**Course Name: Watershed Hydrology**

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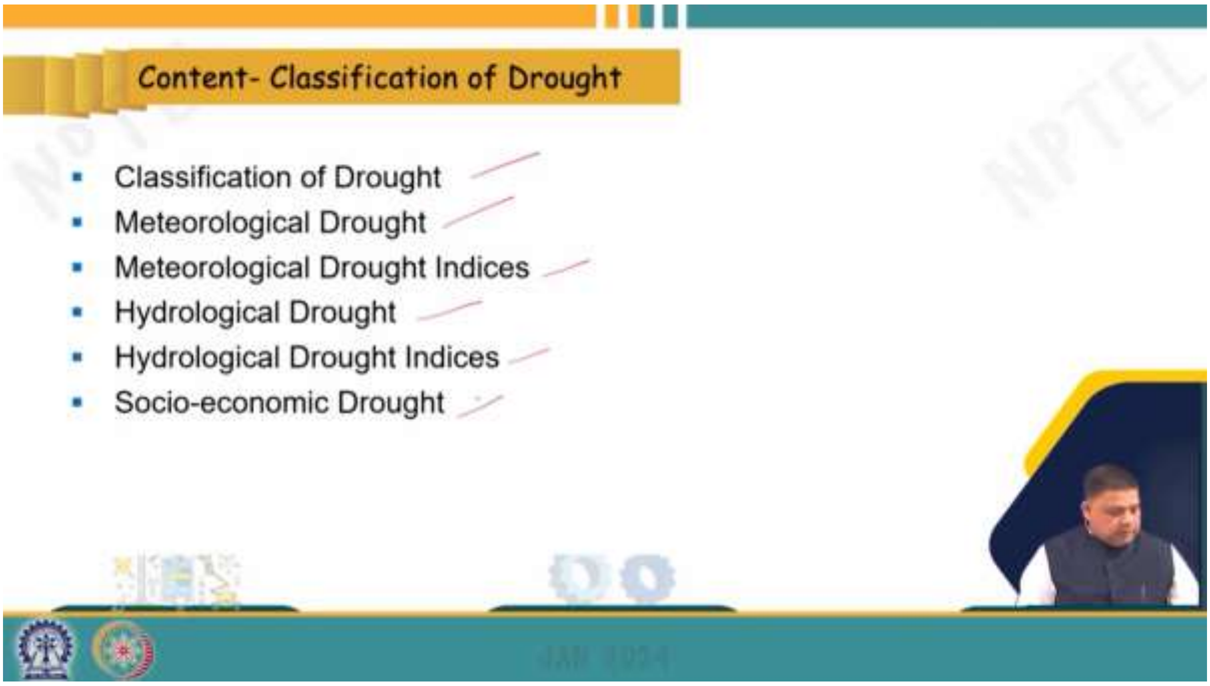
**Institute Name: Indian Institute of Technology Kharagpur**

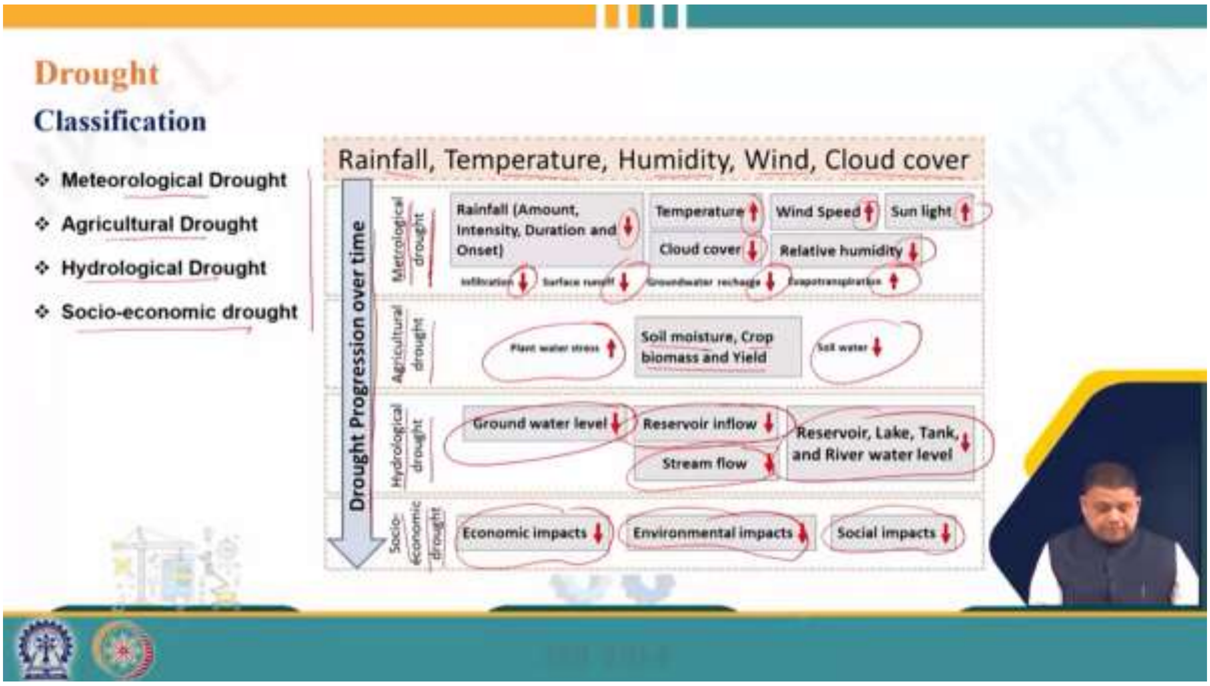
**Week: 11**

**Lecture 52: Classification of Drought**


Hello friends, welcome back to this online certification course on Watershed Hydrology. I am Rajendra Singh, a Professor in the Department of Agriculture and Food Engineering at the Indian Institute of Technology Kharagpur. We are in module 12, this is lecture number 2, and the topic is the classification of drought.

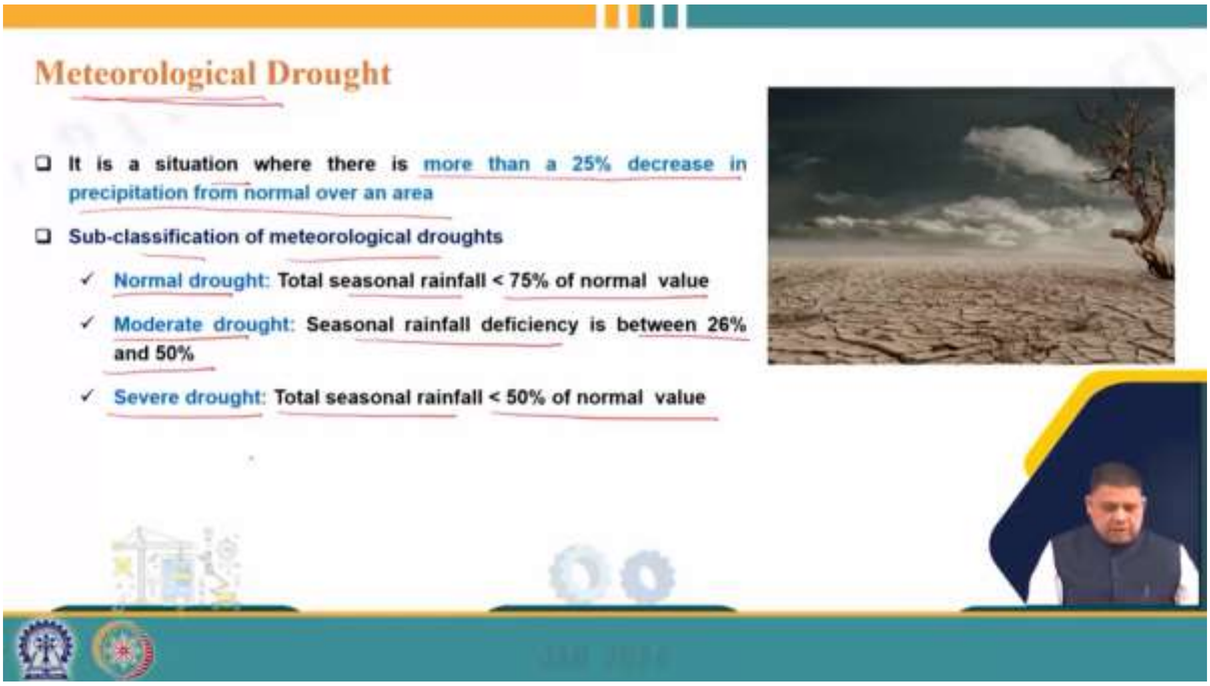



Now, in this lecture, we will classify drought; we will talk about meteorological drought and the indices related to meteorological drought. We will talk about hydrological drought and indices related to hydrological drought, and we will also talk about socio-economic drought. Now, coming to drought classification, droughts are basically classified into four different groups: meteorological drought, agricultural drought, hydrological drought, and socio-economic drought.



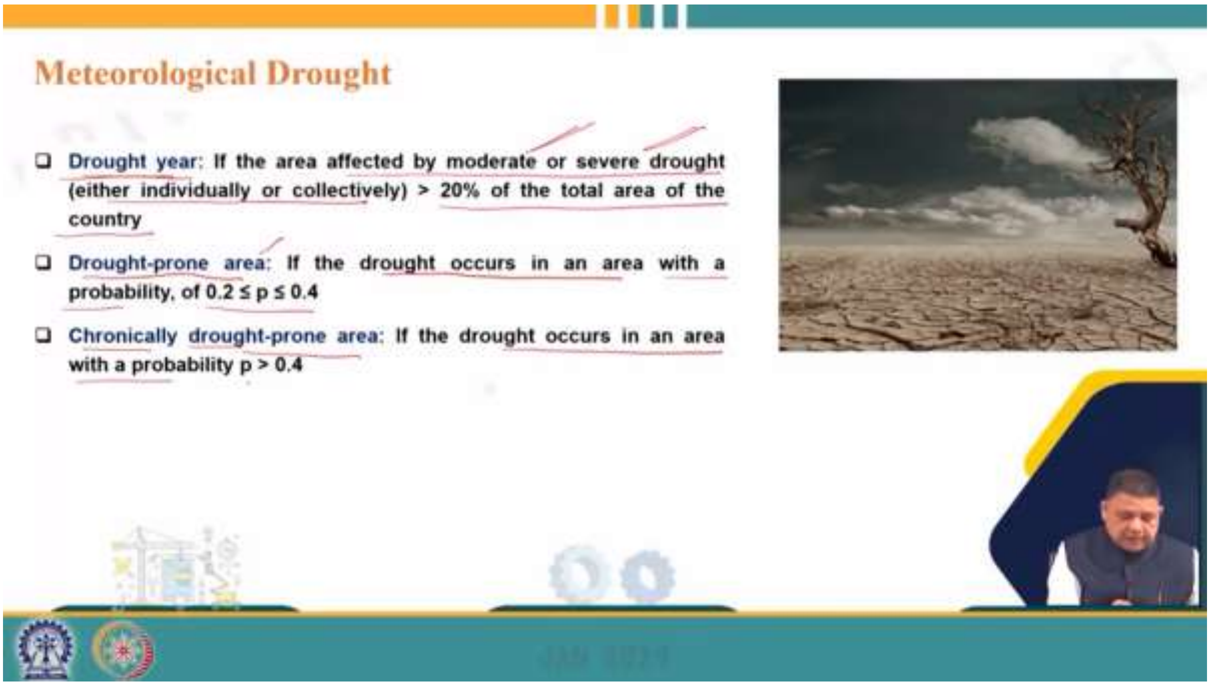

So, four different types of droughts are classified meteorological drought , Agricultural drought, hydrological drought and socio-economic drought and, of course, as the figure shows, based on rainfall, temperature, humidity, wind, and cloud cover, the drought progression over time is shown here. So, obviously, the first and foremost drought is the meteorological drought, and as you can see, the down arrows show reduction. So, that means, rainfall amount, intensity, duration, and onset get reduced; temperature gets increased; cloud cover gets reduced; wind speed gets increased; sunlight gets increased; relative humidity gets decreased, and as a result, infiltration will go down, surface runoff will go down, groundwater recharge will go down, whereas evapotranspiration will go up. So, if all these things happen, that is, rainfall reduces, cloud cover reduces, relative humidity reduces, wherein temperature, wind speed, and sunlight, which all go up, that means infiltration, surface runoff, and groundwater recharge will be low, but evapotranspiration will be high, then that signifies a meteorological drought.

