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Lec 35a: Remote Sensing for Drought Assessment - Part A

Hello everyone, welcome to lecture 35. Today, we will talk about remote sensing applications in drought assessment or drought studies. In the previous lecture, we discussed the basics of droughts. So, before we continue this remote sensing application, we need to understand the drought index. So, let us see the few details about the drought index, what its mathematical expressions are, and what parameters we require to calculate them, because the drought index will be one of the parameters on which you will be able to decide whether a particular area is under stress or whether it is experiencing a severe drought condition. So, you have seen these indices? Percent to normal precipitation (PNP), standardized precipitation index (SPI), Palmer drought severity index (PDSI), surface water supply index (SWSI), reclamation drought index, and the last one is the decile; this is the monthly drought.

DROUGHT INDEX
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❏ **PERCENT OF NORMAL PRECIPITATION (PNP):**

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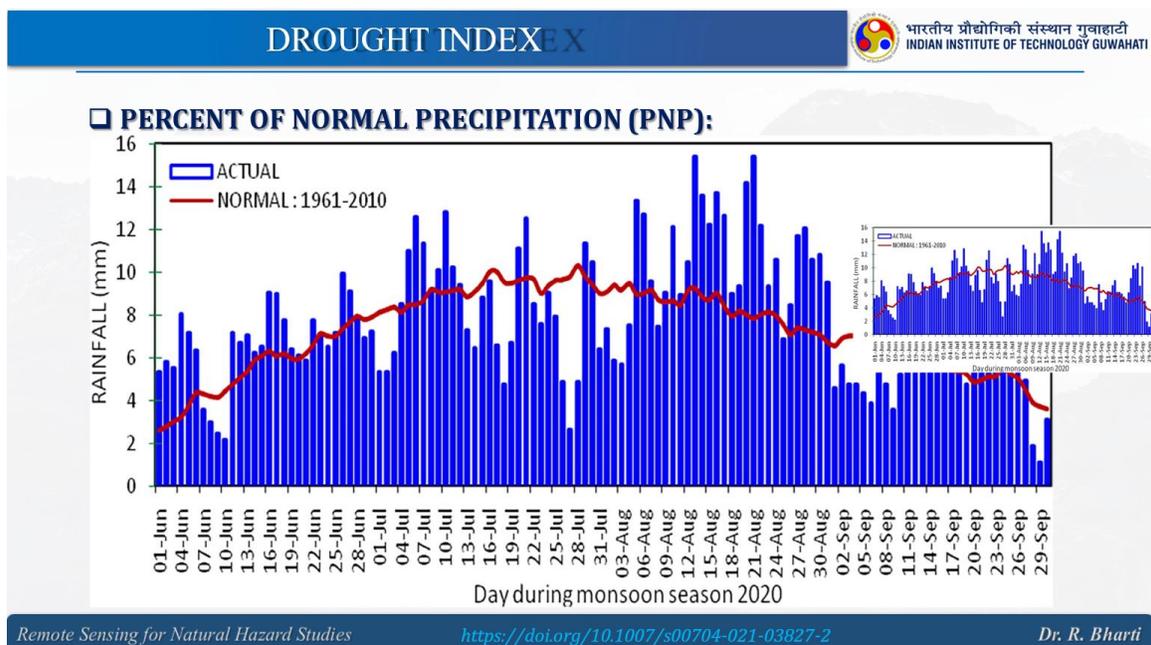
So, a drought index is typically a single number, but it is far more useful than the raw data for decision-making. There are several indices that measure how much precipitation for a given period of time has deviated from the average precipitation, and this average

precipitation can be derived through various methods. So, we call them historically identified. It is useful to evaluate one or more indices before making a decision.

I mentioned this in the previous lecture as well; if you consider using PNP, SPI, PDSI, RDI, or decile, all of them have their own limitations. So, to overcome this situation, we need to use at least 2 or 3 drought indices so that the common area will be accurately identified, and that we can confidently say this area is under water stress. Here, you can see this is for the PNP, and here, the red one is basically your normal, which is identified using the 1961 to 2010 precipitation data. So, for the time being, you can consider this as average precipitation. Now, you see the actual precipitation of this area between the first of June and the 29th of September in 2020 and how it is behaving, how it is changing.

So, you can consider this, and it will help you identify whether a particular area is experiencing stress or not. So, the PNP can be considered a ratio of actual to normal precipitation for a given location and period, expressed in percentage, analyzed for a specific reason and season. Precipitation has a different impact on soil moisture, groundwater, reservoir storage, snow cover, and stream flow. So this PNP index depends on the selection of a monthly, seasonal, or annual period. You can see here that this is from 1st June to 29th September.

