Watershed Management

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Module No. # 09
Lecture No. # 36
Drought Analysis

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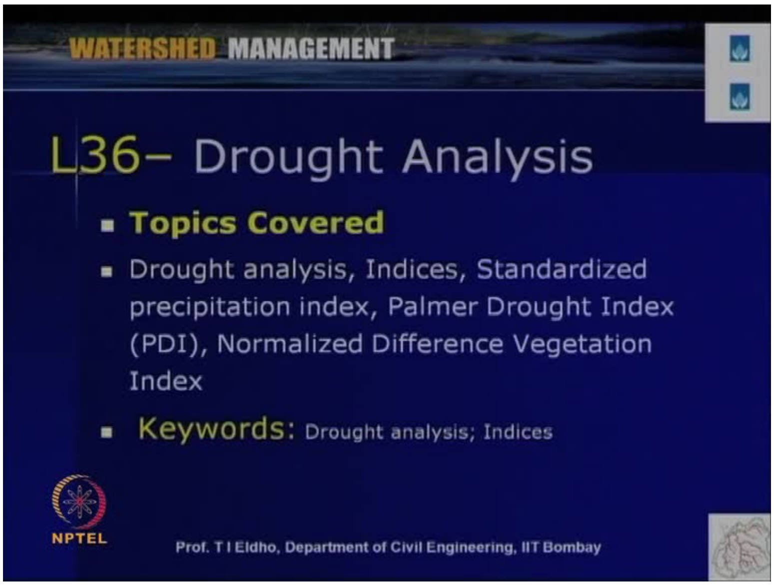

Namaste and welcome back to the video course on “Watershed Management”! In module number nine on drought management in lecture number thirty six, today, we will discuss about drought analysis. So, some of the topics covered in today’s lecture include drought analysis, drought indices, Standardized Precipitation Index, Palmer Drought Index, Normalized Difference Vegetation Index. Keywords are drought analysis, drought indices.

So, as we were discussing earlier, say when we deal with watershed management, we have to deal with, say the plenty of water; that means the flooding and then non-availability of water, say droughts problem.

So, drought analysis, as we have discussed in the last lecture, so drought assessment and then its analysis is very important. So, if there is any possibility of drought like, we have already seen in the last lecture like meteorological drought, hydrological drought, agricultural drought and social sociological or social drought. So, this classification we have seen.

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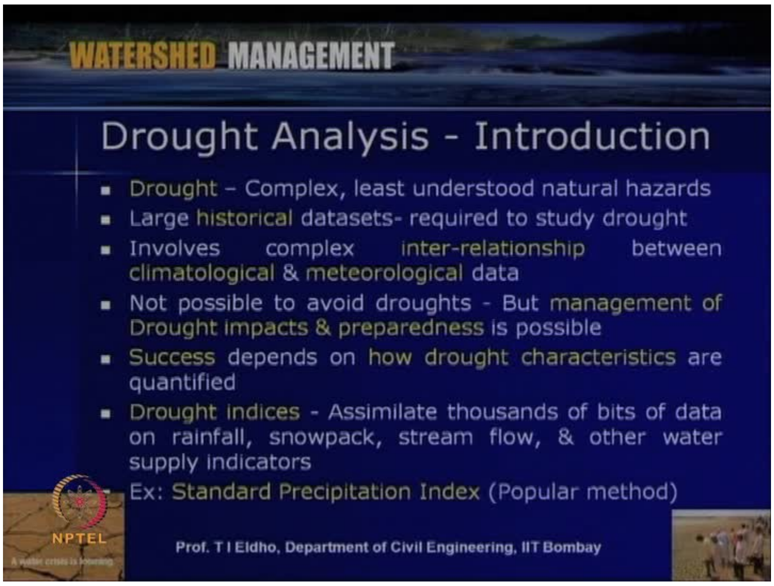

So, when we look into the to the drought analysis, we have to see various aspects of the drought, say the what is the starting, say the starting of our onset of the drought, then the duration of drought, the volume of intensity of drought. So, that way drought analysis is very important. So, since the drought itself is a very complex and say, least understood in natural hazards.

So, that way we have to study the entire details of the drought in detail. So, that way the, say we need to analyze large historical data sets and then we have to come up with the interrelationship between the climatological, meteorological data and then say the agricultural details. All these things, we have to critically analyze and then say we have to come up with a certain indices, so-called drought indices. So, that will say, that give the details like onset of the drought, then the intensity of drought like that.

So, as we discussed in the last lecture, it is not possible to avoid the droughts. But, management of drought impacts and preparedness is possible. So, that way drought mitigation is possible to certain extent. So, that way we have to understand the various aspects of the drought, whether it is the meteorological drought, hydrological drought or whichever the type of drought. So, we have to understand or we have to analyze the drought to understand the starting or may the intensity or the duration. So, like that various aspects we have to understand.

So, the drought analysis; the success depends on, say how drought characteristics are quantified. So, drought analysis means we have to understand the characteristics of the drought. So, the success depends upon how the drought characteristics are quantified in terms of some numbers or indices.

So, that way these drought indices are commonly used to analyze the drought as a tool. So, these drought indices, these are some numbers. So, this numbers assimilate thousands of bits of data on; say for example, rainfall, snowpack, stream flow and other water supply indicators. And then, say these kinds of indices, say give some numbers. So, that numbers shows the intensity of the drought or onset of drought or various characteristics of the drought.

So, some, one of the very commonly used drought index for drought analysis is the Standardized Precipitation Index. So here, say we will be discussing later the details of this methodology. So here, we also identify, say depending upon the watershed characteristics depending upon the various meteorological, hydrogeological characteristics.

We quantify the possibility of drought. It is the severity of drought in terms of a number and that number shows, whether drought is the coming drought, the onset of the drought with respect to that whether it will be severe, moderate or it is a very strong type of drought. So, all these classification or all these aspects, we can identify through drought analysis generally in terms of drought indices.

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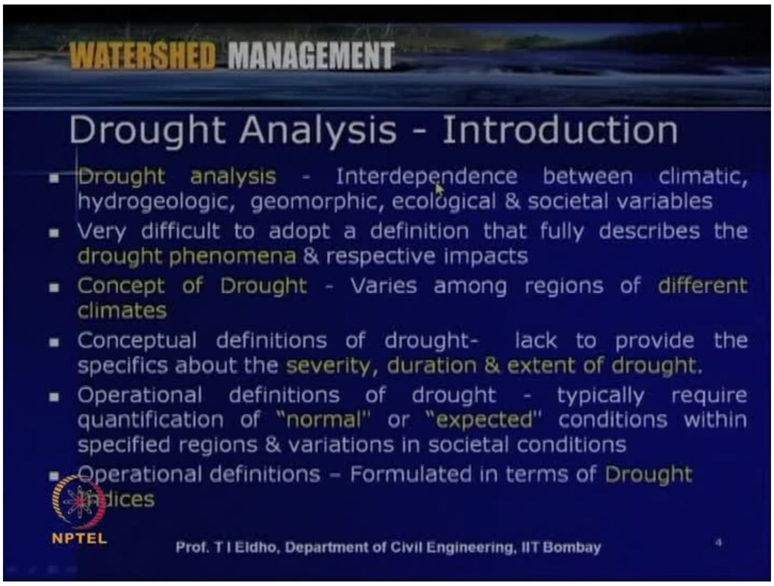

So, as I mentioned drought analysis, actually this drought analysis shows the interdependence between climatic, hydrogeological, geomorphic, ecological and societal variables. So, when we look into the drought, say as we have discussed in the last lecture also. And, there are number of parameters we have to consider. And, these parameters decide, when the drought will be on the onset of the drought or the intensity of drought or the characteristics of the drought.

So, that way, when we deal with, when we discuss the drought analysis, we have to see the interdependence between this various parameters of various variables, say which influence like the climatic variables, hydrogeological variables or geomorphologic variables, like that.

So, say that way, it is very difficult to adopt a definition that fully describes the drought phenomena and respective impacts. So, that way we can see that all these parameters or all these variables are very difficult to quantify and most of the time, we can only put in terms of qualitative terms. So, that way this drought analysis is a very difficult process. And then, say it is very difficult to quantify the impacts. So, that way, as we discuss that last time also; the concept of drought or the, its characteristics vary, varies among regions of different climates. Say for example, say when we, say the quantity of rainfall, which we are getting in some particular location, say if it is, say for example, say hundred centimeter per year. So, but in some places, wherever normally if the average annual rainfall is two hundred and fifty, then if you are getting hundred centimeter in that region then that, we may be able to say that area is drought affected. But, wherever the average annual rainfall is hundred centimeter only. So, where they are getting hundred or say ninety five, that area we will not say a drought affected area. So, that way, we have to see the interdependence of various parameters or variable, various variables. And then, we have to say come up with the conceptual definitions of drought, say with respect to the area, with respect to the hydrogeological parameters and then the severity of the drought, then duration and extent of drought.

So, this is three important parameters. Generally, three important aspects, we look into when we go for drought analysis like, what is the severity of the drought and then how much is the duration and then extent of the drought. So, these are the three important things, which you will be looking when we look into drought analysis.

So, that way, the operational definitions of drought like typically require the quantification of normal or expected conditions within specified regions and variations in in societal conditions. Say, when we look into this aspects are like, for example, say when we see the rainfall, whether the rainfall is the condition is normal or below normal or say the… with respect to expected conditions. So, all those things are very important when we deal with the drought analysis.

So, that way we can have the operational definitions formulated in terms of drought indices. So, as I mentioned one of the tool; generally, we use for drought analysis is by using the drought indices. So, these are formulated, say by considering the various aspects like the climatic aspects, hydrogeological aspects, geomorphic or ecological aspects. So, like that we can have the drought analysis.

So generally, say when we deal with the drought analysis, now one of the most important aspects we will be looking is the hydrological drought. So, in the last lecture we were discussing about the meteorological drought, hydrological drought, agricultural drought, like that. So, that way, when we are trying to quantify or when we are trying to analyze the drought; so, generally it is much easy to analyze in terms of the hydrological parameters. So, that way we can choose the hydrological drought analysis through hydrological models.

