Stochastic Hydrology

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Lecture No # 29

IDF Relationships

Good morning and welcome to this, the twenty-ninth lecture of the course stochastic hydrology. In the previous two lectures we have been discussing about goodness of fit tests for fitting distributions to observe data. What I mean by that is that you have a observed series of data and then you would like to use a particular probability distribution, which will fit that data.

Specifically, we have seen two different types of methods, one is using the probability papers and we also saw how to construct the probability papers, specifically for the normal distribution and also for the exponential distribution using analytical or graphical procedures. Subsequently, in the previous class we have seen, previous lecture we have seen how to construct, how to do the goodness of fit tests using statistical test, which is specifically the Chi-square test and the Kolmogorov-Smirnov test.

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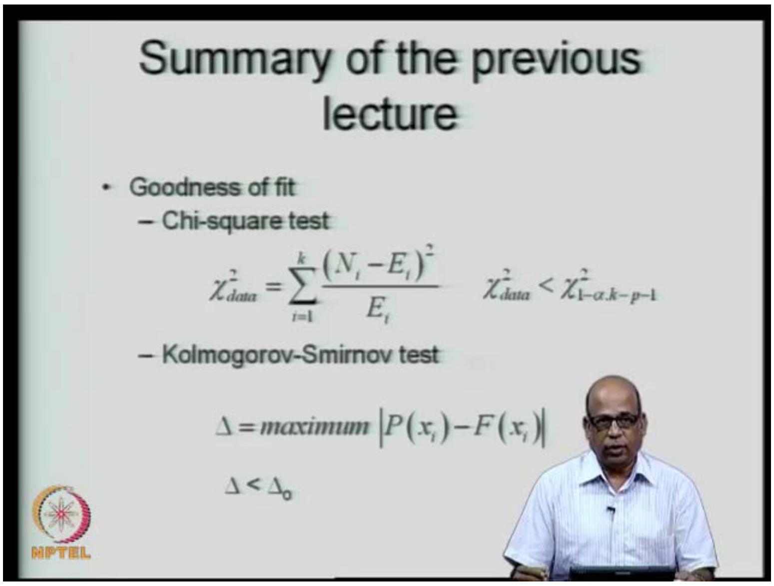

If we summarize what we did in the previous lecture, we focused mainly on the Chi-square and the Kolmogorov-Smirnov test. As I mentioned, you know, these tests will base their observations or base their conclusions on how well the observed relative frequency matches with the expected relative frequency. The observed relative frequency or the observed number that we are looking at based on the class intervals that we have on the data, that is, data is classified into several class intervals. And then, we look at the observed relative frequency of each of the class interval, and that is what is n i. And the expected relative frequency or the expected number of observations arising out of that particular distribution for which we are conducting the test is E i.

And then, this will give you the statistic, Chi-square statistic and we also have the critical Chi-square statistics available through tables. This is a significance level, usually we use 5 percent or 10 percent significance level and p is the number of parameters and k is the number of class interval. So, we get this critical chi-square parameter and then observe, compare it with the Chi-square that is obtained from the data. If the Chi-square, that is obtained from the data is less than the critical Chi-square value obtained from the tables, then we say, that the data passes the test for that particular distribution.

Similarly, in the Kolmogorov-Smirnov test, rather than lumping the values into different classes, it considers the individual values as, that I have been actually observed and then calculates its probability associated with each of these observed values and compares it with the probability that would have arisen if, in fact, fitted a particular distribution. For example, F of x i is the probability associated with that particular distribution normal distribution, exponential distribution, etcetera, for which we are making the test.

And we take the absolute maximum difference between the observed and the expected probabilities and that we call it as data. So, the statistic is simply the maximum of the absolute value of the difference between the observed probability and the expected probability. And for the Kolmogorov-Smirnov test we also have the critical values of the data and if the data, that is so obtained from the observed data is less than the critical values, then we say, that it passes the test and therefore, we accept the hypothesis, that the data, in fact, comes from a population, which fits, that particular distribution for which we are making the test.

Now, we will progress further to a different topic. See, what we have been discussing about is that you have the observed data and from the observed data you know, which distribution to fit. Now, we will ask the question what do we do with this information, specifically for hydrologic designs. We will be interested in, let us say, for a given duration and return period what type of intensity rainfall I must use for the hydrologic designs or from the intensities, we may want to convert it into design hydrographs, which means, peak flows. How much is the peak flow corresponding to a given return period for a given duration of rainfall?

Now, these are the type of questions we need to answer whenever we looking at hydrologic designs, specifically, let us say we are looking at the spillway design, which has to pass a specific discharge, flood discharge or specifically, in urban hydrologic designs.

Let us say, you are talking about designs of culvert, which crosses a road. This needs to be designed for a specific discharge, peak discharge or the urban storm water drainage. There is a specific rainfall, that is occurring and then you would like to have your design such that the peak discharges arising out of this kind of rainfall will be passed smoothly through urban storm water drainage. And in situations where drainage through gravity is not possible, you would like to put in place pumping systems, which also need to assess what kind of recharge they have to pass as a function of time. That means, with respect to time what kind of discharge they have to pass is, specifically, it means, that we need to estimate the hydrographs at that particular location. The basis for most of this analysis is what is called as the IDF relationships, that is, intensity duration frequency relationships.

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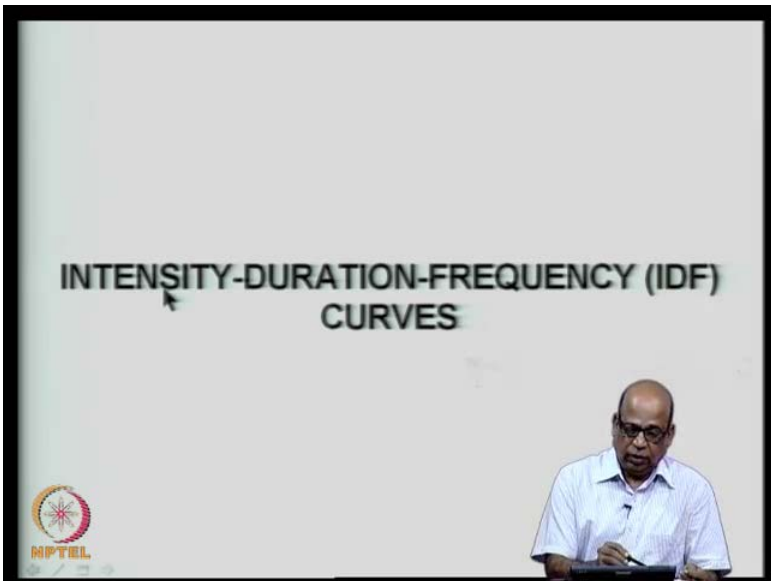

In most hydrologic designs, especially dealing with the extreme rainfalls, extreme floods, etcetera, we need the IDF relationships for making design decisions. So, in today's lecture, we will specifically focus on what are these IDF relationships, what kind of information, that you can derive from them and how to construct the IDF relationships for a particular location?

So, the intensity duration frequency relationships also called as IDF curves. Intensity is the intensity of rainfall we are talking about, this is depth per unit time, so millimeters per hour may be one of the units that you use. Duration is the duration of the rainfall, which is typically in hours. If we are talking about urban storm water drainage, etcetera, it may be of order of a few minutes, 30 minutes, 40 minutes, 12 minutes, etcetera. So, this is the duration and duration is typically the designed duration and frequency is related to the return period, once in about how many years this kind of event is likely to recur. So, frequency is the frequency of occurrence of that particular intensity of rainfall. All these three are related with each other.

So, we need to develop for a given location the IDF relationships and use these IDF relationships for that location as inputs to your hydrologic designs. So, we will see today how to construct the IDF relationships based on the data and also use some empirical relationships, which are derived for various reasons and we will specifically look at the regions within the country.

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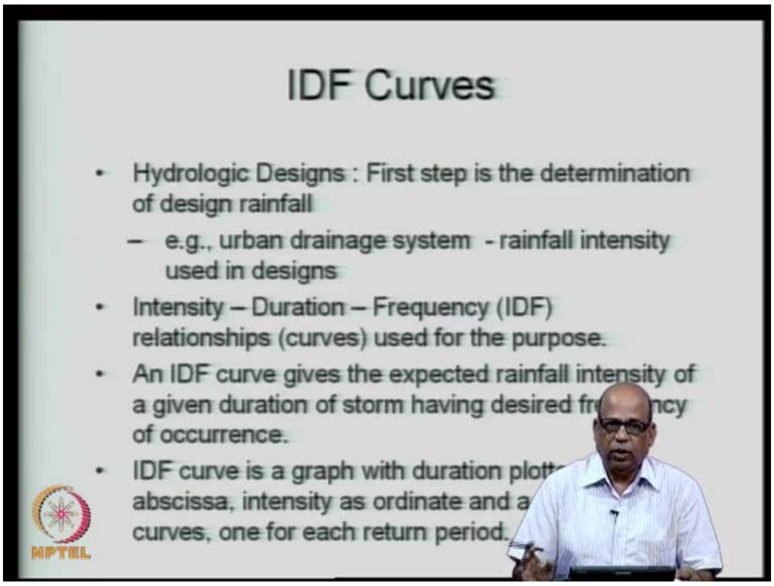

So, as I mentioned the first step in hydrologic designs is what kind of design rainfall that you would like to use. Now, the design rainfall, specifically we mean by design rainfall, we mean the rainfall intensity. Now, the rainfall intensity, as I just mentioned, will depend on the design duration.

Let us say you are talking about design intensity corresponding to a half an hour duration of rainfall, corresponding to 1 hour duration of rainfall, 24 hour duration of rainfall and so on. The design duration itself will depend on several other aspects of the catchment. For example, how fast the flow can take place in that particular catchment and which is related to, what is called as, time of concentration and so on. So, right now we will not worry too much about design duration. We will assume, that for a given design duration, the design duration is given, we will assume, that the design duration is given and then, for that duration we would like to calculate the intensity of the rainfall, that needs to be used in the hydrologic design corresponding to a given frequency or the given return period of that particular event.

Let us say, you are talking about urban flooding, we may be talking about return periods of the order of 5 years, 10 years and so on. Whereas, if you are looking at the designs of spillways, then we may be talking of return periods of the order of 100 years, 500 years and so on. So, the frequency or the return period is a matter of judgment of the designer based on the importance for which the hydrologic designs are made.

