies.

When we talk about the advantages, we have precise identification of at-risk areas and the ability to identify vulnerable infrastructure, which also improves the early warning system, safer and more efficient rescue operations, and targeted resource deployment. Effective evacuation planning, accurate risk modeling, and reducing future risk. So, when we have accurate flood forecasting, it has multiple uses. So, here is one example from the Chungthang Dam location.



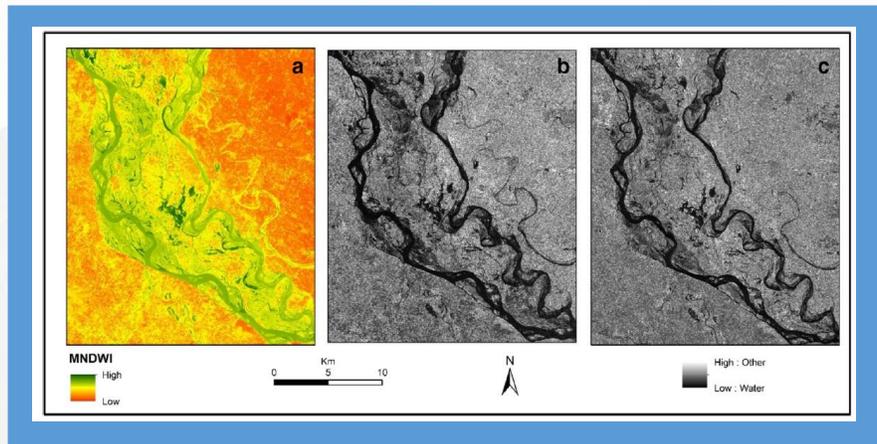
So, this is the Chungthang Dam. So, this is from the NRSC. So, here you can see that this particular map and its details are available. So, I am just trying to introduce what remote sensing can do and how it can help in this aspect. So, here you can see the flood map showing the change detection during the pre-flood events.

Figures A, B, and C are the zoomed portions of the rectangles indicated in the left river with the SAR image as background. The rectangles are overlaid on the Sentinel-2 true color composite image. On the top row is Open Street Maps, also known as OSM, and in the other row, it is to them. Here is the flood map showing the change detection during the post-flood event. Now when we have the pre and the post, we can easily find what changes have happened during a particular event.

Some examples of remote sensing applications in flood studies, especially for flood identification. So, this is again from NRSC. You can see that flood inundation; this is the Kopeli River, This is another example where people have used Sentinel-2 for the Ramganga River, and here they have utilized the microwave data from Sentinel-1 and the VV (vertical vertical) polarization, and for the same area, how they appear and the VH polarized SAR images here. In remote sensing, there are two different domains: one is optical and the other is microwave.

So, let us try to understand what optical remote sensing can do and what microwaves can do. So, this is a brief introduction. So, when we talk about optical remote sensing, it includes inundation mapping, which is flood modeling or mapping. So, we can have visual interpretation; then we can also have digital image processing techniques. And here it is mainly based on the color, texture, size, pattern, and shape when we go for the visual interpretation. When we talk about this digital image processing, density slicing, image classification, and different indices like NDWI are used to identify the flood areas. So, here is one example from this paper; it shows the mapping of flood zones in the Nasia watershed of Ghana.

The figure shows the Landsat 8 precise delineation of the normal flood-prone areas, and the B represents the Landsat ETM precise delineation of the extreme flood-prone areas. So, sometimes what happens is that the same satellite cannot provide you with all the processes. So, sometimes at that particular time, cloud coverage was present because we are talking about optical remote sensing. So, if there is cloud coverage, you will not be able to use them.



(A) The Sentinel 2 MNDWI image of the Ganga and Ramganga River, in which green represents water.
 (B) Sentinel-1 VV polarised SAR image of the same region.
 (C) VH polarised SAR image

Source: Agnihotri, et al., 2019.