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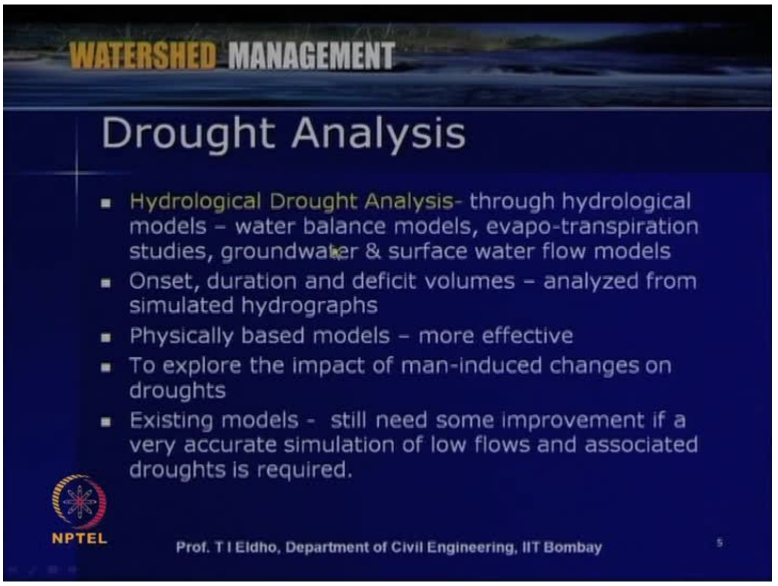

So, generally we can use some, one or another kind of hydrological models like water balance models, evapotranspiration studies, ground water and surface water flow models. So, like this, say we can choose, say any one of these aspects or in combination of these aspects like water balance studies, say using models or evapotranspiration studies in the area of the watershed or the river basin, which we consider. And then, say we can study the ground water and surface water, say analysis in that area through models.

So, like that, we can go for the hydrological drought analysis. And then, as I mentioned, generally we will be looking for the onset of drought duration of the drought and then in terms of water, how much will be the deficit, say if the drought is there, then say with respect to normal condition, how much of water is required and due to drought condition how much of water is not available. So, according to that we can analyze the deficit and then say like, say we can analyze with respect to simulated hydrographs for the area or the outlet of the watershed, like that. So, that way as we have discussed earlier, say we can have the black box models or empirical models or the lumped models or the distributed models, say as far as the hydrological analysis is concerned.

So, but when we deal with a drought analysis, generally it is better to use physically based models, since it is more effective. And then, we get the distribution with respect to space and time. So, that way, the hydrological analysis based on physically based models is generally used for drought analysis.

So, that way in drought analysis, we are trying to explore the impact of the, say if you are looking for the man induced changes on the watershed or the river basins, so then, what will be the effect with respect to man induced changes on droughts. Say for example, if there is a dam is constructed or the reservoir is there, then what will be the effects or the deforestation takes place in the particular watershed or the river basin in an extensive way then what will be the effects, like that.

So, say most of the existing hydrological models we can use for drought analysis. But, depending upon the area and depending upon the various parameters, still need some improvement. If a very accurate simulation of low flows and associated droughts is required. So, generally the available hydrological models, generally we are trying to identify with respect to rainfall runoff and most of the time the flood analysis, etcetera. But, when drought is concerned, it will be… we have to deal with very low flows in the, within the watershed like overland flow or the channel flows are concerned. And, that way some modifications may be required for the, if you are trying to use the existing hydrological models as far as the drought analysis is concerned.

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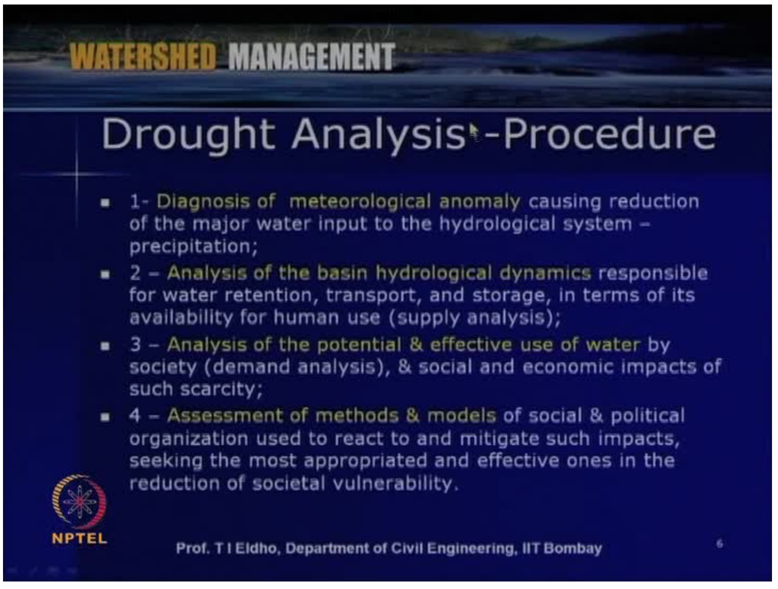

So now, say when we look into drought analysis, say we have to see the various aspects with respect to the drought for the particular area. So, they generally use the procedure. Here, I have put in four steps. So, first one is the diagnosis of meteorological anomaly causing reduction of the major water input to the hydrological systems. So, that means, generally the precipitations or the snow fall. So here, what we are trying to do is, say generally as we discussed the drought is generally due to the, especially if the meteorological drought to the meteorological anomaly as far as the rainfall is concerned. So, with respect to this, say when the rainfall reduces for the particular watershed, say for the hydrological systems, then we have to see the effects of that.

So, what will be the effects of reduction in the precipitation? So, that is, the first step is diagnosis of the meteorological anomaly. So, that is the first step. Then, second one is analysis of basin hydrological dynamics responsible for water retention, transport and storage, in terms of its availability for human use, say just like supply analysis.

So, that way, the second step what we are trying to deal with is the hydrological dynamics. So, with respect to rainfall to runoff with the various processes are there, as we have discussed in many of the lectures. So, that way, like the water retention or the transport and then say how much storage is possible. So, all those things we have to critically analyze in step number two with respect to the drought analysis. Say for example, in hilly regions like the Konkan region in Maharashtra, even though these, there is no meteorological anomaly, the rainfall may be normal. But, still after three, four months of the rainfall, say there is situation for droughts. Since, the geographical conditions, say there is the soil is not retaining the water. All the runoff will be, say transported through the river to the sea. So, that way the water retaining is much low. So, that way, we can see that there is a possibility of drought. So, that way we have to analyze the basin hydrological dynamics as far as the drought is concerned.

Then, third step is analysis of the potential and effective use of water. So here, say we have to do the demand analysis and social and economical impacts of say the water scarcity. We have to see, so say, even though with the less available water, say just like a drought conditions, say if we can say do appropriate demand analysis and use less amount of water, so that way, still we can deal with the drought. Say for example, in a country like Israel where the rainfall is much less, still they are managing their agricultural and all the system very effectively.

So, that is mainly the demand management or the demand analysis. So, in the step number three we have to deal with the analysis of potential and effective use of water. And, step number four is assessment of methods and models of social and political organization used to react to and mitigate such impacts seeking the most appropriated and effective ones in the reduction of societal vulnerability.

So, in the drought analysis, in the fourth step we are dealing with the, say the assessment of methods. The particular methods to understand the societal vulnerability as far as the drought is concerned. And then, what will be its impacts as far as the drought impacts are concerned and then what… effective mitigation measures can be taken.

So, that way, when we deal with drought analysis we can have four steps. First one is the diagnosis of meteorological anomaly; second one is the analysis of the basin hydrological dynamics; third one is analysis of the potential and effective use of water and fourth one is the assessment of methods and models. So, that way, we can go for drought analysis.

So, as I mentioned earlier, say generally as far as droughty analysis is concerned, we quantify the drought in terms of some numbers; so-called drought indices. So, these drought indices, numbers of drought indices are available. So, we can choose particular type of drought index to analyze the drought, say for the given region.

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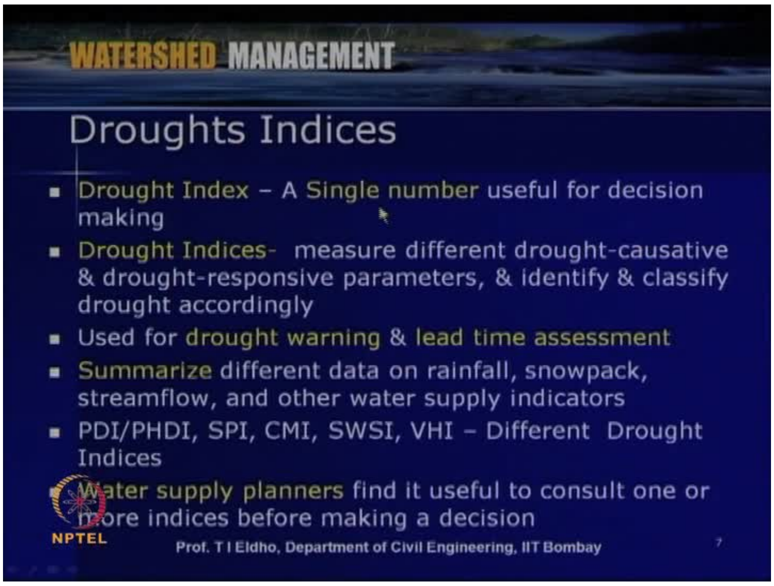

So, let us now look into the drought indices. So, as I mentioned earlier, so drought index is a single number useful for decision making. So, by considering the various aspects, like the meteorological parameters, then hydrological parameters, then the agricultural aspects like that.

So, these drought indices are or, drought indices give measure of different drought causative and drought responsive parameters and identify and classify drought accordingly. So, the particular drought index which we are dealing. So, that is trying to come up with the causative and drought responsibility parameters and we are trying to quantify in terms of some numbers. And then, accordingly by using that we can say the drought is severe or moderate and we can identify and classify the drought.

So, generally this kind of drought index is used for drought warning and lead time assessment. So, the drought index indicates the possible onset and then severity and then the duration of the drought. So that, some indications are given by these drought indices.

So, drought indices summarize different data on rainfall, snowpack, stream flow and other water supply indicators. So, this using, say various say aspects of; say the meteorological parameters like rainfall, snow, then the hydrological parameters like stream flow. So, all these water supply indicators are taken into account. And then, that way only we are deriving the typical drought index for the given area. So, that will be, that is used for the purpose of drought analysis.

So, some of the commonly used drought indices include Palmer Drought Index or Palmer Hydrological Drought Index, then Standardized Precipitation Index, then CMI, SWSI, VHI, like that. Say related to the surface water or related to vegetation or related to crop. There are number of different types of drought indices are available in the literature. So accordingly, say depending upon the type of area and depending upon the type of analysis which we are looking for, we can choose specific type of drought index and then we can do the drought analysis.

So, generally the water supply planners find it difficult to consult one or more indices before, say find it useful to consult one or more indices before making a decision. So, there will be lot of uncertainties with respect to each of these indices, each of the index which we consider. So, that way, say generally water supply planners, say for long term planning and management, and say instead of choosing only one kind of index, we can choose more than one index. And then, say analyze the various scenarios and then come up with certain conclusions. So, that way these drought indices are very useful for the water supply, planning and management, say especially on a watershed basis.