Then the next drought is, of course, agricultural drought, and, of course, it will be because of the meteorological drought, soil moisture, crop biomass, and yield will be affected in the agricultural drought, and because of the meteorological drought, the soil water will go down, as you can see, that there will be less infiltration, less runoff, less groundwater recharge, and plant water stress will go up. Then we go to the third one, hydrological drought; of course, the second and third, difficult to say which one is second, which one is third, but these are the two types, basically. So, let us not call it second and third, but it is agriculture and hydrological drought. So, obviously, in hydrological drought, because of reduced infiltration, surface runoff, groundwater recharge, and increased evapotranspiration, groundwater levels will go down, reservoir inflow will be reduced, stream flow will be reduced, reservoir, lake, tank, and river water levels will go down. So, everything will happen, all these things will happen in hydrological drought, and lastly, there will be a socio-economic drought, that means, all these three will have their economic impacts, that economic will go down, environmental will be impacted, and there will be societal impacts. So, these give you a complete picture of the causes and effects of various types of droughts, and there are four types: meteorological, agricultural, hydrological, and socio-economic droughts.



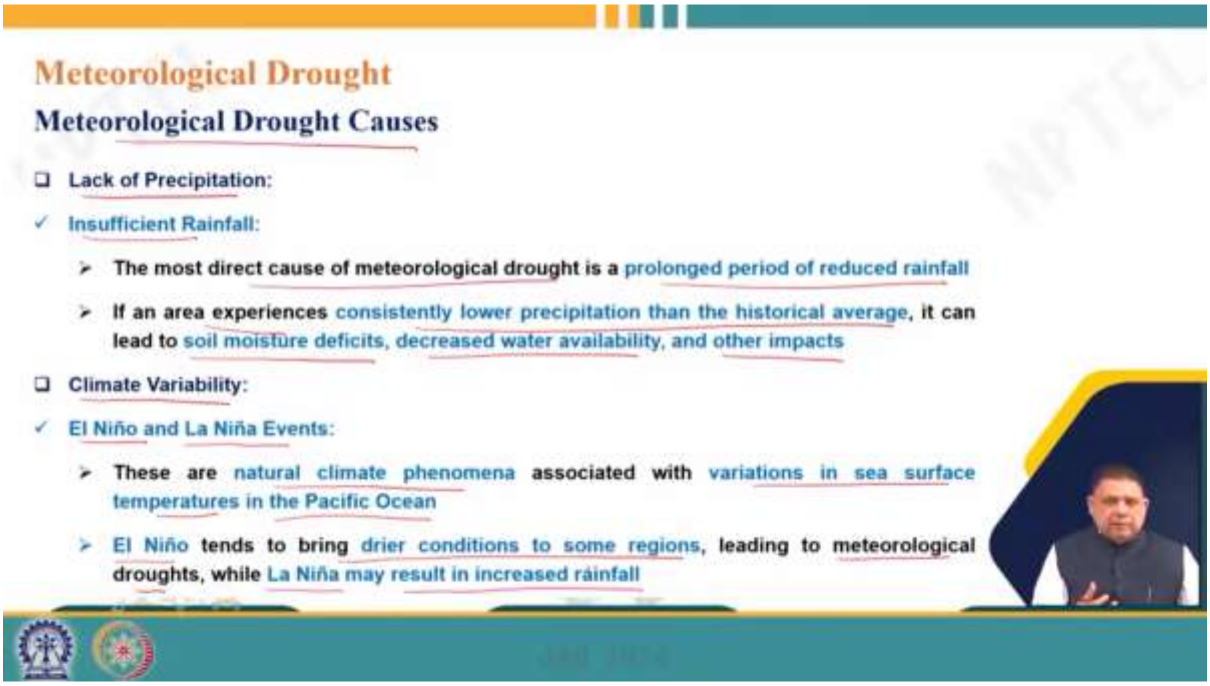

Now, let us start with meteorological drought. It is a situation where there is more than a 25 percent decrease in precipitation from normal over an area. So, if you consider a larger region or area, then if the precipitation decreases or there is a deficiency of 25 percent from normal rainfall of a region, in the previous class also we defined normal rainfall, that is, a long-term average that generally takes 30 years of duration to find out the norm long-term average. So, if the precipitation goes below 25 percent of the normal rainfall in an area, then obviously it leads to a meteorological drought. If you talk about the sub-classification of meteorological droughts, then a normal drought is when the total seasonal rainfall is less than 75 percent of the normal value. So, if it is less than 75 percent, then we call it a normal drought and just the meteorological drought, but if the seasonal rainfall deficiency is between 26 and 50 percent, then we call it a moderate drought, and if the total seasonal rainfall is less than 50 percent of the normal value, then we call it a severe drought.

So, if it is less than 25 percent, then it is a meteorological drought, but if the total deficiency is more than 50 percent or the total seasonal rainfall is less than 50 percent of normal, then it is a severe meteorological drought.



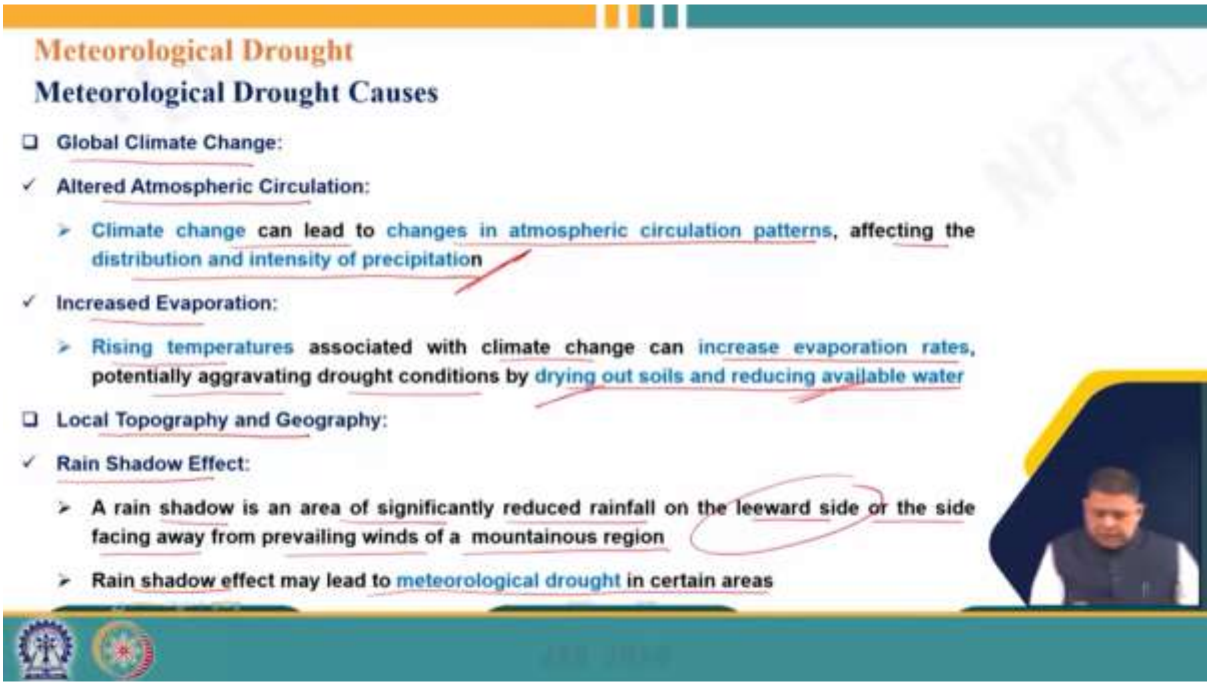

Then there are certain related terms and definitions. Like, there is a drought year if the area affected by moderate or severe drought, either unusually or collectively, is greater than 20 percent of the total area of the country. So, obviously, if total 20 percent of the area of the country has moderate or severe drought, and if we just saw the definition of moderate or severe drought, that there is a deficiency of more than 25 percent or even 50 percent, then it is moderate or severe drought. So, if there is 20 percent of the total area of the country that gets affected due to moderate or severe drought, then that particular year we call a drought year in that particular country or region or state. Then, there are drought-prone areas. We saw in the previous lecture, if you remember, we saw an Indian picture where we had drought-prone areas shown.

So, if the drought occurs in an area with a probability between 20 and 40 percent, then it is called a drought-prone area, and then of course, there are certain areas where drought is a chronic issue, that chronically drought-prone area. So, if the drought occurs in an area with a probability greater than 40 percent or 0.4, then it is a chronic drought-prone area.



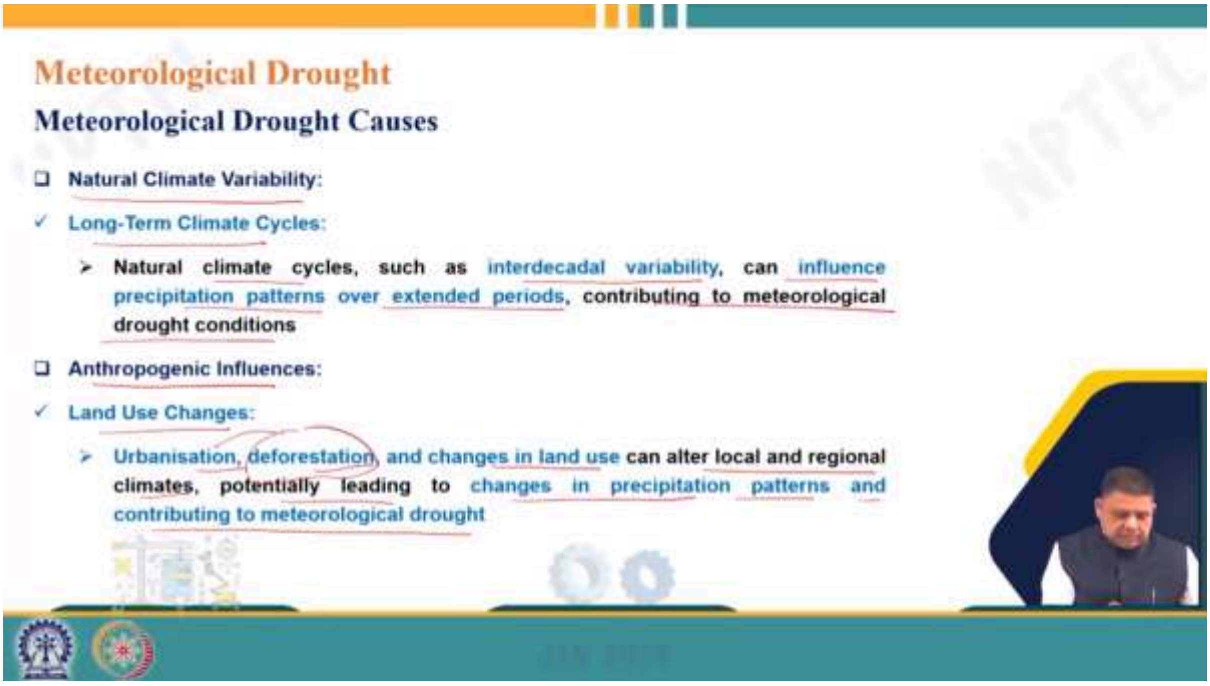

Then, coming to the causes of meteorological drought, some of them we have already discussed while discussing the drought, but specific to meteorological drought, of course, the lack of precipitation is a major reason, and that is the basis on which a meteorological drought is defined. So, insufficient rainfall, the most direct cause of meteorological drought, is the prolonged period of reduced rainfall.