You may have a very critical installation, like a nuclear reactor or some such thing for which you need to provide the drainage, flood, flood drainage, in which case you may want to use a thousand year return period flood and so on. So, once you fix the duration, we must have a relationship between intensity and frequency and that is what we will do in the IDF relationship. So, the IDF relationship, it gives the expected rainfall intensity of a given duration, having a desired frequency of occurrence. And typically, we put the IDF relationships as IDF curves with duration as the abscissa and intensity as ordinate, and we will have those many curves as you have return periods. For example, we may have one curve corresponding to 2 year return period, 5 year period, 10 year return period, 100 years and so on. So, this is how IDF curves are presented.

In the context of stochastic hydrology, the importance here is what kind of distributions we use, what kind of return periods we use for the, the frequency of occurrence of these critical events. By critical events I mean, the intensity of rainfall exceeding the particular intensity and so on. So, we need to priory fix from the data. If we are talking about extreme values what kind of distributions are best suited for the purpose of getting the IDF relationships.

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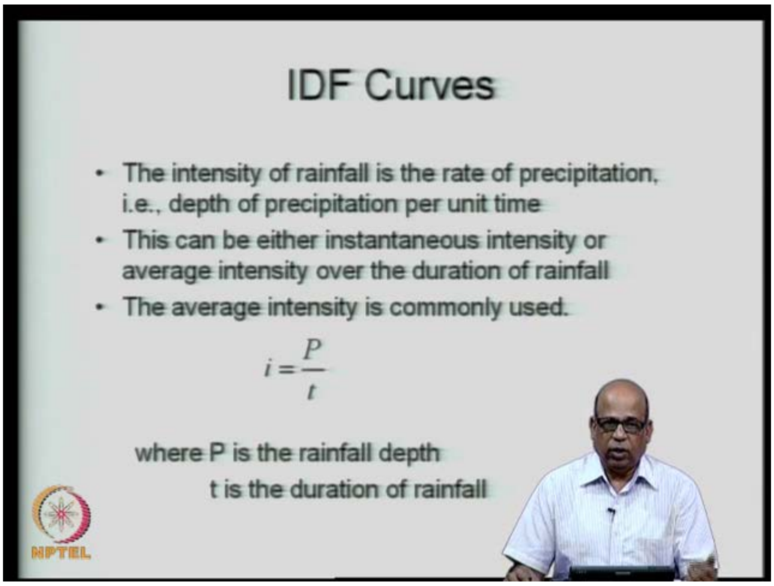

And we have been talking always about intensity when we come to IDF relationships. Now, the intensity is, it can be just instantaneous intensity or a rainfall has occurred over a period of time and then, you are talking about average intensity. Typically, in the IDF relationships that we use for hydrology designs, we construct the IDF relationships using the average intensity of rainfall. Let us say, that the rainfall has occurred over last 3 years, 3 hours and the total rainfall is known, simply divide the total rainfall by the duration, so you get the intensity. So, i is equal to P by t.

What is the assumption there? The assumption is that all through this duration the rainfall has occurred uniformly. However, this need not be true, but for IDF relationships we consider this and typically, the durations we consider are of the order of 1 hour, 2 hours and so on, up to 24 hours. And in fact, in some river based, in sector we are talking about, we will go much beyond.

But when we come to urban drainage or urban hydrologic designs, the duration of the time can be very small. For example, we may talk about 15 minute duration rainfall, half an hour duration rainfall and so on. Why is this so? Because the urban drainage has to address issues related with faster run off. The peaks will occur much faster compared to a non-urban catchment because all the rainfall, that falls, most of the rainfall, that falls, most of the rainfall, that falls, immediately converts itself into run off and therefore, the duration t is much smaller in the urban catchments compared to the duration in non-urban catchments. So, for a given duration, knowing the precipitation, you know the intensity of the rainfall.

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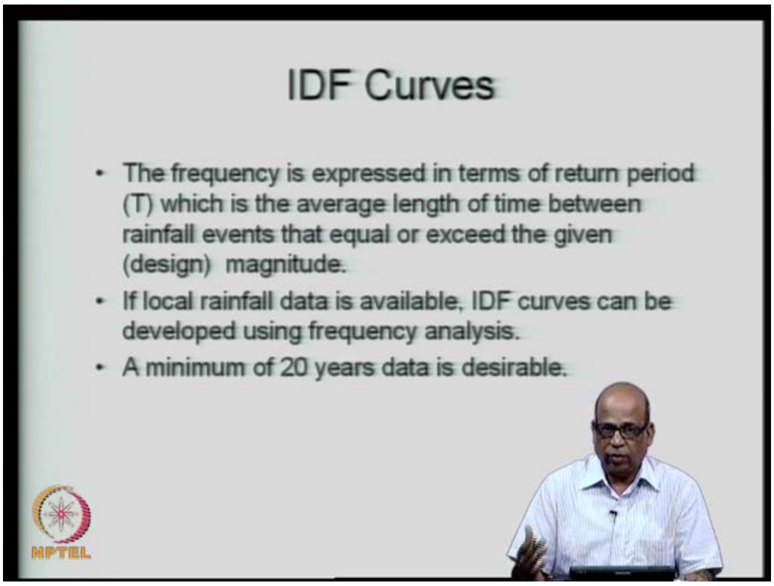

Then, we have the frequency. Frequency, as I mentioned, is in terms, is expressed in terms of the return period and the return period is fixed for a particular design or is examined. Various return periods can be examined for particular hydrologic design based on the judgment, based on the engineering judgment and also, based on the importance of the criticality of the design itself.

Then, IDF relationship we can develop based on the observed data. Let us say, that you have last 30 years, 40 years of data of continuously monitored rainfall or at least, every half an hour you have monitored the data, monitored the rainfall. Then, you have data for every half an hour for last about, let us say, 30 or 40 years. We can use this data and then construct the IDF relationship.

So, the basis for this is that you have the observed data. Observed data is available for half an hour, 1 hour, 2 hours and so on. So, we can also aggregate to get 6 hours rainfall, 12 hours rainfall and so on. So, every half an hour you have made the measurement for last 30 years, all the data is available. Typically, a minimum of 20 years of data is desirable for constructing IDF relationship. If you have less than 20 years, then it may become rather statistically biased. Therefore, a reasonable length of data is necessary for the construction of the IDF relationships.

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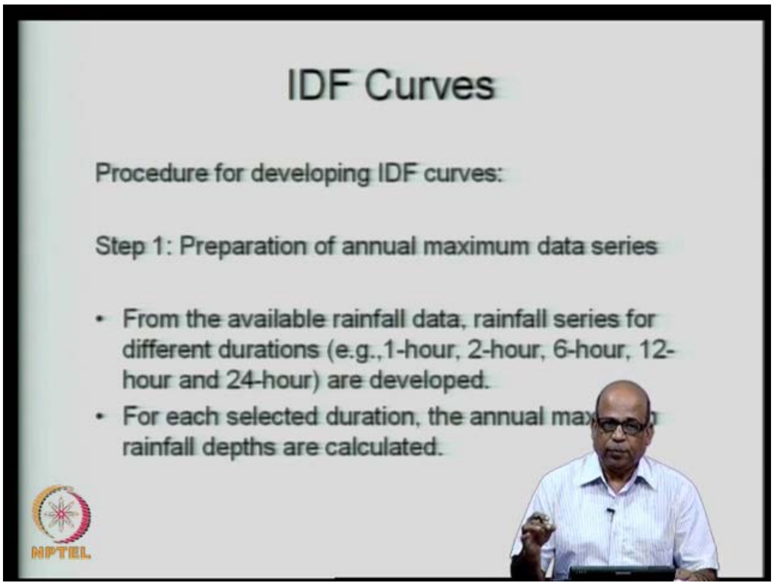

So, what do we do in this? First, from the observed data we construct annual maximum data series for various durations. What do I mean by that? Let us say, you have hourly data of last 30 years, which means what? For, for every hour you are measuring, so in 24 hours you have 24 data, in one year you have 24 into 365 data.

In the 24 by 365 data of every hour, we pick up the maximum occurring in that hour, one hour data you have. So, many values, out of that you pick up the maximum, so that becomes the maximum for that particular year, like this for last 30, 40 years you have one maximum value associated with each of the duration, 1 hour maximum, 2 hour maximum, 3 hour maximum, etcetera for all the 30, 40 years.

So, this is how we first constitute the annual maximum data series.

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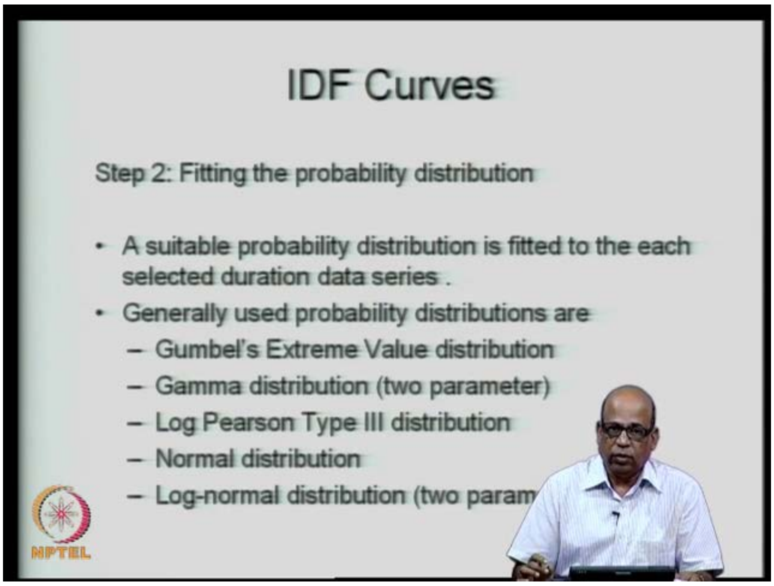

Then, associated with each of these series, now let us say we fix our attention on one of the duration, 1 hour duration or 2 hours duration, etcetera. So, for each of the selected duration we fit a distribution, probability distribution, when we are dealing with extreme rainfall values. Typically, we use the extreme value distributions. However, it is not uncommon to see applications of normal distribution and log number distributions also, but specifically we deal with Gumbel's extreme value type distribution or the gamma, this 2 parameter gamma distribution or the log Pearson type three distribution and so on. And the most commonly used distribution is the three extreme value type one distribution for constructing the IDF relationship. So, you have constructed one hour data series, two hours data series, six hours data series and so on, corresponding to each of these series.

Now, we fit a distribution. What do I mean by fitting a distribution? We calculate the parameters of that particular distribution and then, we have to satisfy ourselves, that the distribution, that we are using, in fact, is a good fit for the data that we have.