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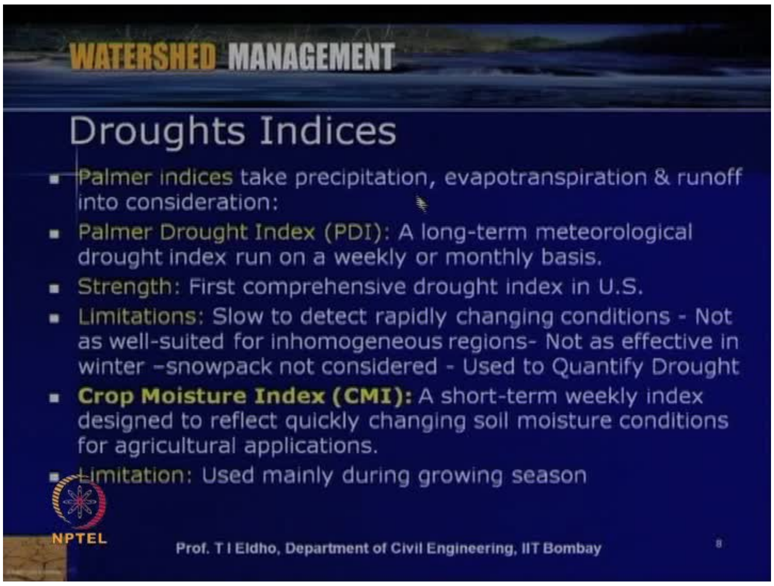

So, now when we deal with a drought indices, as I mentioned different types of drought indices are available in literature. So, one of the most commonly used index is called Palmer Drought Index. So, these Palmer indices take some of the important parameters like precipitation, evapotranspiration and runoff into consideration, while coming with an index for the drought situation for a particular area.

So, that way Palmer Drought Index gives a long term meteorological drought. It is a long-term meteorological drought index that runs on a weekly or monthly basis. So, depending upon the analysis, we can have the drought index; say, either weekly basis or the monthly basis.

So, this is one of the first comprehensive drought index, say started to use in USA in 1960s. So, that way, this is one of the earliest type of drought index used for drought analysis. And, some of the limitations of this Palmer indices are slow to detect rapid changing conditions and not as well as suited for inhomogeneous regions. If the region is homogeneous, then it has been found to be very effective. For inhomogeneous regions, Palmer Drought Index has been found to be not so suitable, then this Palmer index is not as effective in winter. So, especially, so if summer season, summer time, the Palmer index has been found to be very effective, but whenever winter or snowpack, snowfall all those things are there, then this index has been found to be not so effective. So, as we discussed, this Palmer Drought Index is used to quantify drought in terms of a number. So, that we will be discussing later; the Palmer index. And then, another type of index is, say especially related to agricultural droughts. So, that is so-called Crop Moisture Index; so, CMI.

So, this index gives a short-term. It is a short-term weekly index designed to reflect quickly changing soil moisture conditions for agricultural applications. So, with respect to, say in especially, this is used for agricultural regions. So, say starting from the putting the seed and then with respect to the growing conditions of the crop. So, the Crop Moisture Index gives, say whether there is any possibility of the drought with respect to that particular crop is concerned. So, some of the limitation, say one of the limitation of this crop moisture index is, it is used mainly during growing season. So, otherwise, say especially this is useful for agricultural area. So, that is about the Crop Moisture Index.

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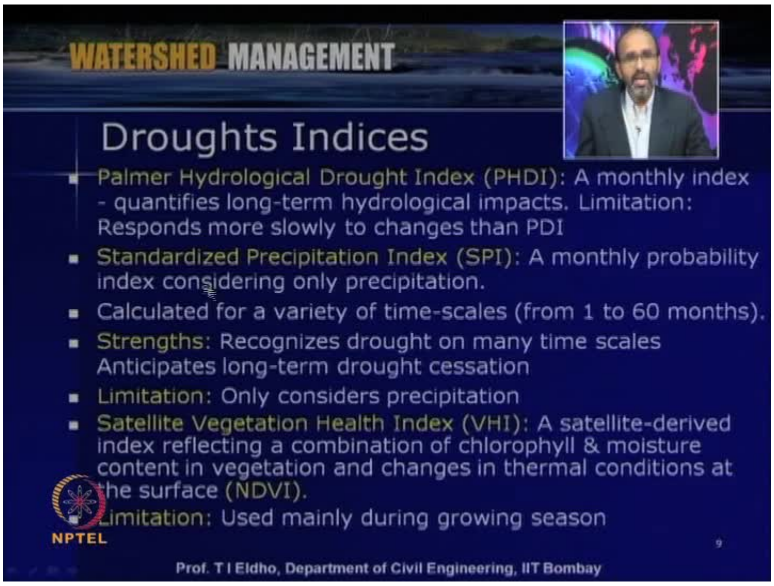

Then, some of the other index like, Palmer Hydrological Drought Index. So, that is, say very similar to Palmer Drought Index. So, Palmer Hydrological Drought Index is just mainly dealing with hydrological aspects as specifically. So, it is a monthly index, generally quantifies long-term hydrological impacts. So, here in this index, that index indicates the long-term hydrological impacts as far as the watershed or the area is concerned. And, say one of the limitations for this method is it responds more slowly to changes than the Palmer Drought Index, what we have discussed earlier.

Then, another most commonly used index is called a Standardized Precipitation Index or SPI. So, this is a monthly probability index considering only the precipitation. So, generally this is one of the commonly used index for drought analysis. So, in the Standardized Precipitation Index, only one parameter is there. That is the precipitation. So, we analyze with respect to the precipitation and then come up with an index. So, that indicates, whether there is any possibility of the drought.

And, this SPI or Standardized Precipitation Index is calculated for a variety of time scales like from one to sixty months. And then, the strengths include the… it recognizes drought on many time scales and then anticipate long-term drought cessation. So, this is mainly based upon the rainfall condition or precipitation condition. So, that way, say the limitation is that it considers only the precipitation.

And then, some other indices like Satellite Vegetation Health Index, so-called VHI or NDVI, sometimes called. So, this is a satellite-derived index reflecting a combination of chlorophyll and moisture content in vegetation and changes in thermal conditions at the surfaces.

So, sometimes we will use this VHI, Vegetation Health Index or we use the Normalized Difference Vegetation Index, NDVI. So, one of the limitation of this VHI is the, generally it is used mainly during the growing season.

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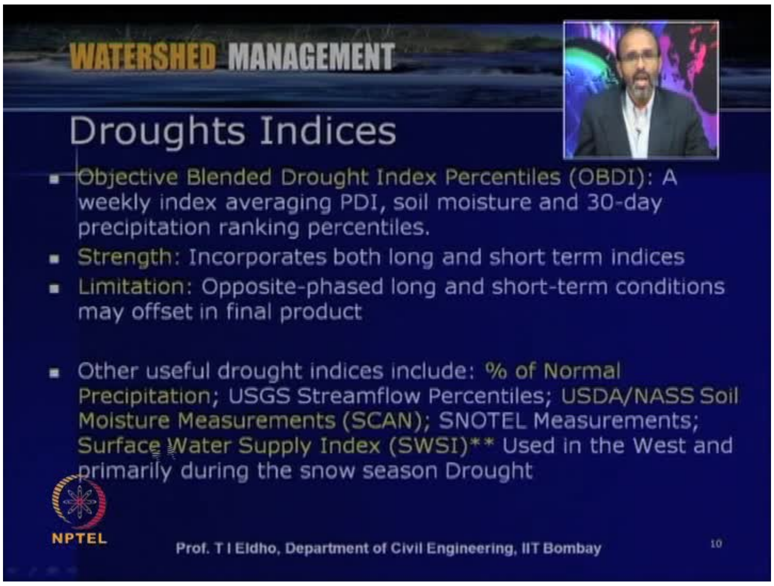

So then, say other kinds of index like Objective Blended Drought Index Percentiles, OBDI. So, this is a weekly index averaging the Palmer Drought Index, then soil moisture and thirty day precipitation ranking the percentiles. So, this is so-called OBDI index.

So, the strength is, it incorporates both the long and short term indices. And, limitation is it is opposite-phased long and short-term conditions may offset in final product. So, that is the limitation of this OBDI.

And, some other useful drought indices include like Percentage of Normal Precipitation; then USGS Streamflow Percentiles; then USDA and NASS Soil Moisture Measurements, so-called SCAN; then SNOTEL Measurements; then Surface Water Supply Index SWSI.

So, this is generally used in the west and primarily during the snow season drought; so, wherever snowfall is there. So, like this in literature, if you go through we can see number of drought indices for the drought analysis. But, commonly used drought indices include the Palmer Drought Index and then the Standardized Precipitation Index. So, we will be discussing the detail of these two indices and also you see some aspect of the vegetation or the health index or the NDVI, we will be briefly discussing.

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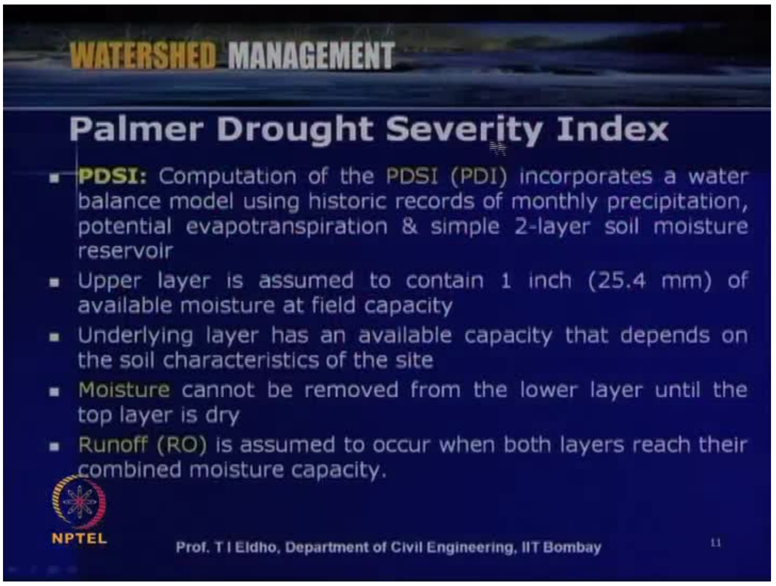

So, now let us look into this the Palmer Drought Index; Drought index of Palmer Drought Severity Index, so sometimes it is called PDI Palmer Drought Index or sometimes, we call it as Palmer Drought Severity Index.

So, this Palmer Drought Severity Index; this is the computation of the PDSI and it incorporates a water balance model using the historic records of monthly precipitation, potential evapotranspiration and simple two-layer soil moisture reservoir.

So, that way, this PDSI or the PDI index is, say somewhat comprehensive index. So, that shows that gives the effects of historic records of monthly precipitation, then water balance, then evapotranspiration effects and then also the soil pattern and the soil moisture storage.

So, we consider here, a two layer soil moisture reservoir. The upper layer is assumed to contain, say about one inch of available moisture at field capacity. And second layer, under lying layer has an available capacity that depends on the soil characteristics of the site. So, that way, here in the Palmer Drought Index, we consider the water balance, then the monthly precipitation effects, then evapotranspiration and soil pattern also.

