Engineering Hydrology
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Module: 02 Lecture 19
Rain Gauge Network

Hello all welcome back. In the last lecture, we were discussing about the measurement of rainfall. In the topic, we have seen different types of rain gauges, those are recording and non-recording types and nowadays we are commonly using the recording type of rain gauges, different types of recording rain gauges we have seen and after that we have seen the radar and satellite-based methods for measuring rainfall.

In the case of hydrologic studies, we need to go for rain gauges, network of rain gauges because the data or the rainfall data which we are obtaining from the satellite measurement contains certain uncertainties. So, for the hydrologic related studies we always prefer to use the rainfall data which is measured by using rain gauges. But in the case of rain gauges, we have seen it is installed at a particular location and it is giving us the rainfall which is falling on that particular location details.

So, that is the point measurement of rainfall data and what we are doing we are assuming that this rainfall is uniformly distributed over certain area. That way we are making an approximation that point rainfall data or the data which we have measured using the rain gauge data will be the same across the area surrounding the rain gauge. That is an approximation, so that for reducing the uncertainty related to that we need to have large number of rain gauges. So, if we are having large number of rain gauges in a particular area, then we can assume that nearby area of the rain gauge will be giving the same rainfall data.

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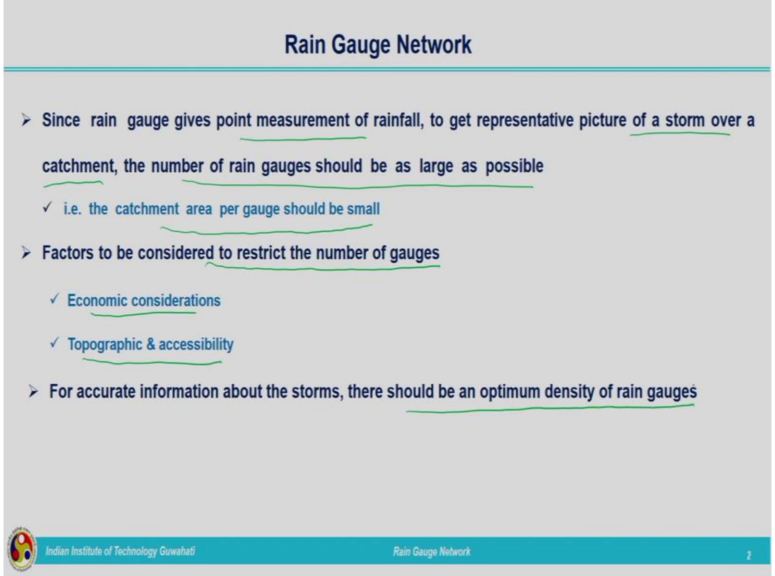

Now, let us look into the rain gauge network. As I told you rain gauges gives us point measurement of rainfall. So, that rainfall we are considering as the storm over a catchment. So, if you are having a single rain gauge at a particular location within a certain area, we are assuming that the rainfall data which is measured by using that particular rain gauge will be giving us the details about the rainfall in the entire catchment.

So, the number of rain gauges should be as large as possible, then only we will get an accurate measurement of the rainfall in that particular catchment. So, the catchment area per rain gauges should be small. Now, different factors to be considered to restrict the number of rain gauges. We cannot give so many number of rain gauges in a particular area, that is good in one way that we are getting measurement at different different location. But economic point of view it will not be okay.

So, factors to be considered to restrict the number of rain gauges are economic consideration and also topographic and accessibility conditions. So, economic conditions we need to take into account because we cannot provide large number of rain gauges if it is not required in that much of small area and other than that topographic and accessibility also matters because where the rain gauge is present, we need to have the accessibility to that particular location. It is not like the satellite measurement of rainfall. So, for accurate information about the storms there should be an optimum number of rain gauges or an optimum density of rain gauges.

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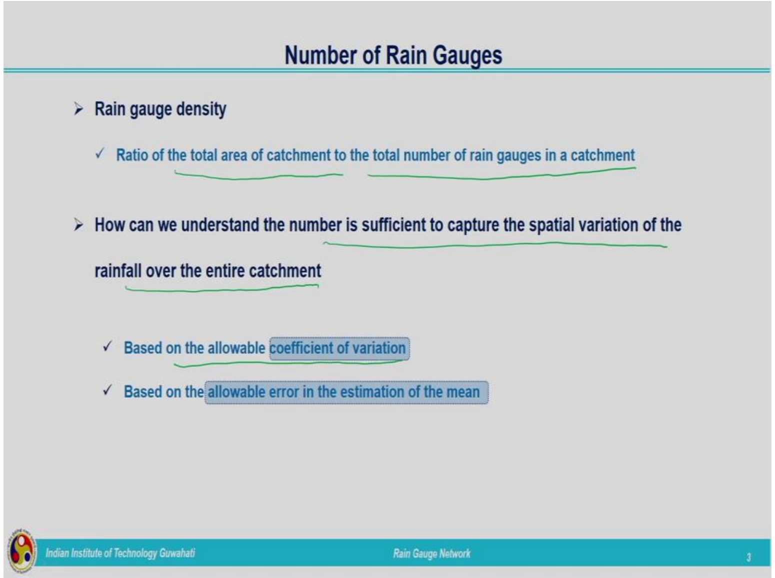