So, for one hour duration you may come up with one distribution, for two hour you may come up with another 24 hours like another and so on. So, corresponding to each of this series you identify the distribution, that fix, that fits, that fits best that particular distribution, that particular data series and then use that distribution to do the further analysis.

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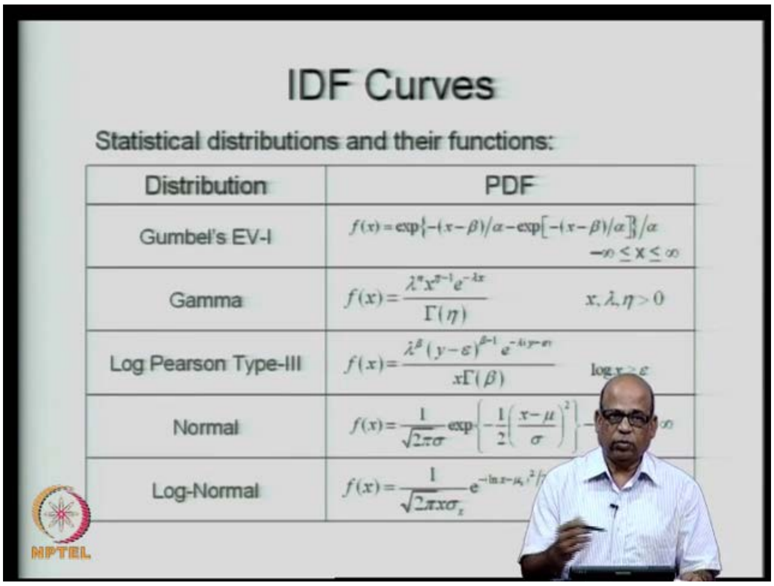

Now, these distributions, most of them we have gone through earlier. So, we typically use either the Gumbel's extreme value type one distribution, mostly when we are dealing with high intensities of rainfall, high peak floods and so on. We use Gumbel's extreme value type one distribution, the PDF is given by this, it has two parameters: beta and alpha, and we know how to estimate. I have given the expressions earlier how to estimate alpha and beta and this is, you know, we also use a transformation, x minus y is equal to x minus beta or alpha as a transformation, in which case we express it as e to the power minus e to the power minus y, it is a double exponential distribution. So, the Gumbel's extreme value type one distribution is most commonly used for obtaining the iDF relationship.

Similarly, we may use Log Pearson type three distribution or the gamma distribution, normal, log-normal, etcetera. All of this we have discussed, except the log Pearson type three, which I discussed in the previous lecture, I think lecture before that I have introduced this. So, all of these distributions can be used for developing the IDF relationships.

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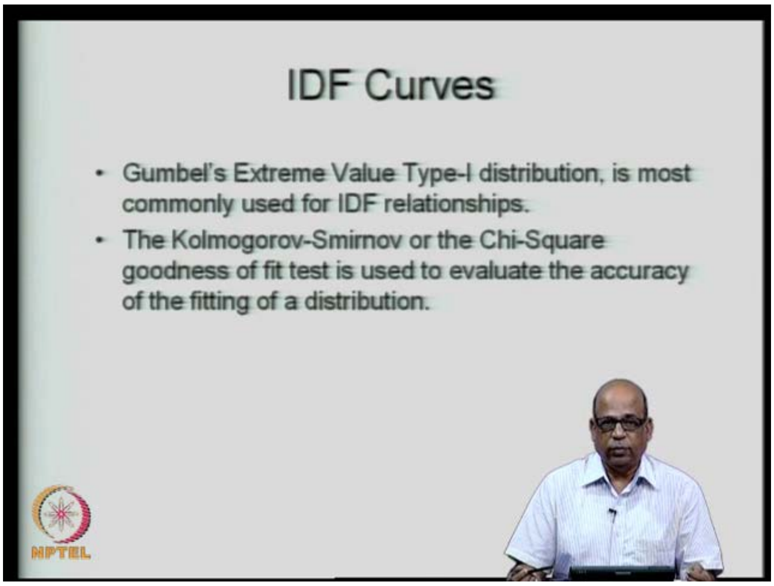

Then, as I mentioned, for each of these durations we fit our distribution based on, and our confidence in fitting this distribution arises out of the statistical test. So, we carry out the Chi-square test or the Kolmogorov-Smirnov test for each of the duration to satisfy ourselves, that the distribution that we are using is in fact, a good fit for the data we have. And once we are satisfied, we fix that distribution for the particular duration and then proceed further.

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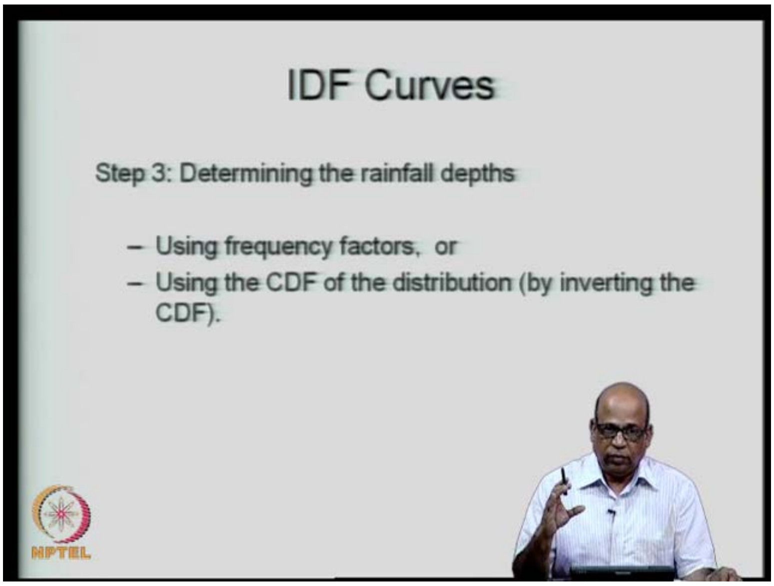

What we are interested in is for a given return period now, we need the rainfall depths, that is, return period of let us say 2 hours 2 years I am sorry 2 years what is the rainfall depth that we need to use 10 years what is the rainfall depth 100 years what is the rainfall depth. So, this is typically done by frequency analysis as we had discussed in the earlier lectures for a given return period how to obtain the critical parameter critical value of the rainfall. So, we can either use the frequency factors which depend on the return period as well as on the distribution or we may use if the return if the distribution that we are using is. In fact, invertible then we can use the c d f of the distribution directly and then obtain the x t.

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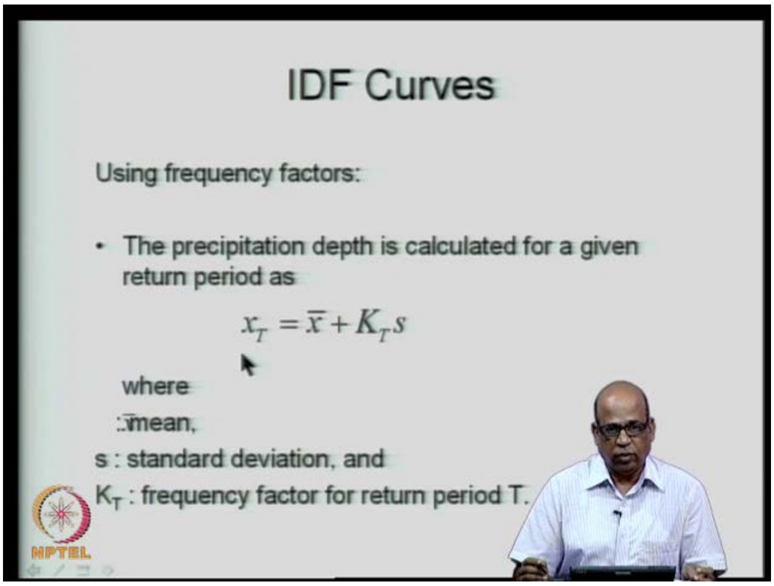

So, for a given return period we know this is a frequency factor uhrelationships that is the frequency analysis relationship that is the x t is equal to x bar plus k t into s where k t is the frequency factor and these are available for various distributions for given return period t and s is a standard deviation x bar is the mean this is x bar is the mean this is x bar. So, from this knowing the return period knowing the distribution we can calculate what is the rainfall depth

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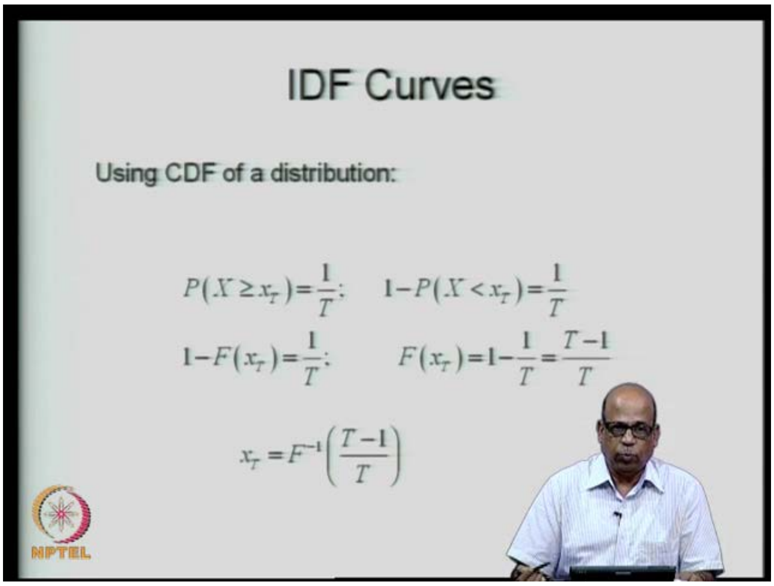

Let us say you are using distribution of the type of extreme value type one or even exponential distribution, which you can easily invert. By inverting I mean, you can express x in terms of F inverse of x. How do we do that? Return period is known, so probability of x being greater than equal to x t is 1 by t. And what we are interested in? Using the CDF, CDF gives you the probability of x being lesser than or equal to x t and this we get by 1 minus 1, that is, x going lesser than or equal to x t is 1 by t. And therefore, F of x t, I write it as 1 minus 1 over t or t minus 1 divided by t. From this we can get x t as F inverse of t minus 1 divided by t. If F can be inverted, then you can get x t. So, this is possible for some of the distribution.

So, you either use the frequency analysis method or use the probability distributions directly and use the inverse of probability distribution to obtain the x t for a return period specified. We now know what is the magnitude of the rainfall, that is to be used, that is, x t.