Let us say this is from 1st January to 31st December 2020. So, for this, you can have an average value, the monthly average value, or the daily average value. So, anything can be considered here. So, it can be monthly, seasonal, or annual, or you can divide them based on the seasons. SPI is a normalized index representing the probability of occurrence of an observed rainfall amount when compared with the historical rainfall data.

It quantifies the precipitation deficit for multiple time scales. These time scales reflect the impact of drought on the availability of various types of water resources. Soil moisture conditions reflect short-scale precipitation anomalies because soil moisture will immediately indicate that precipitation has not occurred in the last 5 or 10 days. Whereas groundwater, surface water, and reservoir storage reflect long-term precipitation anomalies. If there is no precipitation in some areas, then the groundwater will be low, surface water will be less, and the reservoir storage will also be lower.

- Usually SPI is calculated for 3, 6, 12, 24, and 48 month time periods.
- The SPI is an index based on the precipitation record for a location and selected period (months or years),
- SPI Values:

2.0 or high	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2.0 and less	Extremely dry

$$SPI = Z = \frac{(x - \mu)}{\sigma}$$

where μ and σ are the sample estimates of the population mean and standard deviation, respectively.

So, this is a long-term anomaly or long-term phenomenon. The index value is negative for drought and positive for nondrought; we will see that. So you can calculate the SPI using this equation. And here the usual SPI is calculated for 3, 6, 12, 24, and 48 months' time period. The SPI is an index based on the precipitation records for a location and selected periods; it can be months or years. SPI values range between plus 2 to minus 2, and here you can see that 2 or higher indicates extremely wet, while minus 2 or less indicates extremely dry. So, if we are experiencing this situation, this is the extreme period of drought. So, from here on, you will have drought conditions. Then comes the PDSI, or Palmer Drought Severity Index; it is used to identify a meteorological drought. Remember this is for the meteorological drought, which allows comparison between locations and durations. PDSI provides a standardized measurement of moisture conditions. So, this will be based on the moisture conditions of the soil. It is based on the supply and demand concept and the water balance equation, taking into account the precipitation deficit. So, PDSI is calculated using precipitation, temperature, and local available water content (AWC) of the soil, and here the values range between plus 4 to minus 4 or less. So, here you can see this from 0.49 to minus 0.49, which is near normal. Now, from here onwards, the situation is towards drought. And this is the extreme drought condition. Evapotranspiration, soil moisture, recharge conditions, surface runoff, and moisture loss from the surface layer are considered in this particular index. Long-term trends are not considered.

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❑ **SURFACE WATER SUPPLY INDEX (SWSI):**

- It indicates the surface water conditions, including snow cover (mountain).
- Incorporate both hydrological and climatological parameters.
- Used to compare different basins.
- SWSI values range between -4.2 and +4.2
- Required inputs are:
  - ○ *Snow cover*
  - ○ *Stream flow*
  - ○ *Precipitation*
  - ○ *Reservoir storage*

$$SWSI = \frac{aPNstrm + bPNprec + cPNlal - 50}{12}$$

PNstrm, PNprec, and PNlal are a percentage of non-exceedance (%) of monthly streamflow, precipitation, and lake level, respectively, and a, b, and c = weights for each hydrologic component, in which a + b + c = 1. Subtracting 50 centers the SWSI values around zero, and dividing by 12 compresses the range of values between -4.2 to +4.2. The non-exceedance probabilities are taken from probability distributions fitted to each hydrologic component.

Remember that this is the limitation: human impacts on the water balance are not considered in PDSI because we are following the water balance equation. In near real time, Palmer's index becomes a hydrological index referred to as the Palmer Hydrological Drought Index (PHDI). Now comes the SWSI. It can be calculated using this equation, and the details are given here. So, what it says is that it indicates the surface water condition, including snow cover, incorporating both hydrological and climatological parameters.

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❑ **RECLAMATION DROUGHT INDEX (RDI):**

- Define drought severity & duration for predicting a drought (beginning and end).
- It incorporates the precipitation, snow cover, stream flow, and reservoir level data.

$$\alpha_k(i) = \sum_{j=1}^{k} P_{ij} / \sum_{j=1}^{k} PET_{ij}$$

Where,

P_{ij}	= Precipitation in month j of year i
PET_{ij}	= Potential Evapotranspiration in month j of year i
k	= Number of consecutive months in the time period
i	= Year
N	= Total number of years.