And then, the moisture cannot be removed from the lower layer until the top layer is dry. So, that way, this two layer concept is used. And, the runoff is assumed to occur when both the layers reach their combined moisture capacity. So, when both of these layers, which we consider both are saturated and then only, we assume that runoff starts. So then, accordingly this Palmer Drought Severity Index has been designed.

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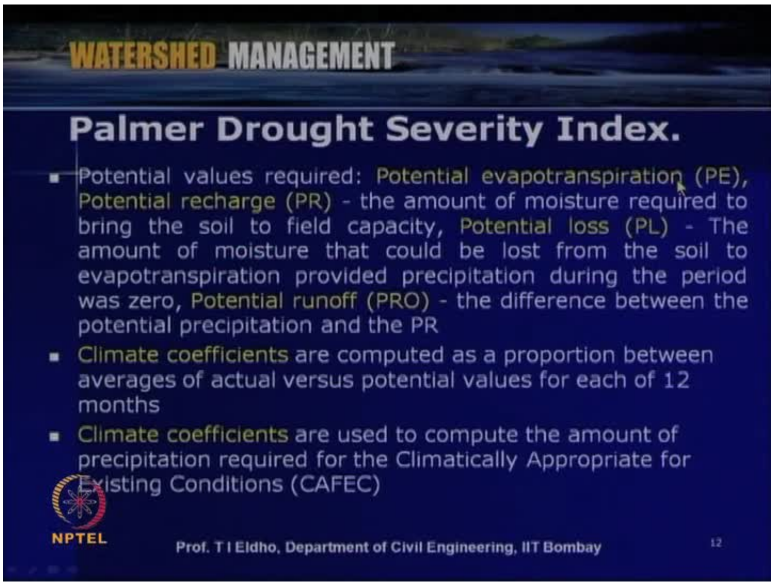

So, the… say as far as the Palmer Drought Severity is concerned, the potential values required, include the potential evapotranspiration, potential recharge for their soil, which you consider the amount of moisture required to bring the soil to its field capacity. And, potential loss like the amount of moisture that could be lost from the soil to evapotranspiration, provided precipitation during the period was zero.

Then, potential runoff from the particular watershed or the particular area; that is, the difference between the potential precipitation and the potential recharge. So, that is the potential runoff. So, that way this Palmer Drought Severity Index is designed. And, the climate coefficients are computed as a proportion between the averages of actual versus potential values for each of twelve months.

So accordingly, say actual versus potential values we can identify and then we can have the climate coefficients. And, the climate coefficients are used to compute the amount of precipitation required for the Climatically Appropriate For Existing Conditions.

So, say based upon the rainfall condition, soil conditions and when various other parameters, we can calculate the climate coefficients. And then, this we can effectively use as climatically appropriate for existing conditions, say that particular precipitation the amount of precipitation. So, accordingly we can derive the Palmer Severity Index.

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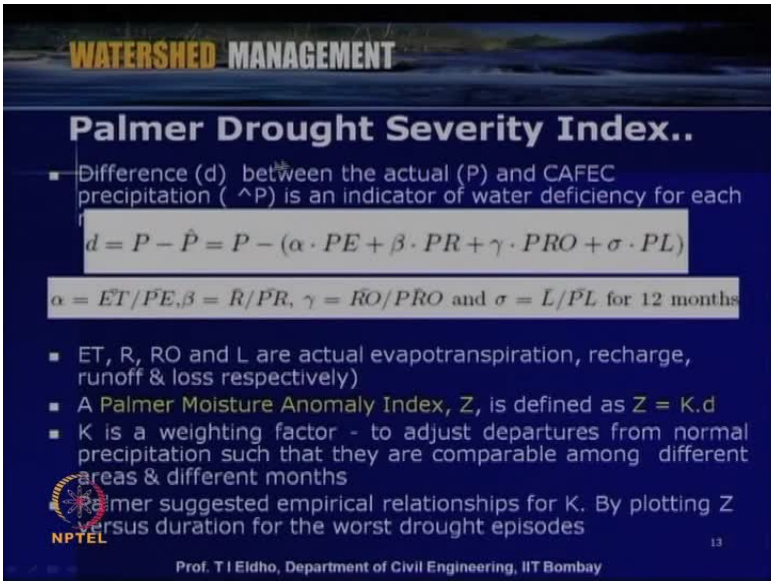

So, here this Palmer Severity Index is obtained from these equations. So, the difference d between the actual P and the CAFEC; the Climatically Appropriate For Existing Condition. So, CAFEC precipitation P hat is an indicator of water deficiency for each case. So, this d is equal to P minus P hat. So, that is equal to P minus alpha into PE plus beta into PR plus gamma into PRO plus sigma into PL. And then, this alpha, beta, gamma and sigma define like this. Alpha is equal to ET bar divided by PE bar; beta is equal to R divided by PR and gamma is equal to RO divided by PRO and sigma is equal to L by PL bar for the twelve months, we consider.

So, here ET, R, RO and L are actual evapotranspiration, ET; recharge, R; RO is runoff and L is the loss respectively. And then, that way Palmer Moisture Anomaly Index, Z, is defined as Z is equal to K into d; where K is a weighting factor. So, to adjust the departures from the normal precipitation such that they are comparable among the different areas and the different months. So, Palmer suggested empirical relationship for this K; so, where z is equal to k into d. So, d is defined here and k is the weighting factor. So, by plotting Z versus duration for the worst drought episodes, we can obtain this, the variation.

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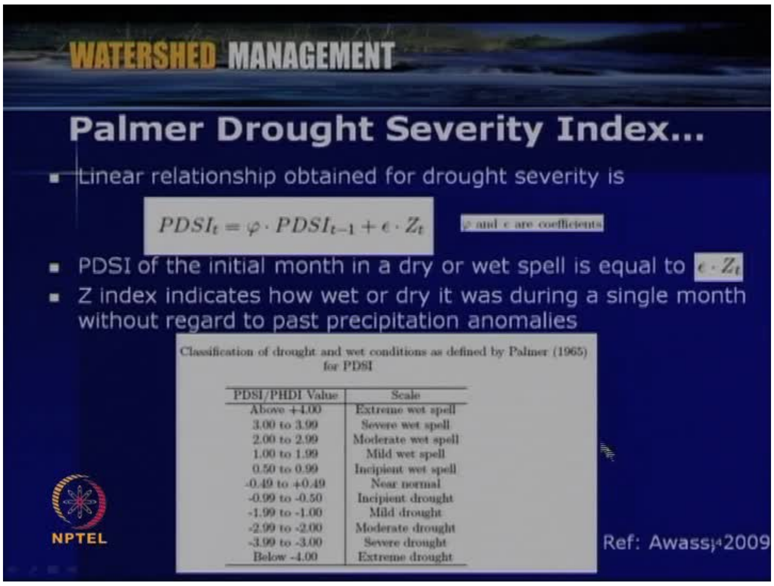

And then, the linear relationship obtained for drought severity. We can obtain as PDSI t is equal to psi into PDSI t; that say, the PDSI t one plus epsilon into Z t; where psi and epsilon are some coefficients.

So, the Palmer Drought Severity Index of the initial month in a dry or wet spell is equal to epsilon into Z t. So, Z t is this part. So, Z t means the Z index for the particular time period. So, Z index indicates how wet or dry it was during a single month without regard to past precipitation anomalies.

So, there may be past precipitation anomaly. And then, but here for a single month we are considering. So, according to the Palmer Drought Severity Index, the classification of drought and wet conditions as defined by the Palmer for PDSI is given here. So, PDSI or PHDI value; so, above four, it is extremely wet spell and say, so much of rain is there and between 3 to 3.99, severe wet spell; then 2 to 2.99, moderate wet spell; 1 to 1.99 it is a mild wet spell.

Then, 0.5 to 0.99 is incipient wet spell, for minus 0.49 to 0.49 near normal and minus 0.99 to minus 0.5 incipient drought. Then, say minus 1.99 to minus 1 is mild drought; minus 2.99 to minus 2 is moderate drought; minus 3.99 to minus 3 is severe drought and below minus 4 is extreme drought.

So, as given in the reference Awass 2009; so, accordingly the palmer drought severity index we can identify. So, drought is concerned when this Palmer Drought Severity Index is negative. So, especially if it is less than minus 0.5, so then there is starting from mild drought to extreme drought below minus 4. So, that way, this Palmer Drought Index has been derived. And then, depending upon the area we can identify, we can quantify this Palmer Drought Index. And then, we can predict, whether there is any possibility of the drought, whether it is mild, moderate, severe or extreme.

So, this is, generally we do with respect to the historical available data, since the rainfall prediction is possible only for few days, conditions. But, according to the historical data we can analyze and then say do the drought analysis. So, that is about the Palmer Drought Severity Index.

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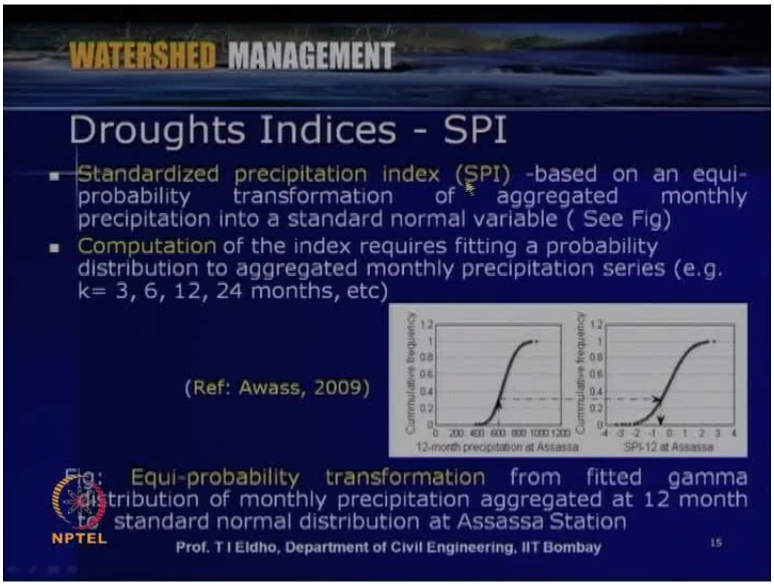

Now, another type of drought index is the very commonly used drought index is called Standardized Precipitation Index. So, let us look into various aspects of this Standardized Precipitation Index. So, this SPI is based on an equi-probability transformation of aggregated monthly precipitation into a standardized normal variable. So, we, what we do? We try to standardize with respect to the rainfall condition, with respect to cumulative frequencies. We try to standardize and then, say for example, at location called ASSASA, SPI, we can derive and that is with respect to the cumulative frequency.

So, the computation of the index requires fitting a probability distribution to aggregated monthly precipitation series like K is equal to three, six, twelve or twenty four months, like that. So, say for example, this figure shows the equi-probability. This transformation from fitted gamma distribution of monthly precipitation aggregated at twelve month to standard normal distribution at the ASSASA station, a particular location as reported in this reference; AWASS,2009.