So, in the end what did we obtain? We obtained this as the intensity of the rainfall associated with a specified return period for a given duration. Where is the duration come? Because we are talking about this analysis for a given duration and similarly, for the next duration you are compute this, x t and so on.

So, like this you, for various duration you compute x t for various return periods. So, you will have a relationship between intensity, which is obtained as x t; the duration like 1 hour, 2 hour, etcetera for a given return period of 2 years, 5 years, 10 years and so on. So, this is how you specify the IDF of relationships, intensity duration frequency relationships, which can be used for any of the hydrologic designs.

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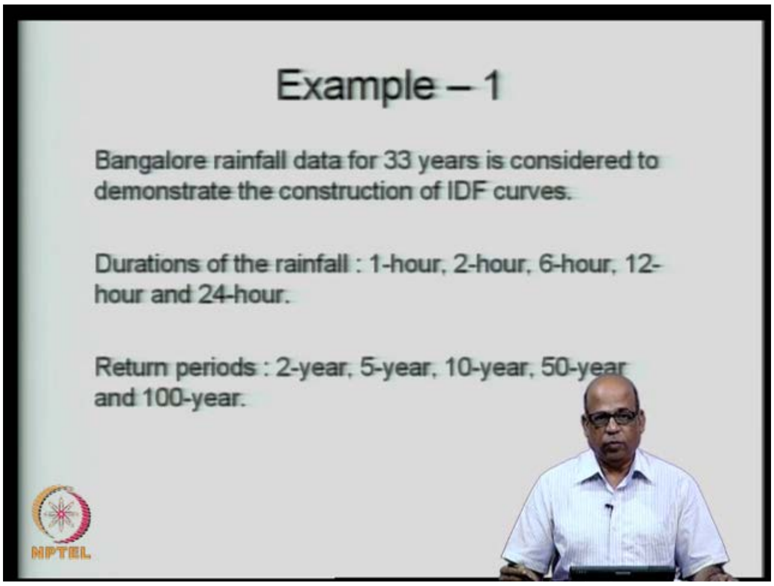

Let us take an example now and see how the idea of relationships can be derived. We will take the Bangalore city rainfall and this data has been obtained from the IMD, India meteorological department. So, for the last 33 years, we, we consider the rainfall for the construction of the IDF curves.

Now, although we have rainfall data for half an hour, 15 minutes, etcetera, for the purpose of this demonstration, I will start with 1 hour duration, 2 hour duration, 6 hour, 12 hour and 24 hour durations. And we will consider the return periods of 2 years, 5 years, 10 years, 50 years and 100 years and we will determine the IDF relationship for this particular data.

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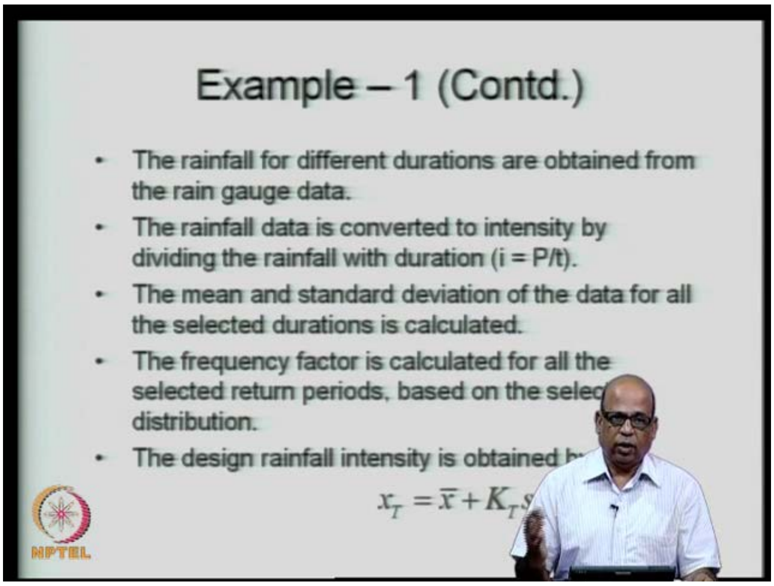

Now, these data are available from observed rain gauge data specifically, IMD makes it available for durations of half an hour, 1 hour and so on. So, once you have the half series, you may also construct 1 hour series, 2 hour series, up to 24 hour series. Then, the rainfall data is given in millimeters. So, first we convert it into intensities and typically we consider the average intensity of rainfall. So we take it as average intensity is equal to P by t, where P is the precipitation in millimeters and t is the duration of the rainfall.

Now, corresponding to each of the duration, 1 hour, 2 hour, etcetera, we compute the statistics, typically the mean and the standard deviation, which are necessary for your frequency analysis. Then, based on a selected distribution, as I said, typically we start with x t value type one distribution. We get the frequency factors corresponding to different return periods. So, we are using this expression x t is equal to x bar plus K t into s. x bar is estimated, s is estimated from the sample values, that you have for that particular duration and K T is the frequency factor, which we obtain for this particular selected distribution. Let us say it is extreme value type one distribution, you have K T for various return periods T.

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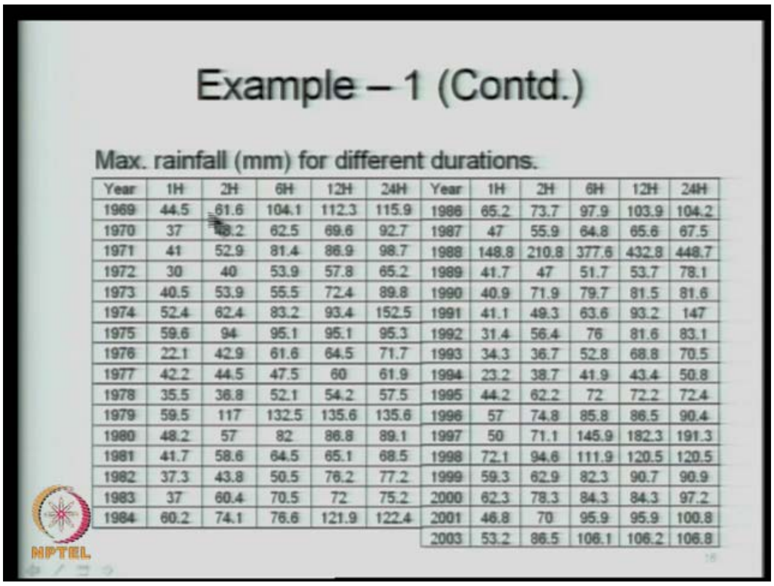

Year	1H	2H	6H	12H	24H	Year	1H	2H	6H	12H	24H
1969	44.5	61.6	104.1	112.3	115.9	1986	65.2	73.7	97.9	103.9	104.2
1970	37	[illegible]	62.5	69.6	92.7	1987	47	55.9	64.8	65.6	67.5
1971	41	52.9	81.4	86.9	98.7	1988	148.8	210.8	377.6	432.8	448.7
1972	30	40	53.9	57.8	65.2	1989	41.7	47	51.7	53.7	78.1
1973	40.5	53.9	55.5	72.4	89.8	1990	40.9	71.9	79.7	81.5	81.6
1974	52.4	62.4	83.2	93.4	152.5	1991	41.1	49.3	63.6	93.2	147
1975	59.6	94	95.1	95.1	95.3	1992	31.4	56.4	76	81.6	83.1
1976	22.1	42.9	61.6	64.5	71.7	1993	34.3	36.7	52.8	68.8	70.5
1977	42.2	44.5	47.5	60	61.9	1994	23.2	38.7	41.9	43.4	50.8
1978	35.5	36.8	52.1	54.2	57.5	1995	44.2	62.2	72	72.2	72.4
1979	59.5	117	132.5	135.6	135.6	1996	57	74.8	85.8	86.5	90.4
1980	48.2	57	82	86.8	89.1	1997	50	71.1	145.9	182.3	191.3
1981	41.7	58.6	64.5	65.1	68.5	1998	72.1	94.6	111.9	120.5	120.5
1982	37.3	43.8	50.5	76.2	77.2	1999	59.3	62.9	82.3	90.7	90.9
1983	37	60.4	70.5	72	75.2	2000	62.3	78.3	84.3	84.3	97.2
1984	60.2	74.1	76.6	121.9	122.4	2001	46.8	70	95.9	95.9	100.8
						2003	53.2	86.5	106.1	106.2	106.8

So, this is the data that we have, maximum rainfall for different duration, year 1969 to 2003. Remember here, for each of these values, let us say one hour maximum rainfall is what I am talking about, 1969 one hour maximum rainfall is 44.5.

How did I obtain this particular value? You have one hour observed data for every day for all the 365 days in 1969. So, from this, 1 into 24 into 365, one hourly data you pick up the maximum value occurred, that is 44.5 millimeter. Similarly, six hours, so every six hours you have data. So, in an, in a day you have four such data and 365 such days. So, 4 into 365, out of that you pick up the maximum, that is, this value and so on. So, for daily you have 365 values, out of 365 values you pick up this value. So, this constitutes the series of maximum day rainfall for different duration.

So, for one hour you have a series, for 24 hours you have a series and so on. So, for a given duration you have the series. Every series will have 1969 to 2003, those many values now.

Now, from the rainfall depth we convert it into intensities first. So, for 1 hour it is 44.5 by 1 and therefore, 1 hour rainfall depth itself becomes intensity. For 2 hours, it will be 61.6 by 248.3 by 2. So, this is the total rainfall that has occurred in 2 hours.