So, what is meant by this rain gauge density? Rain gauge density is the ratio of the total area of the catchment to the total number of rain gauges in that particular catchment. So, that is meant by rain gauge density. Now, how can we determine or how can we understand that that number of rain gauges which is present in a catchment is able to capture the spatial variation of the rainfall over the entire catchment.

So, we need to have an idea these many rain gauges should be present in a particular catchment based on the area. So, that is what we are going to see now. So, this can be attained by looking into certain factors that is based on the allowable coefficient of variation and based on the allowable error in the estimation of the mean, that is allowable error in the estimation of the mean rainfall.

So, two ways we will be understanding whether the number of rain gauges which are present in the catchment is optimal or not. So, we will see one by one. First one is based on the allowable coefficient of variation, another one is the allowable error in the estimation of the mean. These coefficients of variation, mean, all these things are some statistical terms. So, we need to have some preliminary knowledge about basic data.

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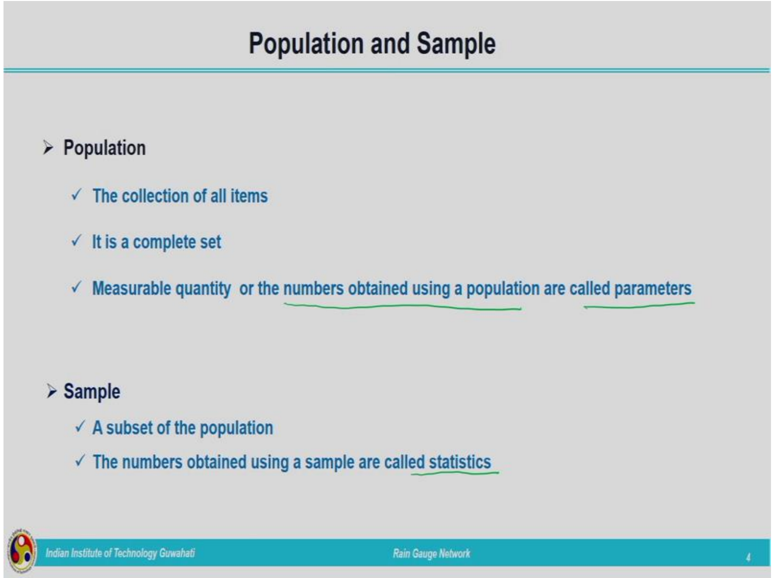

So that is common terminologies which we will be using in statistics are population and sample. So, the difference between these 2 should be clear: population and sample. What is meant by this? Population is the collection of all items that is if we are talking about rain gauge or rainfall data, we will be considering all the rain gauges present.

So, it is a complete set, but in the case of sample a subset of the population will be considered. We will not be having access to the entire rain gauge data or sometimes we are not interested in that. So, we will be selecting certain sample from the population. So, it is a subset of the population and the measurable quantity or the numbers obtained using population are called the parameters, parameters of the population. But in the case of sample it is termed as the statistics.

So, both are representing data only. Population represents the complete set and sample represents the subset of the complete set and the measurable quantities or the numbers which we are deriving based on the population data is termed as the parameters and in the case of sample we will be calling it as statistics. So, why I am talking about these population and sample here, this coefficient of variation that is in the first method of getting the optimal number of rain gauges, we are talking about the sample, we are not dealing with the population.