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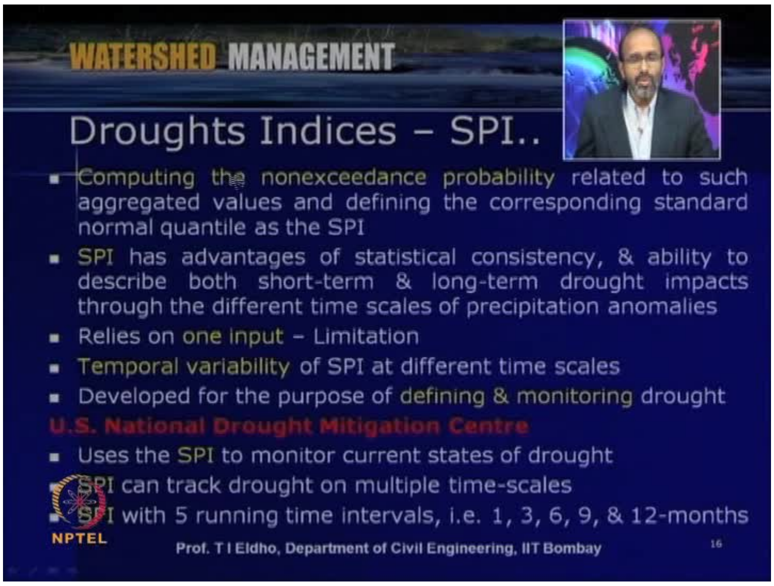

So, that way depending upon the precipitation for that particular region, we can derive the Standardized Precipitation Index. So, this SPI, generally we will use to compute the nonexceedance probability related to such aggregated values and defining the corresponding standard normal quantile as the SPI.

So, say this SPI is the advantage that only one parameter is there. So, there is a statistical consistency and then ability to describe both short-term and long-term drought impacts through the different time scales of precipitation anomalies like, as we discussed with respect to three months, six months, twelve months or twenty months.

So, the limitation, this is based only on the precipitation. So, that is one of the main limitation. And, temporary, temporal variability of SPI at different time scales we can identify. And, this SPI is developed for the purpose of defining and monitoring the growth. So, this is one of the most commonly used drought analysis techniques or the drought index is the Standardized Precipitation Index.

Since, it is much more simple and then easy to understand and then easy to derive for a particular area. Say for example, US national drought mitigation center use this SPI to monitor the current states of drought. And then, SPI can track drought on multiple time scales. And, this SPI with five running time intervals like one month, three months, six months or nine and twelve months. So, that way these are some of the advantages of the SPI based drought analysis.

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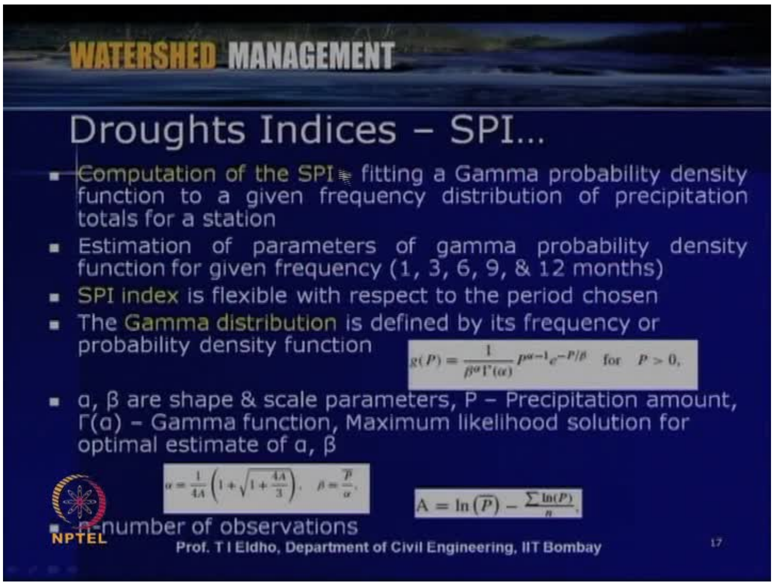

Then, as far as that the SPI calculation is concerned, computation of the SPI is based upon fitting a gamma probability density function to a given frequency distribution, as shown in the previous slides, of precipitation totals of a station.

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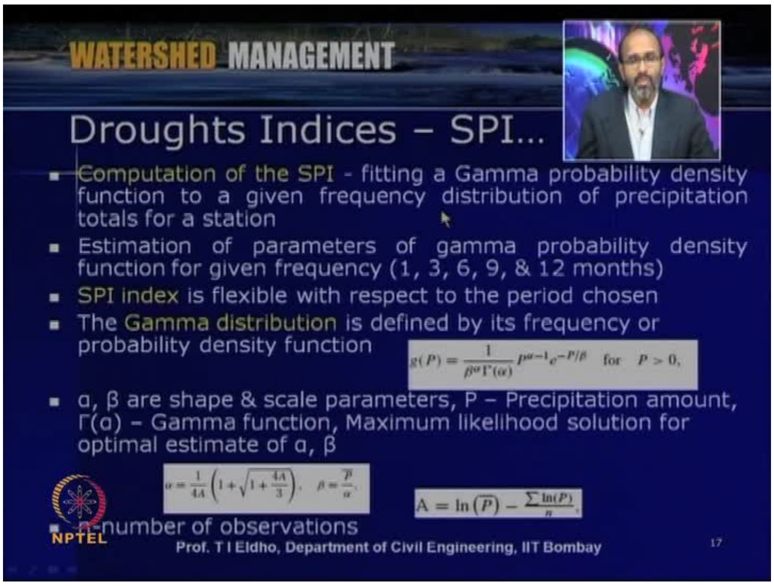

So, as I mentioned like this, we do a gamma distribution curve, fitting a gamma probability density function. Then, estimation of parameters of gamma probability density function for a given frequency. Then, SPI index is flexible with respect to the period chosen. And, the gamma distribution is defined by its frequency or probability density function like g P is equal to one by beta to the power alpha tau alpha P to the power alpha minus 1 e to the power minus P by beta, for P is greater than zero.

Here alpha and beta are the shape and scale parameters, P is the precipitation amount, tau alpha is a gamma function, maximum likelihood solution for optimal estimate of alpha and beta can be obtained like alpha is equal to one by four a into one plus square root of one plus 4 a by 3. Beta is equal to P bar by alpha and A is equal to l n P bar minus sigma l n P by n, where n is the number of observations.

So, that way for the particular watershed or particular river basins depending upon the number of observations available, we can derive this SPI, the Standardized Precipitation Index. And then, accordingly we can identify whether there is any possibility of drought, whether it is the moderate, severe or extreme, like that.

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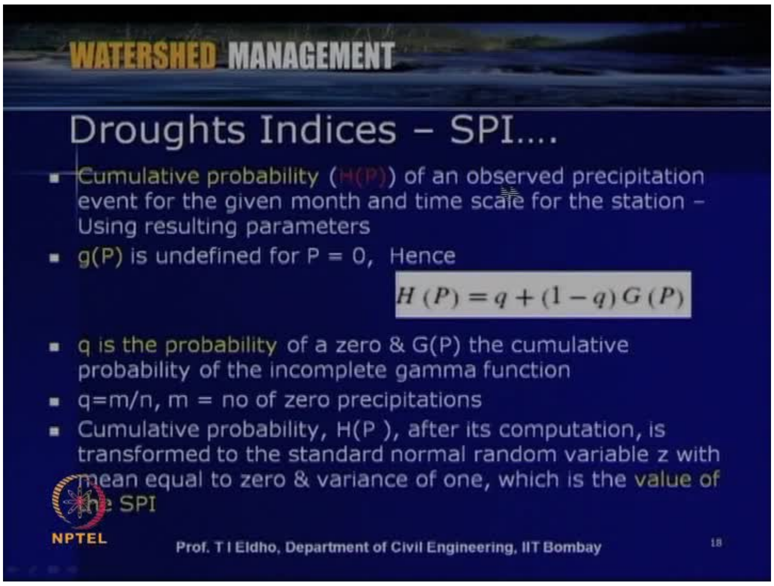

And, this cumulative probability of an observed precipitation event for the given month and time scale for the station using the resulting parameters like g P is undefined for P is equal to zero, with respect to the earlier equation. Then, H P is equal to q plus one minus q into G p. So, q is the probability of a zero precipitation and G P the cumulative probability of the incomplete gamma function.

And then, this q is equal to m by n, n is the number of observations and m is a number of zero precipitations as far as that particular area is concerned. Then, cumulative probability H P, after its computation is transformed to the standard normal random variable Z with mean equal to zero and variance of one; that is the value of the SPI.

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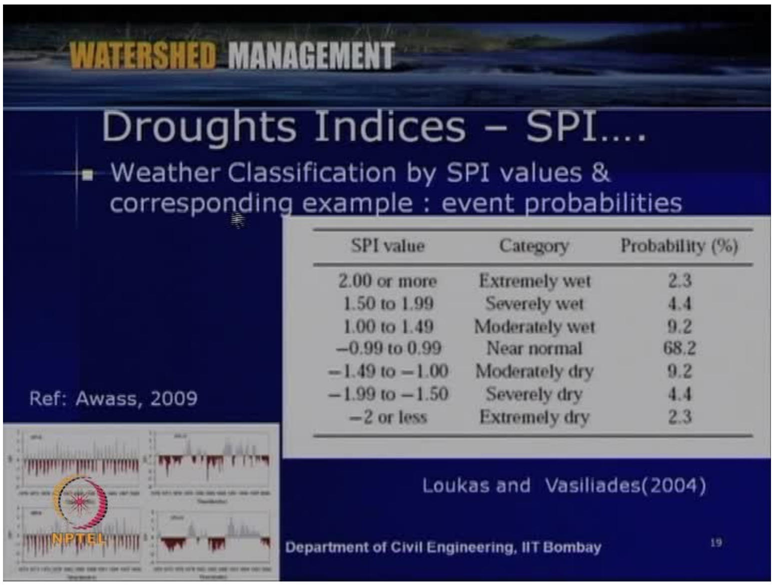

So, generally this SPI varies from, say like, these kind of variations we can identify, we can calculate the SPI. And then, so according to the weather classification by SPI values and corresponding example, say based upon what is the probability of events. So, two the, when SPI is more than 2.00 or more, then its category is extremely wet. 1.5 to 1.99, severely wet, then 1.00 to 1.49, moderately wet; minus 0.99 to 0.99, near normal and minus 1.49 to minus 1.00, moderately dry; minus 1.99 to minus 1.50, severely dry and minus 2 or less, extremely dry.

So, corresponding, say this is a particular station. So, corresponding probability we can identify, depending upon the area and depending upon the data. So, the probability percentage we can identify for the given area and from that, say we can identify or whether there is any possibility of drought, how much is the particular area is same, say unable to the drought.