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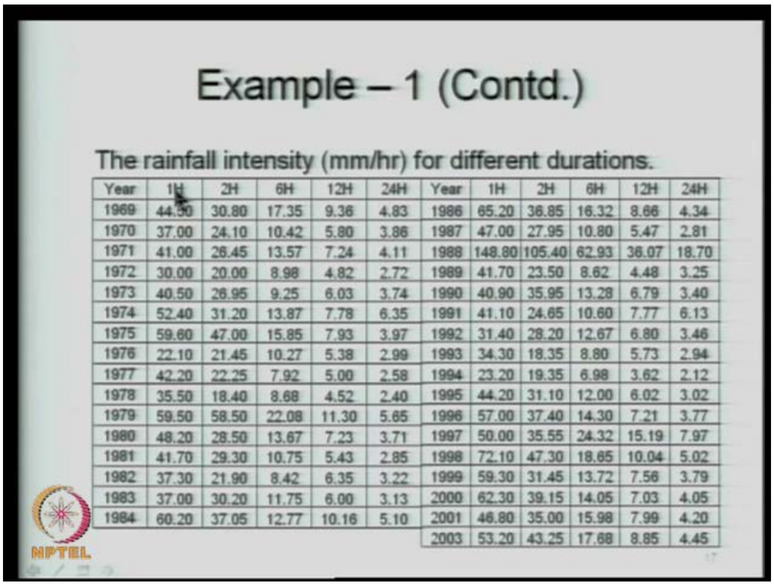

Year	1H	2H	6H	12H	24H	Year	1H	2H	6H	12H	24H
1969	44.50	30.80	17.35	9.36	4.83	1986	65.20	36.85	16.32	8.66	4.34
1970	37.00	24.10	10.42	5.80	3.86	1987	47.00	27.95	10.80	5.47	2.81
1971	41.00	26.45	13.57	7.24	4.11	1988	148.80	105.40	62.93	36.07	18.70
1972	30.00	20.00	8.98	4.82	2.72	1989	41.70	23.50	8.62	4.48	3.25
1973	40.50	26.95	9.25	6.03	3.74	1990	40.90	35.95	13.28	6.79	3.40
1974	52.40	31.20	13.87	7.78	6.35	1991	41.10	24.65	10.60	7.77	6.13
1975	59.60	47.00	15.85	7.93	3.97	1992	31.40	28.20	12.67	6.80	3.46
1976	22.10	21.45	10.27	5.38	2.99	1993	34.30	18.35	8.80	5.73	2.94
1977	42.20	22.25	7.92	5.00	2.58	1994	23.20	19.35	6.98	3.62	2.12
1978	35.50	18.40	8.68	4.52	2.40	1995	44.20	31.10	12.00	6.02	3.02
1979	59.50	58.50	22.08	11.30	5.65	1996	57.00	37.40	14.30	7.21	3.77
1980	48.20	28.50	13.67	7.23	3.71	1997	50.00	35.55	24.32	15.19	7.97
1981	41.70	29.30	10.75	5.43	2.85	1998	72.10	47.30	18.65	10.04	5.02
1982	37.30	21.90	8.42	6.35	3.22	1999	59.30	31.45	13.72	7.56	3.79
1983	37.00	30.20	11.75	6.00	3.13	2000	62.30	39.15	14.05	7.03	4.05
1984	60.20	37.05	12.77	10.16	5.10	2001	46.80	35.00	15.98	7.99	4.20
						2003	53.20	43.25	17.68	8.85	4.45

So, we convert these into intensities and that is how we constitute the series corresponding to the rainfall intensities. Now, from the depth we have come to the intensities. So, this is the series for different durations. Corresponding to each of the series now, we now compute x bar and s.

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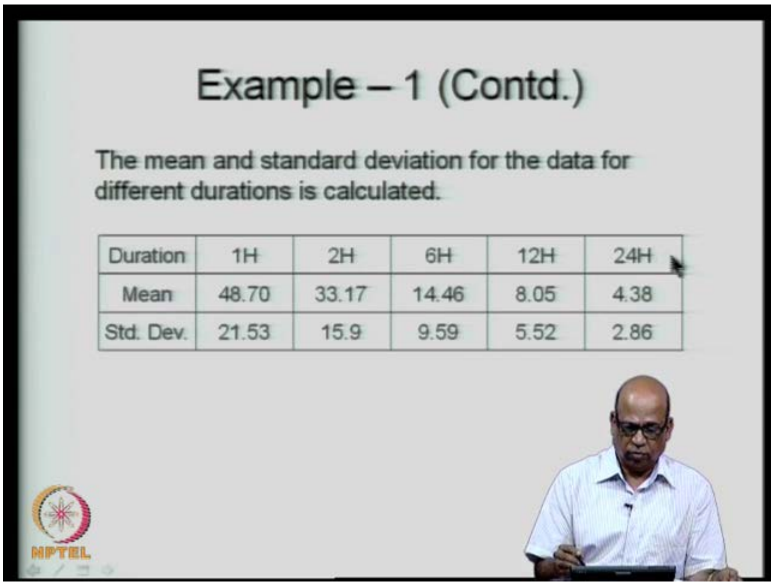

Duration	1H	2H	6H	12H	24H
Mean	48.70	33.17	14.46	8.05	4.38
Std. Dev.	21.53	15.9	9.59	5.52	2.86

So, the mean and standard deviation for 1 hour, 2 hours, 6 hours, 12 hours, 24 hours is computed from this data. 1 hour, 2 hours, etcetera we compute these values now. Now, this is intensity, therefore the units are 48.7 millimeters per hour. This is millimeters per hour and so on. Similarly, standard deviation, so this forms x bar now and this is s.

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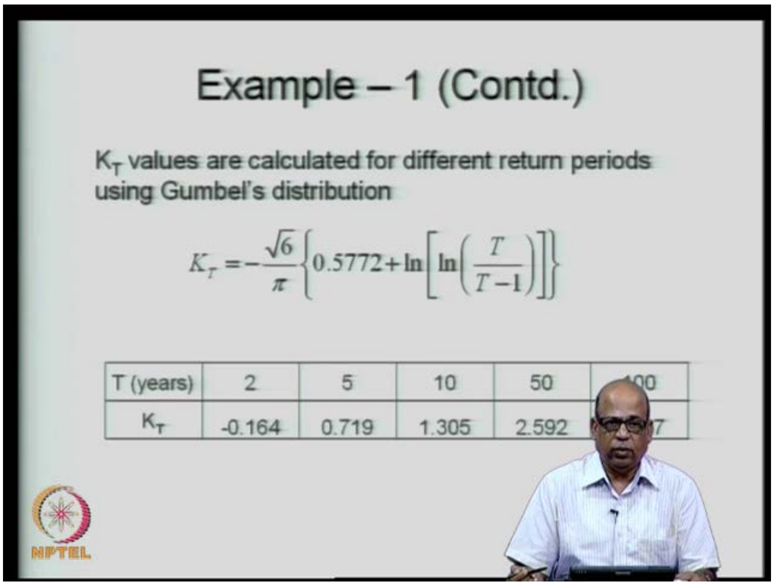

And we use the Gumbel's distribution and obtain the associated K T values for various values of T, that is, a return period. Now, although directly I have used the Gumbel's distribution, in this case you may carry out the statistical test, like Chi-square test or the Kolmogorov-Smirnov test to satisfy yourself, that the distribution, in fact, fits all the duration rainfall. That means, it should fit 1 hour, 2 hour, etcetera and so on.

Now, it may so happen, that for one particular duration you may use a different distribution altogether. For example, log Pearson type three distribution, that may fit that particular duration better. So, you must use the distributions that fit the data series constructed for these specific durations of rainfall. Now, because we are using the Gumbel distribution, we are assuming, that the Gumbel distribution fits, in fact, all the durations. And the KT, if you recall, is given by this expression for a given return period.

For Gumbel's distribution, Gumbel's distribution is also called as extreme value type one distribution and it is most commonly used for constructing the idea of relationships. So, for a return period of 2, I use this expression, I get the K T of minus 0.164. Similarly, I get all of these K T value. We use these K T values to obtain the associated x T values now.

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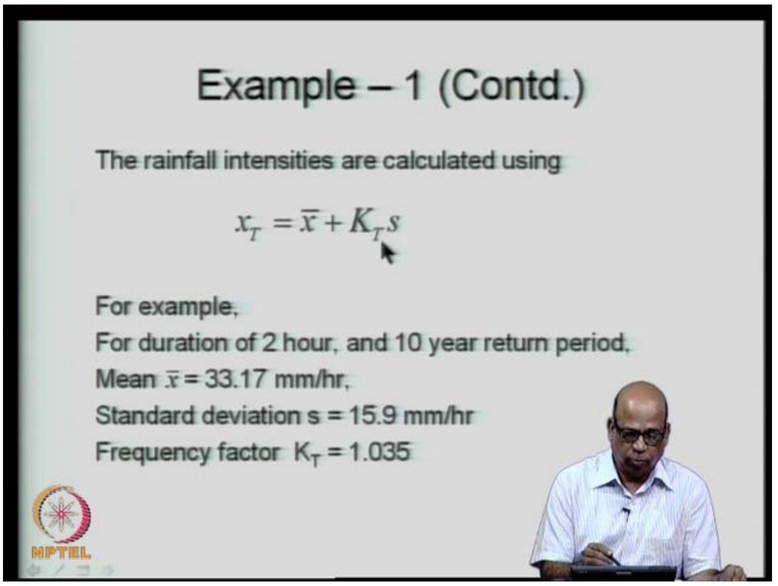

So, x T is equal to x bar plus K T s. We know the K T value corresponding to a return period for a specified duration. We know what is x bar and s for that specified duration, we get the x T.

For example, you take 2 hour duration. Now, 2 hour duration, we have calculated the mean as 33.17 millimeters per hour and the standard deviation as 15.9 millimeters per hour; we use that and then get the frequency factor. A frequency factor is obtained here for a return period of 10 years. We are talking about 10 year return period and with the frequency factor we have obtained it as 1.305. So, 1.305 is K T, you have the x bar 33.17, you have the s, therefore you can get x t. This x T is for duration of 2 hours.

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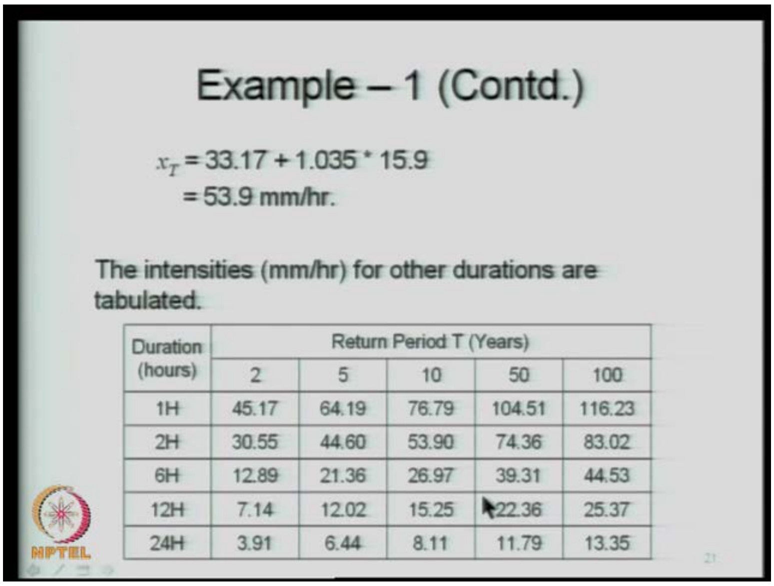

Example – 1 (Contd.)