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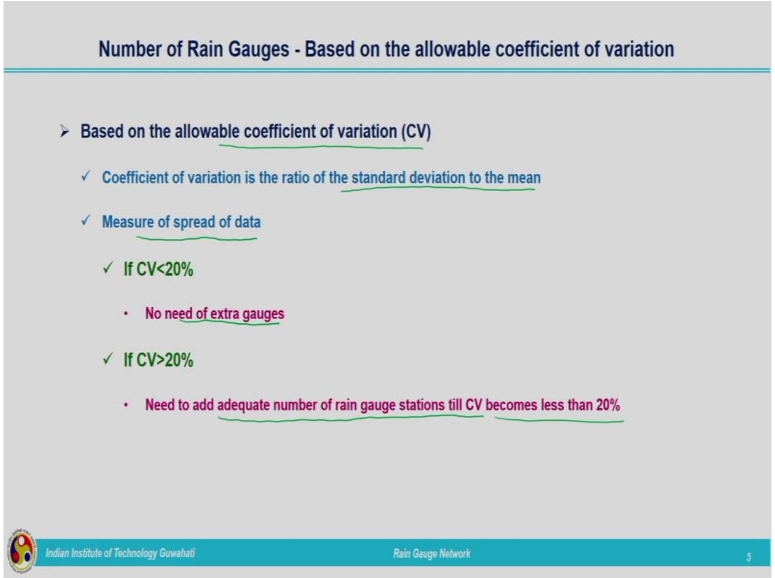

We will come to it, that is the first method for attaining the optimal number of rain gauges is based on the allowable coefficient of variation. What is meant by coefficient of variation? Coefficient of variation is the ratio of the standard deviation to the mean. So, this is giving us an idea about the dispersion in the data.

So, coefficient of variation is the ratio of the standard deviation to the mean. So, it gives us some idea about the spread of the data, how our data is, how much dispersion is there in our data set. That we can understand based on the coefficient of variation. If coefficient of variation is less than 20 percentage and greater than 20 percentage based on this we will be telling whether the number of rain gauges present is correct or optimal.

So, if CV or the coefficient of variation is less than 20 percentage, there is no need of extra rain gauges, but in the case of CV greater than 20 percentage there is a need to provide some more rain gauges along with the existing rain gauges in a particular area. So, there is a need to add adequate number of rain gauge station till CV becomes less than 20 percentage. After adding the rain gauges, we can collect the data from that and based on that we will again calculate the CV if it is coming less than 20 percentage then the number which is provided is optimal.

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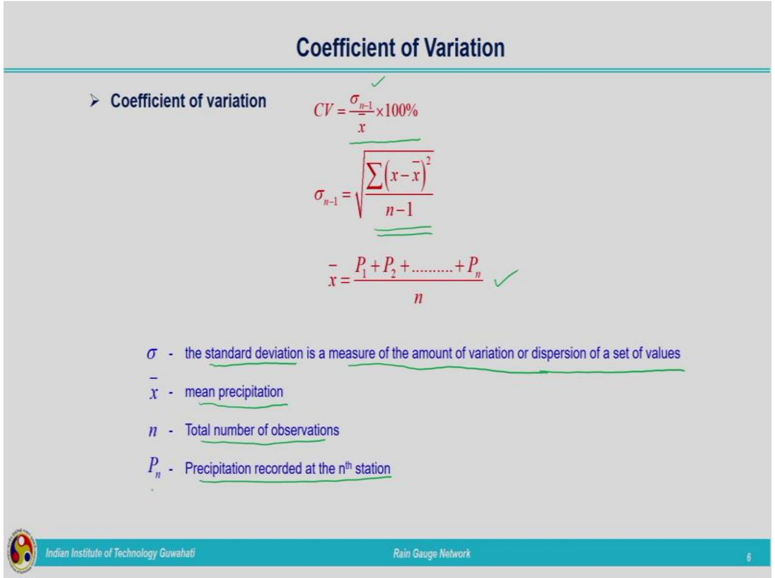

Now, how can we calculate coefficient of variation? So, coefficient of variation can be calculated by using this formula.

$$CV = \frac{\sigma_{n-1}}{\bar{x}} \times 100\%$$

So, you should understand that in this case we are doing the calculation based on the sample data. So, $CV = \frac{\sigma_{n-1}}{\bar{x}} \times 100\%$ and we are representing in percentage that is by this multiplied by 100.

So, what is σ_{n-1}? Sigma is the standard deviation. Standard deviation that is the measure of the amount of variation or dispersion of set of values. We are having the rainfall data which is measured from the rain gauges and we are finding out the standard deviation or the measure of the amount of variation or dispersion in the data.

So, σ and the denominator of the ratio that is coefficient of variation is $\frac{\sigma_{n-1}}{\bar{x}}$, σ_{n-1} is the standard deviation and $\bar{x}$ is the mean precipitation. How can we calculate this? σ_{n-1} can be calculated by using this formula, that is

$$\sigma_{n-1} = \sqrt{\frac{\sum(x-\bar{x})^2}{n-1}}$$

This is $n-1$ because it is something related to the sample data.

Now, coming to the main precipitation $\bar{x}$ will be calculating by using this formula that is

$$\bar{x} = \frac{P_1 + P_2 + \dots\dots + P_n}{n}$$

n is the total number of observations. So, by making use of these formula we can calculate the coefficient of variation. What are the things we are calculating? We are calculating the standard deviation and mean of the data series corresponding to the sample which we are considering.