If an area experiences consistently lower precipitation than the historical average, it can lead to soil moisture deficit, decreased water availability, and other impacts which we have already discussed and read detailed in the previous class also. Then there is, of course, climate variability like events like El Nino and La Nina. These are natural climate phenomena associated with variations in sea surface temperatures in the Pacific Ocean. El Nino tends to bring drier conditions to some regions leading to meteorological drought, while La Nina brings increased rainfall. So, obviously, if in a particular year an El Nino or La Nina year occurs, then obviously, in that year, the place where the event is likely to occur will have a drought-like situation.



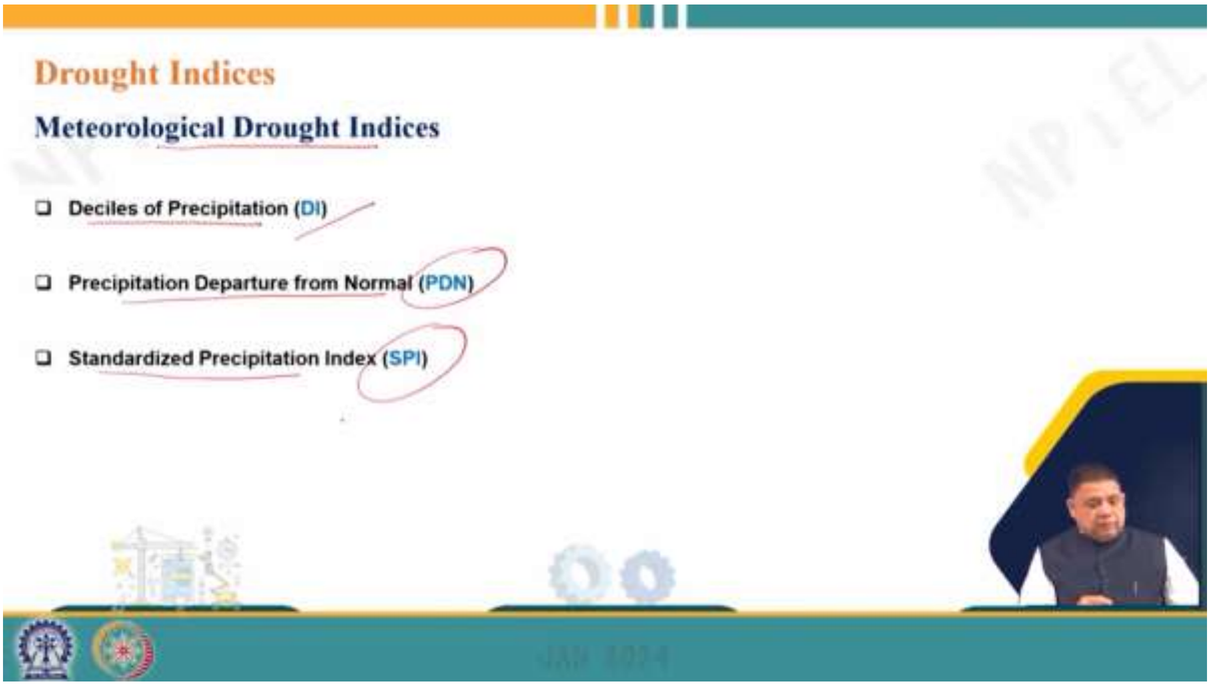

Then, of course, global climate change is a major reason for meteorological events. Altered atmospheric circulation, that is, climate change, can lead to a change in atmospheric circulation patterns affecting the distribution and intensity of precipitation. So, obviously, if the distribution of precipitation intensity reduces or changes, then it will change the rainfall nature, rainfall pattern, and rainfall magnitude, and then it can cause a meteorological drought.

Increased evaporation and, of course, an even more sure impact of climate change is the rising temperatures. Rising temperatures with climate change can increase evaporation rates, potentially aggravating drought conditions by drying out soils and reducing water availability. So, increased evaporation means the loss to the atmosphere is higher, which means soils will get dry or the water bodies will get dry with time. Another cause could be local topography and geography, one of them is the rain shadow effect. A rain shadow is an area of significantly reduced rainfall on the leeward side of the side facing away from the prevailing winds of a mountainous region. Rain shadow effect may lead to meteorological drought in certain areas. So, obviously, the leeward side of a mountainous region always has the possibility of meteorological drought.

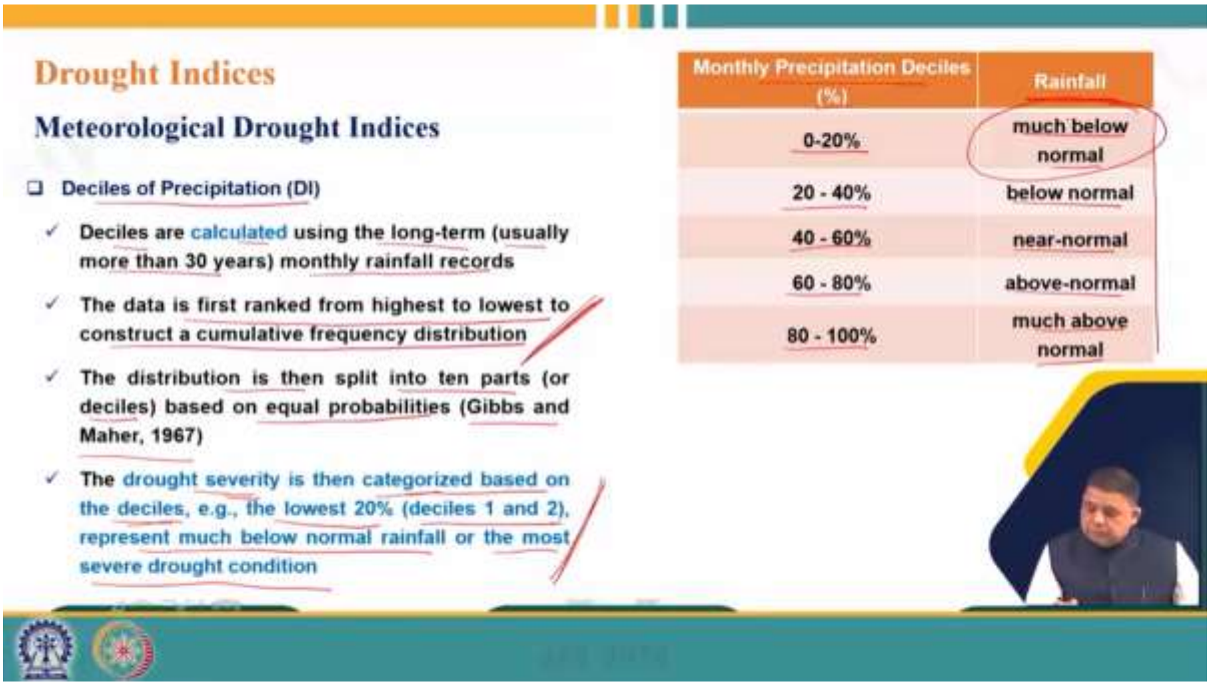



Then, of course, there is natural climate variability, that is, long-term climate cycles. Natural climate cycles such as this interdecadal variability can influence precipitation patterns over extended periods, contributing to meteorological drought conditions. That is why we know that there is an interdecadal variability in the climate pattern, and that is why while defining normal rainfall, we take a longer period, that is, 3 decades or 30 years of data we take.

So, because these are natural climate cycles, they can also lead to a meteorological drought condition over a few years in a particular area. And of course, there are anthropogenic influences like land use changes, urbanization, deforestation. Changes in land use can alter local and regional climates, potentially leading to changes in precipitation patterns and contributing to a meteorological drought. So, obviously, deforestation, of course, we have discussed in great detail, and this urbanization, deforestation, they are all linked. If an area gets deforested, that means 20 to 40 percent of water rainfall gets converted into runoff that probably goes out of the region, and their tendency to store water in the soil regime will go down obviously, because of deforestation.




Then we come to meteorological drought indices, that is, the indicators which we may use, and there are 3 major indices which we use. So, the first one is deciles of precipitation (DI). The other is precipitation departure from normal (PDN), and the third is the standardized precipitation index (SPI). So, these are the 3 indices which may be used to analyse the meteorological drought characteristics.

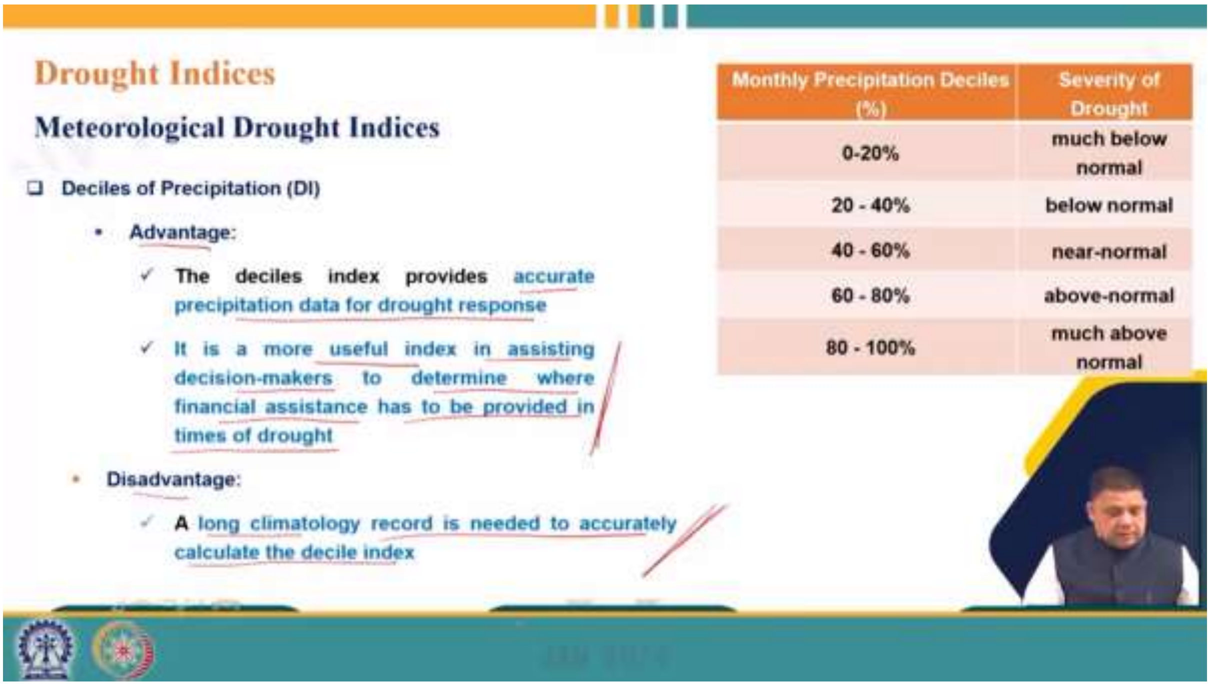



Now, the first one let us take is deciles of precipitation (DI). Deciles are calculated using the long-term, usually more than 30 years, monthly rainfall records. So, obviously, we take long term so that the nature of climate variability is taken care of.