$x_T = 33.17 + 1.035 * 15.9$

$= 53.9$ mm/hr.

The intensities (mm/hr) for other durations are tabulated.

Duration (hours)	Return Period T (Years)				
	2	5	10	50	100
1H	45.17	64.19	76.79	104.51	116.23
2H	30.55	44.60	53.90	74.36	83.02
6H	12.89	21.36	26.97	39.31	44.53
12H	7.14	12.02	15.25	22.36	25.37
24H	3.91	6.44	8.11	11.79	13.35

So, we get x T for 2 hours is 53.9 millimeters per hour for a return period of 10 years. Like this, for different durations, we calculate for different return periods the rainfall intensities. These are the rainfall intensities obtained using the procedure that I just enumerated.

What does this table give? This gives, in fact, the IDF relationship. This is, these are the intensity values, these are durations and these are the return period or the frequencies. So, this table, thus, gives the complete IDF relationship.

Typically, the IDF relationships are shown in the form of curves, you can also observe that for a given duration. As the return period increases, the rainfall intensity increases and therefore, you must keep in mind that we are talking about the design intensity that need to be used. Otherwise, intuitively, it may appear, as if for 1 hour duration how can it be different for different return periods, because the duration is only 1 hour how can the rainfall be different?

We are talking about the intensities of rainfall, that need to be used in hydrologic designs and these intensities will be different for different return periods. So, for example, 76.79 millimeters per hour occurs once in about 10 years and this is the interpretation you, you should keep always in mind. Also, as the duration is increasing, for the same given return period the intensities will be coming down, 76.59, 79, 53.90 and so on.

So, for a given return period as the duration increases, the intensities will be smaller and smaller, which is obvious. Because if we are talking about a large catchment, which your duration, design duration may be of the order of 24 hours, the amount of rainfall, that you may be want to use, the intensity of rainfall, that you need to use will be much smaller compared to a 1 hour duration for the same return period.

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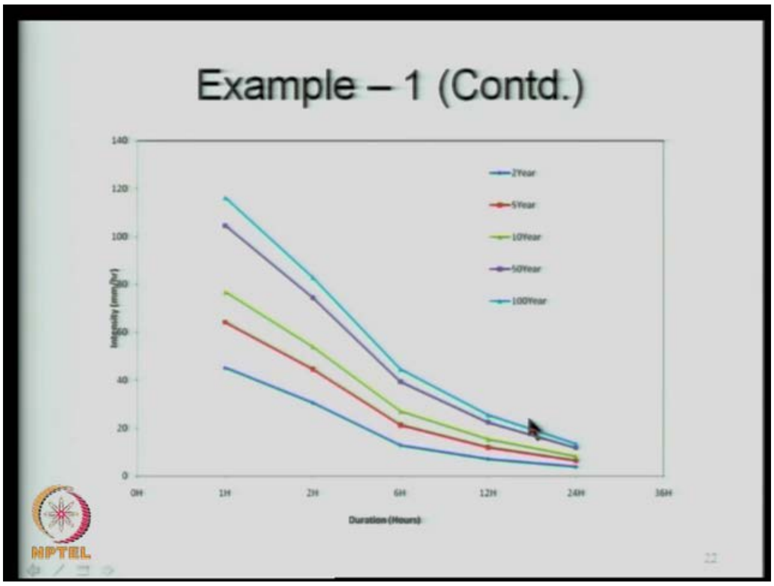

Now, these are shown, the IDF relationships are shown by the curves like this. We use this data and then draw curves associated with each of the return period. Each of this line corresponds to a particular return period, let us say, this is 2 year return period, then you have five, I am sorry, this is 2 year return period and this is 5 year return period, 10 year return period and so on, 50 years and 100 years.

Using this for a given distribution, we can pick up the associated intensities. Let us say, you are doing a design for 5 year return period and 2 hour duration, you go to this curve and then pick up the intensity 44 or something millimeters per hour and that is the intensity that goes into your hydrologic designs.

Now, this is the way we construct the IDF relationships based on the observed data. Now, many times what may happen is that you may not have a complete series of observed data, that is necessary for constructing the IDF relationship and typically, the IDF relationships are given for different locations, different regions, etcetera by metrological departments typically. In India, it is given by IMD, that is, Indian

Metrological Department. They may give region-wise, they may give state-wise, they may give city-wise and so on.

But for hydrologic designs pertaining to urban areas, it is best to construct the IDF relationships ourselves, the hydrologic designers, based on the actual observed data. And typically, as I mentioned, we go much below 1 hour, that is, we may also have data on half-an-hour duration, 30, 15 minutes duration, 12 minutes and 5 minutes and so on. So, specifically, for urban drainage designs you must have data, preferably, continuously monitored data or at least once in 10 minutes data must be available, in which case, you also extend this beyond based on the actual observed data, and then use that region typically for urban designs. We use region between 0 hour and 1 hour duration.

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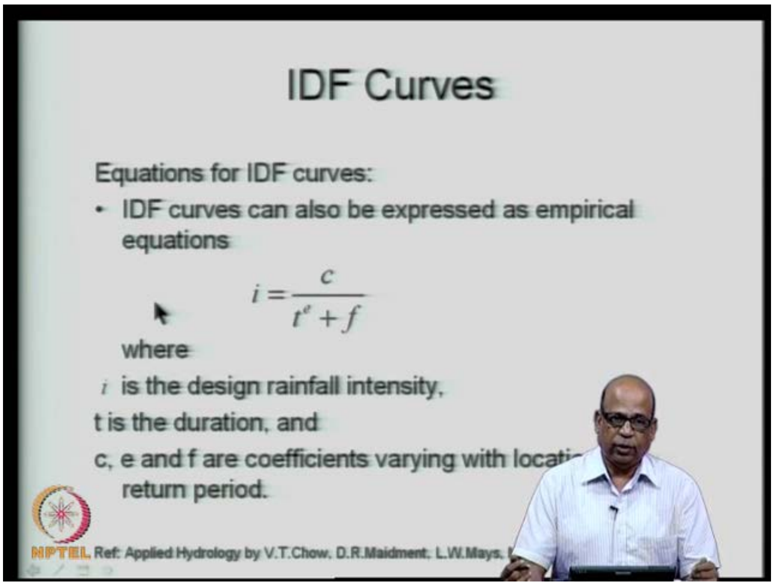

Then, when we do not have the observed data, we have certain empirical relationships available for constructing the idea of relationship. What we will now do is we will go through some of these empirical relationships and also those proposed specifically for the Indian regions by many Indian researchers and we will see how to use them to construct the IDF relationship.

Now, one of the classical way of expressing this is, i is equal to c divided by t to the power e plus f; i is the intensity, c is the constant, t is the duration and f is another constant. These constants: c, e and f are typically, they vary with location and the return period. So, for various return periods and for different locations, these constants must be available. And for several locations they are, in fact, made available by the previous researchers, by many previous researchers. So, from this, then if you specify the return period for a given location, you obtain c, e and f, so which are functions of the return period and you have the duration.

Now, the duration is design duration, which again we fix it based on the catchment characteristics, typically related to the time of concentration. How much time it may take for the water to flow from the furthest region of the catchment, that decides in some sense the design duration, and from that you can get i, which is the rainfall intensity to be used in the hydrologic designs. So, this specifies i, d, f; i for intensity, d is the design duration and f is the frequency, which in fact, gives us these three constants, c, e and f for a given location. So, that is how we use the IDF relationship.

Now, there is a modification for this proposed also by (( )) where it includes the return period explicitly. For example, it can be written as, with another constant, here i is equal to c T to the power m t e plus f. So, you may bring in the return period explicitly here, rather than making the e, m and c as functions of return period. So, we bring in the return period explicitly. So, such forms are also available in which case you are again introducing another constant there, which is m. This is also available in the reference that I have given here.

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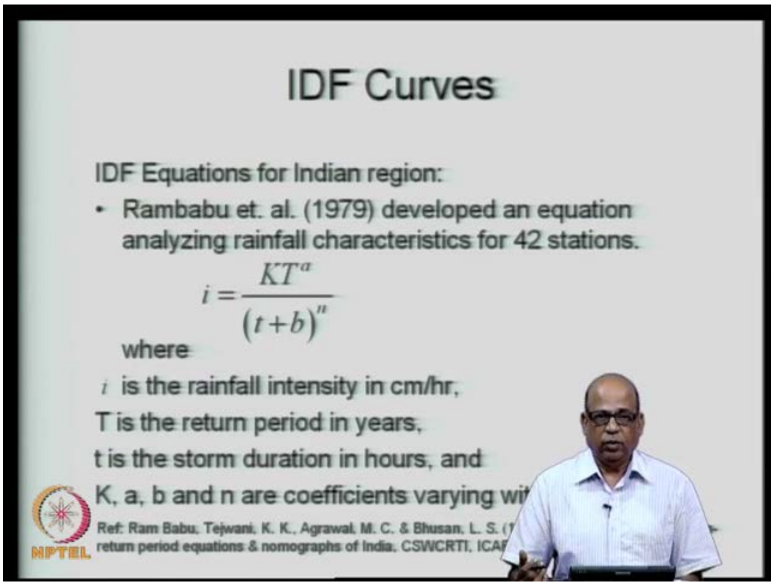

Then, for Indian region, many of the Indian regions, there are some empirical relationships that are available. I will provide this specifically two of them, one is Rambabu et. al. in 1979. Now, they have provided for various regions in the country, the constants in this particular expression. So, this is the empirical relationship that they proposed where intensity is given. This is the time of concentration and this is the duration, I am sorry, not time of concentration, this is return period, intensity, return period and the duration.

You have constants k, a and n here. Now, they studied 42 different stations spread all across the country and then provided the constants for constant values k, a and n; k, a, b and n. So, k, a, b and n are coefficients varying with location and t is the return period and i is the rainfall intensity. In this particular expression, the intensity is in centimeters per hour, not in millimeters per hour; it is a empirical relationship.