So, based on this formula we will be calculating the coefficient of variation. Once coefficient of variation is calculated we will be checking whether it is less than 20 percentage or greater than 20 percentage. Based on that we can suggest if there is a need of extra rain gauges. So, CV can be calculated by using the particular formula given for the sample and how can we understand extra rain gauges are required, that is we need to have an expression for calculating the number of rain gauges.

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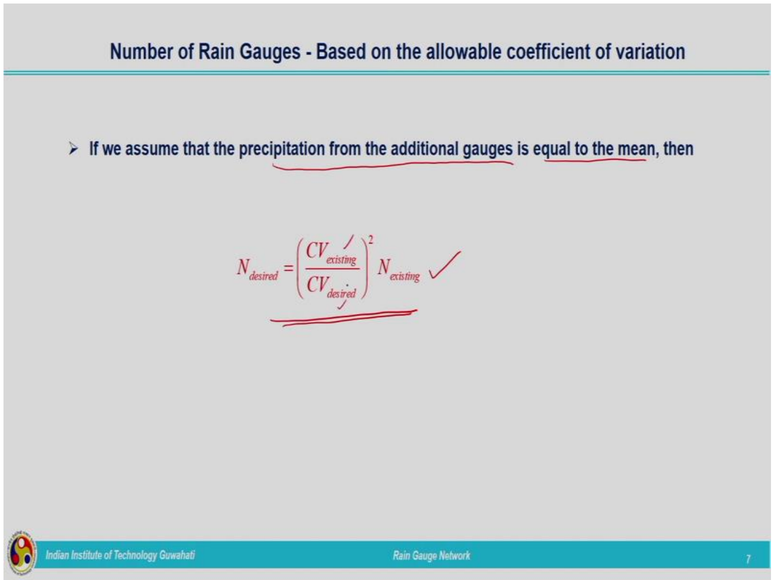

So, how can we get the extra number of rain gauges? In that case what we are doing, we are assuming that the precipitation from the additional gauges is equal to the mean, mean we have already calculated and we are assuming extra rain gauges will be providing the rainfall equal to the mean. After that, we will be making use of this formula

$$N_{desired} = \left(\frac{CV_{existing}}{CV_{desired}} \right)^2 N_{existing}$$

So, what we are doing? We are assuming that some extra rain gauges in the catchment in the particular area and those rain gauges will be giving us the mean rainfall data.

This is an assumption, based on that we can calculate the extra number of rain gauges or the desired number of rain gauges, actually the desired number of rain gauges or the required number of rain gauges in a particular area can be calculated. So, once the required number of rain gauges calculated we can calculate the extra number of rain gauges required.

So, the desired number of rain gauges can be calculated by using this formula,

$$N_{desired} = \left(\frac{CV_{existing}}{CV_{desired}} \right)^2 N_{existing}$$

So, you can see $N_{desired}$ is that actual number of expected numbers of rain gauges to be present in a particular area. So, there are certain number of rain gauges already existing. So, desired number we will be calculating by using this formula $N_{desired} - N_{existing}$ will be giving you extra number of rain gauges which need to be provided in a particular area.

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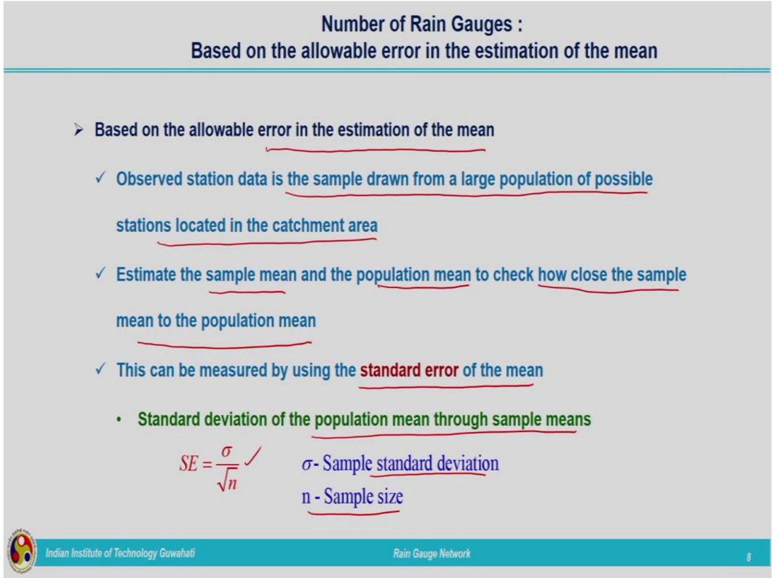

Now, let us move on to the second method that is based on the allowable error in the estimation of the mean. So, here what we are doing, observed station data is a sample drawn from a large population of possible station located in the catchment area. We are having a population, from that we are considering a sample data.