In this work, Agnihotri et al. (2019), the Sentinel-2 image taken during the flood and the altered courses of the Ganga and Ramganga rivers are depicted in this Sentinel-2 image from September 14th, 2018. The yellow triangles indicate the location of the gauge station. So, here you can see that these are the gauge stations. So, they have utilized this information, and then they used it in the flood studies. When we talk about microwave remote sensing, in the urban case, this particular slide will try to explain what happens during a flood situation and what the advantages are when we use microwave remote sensing. So, in the urban areas and in the forest area, how it works and how it provides you with the information, the backscattering will be from this place. So, this is a summary of microwave remote sensing. Now, here we are talking about the unsupervised flood mapping that makes use of a localized morphological active contour model. So, this particular slide gives you an idea of how both optical and microwave remote sensing are used in this study.³ This particular slide will try to provide you with information on how Sentinel-1 data, which is microwave data, is being used in flood studies. So, if you are interested, you can refer to this paper and read more about it. Then comes the digital elevation model, which is one of the very important parameters in flood studies. So, we all know the digital elevation model represents height information, where the z value represents height, x and y will be the location, and z will be your height information along with the latitude and longitude of the topography. And here, the slope aspect and basin information are extracted correctly. So, you can easily extract the slope aspect and the basin information, or the watershed boundary can be delineated using this digital elevation model. And there are many digital elevations available nowadays for free in the public domain; you just have to register and download the data. This is one example of

flood inundation mapping. So, this is from NRSC again; this is another example of NRSC's work.

So, it is useful for flood assessment through UAVs. Now, when we talk about the UAV, sometimes what happens is that the microwave sensors do not pass through that particular area, and the optical remote sensing sensors are not able to capture the data because of the bad weather conditions. So, in such a situation, UAVs will be your third eye. So, it helps you provide the accurate digital elevation model and DTM digital terrain models. It improved hydraulic modeling and real-time inundation mapping that will be able to capture and monitor the structures to identify potential breaching zones. Monitoring channel morphology changes facilitates easier search and rescue operations because this is very important to save lives and property.

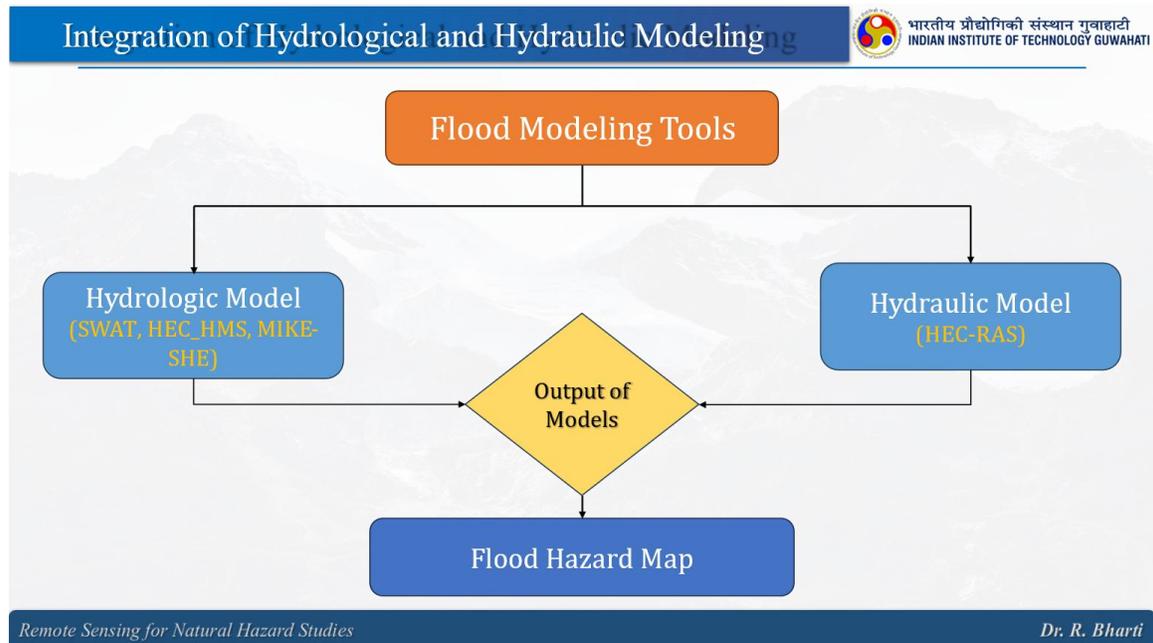
Vulnerability mapping becomes easier with this because you have high-resolution DEM, DTM, and visible or optical datasets. So, here is one example of how these UAV datasets are used; here you can generate the point clouds, then you can edit them, and you can generate the DEM. Then comes LIDAR, which provides topographic mapping using LIDAR data that offers a higher accuracy digital elevation model. So, this lidar is very accurate and cost-effective, and the predominant source of topographic data nowadays; it is very common, and the floodplain delineation will be very easy. Now, let us talk about ground-based observations to identify floods. So, these are sites on a stream or river where the systematic observation of the gauge height, that is, water level, and discharge, that is, flow rate, is measured.