4 and high	Extremely wet
1.5 to 4	Moderately wet
0 to 1.5	Normal to mild wetness
0 to -1.5	Normal to mild drought
-1.5 to -4	Moderate drought
-4 and less	Extreme drought

So, both hydrological and climatological parameters are included here. Remember to always use it to compare different basins. SWSI value ranges between minus 4.2 and plus 4.2, and the required inputs to calculate this SWSI are snow cover, stream flow,

precipitation, and reservoir storage. So, all of these are used together in SWSI. Now we have the RDI (Reclamation Drought Index), and the expression is given here. So it defines the drought severity and duration for predicting the beginning and end of a drought. It incorporates the precipitation, snow cover, stream flow, and reservoir level data, and here the value ranges between plus 4 to minus 4; this indicates extremely wet and extremely drought conditions. So, from here, you can observe the drought condition.

Then comes the monthly drought that is decile. In the first step of this decile, arrange all the historic average monthly rainfall data for a particular month and for a specific location from lowest to highest. Now, here you have to sort the data. Then divide them into 10 equal parts; each of these equal parts is known as a decile. Remember, you have historical average monthly rainfall data sorted from lowest to highest, and then divide it into 10 equal parts. The first decile is the rainfall amount not exceeded by the lowest 10 percent of precipitation occurrences. The first part will be the lowest 10 percent. The second decile is the precipitation amount not exceeded by the lowest 20 percent of occurrences. These deciles continue until the rainfall amount identified by the 10th decile is the largest precipitation amount within the long-term record. Now this will be 100 percent, and this is 90 percent, 90 to 100.
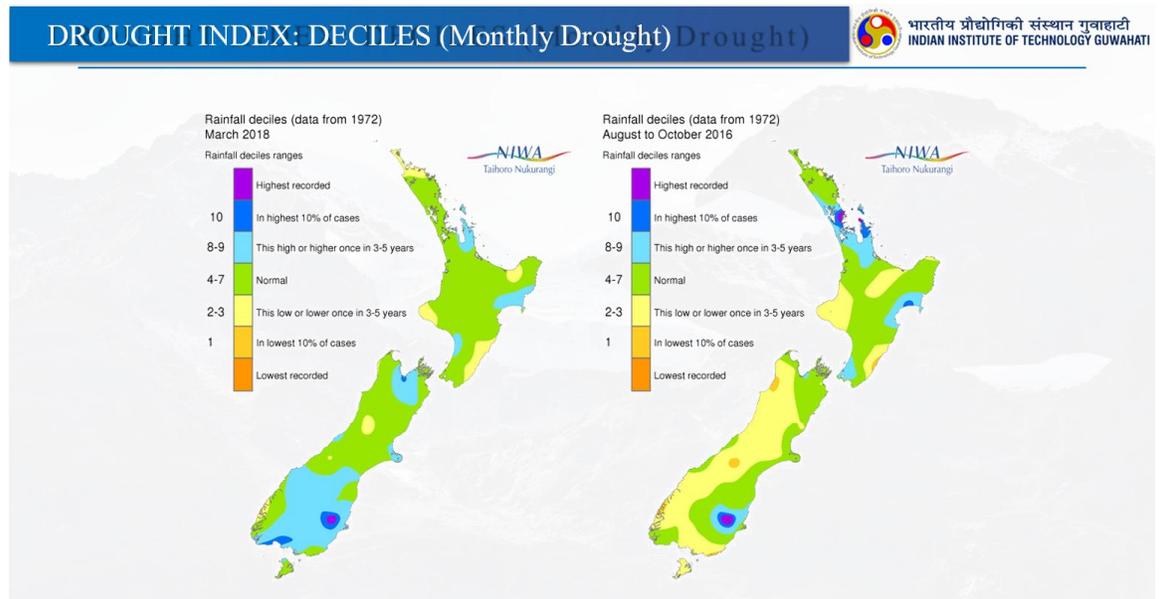
So, here the deciles are grouped into 5 classes: decile 1 to 2, which is the lowest 20 percent, much below normal. Decile 3 to 4, which is the next lowest 20 percent here, then becomes the 40 percent, and this is below normal. Deciles 5 to 6 are in the middle 20 percent, which is near normal. Decile 7 to 8 is the next 20 percent, and this is above normal. Decile 8 to 10 highest 20 percent much above normal. So, this is how we are going to interpret our deciles. So, for example, if a month's rainfall in February 2018 for a particular area is in the first lowest decile, then its total is less than 90 percent of the February rainfall totals for

that particular area. I hope this is clear. If the monthly rainfall for a particular month of a year in a particular area falls in the first decile. The first decile is the first 10 percent; thus, its total is less than 90 percent of the total rainfall that occurred in that particular month.