So, we can also have, say with respect to the rainfall pattern, we can also derive the SPI like this. So, these details are also given in the reference Awass, 2009. And, this table is taken from Loukas and Vasiliades, 2004. This reference details are given at the end.

So, that is about the SPI or Standardized Precipitation Index. So, this is, as I mentioned this is one of the commonly used drought analysis index. So SPI, then the Palmer Drought Index, either PDI or SPI are the most commonly used drought analysis index.

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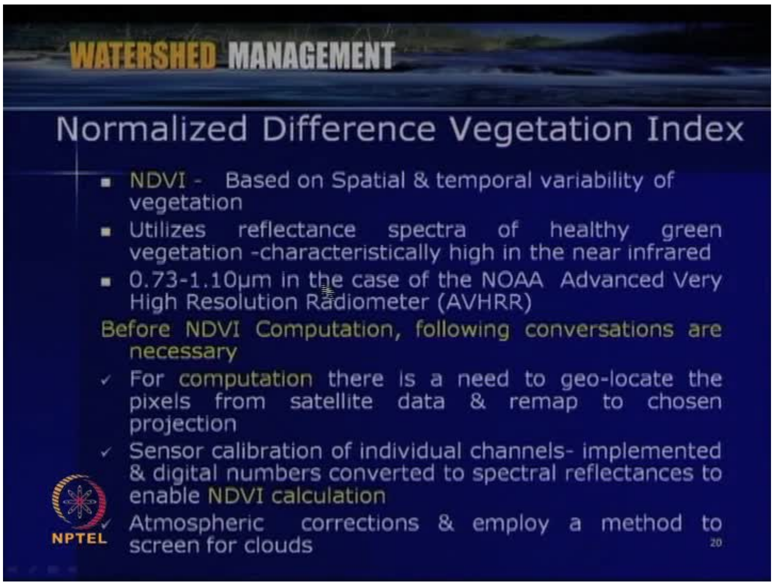

Then another type of index, which we can use for this kind of purposes is called Normalized Difference Vegetation Index. So, as we discussed, nowadays remote sensing is one of the commonly used tool to identify the land use and land cover pattern for the given watershed or the given area. So, through remote sensing we can get the vegetation index for the given area. And then, we can derive a parameter called NDVI or Normalized Difference Vegetation Index.

So, this NDVI is based on spatial and temporal variability of the vegetation. And, NDVI utilizes reflectance spectra of healthy green vegetation. And, characteristically it is high in the near infrared region. And, say this varies from 0.73 to 1.1 micro meter in the case of NOAA, Advanced Very High Resolution Radiometer AVHRR.

So, before NDVI computation, say we can, we have to do following conversations. We have to do the following for, like for computation there is a need to geo-locate the pixels from satellite data and then remap to chosen projection.

So, as I mentioned, this is based upon the satellite data. So, we have to geo-locate the area and the pixels. And then, from the satellite data we have to remap the chosen projections. And then, say we have to do the sensor calibration of individual channels, then implemented and digital numbers converted to spectral reflectance’s to enable the NDVI calculation.

So, we can say, using a specific formula we can get the NDVI. And then, that can be used in the analysis. And then, atmospheric corrections we have to do and employ a method to screen for clouds. So, the cloud effect will be there. So, that also we have to consider. Since, this methodology NDVI is based upon the satellite data. So, the cloud effect, then the atmospheric corrections, all those things we have to apply.

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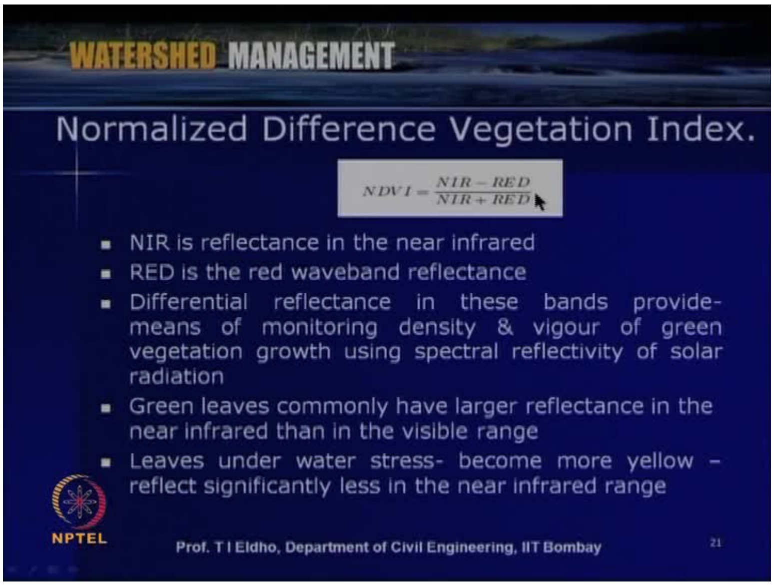

So, finally the NDVI we can obtain as NIR minus RED divided by NIR plus RED; where NIR is reflectance in the near infrared region and RED is the red waveband reflectance for that particular image. Then, differential reflectance in these bands provides means of monitoring the density and vigour of green vegetation growth using the spectral reflectivity of solar radiation.

And, the green leaves commonly have larger reflectance in the near infrared than in the visible range. And, leaves under water stress become more yellow and reflect significantly less in the near infrared range. So, using this concept, using the remote sensing data, we can identify the NDVI, Normalized Difference Vegetation Index. And, that shows the variation.

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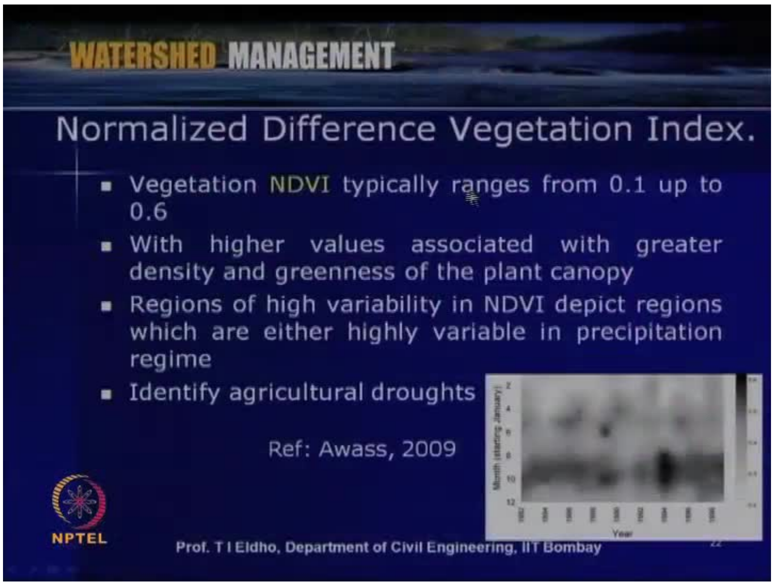

So, the vegetation NDVI typically ranges from 0.1 up to 0.6. So, with higher values associated with greater density and greenness of the plant canopy. So, if this value is high, wherever you can see, say for example, this is also taken from Awass, 2009. So here, wherever this black area that is more intense, the intense vegetation is there. So, there the, we will be having higher NDVI and then wherever this is white, means it is lowest.

So, with higher values associated with a greater density and greenness of the plant. Canopy, then regions of high variability in NDVI depict regions, which are either highly variable in precipitation regime. And then, so generally this NDVI thing is, generally we used for identifying the agricultural droughts or the agricultural lands, how the system is, how the vegetation is varying and then what will be… how with respect to NDVI we can identify, whether that particular crop is prone to drought through this NDVI index.

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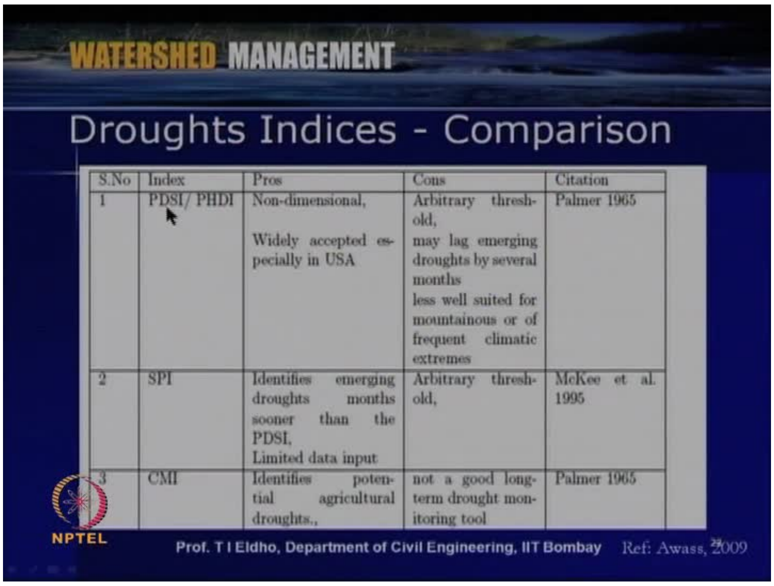

Now, so before closing, this drought indices, let us have a brief comparison between three commonly used indices like the Palmer Drought Severity Index or Palmer Hydrological Drought Index. And then, Standardized Precipitation Index and crop moisture index, this CMI is generally for agricultural area.

So, some of the pros and cons are discussed here. So, the advantages like it is non-dimensional, widely accepted especially in USA. Then, the limitations include, it is based upon arbitrary threshold, then may lag emerging droughts by several months, less well suited for mountainous or of frequent climatic extremes. So, this has been derived by Palmer in 1965,

Then, Standardized Precipitation Index generally identifies the emerging droughts months sooner than the Palmer Drought Index. And, so this is the advantages that only the precipitation data is in…, then here also the limitation or cons. This is arbitrary threshold, since only the drought analysis based only on the precipitation and it is given by McKee et al in 1995.

And then, Crop Moisture Index; this is mainly for agricultural droughts. So, this identifies the potential agricultural droughts and this is not a good long-term drought monitoring tool. Since, the meteorological aspects are not included.

So, that way, if when we compare, we can see that, say as far as drought analysis is concerned, generally we use either Palmer Drought Severity Index or the Standardized Precipitation Index. These two are the most commonly used techniques as far as the drought analysis concerned.