So, here you can have the manual station, or here you can have the real-time station, which is the automated one. So, here is from two locations that are available in this particular weather station and the measurement of rainfall. A rain gauge measures the rainfall over a particular area in a given time period, and there are different types of rain gauges that are used for point precipitation measurement. So, here we are talking about in situ measurement. So, we have cylindrical container type, recording weighing type, float type, or tipping bucket type.

So, these are used for point precipitation measurement. The weather station and measurement of rainfall, the estimation of aerial precipitation is very important because when we are working with spatial data and utilizing remote sensing data, we should also have rainfall for each pixel. So, we can then go for the aerial precipitation measurement. So, the better estimation of true volume over a given area is because point measurements are limited to that particular location, but when we talk about aerial coverage, that means for each pixel, you have the precipitation information that will be more accurate for calculating the total precipitation in that particular catchment. So, a dense network of point measurements is required to generate such high spatial datasets, or we need to have the radar estimate.

So, here the radar will be used to estimate precipitation. So, when we talk about this aerial precipitation, we use different methods to generate a high spatial resolution rainfall dataset from this radar estimate. Then comes the water sensor that we are using. So, it detects the rise in water levels because that is one of the very important indicators of what the situation is on the ground in the river. Then an automated alert can be triggered before floodwater breaches the danger level. Then, timely evacuation is possible. Why? Because if we talk about this particular section, suppose we have put a sensor here; if this goes beyond it, then it will immediately start giving alerts.

So, we will not wait for it to reach this particular level, and then we will also inquire what the situation is at the upstream. So, advanced surveying equipment is used in flood measurement. So, here you have the pressure transducers, which are connected through a cable, and we have the data logger, then crest stage and staff gauges, and it goes to this station, and then it will be relayed, which means it will be transmitted. So, this will help to inform the people living in that particular area that the river is going beyond this particular level. So, we should be careful Integration of hydrological and hydraulic modeling. So, when we talk about this flood modeling tool, we have two different types: hydrological model and hydraulic model.



So, here are the different methods or software that are available commercially to evaluate the potential of flood vulnerability for a particular area. And these two models will give you the output, and the output models can be studied together, and then a flood hazard map can be generated that will be very, very accurate. Then comes the flood hazard and risk mapping.

So, there is the flood hazard and risk mapping. It is important in the analysis of flood risk. It helps to estimate the spatial extent of the flood characteristics, such as depth, frequency, and velocity, useful for flood management practices. So, these are the suggested readings, and I hope you will go through these papers because this will help you gain more information about the flood studies used with different methods. So, these references are used in this lecture, and you can go through them because they will explain all the details of the various models used in their study.

Thank you very much.