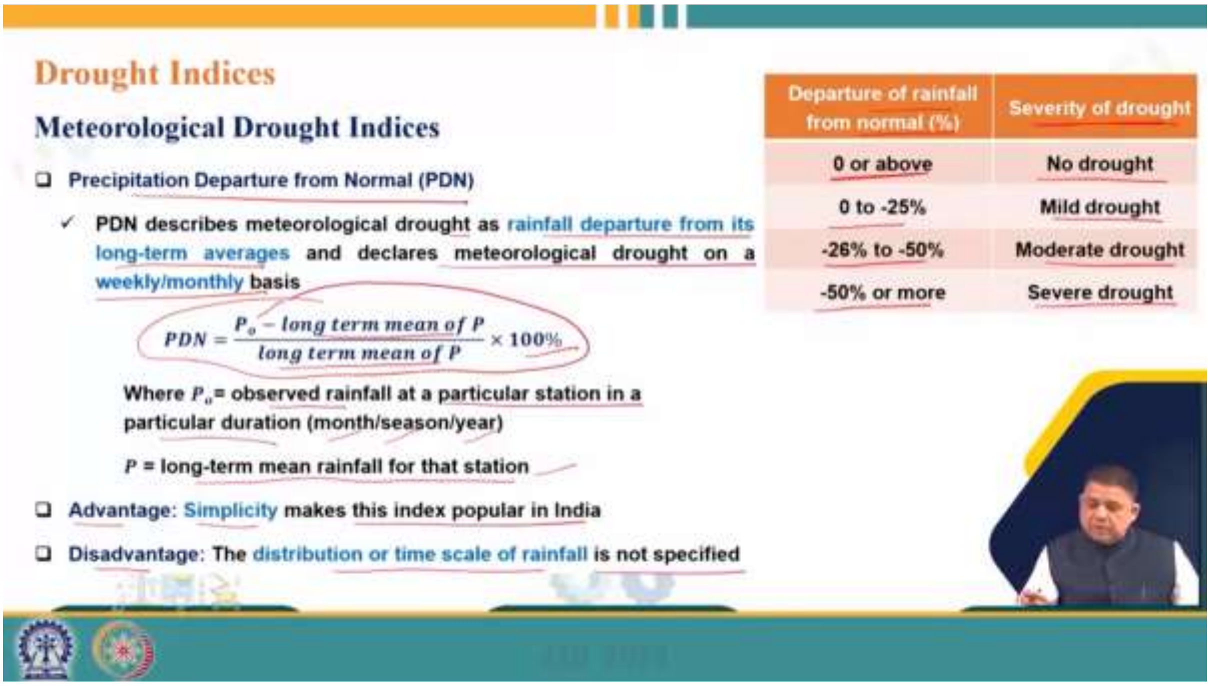
The data is first ranked from highest to lowest to construct a cumulative frequency distribution. So, obviously, that we have discussed in cumulative frequency distribution or any probability analysis that we rank the data from highest to lowest, and that is what is done here. The distribution is then split into 10 parts or deciles based on equal probabilities. This procedure was given by Gibbs and Maher in 1961. So, obviously, you will have 10 percent, 20 percent, and so on, you will decide the deciles. The drought severity is then categorized based on the deciles, that is, the lowest 20 percent, decile 1 and 2, represent much below-normal rainfall or the most severe drought conditions.

So, obviously, then we define drought severity based on the deciles, such deciles. So, the procedure is very clear: you take long-term monthly rainfall, you list them from highest to lowest, and then you split them into 10 parts with equal probability. So, that means, 10 percent, 20 percent, 30 percent, 40 percent, and so on, and then the drought severity will be categorized based on deciles. So, the lowest 20 percent will be obviously, decile 1 and 2, 10 and 20, they represent much below-normal rainfall. So, basically, monthly precipitation this size based on that we can analyse how the rainfall is.

So, 0 to 20 percent means much below normal rainfall, 20 to 40 percent is below normal, 40 to 60 percent is near normal, 60 to 80 percent is above normal, and 80 to 100 percent is much above normal. So, obviously, this will show you if it is much normal rainfall then much below normal rainfall, then obviously, it will show that it is a severe drought condition. So, just the reverse of this will give you an idea about the drought. So, that is how deciles of precipitation are important.




Now, deciles of precipitation have certain advantages like it provides accurate precipitation data for drought response. So, you analyse the data, and then you come out with the root cause and the effect. It is a more useful index in assisting decision-makers to determine where financial assistance has to be provided in times of drought. So, obviously, depending upon the severity of the drought, the decision-makers can make a decision that financial assistance needs to be provided and to what extent. But at the same time, it has a disadvantage also; a long climatological record is needed to accurately calculate the decile index. So, obviously, you need a longer long-term period of data, and if you do not have that, then probably DI will not be an appropriate way of deciding the severity of meteorological drought.



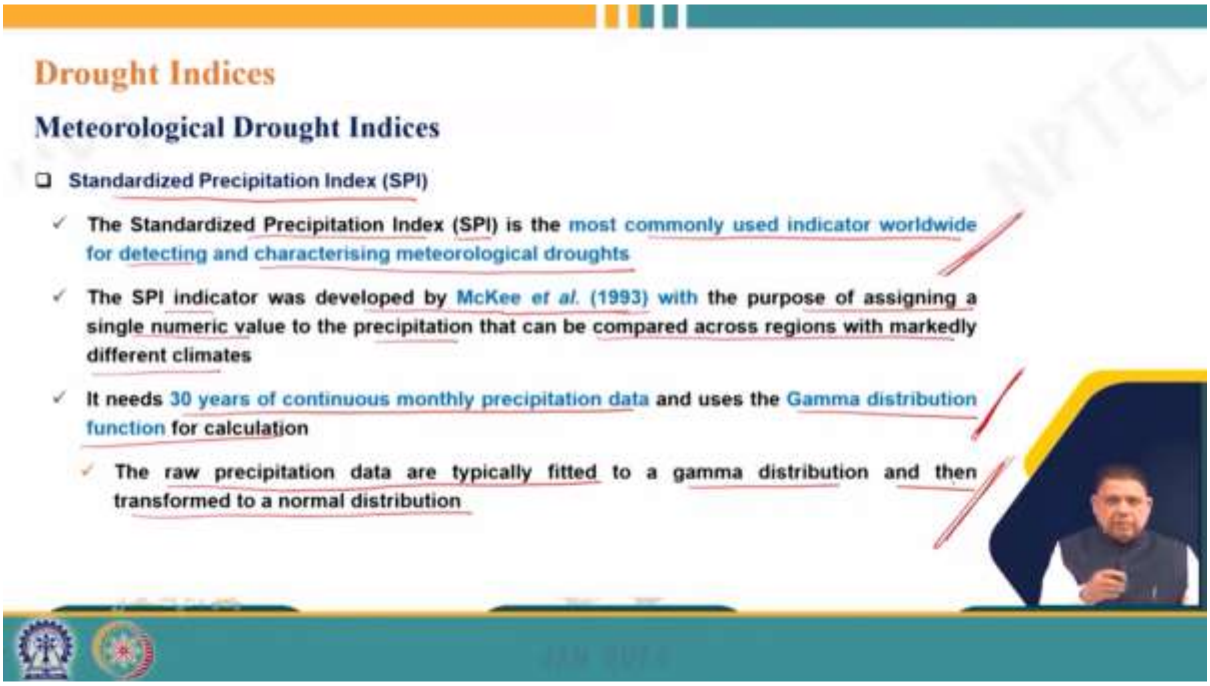

Then we go to the next one, that is, precipitation departure from normal (PDN). PDN describes meteorological drought as rainfall departure from its long-term averages and declares meteorological drought on a weekly or monthly basis. And it is calculated using this formula:

$$PDN = \frac{P_0 - long\ term\ mean\ of\ p}{long\ term\ mean\ of\ p} \times 100\%$$

P0 which is the observed rainfall at the particular station in a particular duration. It could be a month, season, year, week, that is the time scale over which you want to declare and analyse the data. Then, P0 minus the long-term mean of P divided by the long-term mean of P 200.

So, P is the long-term mean rainfall of that particular station. So, P0 minus P divided by P, where P is the long-term mean rainfall and P0 is the observed rainfall. As you can see, it is very simple, and it has an advantage that it is pretty popular because of the simple calculations involved. And the disadvantage is that the distribution or time spell of rainfall is not specified when the rain is really happening; that is not being known here. Basically, you just take the week and then long-term rainfall and then make a decision.

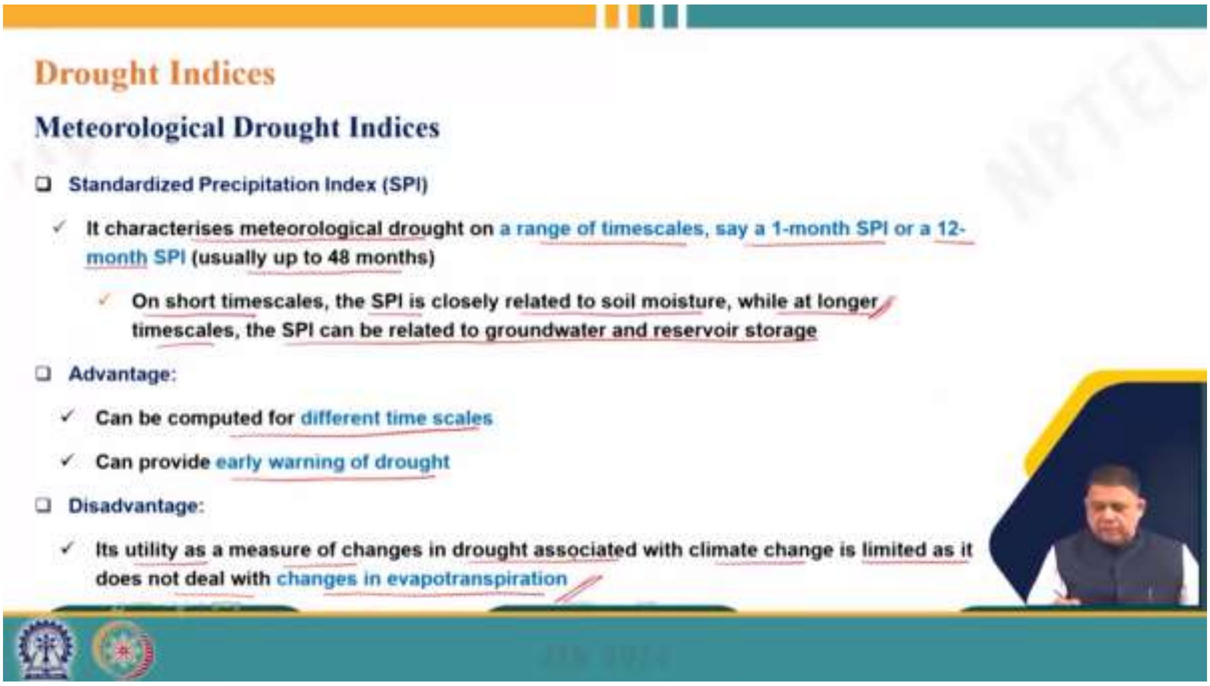
So, departure of rainfall from normal percent is basically then used to analyse the severity of drought or to index the severity of drought. So, if there is a departure from rainfall of 0 or above, then there is no drought. If there is a 25 percent deficit, then it is a mild drought; if the deficit is between 26 and 50 percent, then it is a moderate drought, and if it is 50 percent, then it is a severe drought. So, very similar to the meteorological drought definition, but the calculation procedure is slightly different.