After that, we will estimate the sample mean and also the population mean to check how close the sample mean to the population mean. We will be comparing the sample mean and the population mean. From the population data, we will be drawing out the sample. So, sample mean will be calculated, population mean will be calculated, and we will be comparing these two means. That the data corresponding to a particular sample and based on that we can calculate the standard deviation of those data points and we can calculate the standard error by using

$$SE = \frac{\sigma}{\sqrt{n}}$$

Where σ is the sample standard deviation and *n* is the sample size.

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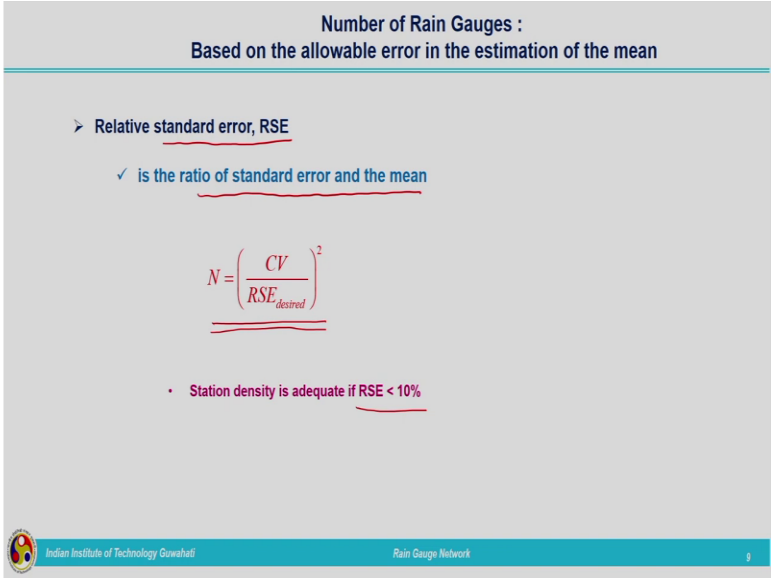

Now, another term which is important is we need to calculate the relative standard error, RSE. It is the ratio of standard error and the mean. So, once relative standard error is calculated and it is with us, then we can get the desired number of rain gauges by using this formula that is

$$N = \left(\frac{CV}{RSE_{desired}} \right)^2$$

So, we need to calculate the relative standard error and coefficient of variation we will be calculating as explained in the previous method. So, after that, we will be computing the ratio of $\frac{CV}{RSE_{desired}}$ and you will be squaring that particular value which will be giving you the number of desired numbers of rain gauges in a particular area.

After getting the desired number of rain gauges based on the existing number, what are the extra numbers required we can calculate. So, station density is adequate, if RSE is less than 10 percentage. Relative Standard Error is less than 10 percentage we can make sure that the station density is adequate.

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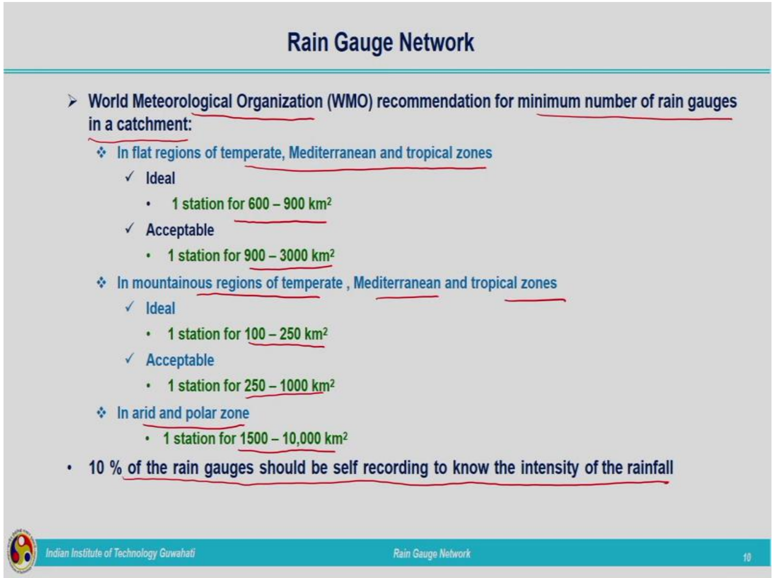

WMO that is world meteorological organisation has given certain recommendation for minimum number of rain gauges in the catchment, depending on the topography of the area, some may be flat area some may be undulating area, hilly areas, mountainous area, so, that way different locations will be having different topographic features.