If the monthly rainfall total is in the bottom 3 deciles, then rainfall is much below normal and drought may be possible. If the 3-month rainfall total is in the bottom 3 deciles, then drought conditions are probably evident. So, like that, we have to prepare this kind of spatial map using remote sensing and GIS, and here you can see different colors representing different deciles. and these can be clearly identified as to which class a particular area belongs. So, for this particular color, it is this low or lower once every 3 to 5 years.

Then the crop moisture index identifies potential agricultural drought. Uses a metrological approach to monitor week-to-week crop conditions designed to evaluate short-term moisture conditions across major crop-producing regions. Because this moisture condition is very important in the initial phase of the cropping. Based on the mean temperature, total precipitation for each week, and CMI value from the previous week for a specific reason. Respond rapidly to changing conditions; it is weighted by location and time, and it is used to compare moisture conditions at different locations because you can perform the same analysis for 2 or 3 different locations and make comparisons.

WATER BALANCE EQUATION

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- Used to describe the flow of water in and out of a system (e.g. column of soil, drainage basin.
- It also involves organism (including plants/vegetation) which helps to maintain water in dry or hot conditions.
- General Water Balance Equation:

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

where, P = Precipitation,

Q = Runoff / Streamflow,

ET = Evapotranspiration,

ΔS = Change in storage.

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Used to describe the flow of water in and out of a system, for example, a column of soil and a drainage basin. It also involves organisms, including plants and vegetation that help to maintain water in dry or hot conditions. The general water balance equation that is being used here. So, this is P equal to Q plus Et plus delta S, and here are the precipitation runoff, evapotranspiration, and change in storage are used together. So, this change in the storage

can be easily calculated, so that delta s will be equal to the inflow minus outflow. If we have this, then we can use this equation in a different way; we can modify it as required, and we can evaluate the water condition in our area. It is very useful in evaluating the components of the hydrological cycle, snowmelt simulations, climate change impact assessment, flow forecasting, and agricultural water management. This has a wide application in water resource engineering as well as in drought assessment. Now comes the intensity-duration-frequency.

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Change in storage (ΔS) = Inflow — Outflow

Very useful in **evaluating the components** of the **hydrologic cycle, snowmelt simulation, climate change impact assessment, flow forecasting, agricultural water management.**

So, the relationship between drought intensity, duration, and frequency can be studied with a conceptual model. It deals with meteorological drought lasting for at least 1 year. The climate types are defined in terms of the ratio of mean annual precipitation Pma, remember this, and global terrestrial precipitation Pag. So, this is the annual global terrestrial precipitation. And the ratio of annual potential evapotranspiration Eap to the mean annual precipitation Pma.

❑ **Intensity-duration-frequency:**

- To complete the description, the Length of Rainy Season (L_{rs}) is also indicated.

- For any year with precipitation (P), drought intensity is defined as the ratio of the **Deficit (P_{ma} - P)** to the **Mean Annual Precipitation** (P_{ma}).

- For drought events longer than one year, intensity is the summation of the annual intensities.

So, from where will you get that I have a table for you that you will be referring to for the values? To complete the description, the length of the rainy season is also indicated for any year with precipitation; P drought intensity is defined as the ratio of deficit. So, the deficit will be calculated using this Pma minus P for the mean annual precipitation. So, this is Pma. For drought events longer than 1 year, intensity is the summation of the annual intensity. So here is the table from which you can identify the values, and here hyperarid, arid, semiarid, subhumid, humid, and hyperhumid are given, along with the return period.