Then we go to the third one, that is, SPI, the Standard Precipitation Index, and the Standard Precipitation Index (SPI) is the most commonly used indicator worldwide for detecting and characterizing meteorological drought.

So, that is the beauty of it, that is the most popularly used indicator. SPI was developed by Mackey and others in 1993 with the purpose of assigning a single numerical value to the precipitation that can be compared across regions with markedly different climates. So, that gives you a single numerical value with which you can compare different types of climates. It needs 30 years of continuous monthly precipitation data and uses the gamma distribution function for calculation. So, obviously, it basically uses the probability distribution function, gamma distribution, which we have studied earlier.

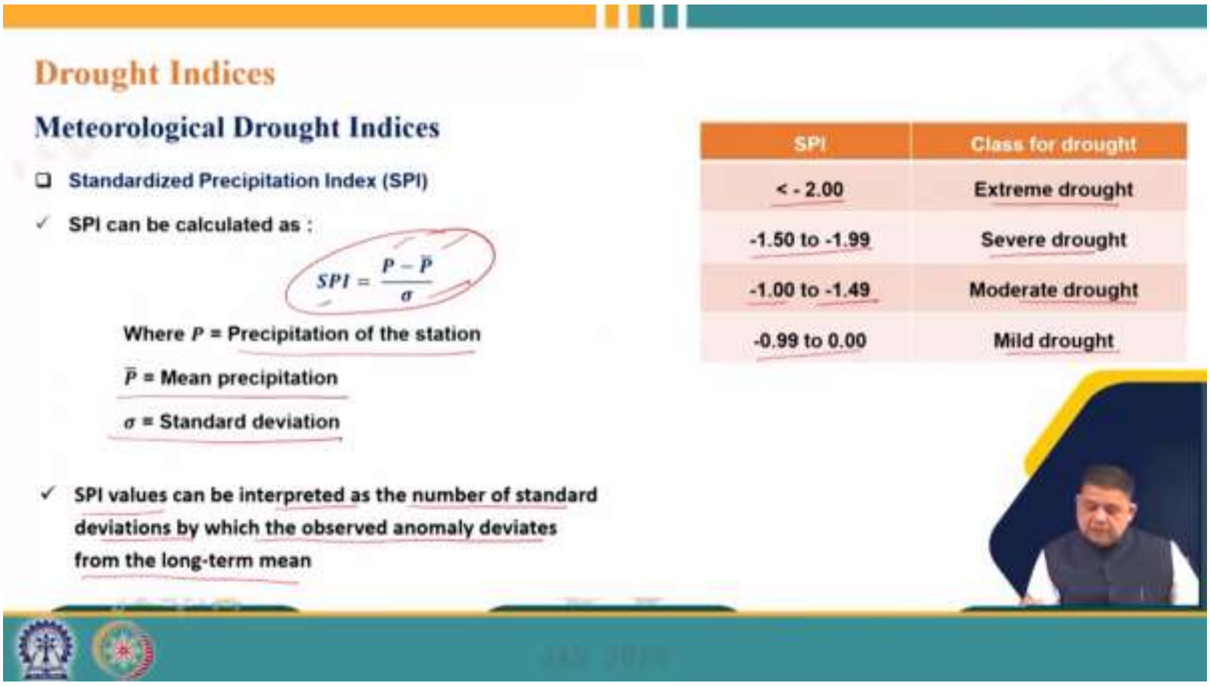
The raw precipitation data are typically fitted to a gamma distribution and then transferred to a normal distribution. So, the typical practice, recently in floods also we saw that we use the Gumbel distribution first and then convert data into a normal distribution. So, a similar procedure is used here, gamma distribution is used.




Now, it characterizes meteorological drought on a range of time scales, say a 1-month SPI or a 12-month SPI. So, usually up to 48 months. So, you can use up to 48, 36, 12 months SPI, 24-month SPI, 36-month SPI, 48-month SPI, and so on, to characterize the meteorological drought. On short time scales, SPI is closely related to soil moisture, while longer time scale SPI can be related to groundwater and reservoir storage. So, obviously, immediately, the soil moisture availability will be the main player, but over a long time, the groundwater and storage water which is available that becomes important. So, that is reflected by SPI. And coming to advantages, it can be computed for different time scales.

So, as you see, 1 month, 3 months, 9 months, 12 months, you can calculate it, it can provide early warning of drought. So, if you calculate for 1 month and then probably for the next month, you know that there is a possibility of drought continuing. And its utility as a measure of changes in the drought associated with climate change is limited as it does not deal with changes in evapotranspiration. So, it only focuses on precipitation data. So, obviously, the temperature part is not taken into account.

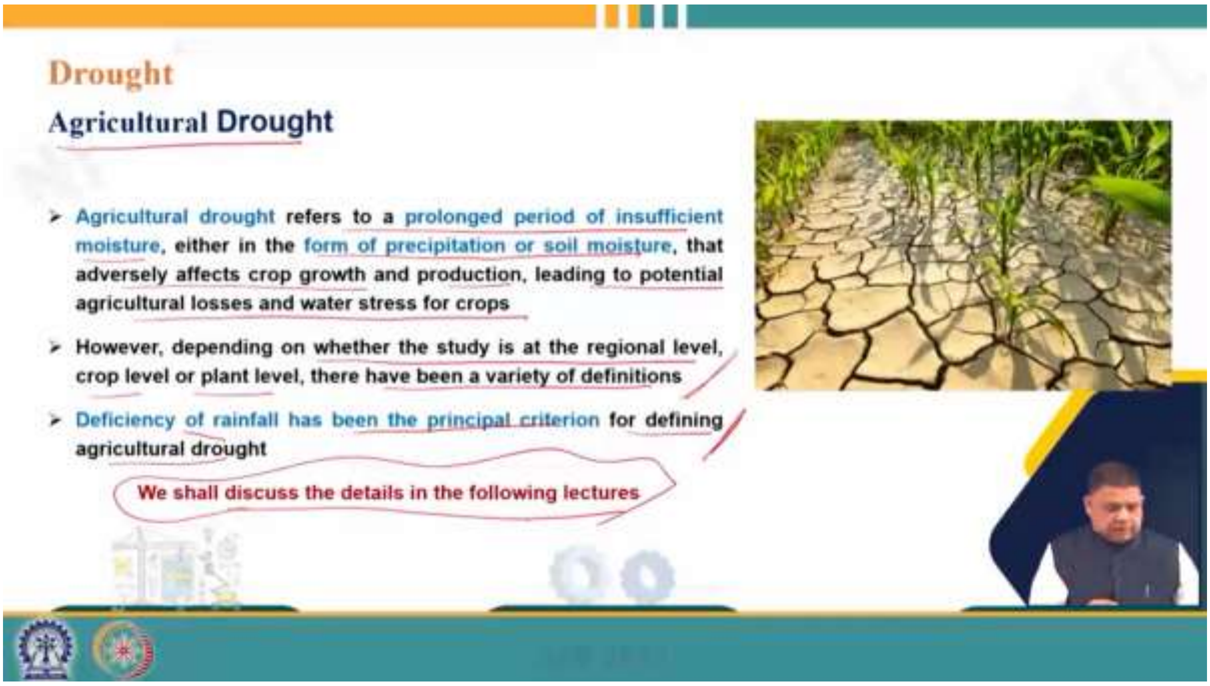
So, that is the advantage disadvantage, but still, as mentioned earlier, it is one of the most popularly used indices for meteorological drought around the world.



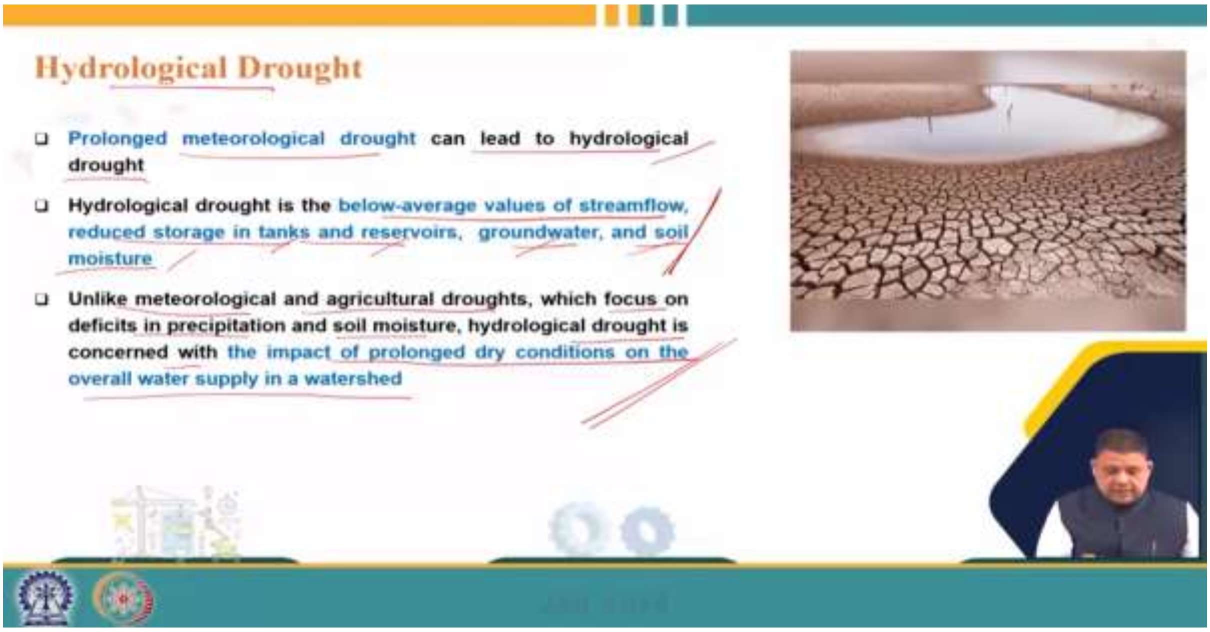

Now, coming to calculation, it can be calculated using this relationship, which is a very standard relationship which we have already seen:

$$SPI = \frac{P - \bar{P}}{\sigma}$$

where P is the precipitation of the station, P bar is the mean precipitation, sigma is the standard deviation. So, obviously, you fit the distribution, get the mean, standard deviation, and then you calculate. SPI values can be interpreted as the number of standard deviations by which the observed normally deviates from the long-term mean. So, how the mean is deviated from the long-term mean, that is how it is interpreted. SPI value is less than -2 indicates extreme drought, between -1.5 to -1.99 it is a severe drought, between -1 to -1.49 is a moderate drought, and between 0 and -0.99 is a mild drought. So, that is how you calculate SPI, and you classify your drought severity based on that particular data.