So, WMO has given certain recommendations related to the number of rain gauges present in a particular catchment. In a flat region of temperate Mediterranean and tropical zones, mountainous region of temperate, Mediterranean, tropical zones and arid and polar zones. Let us see, how much is the number of rain gauges required based on WMO recommendation.

Ideal condition is that one station for around 600 to 900 kilometres square in a flat region. Acceptable is even though it is not satisfying the ideal condition 900 to 3000 kilometres square one station is acceptable in the case of flat region. And in the mountainous region, it is ideal that one station for 100 to 250-kilometre squares.

We know the type of precipitation itself is changing, orographic precipitation is present in the hilly, mountainous region, whenever there is an obstruction the rainfall is due to the orographic action. So, in that mountainous region the recommended value is one station for 100 to 250 kilometres square. Acceptable is one station for 250 to 1000 kilometre square and in the case of arid and polar zone, one station for 1500 to 10,000 kilometres square and what is recommended that out of these total number of rain gauges 10 percentage of the rain gauges should be self-recording to know the intensity of rainfall.

So, almost 10 percentage of rain gauges should be recording type. Non recording it is very difficult to get the accurate data. If you are having the recording type it will be recording and it can be transferred to the computer through the data logger. So, that is why it is recommended to make use of this recording type of rain gauges. Now, majority of the rain gauges are replaced, non-recording rain gauges are replaced by recording rain gauges.

So, these are the WMO recommendations related to the minimum number of rain gauges per area of the catchment. So, depending on the topographic region we can choose whichever is required. So, we have seen two methods for calculating the number of rain gauges optimal number of rain gauges in a catchment. So, we need to calculate this by using this formula, we need to solve one example.

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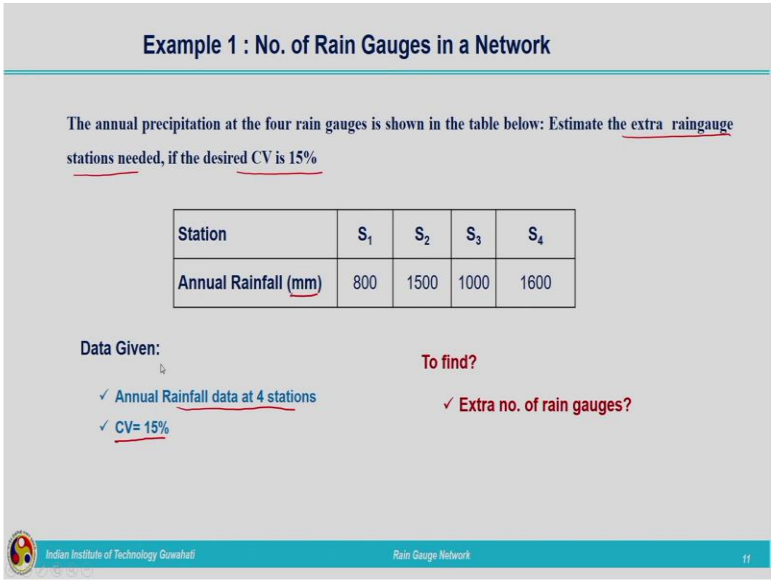

So, let us look into the example related to this precipitation at four rain gauges is shown in the table below. Estimate the extra rain gauges, rain gauge stations needed if the desired coefficient of variation is 15%.

If CV value desired is not given to you, you can assume it to be 20%. Otherwise whatever given in the question you can make use. So, here we have been given annual rainfall data from the 4 rain gauge stations. Rain gauge stations are denoted from S1 to S4 and we are having the rainfall data, annual rainfall data, that is the annual rainfall data at 4 stations in millimetres is given to you, CV is also given 15%, we need to calculate the extra number of rain gauges. We need to check whether there is a need of an extra rain gauge or extra rain gauges, if extra is required how many extra should be provided.