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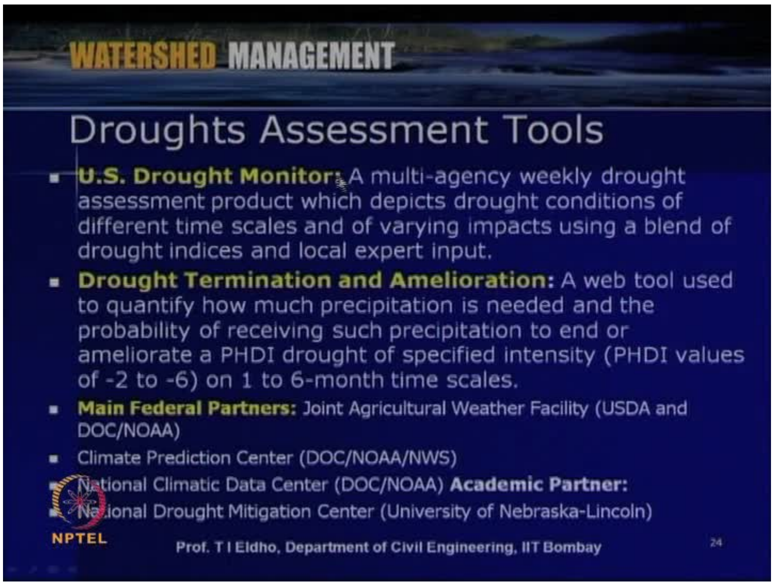

Now, say before closing this lecture, say let us look into some of the drought assessment tools. So, different countries, say how developed a drought monitoring tools or assessment tools. So, this drought monitoring, monitor, say one of the tool is called U.S. Drought Monitor. And, it is a multi-agency weekly drought assessment product which depicts a drought conditions of different time scales and of varying impacts using a blend of drought indices and local expert input.

So, as we discussed earlier, so I have some of the drought indices, specific type of drought indices are used. And then, in United States, this U.S. drought monitor has been developed and this is used as a drought assessment tool.

Then, Drought Termination and the Amelioration; so, this is a web based tool used to quantify how much precipitation is needed and the probability of receiving such precipitation to end or ameliorate a Palmer Hydrological Drought Index drought of specified intensity, say like minus 2 to minus 6 on one to six months’ time scale.

So, this is, say another drought assessment tool is called Drought Termination and Amelioration Tool. So generally, say many of these agencies in United States like, say joint agricultural weather facility of USDA and NOAA. Then climate prediction center, then national climate data center, then national drought mitigation center and various universities, they have come together to have this drought monitor by considering the various indices and then the various pattern, various changes. So, generally in United States they used a U.S. Drought Monitor or Drought Termination and Amelioration model.

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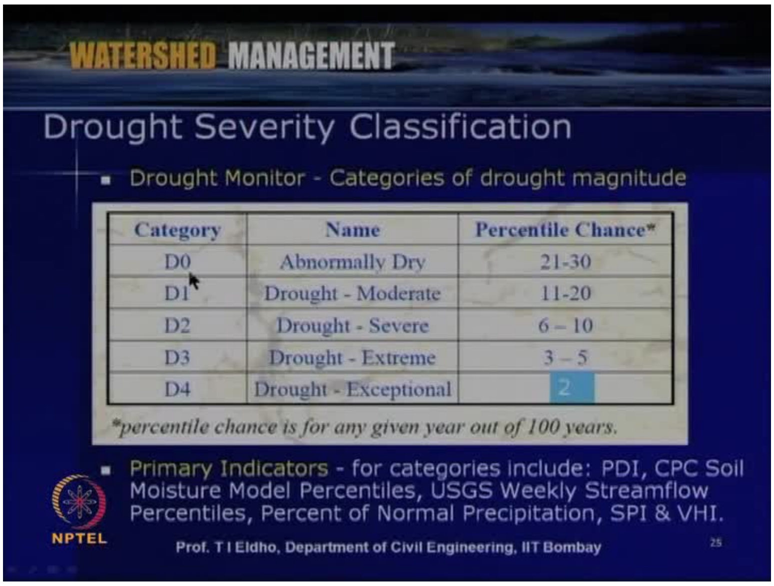

So, in most of this drought assessment tools, say the drought severities are classified according to the drought magnitude. So, like the category, like D0, D1, D2, D3, and D4. So, D0 means abnormally dry. So, the percentile chance is 21 to 30. Say for example, say in a country like United States, So this there, say depending upon the area specific percentile chance can be obtained percentile chance for any given year out of hundred years.

Then D1 is drought is moderate percentile, say chance is 11 to 20. Drought, say severe droughts is to 10 percentile chance; drought extreme, 3 to 5; drought exceptional, say percentile chance is 2.

So, some of the primary indicators like, say PDI,CPC, Soil moisture Model Percentiles, then USGS Weekly Streamflow, Percentiles, Percent of Normal Precipitation, SPI like that the various parameters or various indices are used to have such kind of, say severity classification.

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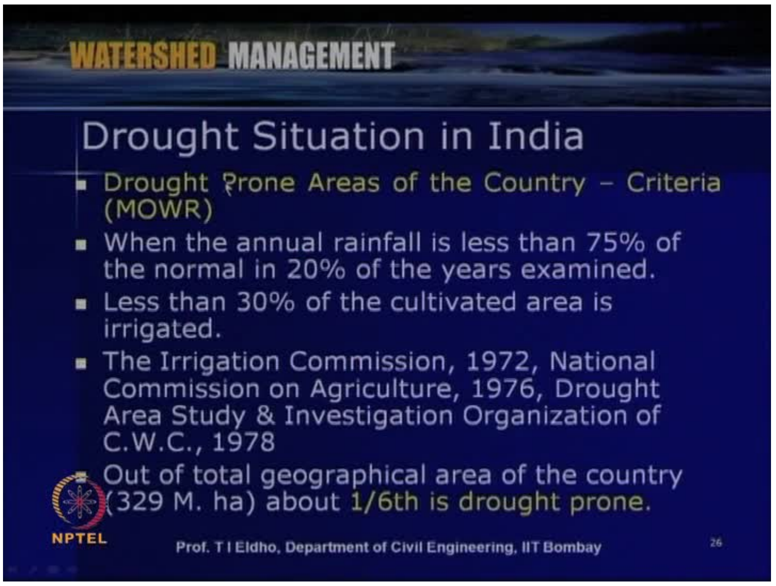

Then before closing today's lecture, just let us have a brief look into the drought situation in India. So, as I mentioned in the last lecture, also India is very much prone to droughts. So, the, say large drought problems have been reported in the last century, a number of years. So, say some of the criteria used by ministry of water resource to identify the drought prone areas of the country like when the annual rainfall is less than 75 percentage of the normal in 20 percentage of the years examined. Then, less than 30% of the cultivated area is irrigated. So, these are generally two important criteria to assess or to analyze that the particular year or particular area is drought prone or drought year.

So, then say for example, the first assessment of the drought situation has been assessed by The Irrigation Commission, 1972. Then, again this has been revisited by National Commission on Agriculture in 1976. And, further drought area study and investigation has been done by Central Water Commission in 1978.

A large and extensive studies throughout the country showed that, out of the 329 million hectare of the area of the country about one-sixth is drought prone; say about 50 million hectare is drought prone as far as India is concerned.

So, this is as reported in the ministry of water resources website. So, that way we need number of drought mitigation measures. Drought is frequently occurring in many parts of the country.

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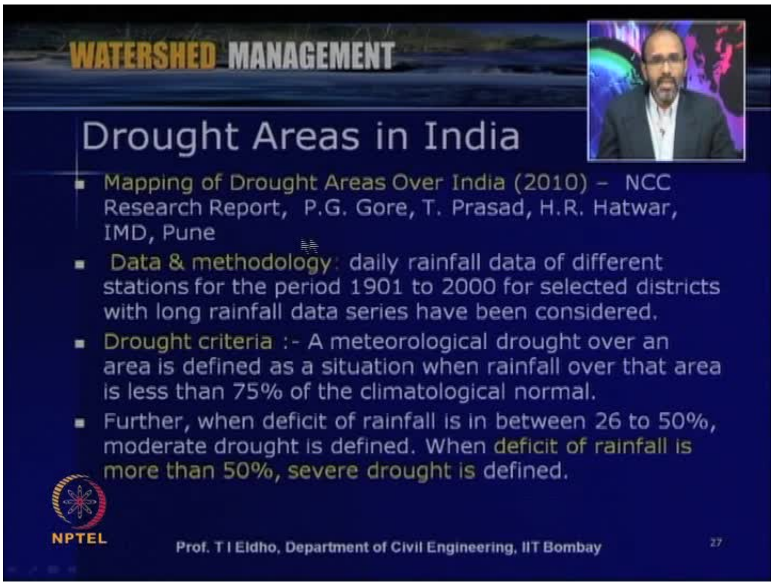

And then, say another drought assessment done by the National Climate Change Research Report by P. G. Gore, T. Prasad and H. R. Hatwar, Indian Meteorological Department, Pune, published in 2010 of drought area over India.

So, they analyzed the rainfall and various other parameters like evaporation for hundred years, say for 1901 to 2000 for selected districts with long rainfall data series have been considered by this National Climate Change Research Center under Indian Meteorological Department.

And, drought criteria has been, say put as a meteorological drought over an area is defined as a situation when rainfall over that area is less than 75 percentage of the climatological normal, very similar to the ministry of water resource criteria.

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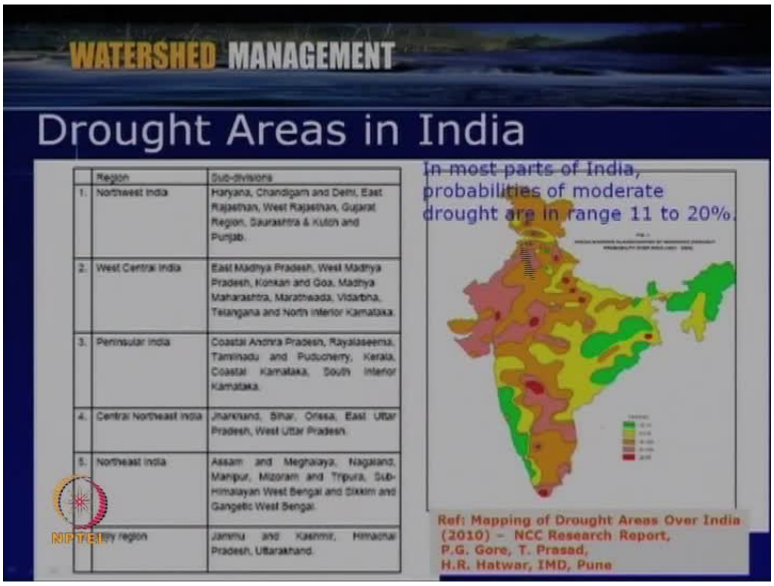

Then, further when deficit of rainfall is between 26 to 50%, moderate drought is defined. And, when deficit of rainfall is more than 50 percentage, severe drought is defined. So, accordingly the Indian meteorological Department, they have done a detailed study by considering the rainfall pattern, precipitation pattern for the twentieth century 1901 to 2000. And then, say they have come up with some results, say we, they have identified which of the area will be most drought prone and then they have come up with the moderate drought prone areas and severe drought prone area.