So, you have to check all these elements, and then you have to choose the value appropriately. So when we talk about the drought assessment, what are the parameters that are required to study or identify whether a region is vulnerable to drought or whether it is under water stress? So we need to have these parameters. First, there is the temperature; then we have radiation, wind speed, and relative humidity. And if you just try to understand why we are using these four parameters here, it is because temperature, radiation, wind speed, and relative humidity all have a direct or indirect impact from the scarcity of water. So, when we use them together, we can calculate the potential evaporation, and then we can also calculate evapotranspiration; then we have the meteorological drought criteria.
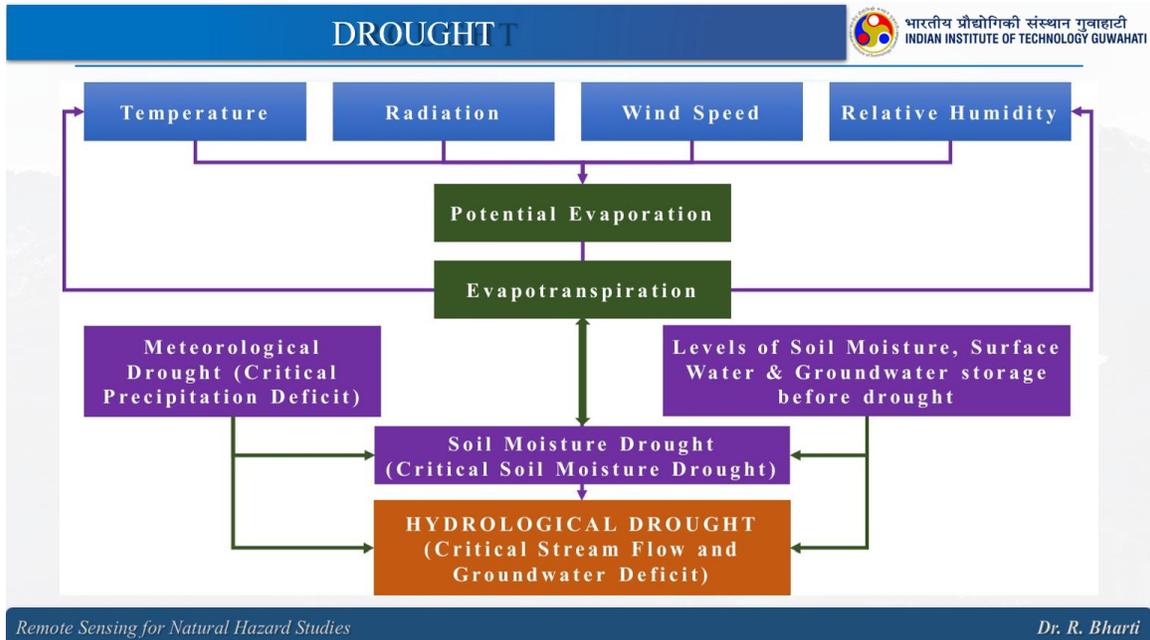
So, this is the level of moisture, soil moisture, surface water, and groundwater storage before drought. So, all of them will go into this together, and then we can identify soil moisture drought, and further, we can study the hydrological drought. So, this flow chart is one of the methodologies by which you can study the hydrological drought. However, multiple flow charts or methodologies are available in published literature that you can follow. So, let us understand these drought indices and the parameters.

So, the parameter that we discussed in the previous slide is the indicator. So, how are these two different from each other? So, indices versus indicators. So, indicators are specific variables like precipitation, temperature, stream flow, groundwater level, soil moisture, and snowpack that describe the drought condition. So, these are the indicators, but indices are numerical representations derived from indicators to assess drought severity over a specific time period. Now, you need to remember what an indicator is and what indices are.

So, our index is based on the indicators, and we have some numerical values. Based on the numerical values, we can say that this particular area is under drought, or whether this area is under flood, or if it is in normal condition. But the indicators are simply the indicating factors or the parameters that indicate there is a chance of water scarcity. Indices simplify complex climatic data and serve as a useful tool for communication with diverse users. Monitoring at various time scales helps identify short-term wait periods within long-term drought and vice versa. So, let us say there is a 10-year drought period, but in between, there might be a possibility of rainfall, and if we evaluate this particular time individually, this will not qualify as a drought condition. So, indices help to quantify the severity, location, timing, and duration of drought events. Severity refers to how much an index deviates from normal conditions, with set thresholds marking drought onset and end. Location defines the geographic area affected, while timing and duration determine when

a drought starts and ends. The impact of drought depends on its interaction with exposed elements like agriculture, water supplies, and the human population.

 I hope you have understood the basic concept behind this drought assessment, and you might have an idea of how difficult it is to analyze or assess the drought situation over a large aerial extent. So, in such a situation, remote sensing proved to be an important tool for providing you with information about the large aerial extent. So, drought monitoring is a complex phenomenon due to its spatio-temporal variability and severity. Traditional methods rely on climate-based indicators like this standardized precipitation index and the Palmer Drought Severity Index (PDSI). So, these indicators are effective but have limitations in capturing local-scale drought variation. Improved drought monitoring approaches are needed for early warning systems and proactive drought planning. So, with this remote sensing coming into the picture, we will be covering it in the next part of this lecture 35.

Thank you very much.