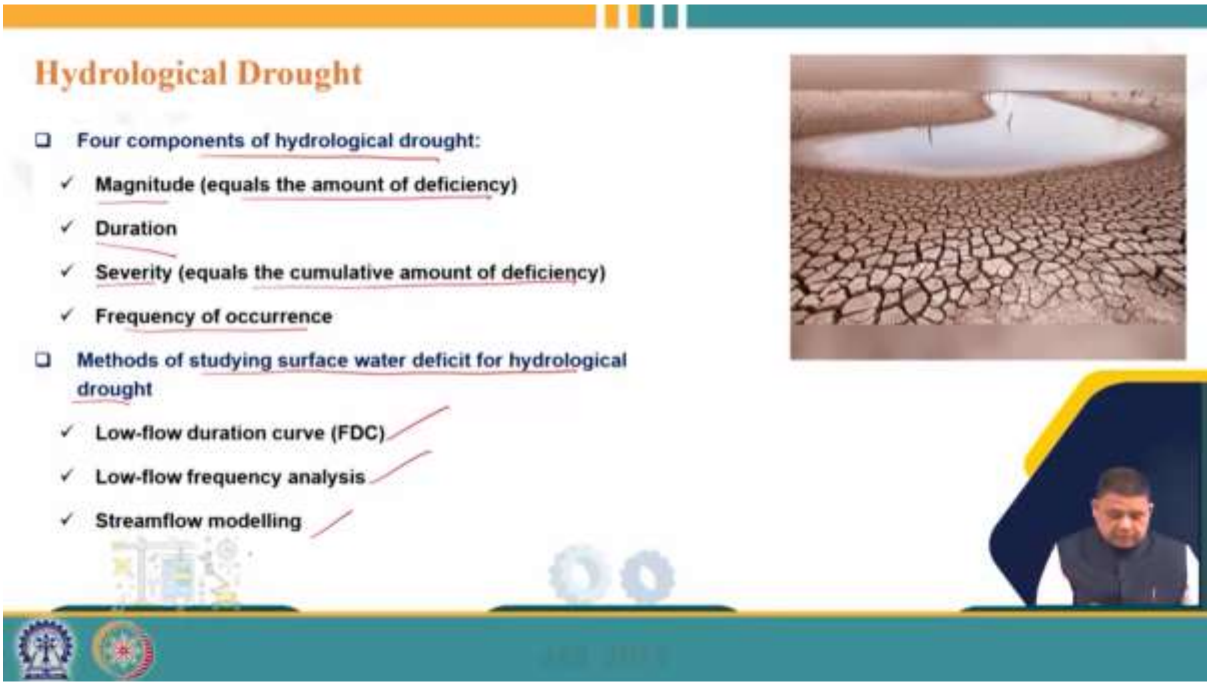



Then we come to the next category of drought, that is, agricultural drought. It refers to a prolonged period of insufficient moisture, either in the form of precipitation or soil moisture, that adversely affects crop growth and production, leading to potential agricultural losses and water stress for crops. So, basically, the non-availability of water for crop production is the main focus of agricultural drought. However, depending on whether the study is at the regional level, crop level, or plant level, there have been a variety of definitions, but as I said, the focus is mostly on the availability of soil moisture or water for agricultural purposes. Deficiency of rainfall has been the principal criteria for defining agricultural drought, which is quite obvious. So, obviously, when there is a meteorological drought, it will lead to agricultural drought in the region, and we shall discuss the details of agricultural drought in the coming lecture. So, we are leaving agricultural drought at this stage only.



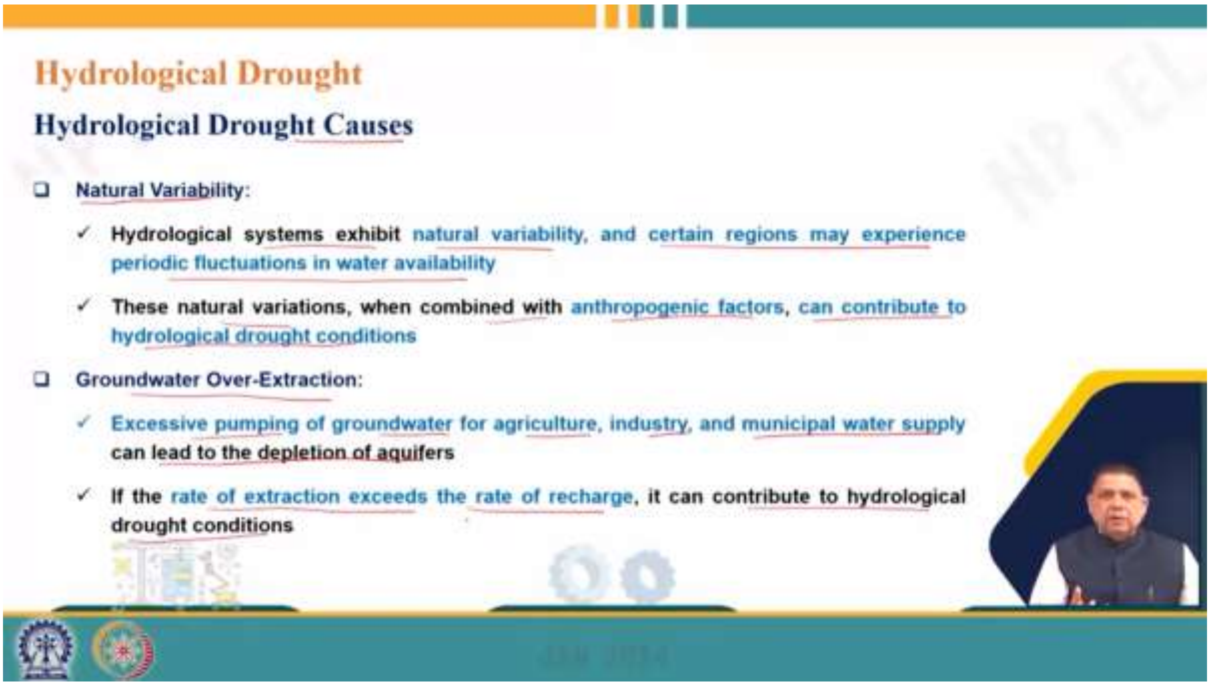
Then we go to hydrological drought, and a prolonged meteorological drought can lead to hydrological drought. So, obviously, as we have seen, hydrological drought means availability of water, that means the inflow part of it, the precipitation, and hydrological drought represents the availability of water in water bodies or water storage structures, including groundwater. So, obviously, if there is a prolonged meteorological drought, that means when the source is not there, then obviously, there will be no water available in water bodies or even in soil storage or in the groundwater storage, and we will have the condition of hydrological drought.

It is a below-average value of stream flow, reduced storage in tanks and reservoirs, groundwater, and soil moisture. So, when all these water storage places, be it river or tanks, reservoirs or groundwater, all the soil column itself, then there leads to hydrological drought. Unlike meteorological and agricultural droughts, which focus on the deficit in precipitation and soil moisture, hydrological drought is concerned with the impact of prolonged dry conditions on the overall water supply in the watersheds. Obviously, the focus of agricultural drought is basically agriculture, but hydrological drought affects water availability for anything and everything that is concerned with hydrological drought.



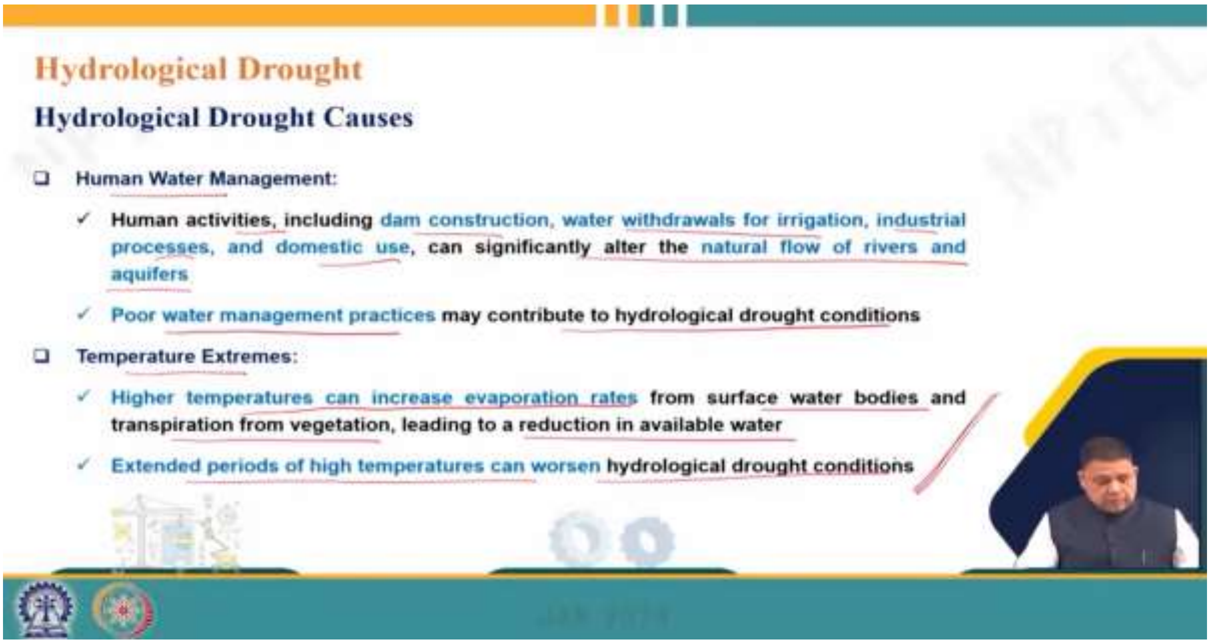

There are 4 different components of hydrological drought that may be considered: magnitude, which equals the amount of deficiency, duration, severity, which equals the cumulative amount of deficiency, and frequency of occurrence.

So, these are the 4 variables based on which we can categorize hydrological drought, and methods of studying surface water deficit or hydrological droughts could be low flow duration curves, low flow frequency analysis, and stream flow modelling. Already we know flow duration curves, we have discussed flow frequency analysis, and we have discussed stream flow modelling, but in this case, we will be focusing more on earlier focus in hydrology is more on peak flow, but here we will be more concerned with the low flow data. So, the low flow periods, there where the analysis will focus, that is for hydrological drought.




Then, coming to causes, of this most of the causes, of course, are interrelated. So, some things may be repetitive. So, obviously, natural variability could be one primary cause, that is the hydrological systems exhibit natural variability and certain regions may experience periodic fluctuations in water availability.

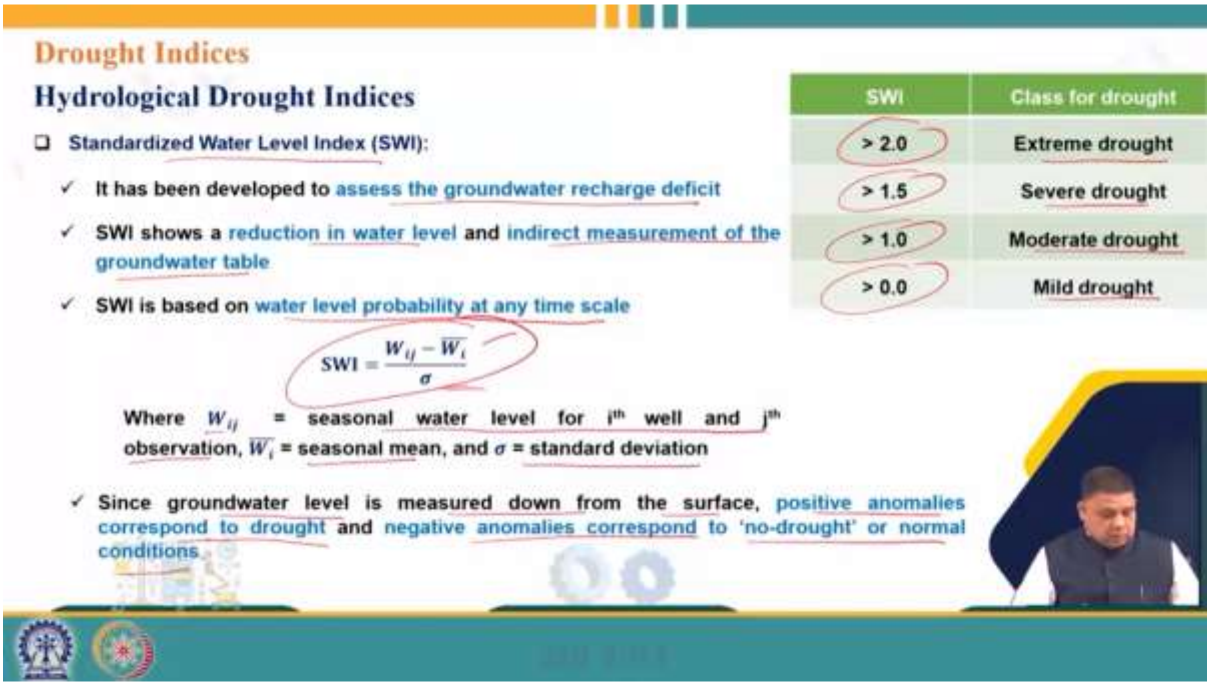
These natural variations, when combined with anthropogenic factors, can contribute to hydrological drought conditions. Groundwater overexploitation or overextraction, excessive pumping of groundwater for agriculture, industry, and municipal water supply can lead to depletion of aquifers. And if the rate of extraction exceeds the rate of recharge, it can contribute to hydrological drought conditions. So, obviously, when you are not saving anything and you are only extracting water from any source, then obviously, it will lead to hydrological drought conditions.