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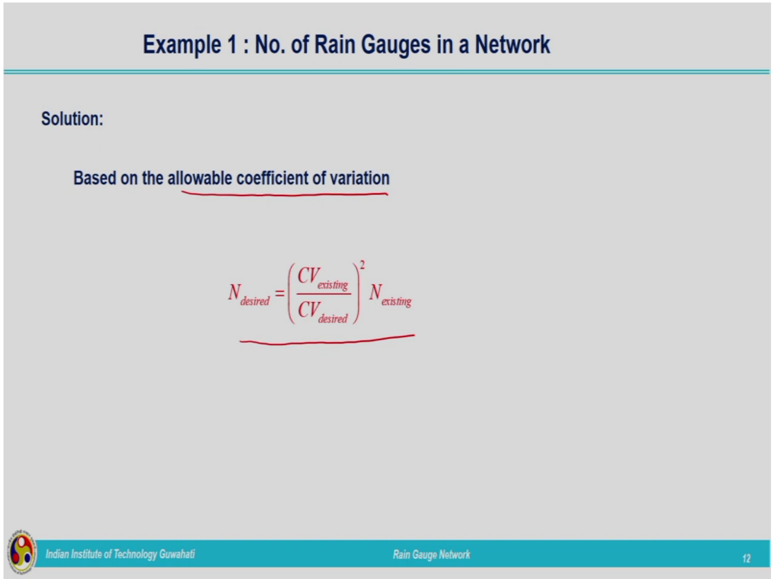

So, first we will make use of the method the allowable coefficient of variation. The formula for the desired number of rain gauges is N desired is equal to

$$N_{desired} = \left(\frac{CV_{existing}}{CV_{desired}}\right)^2 N_{existing}$$

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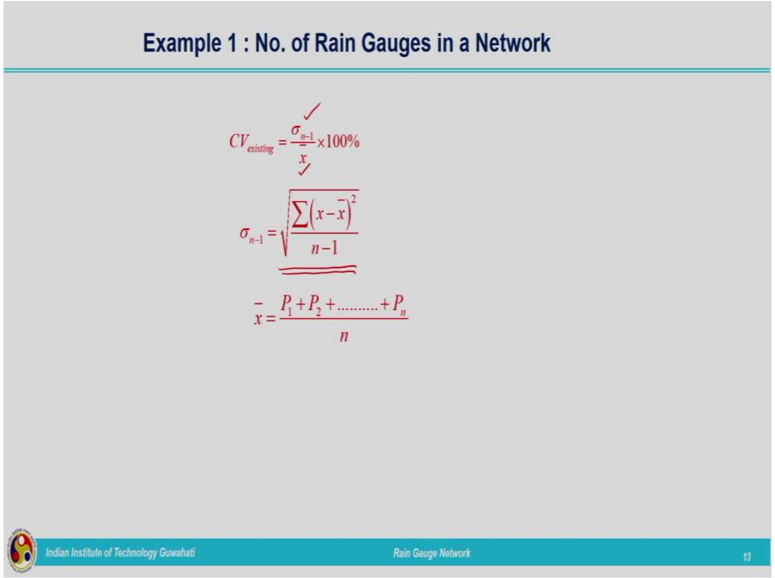

So, CV existing how can we calculate? We can calculate CV existing using the standard deviation of the sample data (σ_{n-1}) and mean of the sample data ($\bar{x}$). So,

$$CV_{existing} = \frac{\sigma_{n-1}}{\bar{x}} \times 100\%$$

$$\sigma_{n-1} = \sqrt{\frac{\sum\left(x-\bar{x}\right)^2}{n-1}}$$

So, this is something related to sample, sometimes it is written as instead of σ_{n-1} it is written as *S*. So, do not get confused σ_{n-1} and *S* is representing the same that is the standard deviation corresponding to the sample data. And in the case of sample data mean is represented by $\bar{x}$, in the case of population data it is represented by the notation μ.

So, from the notation itself we can make sure that whether it is something related to population or sample. So, here we are talking about the sample, from the table itself it is clear that we are having four rain gauge stations. So, the data corresponding to four rain gauge stations are the, this is the sample which is drawn from a large number of data or from the population. So, we can make use of the statistics corresponding to the given data.

$$\bar{x} = \frac{P_1 + P_2 + ... + P_n}{n}$$

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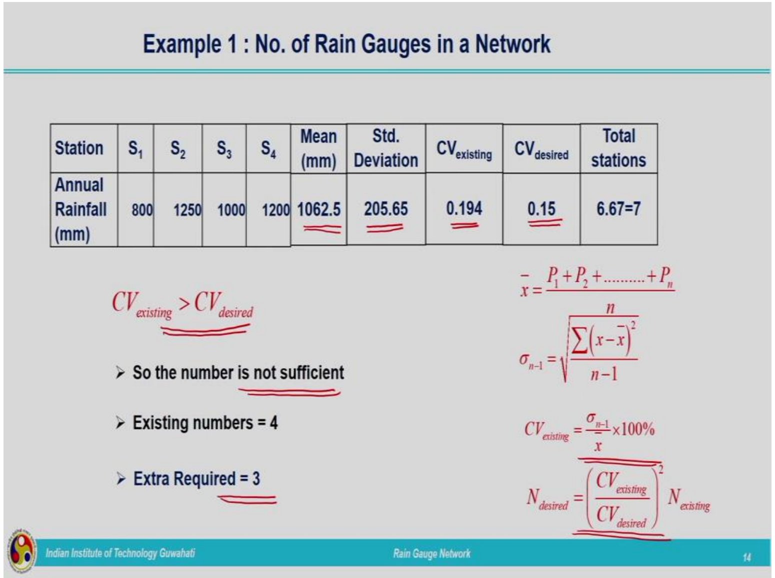