So, according to their analysis, the drought prone areas include North-West India like some of the subdivisions of Haryana, Delhi, East Rajasthan, West Rajasthan, Gujarat, Saurashtra, Kutch, and etcetera. Then, West Central area like east Madhya Pradesh, west Madhya Pradesh, Konkan, Goa, Maharashtra, etcetera. Then, Peninsular India like coastal Andhra Pradesh, Rayalaseema, Tamilnadu and Pondicherry, some part of Kerala, like that. Then, Central North-East India like Jharkhand, Bihar, East Uttar Pradesh, West Uttar Pradesh, like that. Then, North-East India like Assam and Meghalaya, Nagaland, Manipur, etcetera. Then, hilly regions like Jammu and Kashmir, Himachal Pradesh, and Uttarakhand. So, these are some of the frequent drought prone areas for the, based upon the analysis for hundred years of the twentieth century.

So, and then based upon this data, they have come up with a map. So, mapping of drought areas over India by, is in this report. So, then we say, you can see the probabilities of moderate droughts. Say for example, it is, moderate drought is indicated from 11 to 20 percentage; so, given by this color. So, that is distributed like this; so that, with respect to the moderate drought, they come up with this map based upon the data analysis for hundred years.

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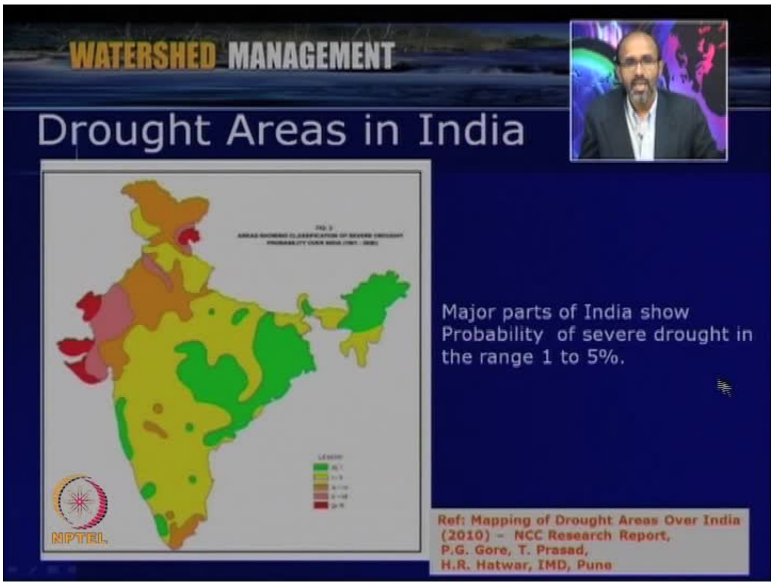

Then, say the, with respect to severe drought conditions, they studied and then come up with, say for example, the probability of severe drought in the range of 1 to 5 percentage is possible. Say for example, this, say most of the parts of the country, say like given by this, in this yellow color. So, like that, they come up with the maps. So, this shows an indicator. And then, based upon this historical data, we can analyze the drought situation.

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And, as far as drought management in India is concerned, I mean larger thrust for watershed development under Drought Prone Area Programme is given by Government of India.

So, some of the important aspects of this drought management in India like dry land farming and water resource development schemes; then, dovetail crop production activities into the watershed project along with the soil conservation activities; then, take up large scale dry land farming demonstrations. Then, undertake research on efficacy and economics of sprinkler and drip irrigation systems; then, construction of suitable water harvesting structures, conservation and optimal use of surface water and recharge of underground aquifers. Then, afforestation and pasture development; then, animal husbandry and fodder development. And then, most important aspect is the people’s participation in drought proofing.

So, that way the drought management measure, say put forward by Government of India includes the various schemes like Drought Prone Area Programme by considering the water aspects, the water resource aspects like rainwater harvesting, water conservation, then soil conservation, then the afforestation measures, then the, say various schemes for people living like animal husbandry, fodder development. All those things, the Government was put in such a way that, people’s participation should be given the most; say, the most important aspect is the people’s participation.

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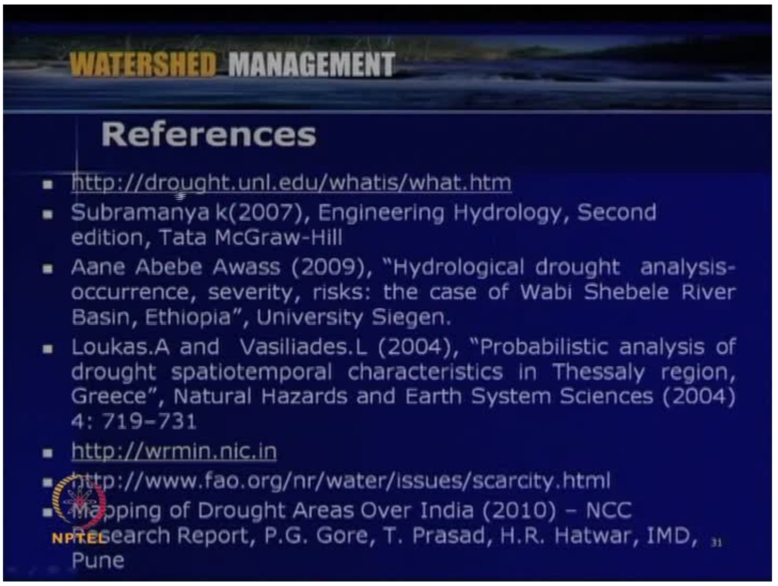

So, now some of the references used for today's lecture include, especially like these Loukas and Vasiliades, 2004 published in "Natural Hazards and Earth System Sciences". And then, Awass, "Hydrological Drought Analysis"; so, these are two important references used for today's lecture.

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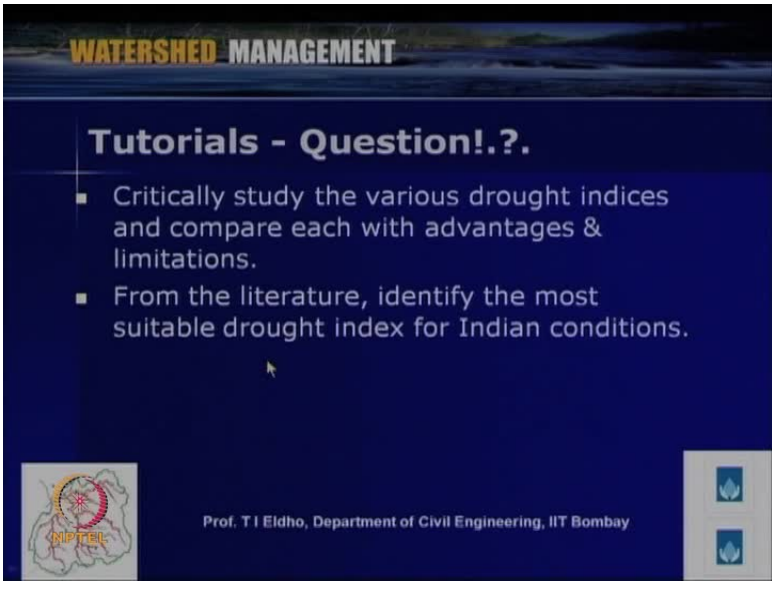

So, before closing, we can see few questions, tutorial questions; "critically study the various drought indices and compare each with advantages and limitations". Then, "from the literature, identify the most suitable drought index for Indian conditions".

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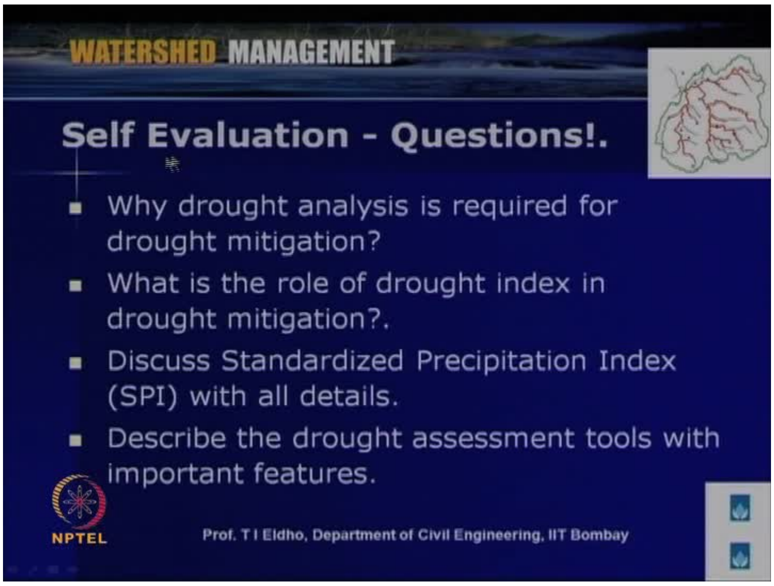

So, based upon today’s lecture and some, say details from the internet, we can get the details. Then, some self-evaluation questions. “Why drought analysis is required for drought mitigation?”; “What is the role of drought index in drought mitigation?”; “Discuss Standardized Precipitation Index with all details”; then, “describe the drought assessment tools with important features”.

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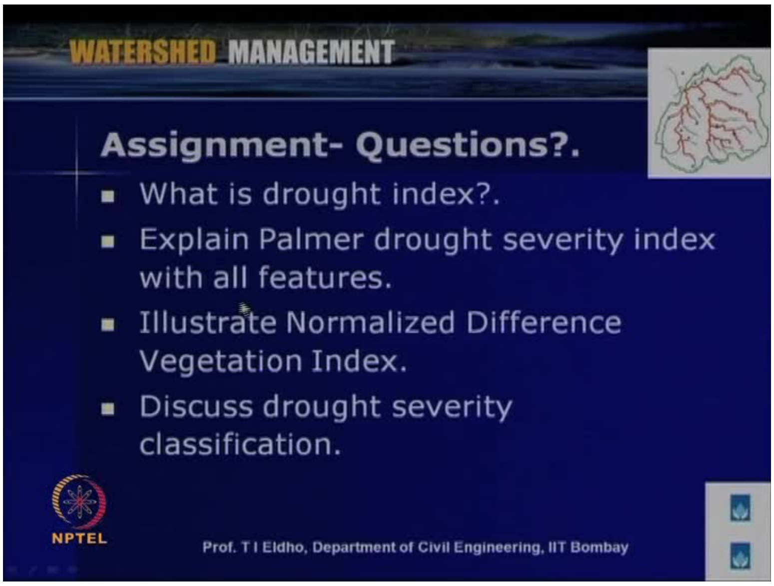

Then, few more questions, assignment-questions: “What is drought index?”; “Explain Palmer Drought Severity Index with all features”; “Illustrate Normalized Difference Vegetation Index”; “Discuss drought severity classifications”.

So, today what we discussed is the drought analysis; the methodologies by using drought indices. So, in the last lecture we are discussing about drought assessment. Today, we discussed about the drought analysis. Now, in the last lecture, in this module on drought management, we will discuss the drought mitigation measures. Thank you.