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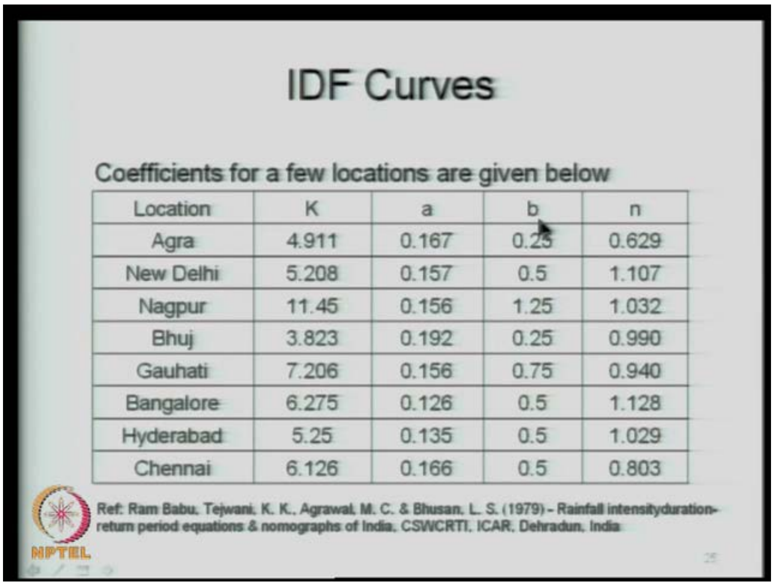

Location	K	a	b	n
Agra	4.911	0.167	0.25	0.629
New Delhi	5.208	0.157	0.5	1.107
Nagpur	11.45	0.156	1.25	1.032
Bhuj	3.823	0.192	0.25	0.990
Gauhati	7.206	0.156	0.75	0.940
Bangalore	6.275	0.126	0.5	1.128
Hyderabad	5.25	0.135	0.5	1.029
Chennai	6.126	0.166	0.5	0.803

And these coefficients have been proposed by them for various locations. For the purpose of this lecture I just picked up few locations, for example, Agra, New Delhi, Nagpur; k, a, b and n are provided. And once k, a, b and n are known, for a given return period you can get i specifying the duration. Therefore, the IDF relationship gets fixed. So, these are for various locations.

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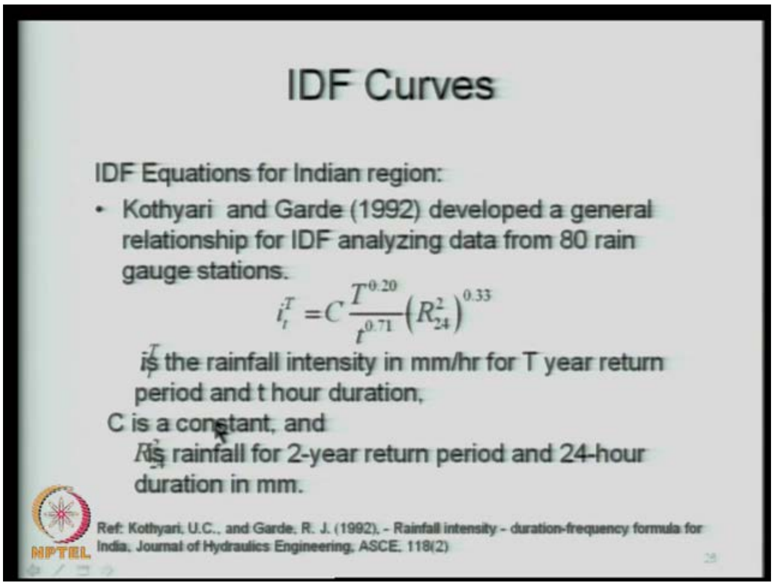

Similarly, more recently Kothyari and Garde have developed another general relationship, I would encourage all of you to have look at this particular paper, this, this is the most recent one. And they have done an extensive study of eighty rain gauge stations and then, they arrived at such a relationship intensity corresponding to a return period of capital T for a duration of small t is equal to C, which is a constant; capital T, which is a return period and small t, which is the duration.

R 24 2, this is a 2 hour 24, I am sorry, 24 hour 2 year return period rainfall. So, if we have this 2 year return period 24 hour duration rainfall, then we can calculate this. So, this is R 24 2 here, I am, I think it is not coming out clearly, so let me rewrite this. This is R 24 2, this is the rainfall for 2 year return period and 24 hour duration in millimeters. We are not talking about intensity there, it is the depth. Given 1 hour rainfall or given any duration rainfall, they have also explained how to obtain the 2 year return period and 24 hour duration in millimeter. So, we can use this and obtain i t T.

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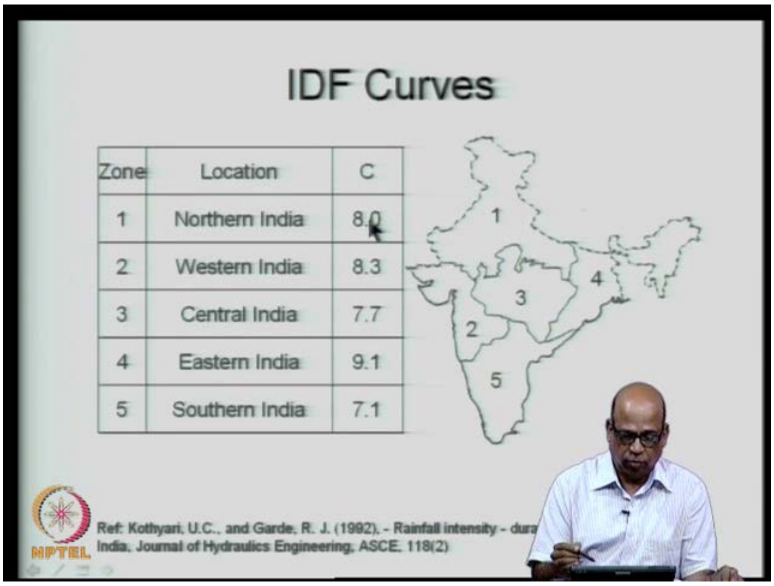

And they have given the constant C, in this particular case they is only one constant C and this is worked out for several regions. For example, north India, you take the region as 1 here, you can use the C as 8.0 and western India, they have given C as 8.3 and so on. Like this, southern India, we may have, relationship, a constant of C of 7.1.

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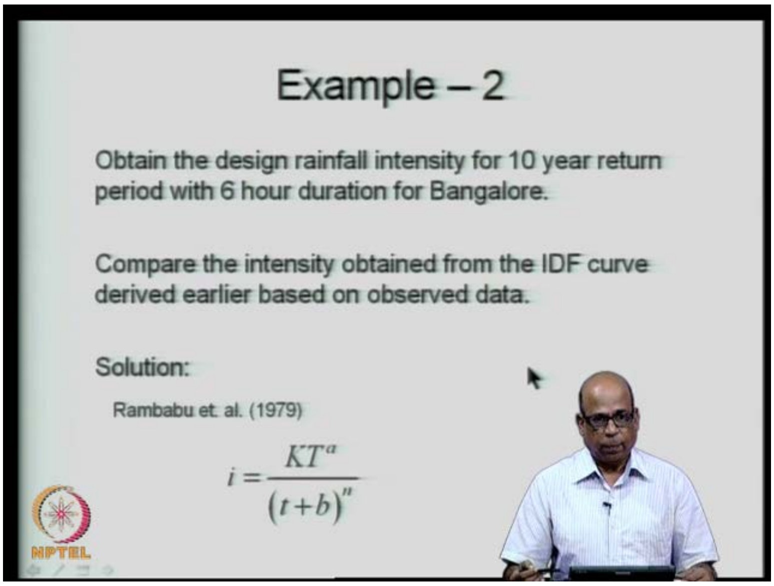

What we will do is we will take an example now of the same Bangalore city rainfall, that I considered previously for constructing the IDF relationship. We will apply these empirical relationships as provided by Rambabu et. al., as well as, Kothyari and Garde and see what kind of intensities we get for a specified return period, 10 years, for a given duration, 6 hour, and try to compare it with what we obtained from the observed data, how different they are from each other.

So, in the Rambabu et. al. we have i is equal to K T to the power a t plus b to the power n; t is the return period, we are talking about 10 years return period; small t is the duration, we are talking about 6 hour, return, 6 hour duration; i needs to be obtained and K a and n, K, a, b and n are constants, which are available for different cities.

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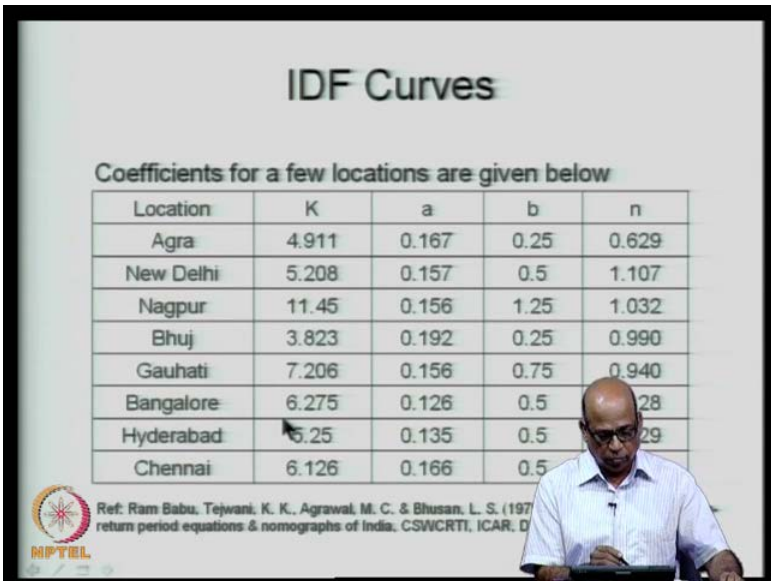

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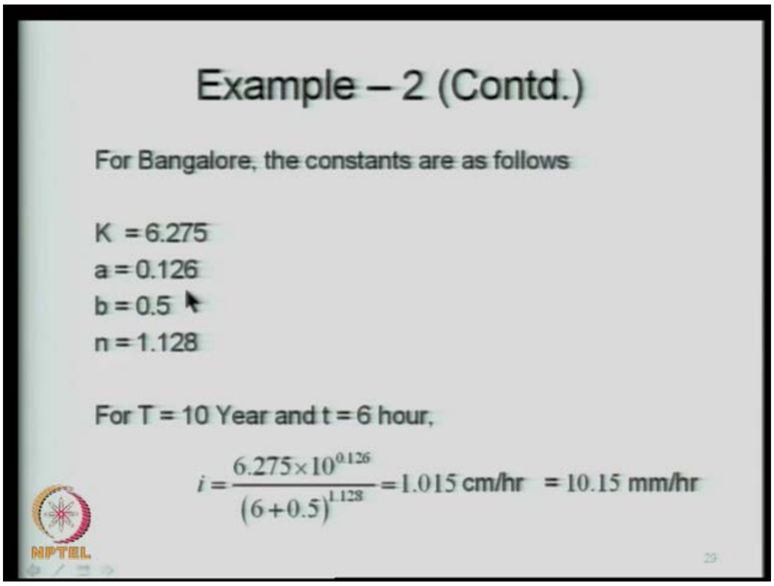

So, we will pick up for the Bangalore city what it gives. So, for Bangalore city, these are the values 6.275, 0.126, 0.5 and 1.128. So, these are the constants, that we pick up for Bangalore city and then apply this. So, K, a, b and n are obtained from that table, that I just showed. So, for T is equal to 10 years and small t is equal to 6 hours, we obtain the intensity using the empirical relationship as 1.015 centimeters per hour. Now, this is the expression, that we are using, this is from this, from the expression provided by Rambabu et. al.