These are the data given to us. From the four rain gauge stations, we are having the annual rainfall data in millimetres. What we need to calculate? We need to calculate the mean value corresponding to this data. So, mean is calculated to be 1,062.5 millimetres. Then we need to calculate the standard deviation corresponding to the sample. So, that can be calculated by using this formula $\sigma_{n-1} = \sqrt{\frac{\sum(x-\bar{x})^2}{n-1}}$, it is coming out to be 205.65. After that we will calculate CV with the existing data, what is the coefficient of variation?

So, that is given by this formula $CV_{existing} = \frac{\sigma_{n-1}}{\bar{x}} \times 100\%$ and it is calculated to be 0.194. $CV_{existing}$ is 0.194 and $CV_{desired}$, it is given in the question that $CV_{desired}$ is 0.15. We have calculated $CV_{existing}$ as 0.194, it not in percentage, it is 19.4% and the desired CV value is 15%. So, definitely we need to provide extra rain gauges to satisfy the condition of coefficient of variation. So, the number is not sufficient in this case. How can we calculate the desired number?

$$N_{desired} = \left(\frac{CV_{existing}}{CV_{desired}}\right)^2 N_{existing}$$

That is calculated to be 7, Calculated is 6.67. 6.67 it should be rounded up, it is a number, rain gauge number.

So, 6.67 should be 7 even if it is coming to be 6.1, 6.2 will be going to the higher end, rounding off should be given in the highest side. So, it will be equal to 7. So, the desired number of rain gauges is 7. How many are there in the catchment now? As of now 4 rain gauges are there. So, extra we need to provide 3 more. Existing 4 number of rain gauges are there and extra required is $N_{desired} - N_{existing}$ that is coming out to be 3.

So, in this particular catchment which was providing this much of annual rainfall from each of the rain gauges, we need to provide extra 3 more number of rain gauges, so, that we will get the accurate measurement, accurate spread of the rainfall data within that particular catchment. This is very important some of the cases we are not having the sufficient number of rain gauges in that case we will be assuming that the same rainfall is acting all over the entire area. But it may not be always correct.

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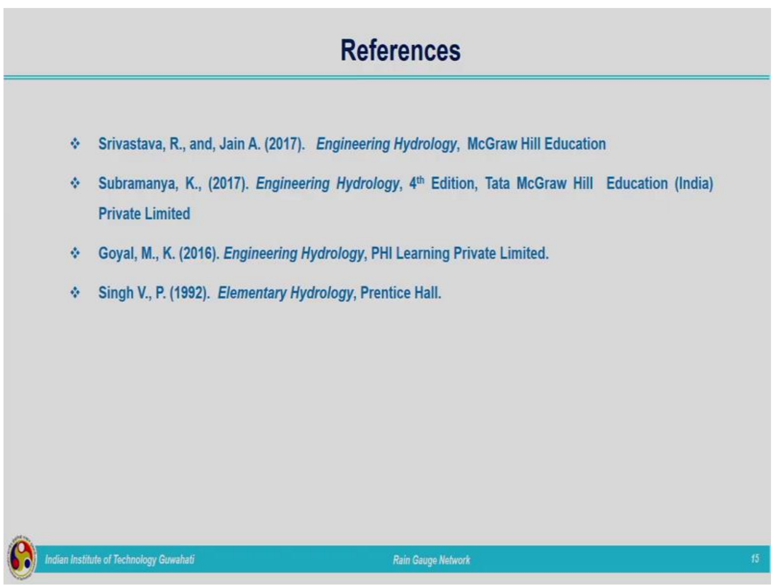

You can go through the textbook material related to this topic number of rain gauges required in a particular catchment, certain catchments will be having larger area, certain of will be smaller area. So, depending on the area, how can we provide accurate number of rain gauges, there should be an optimal number of rain gauges present in a particular catchment.

So, these optimal number of rain gauges can be calculated by two methods that is based on the coefficient of variation and also based on the error in the mean. So, these two methods we have seen and we have seen the numerical example related to that and after getting the desired number of rain gauges, we can calculate the extra number which needs to be provided in a particular area. So, here I am stopping the topic related to rain gauge network. Thank you very much.