Then, human water management, that is human activities including dam construction, water withdrawal for irrigation, industrial processes, domestic use, can significantly alter the natural flow of rivers and aquifers. So, obviously, if suddenly dams are constructed in series, then downstream sectors will be affected, and poor water management practices may contribute to hydrological drought conditions.

Then, temperature extremes like higher temperatures can increase evaporation rates from surface water bodies and transpiration from vegetation leading to reduced availability of water. Then, an extended period of high temperatures can worsen hydrological drought conditions. So, obviously, we saw that if evaporation will be higher, the water bodies and the water availability in the water bodies will be affected to a great deal.


Then, we come to indices, hydrological drought indices, and there are three different indices we can use: standardized water level index (SWI), surface water supply index (SWSI), and reclamation drought index (RDI), these are the three different ones.

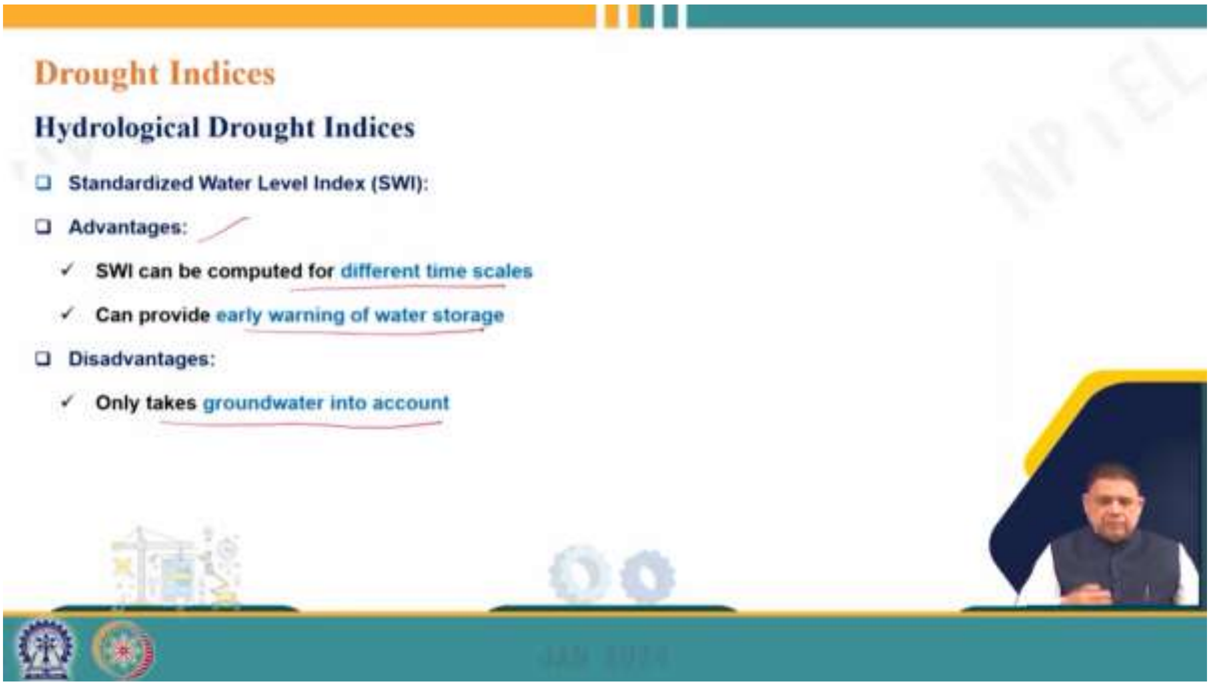



And let us start with the standardized water level index (SWI), it has been developed to assess the groundwater recharge deficit. It shows a reduction in water level and indirect measurement of the groundwater table. So, basically, it focuses on the groundwater availability and it is based on the water level probability at any time scale, and this is how it is calculated

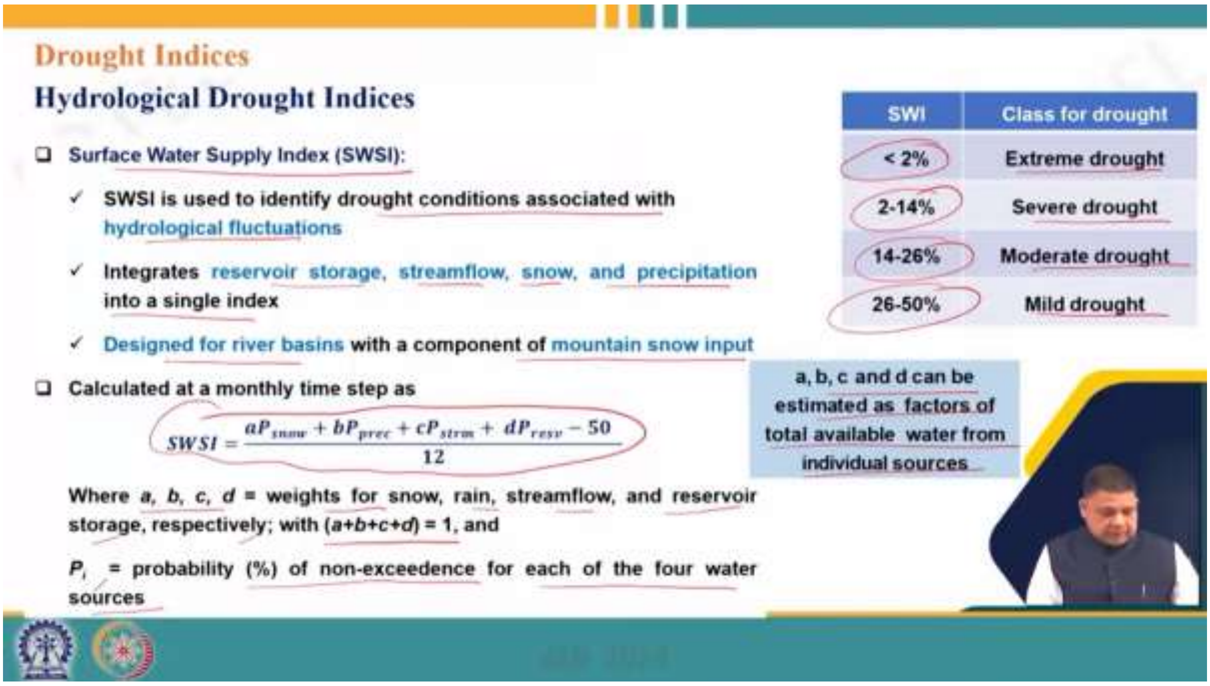
$$SWI = \frac{W_{ij} - \overline{W_i}}{\sigma}$$

where $W_{ij}$ is the seasonal water level for the ith well and jth observation, $-\overline{W_i}$is the seasonal mean, and $\sigma$ is the standard deviation. So, if you have water well data available, then you can get the mean and standard deviation, and then we can have a particular well several measurements over the period, and then that is how we can calculate SWI. Since groundwater level is measured down from the surface, positive anomalies correspond to drought and negative anomalies correspond to no drought or normal conditions.

So, that is how values have to be analysed. So, if SWI value is greater than 2, it shows extreme drought, greater than 1.5 severe drought, greater than 1 moderate drought, and greater than 0 mild drought. So, it has to be in a negative value for no drought condition.



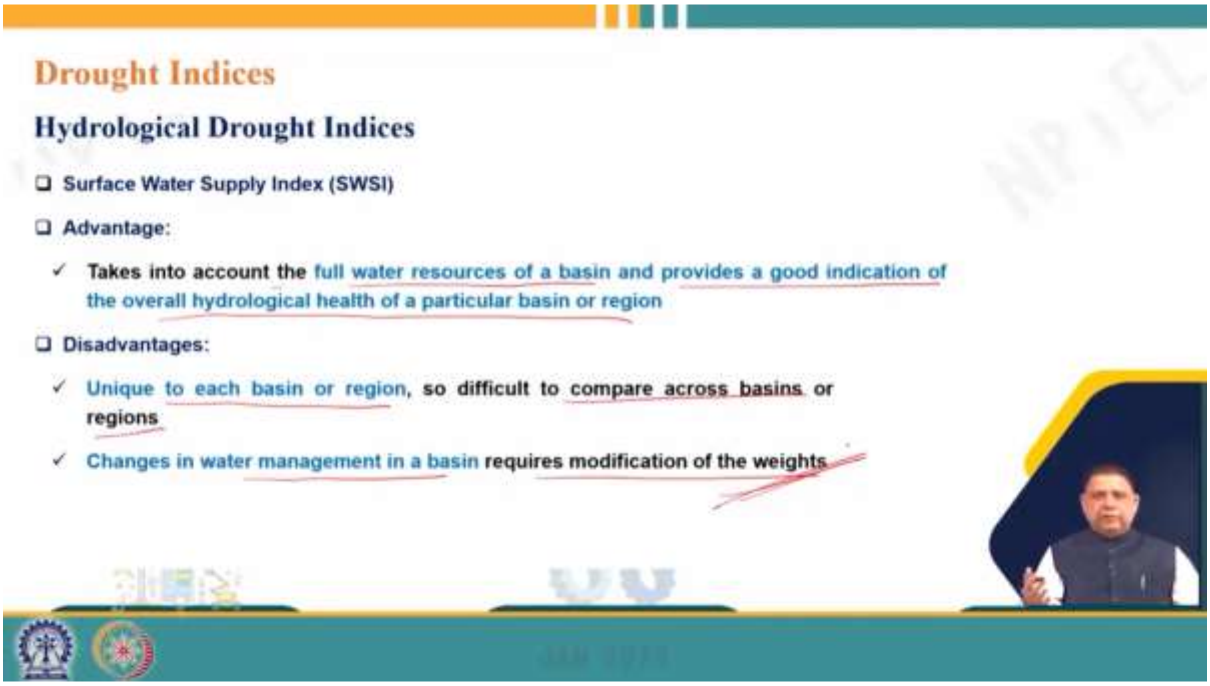

Then it has advantages like it can be computed for different time scales and it can provide early warning of water storage because you are measuring continuously. So, if you know the water table is getting down, obviously, you know that there is a drought kind of situation. This advantage is that it only takes groundwater into account, no other water supply, here water surface is considered.



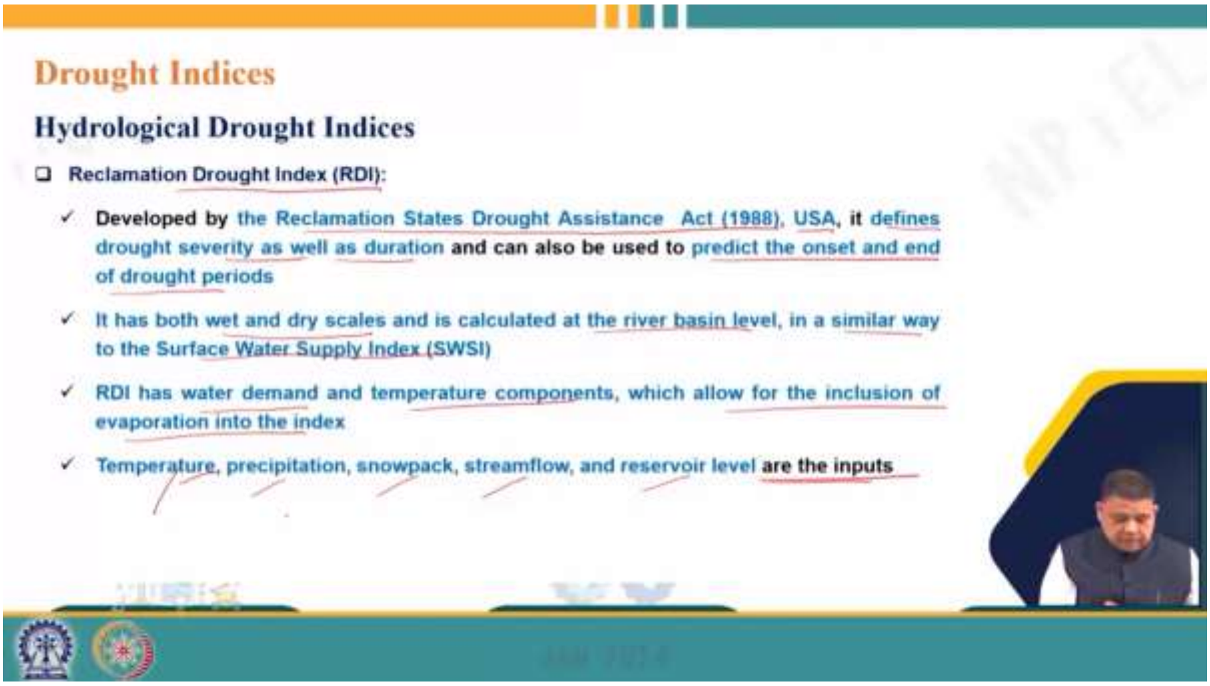

Then we come to the next one, that is surface water supply index. Now, as the name suggests, it focuses on surface, focuses on surface water. So, it is used to identify drought conditions associated with the hydrological fluctuations, integrates reservoir storage, stream flow, snow, and precipitation into a single index, and it is designed for river basins with a component of mountainous snow input.

So, if there is mountainous snow input, then SWSI is more appropriate, and this is how it is calculated in the monthly time step. So, here ABCD are weights for snow, rain, stream flow, and reservoir storages respectively, and some has to be 1, and P i of P snow, P precipitation is the probability of non-accidents of each of the 4 water sources. So, obviously, we have to have some kind of distribution fitted, and ABCD can be estimated factors of total available water from its usual sources. So, obviously, in an area if you know that the total water available is x percent, and then you also know that how much is coming from which source based on that you can calculate the weightage.

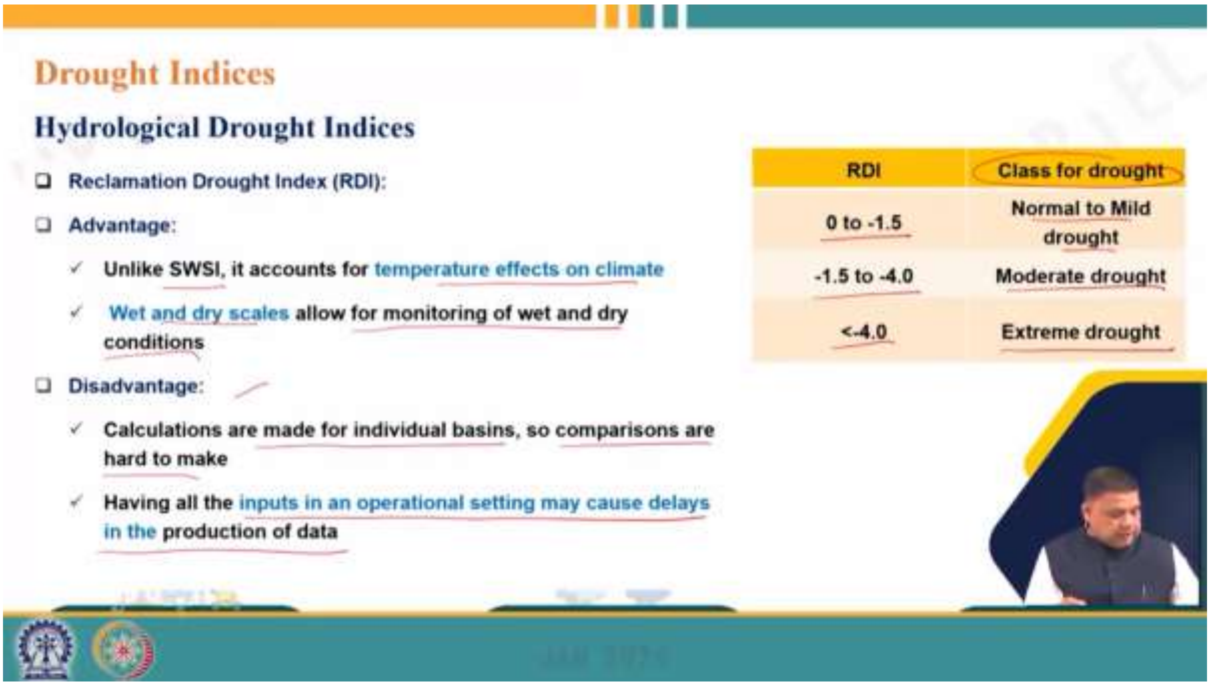
And as far as classification of drought is concerned, if SWI is less than 2 percent, then it is extreme drought, 2 to 14 severe drought, 14 to 26 moderate drought, and 26 to 50 percent is mild drought.




And the advantages of SWSI are that it takes into account the full water resources of the basin, provides a good indication of the overall hydrological health of a particular basin origin, and disadvantage that is unique to each basin origin. So, difficult to compare across basin origins. So, based on SWSI you cannot compare two different basin origins and changes in water management in a basin require modifications of the weight. So, if there are certain changes then weights will get affected. So, obviously, you may have to reassess the weights quite frequently.

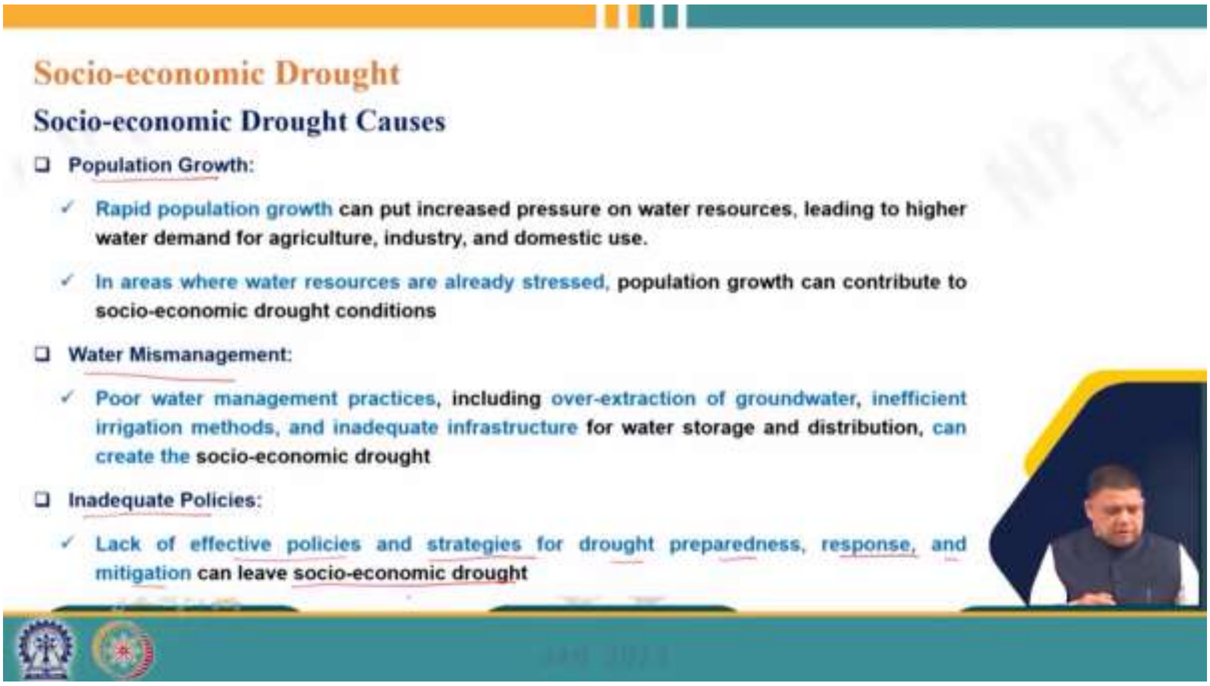



Then comes the reclamation drought index RDI which was developed by reclamation states drought assistant act USA which defines drought severity as well as duration and can be used to predict the onset and end of drought periods. It has both wet and dry scales and is calculated with the Reimer scale in a similar way as the SWSI. RDI has water demand and temperature components which allow for the inclusion of evaporation into the index. Temperature precipitation snowpack streamflow and reservoir level are the input. So, it is more comprehensive that is why it requires more data on different dimensions like you require temperature precipitation snowpack streamflow and reservoir all kinds of data are needed.




It advantage is unlike SWSI, it accounts for temperature effects on climate, and wet and dry scales allow for monitoring of wet and dry conditions. A disadvantage is that calculations are made for individual basins, so comparisons across basins are not possible, and having all the inputs in an operational setting may cause delays in the production of data, so data availability could delay the analysis part also. As far as the drought class is concerned, if RDI is between 0 to minus 1.5, it is normal, while mild drought is between 1.5 to minus 4, and moderate drought is less than minus 4, it is an extreme drought condition.


Lastly, we come to socioeconomic drought, which combines aspects of agricultural, hydrological, and meteorological droughts with the supply and demand of a particular economic good. If the situation where the demand for an economic good exceeds the supply is a result of weather-related shortfall in water supply that is reduced hydroelectricity power, migration, increased price of commodities, stress, and the process of supply and demand in terms of time and space determine when drought occurs and how severe they can become. So, obviously, when there is an area with a hydrological drought, meteorological drought, the agricultural drought, the supply and demand condition will be affected, and that will apply to the socioeconomic condition of a particular region, and that is what is analysed in this particular drought.




And, of course, there could be several reasons like population growth, water mismanagement, inadequate policies like a lack of effective policies and strategy for drought preparedness, response, and mitigation can lead to socioeconomic drought. Of course, all these reasons we have discussed, and because it is the last one, so the combined impact of all other droughts will be reaching here. So, with this, we come to the end of this lecture; we have classified drought into 4 different categories. We also studied hydrological, meteorological drought in a great way, and agricultural drought, as we say, will be discussed in great detail in coming lectures.

Thank you very much; please give your feedback and also raise questions or doubts; we shall be happy to answer.