Remember, here this study was carried out in 1979 with the data, that was available at that time and they also studied 42 different rain gauges at all over the country and then arrived at this, which was extremely useful.

However, as time progresses, as more and more data becomes available, your relationships, empirical relationships can change or your constants can change for various regions because the rainfall pattern would have changed over a period of time. So, this is a fairly old relationship, whereas Garde and Rangraju, I am sorry, Kothyari and Garde, that relationship is more recent.

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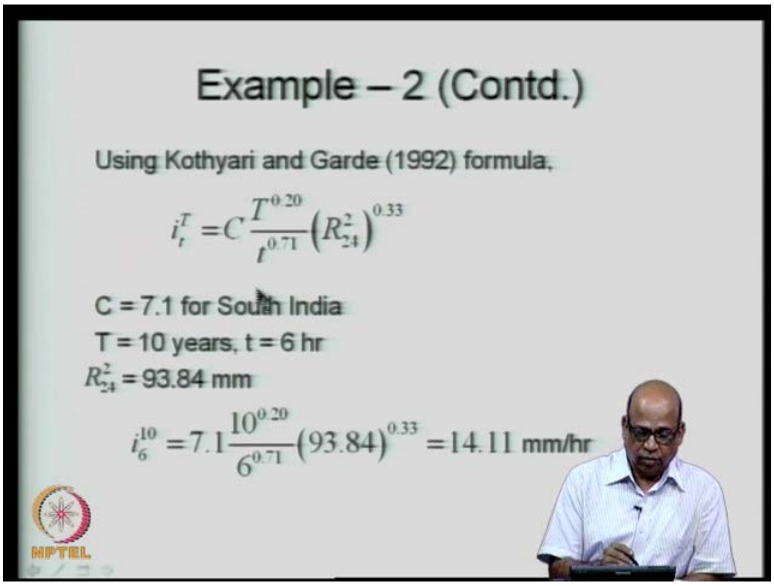

So, we will use Kothyari and Garde relationship, which is provided in 1992 with the data that was available. Also, they studied 80 rain gauges, that were spread all across the country and therefore, this may be slightly better one. Now, we use this and they have given for south India the constant C as 7.1, we are using T is equal to 10 years for this example and the duration is 6 hours and this R 24 2 is 93.84. This I am directly picking up from our data, which is available.

However, they have also explained how to give, how to obtain these values for R 24 2, that is, 24 hour 2 year return period rainfall values in depth units for a given data series, that you have. So, from that you should calculate this and then substitute this, we get intensity of 14.11 millimeters per hour.

From the earlier relationship, we got intensity of 10.15 millimeters per hour from our IDF relationship. As we derived earlier from the data, that we had we can pick up 10 years 6 hour rainfall, that is, 10 year is here and 6 hour rainfall, we may get a certain intensity, it may come to about some 23 and some such things. This is based on the observed data up to 2003, from 1969 to 2003 and this is based on the relationship provided in 1979. Based on the data, that was available, they have provided this relationship and this is the relationship provided in 1992.

So, as time progress progresses your relationships may become different and therefore, the intensities, that you may want, you may have to use in hydrologic designs, can be different. This means, that there is some non-stationarity in the IDF relationships themselves. That means they do not remain stationary as you progress in time.

Let us say, every decade you start computing IDF relationship afresh, then this can be quite different. For certain locations the intensity, that you are getting for a particular return period can be much higher for the same duration compared to the previous IDF relationship, compare to those obtained by previous IDF relationships.

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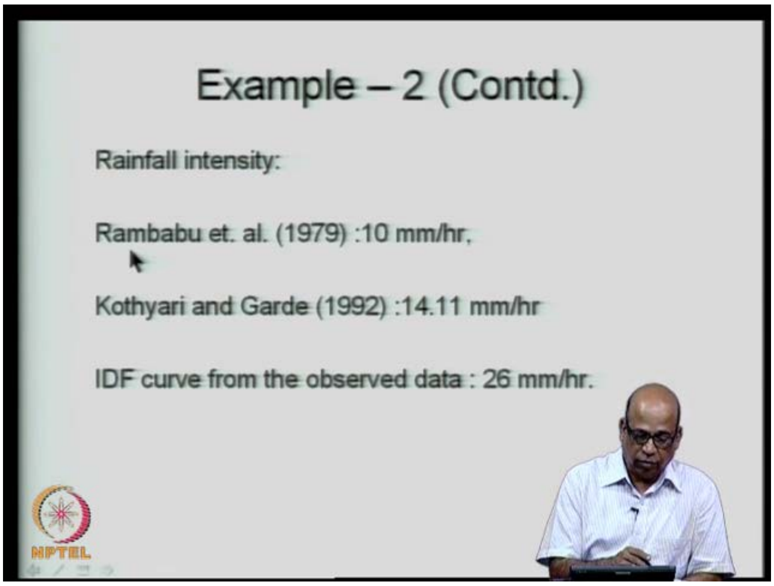

So, if we compare now what we obtained from various, various methods for the same data, from Rambabu et. al. we get approximately 10 millimeters per hour, from Kothyari and Garde, in 1992 we obtained 14.11 millimeters per hour. But when we used the observed data up to 2003, remember this was, they had, they would have used data as available in 1992, but up to 2003 when we use and then use an extreme value type one distribution and obtain the intensity, rainfall intensity, we get a much higher intensity of 26 millimeters per hour.

For the same location, for the same duration s, and for the same return period, as time progresses with more and more information available to you, you may get different intensities of rainfall for use in the designs. This is the important concept, that you must remember and therefore, when you are making hydrologic design today and then hydrologic design is supposed to serve you for next 30 years, 40 years, etcetera.

You must have a mechanism or a method by which you should be able to assess, whether my IDF relationships can be held constant or they need to be changed as time progresses. And therefore, use certain correcting factors for using the hydrologic designs. This is especially true in the current context of climate change where the relationships are known to be non-stationary.

Now, there is a significant non-stationarity, that has been introduced because of climate change and therefore, the IDF relationship cannot be held fixed and we must have a mechanism by which we should be able to project. Given that we are, we have a particular IDF relationship today, in what way the IDF relationships are likely to change in two decades, three decades, twenty, twenty, forty, etcetera because our hydrologic designs, that we are putting in place today are supposed to serve us for next 30 years, 40 years and so on, and therefore, we must be able to use the corrected IDF relationship.

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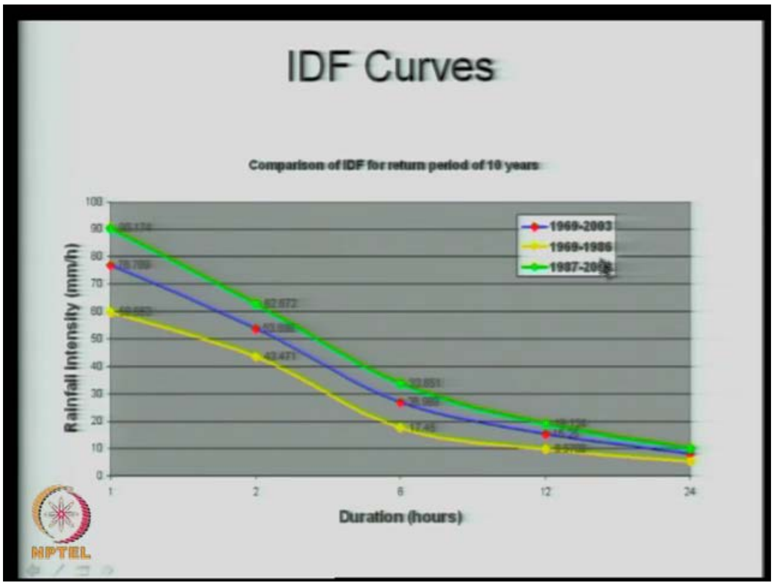

If we look at how the how the Bangalore IDF relationship has changed for the last few years, I will just show you based on the observed data. We had the data from 1969 to 2003, let us say we split this into two parts, one is 1969 to 1986 and another is 1987 to 2003. Remember, both of these do not have sufficient data, both the series do not have 20 years data at least.

However, let us see how it looks like. So, if you consider only 1969 to 1986 data and then derive the IDF relationship, this is how it looks like. That means, for a given duration this is, I am showing it for a particular return period of 10 years. So, for a given duration you may get a much lower rainfall intensity compared to that obtained for 1987 to 2003. So, for 1987 to 2003 you are getting much higher intensity of rainfall for the same duration, for a given period of 10 years, and if you consider the entire series this is how we have obtained earlier. So, for example, two hour duration, you have got 53.9 hours approximately. This indicates that as time progresses, at least from this limited analysis, as time progresses intensity appears to be increasing for the same given duration.

So, to summarize, now what we have seen in today's lecture is that we started with the construction of IDF relationship intensity duration and frequency relationship. Now, these are essential for hydrologic designs where we would like to obtain the design intensities of rainfall i for a given duration d and for a given specified return period f, that is, the frequency, f is the frequency.

We have seen how to construct such IDF relationships from the observed data specifically. We construct series of 1 hour duration, 2 hour duration, half hour duration, etcetera, construct different series and then fix extreme value situation. Typically, we use the Gumbel's extreme value type one distribution and obtain the x T, which is the magnitude of the rainfall and magnitude of the rainfall intensity, what we will be specifically interested in corresponding to a return period T and then, from that we construct IDF relationship.

There are also empirical relationships available and I discussed a few for constructing the IDF relationship. And typically, in India we have IDF relationships provided by Rambabu et. al. in 1979 and Kothyari and Garde in 1992. They also specified for this, for the particular empirical relationship, that they propose. They also specified the constant values that we need to use for various locations. So, in case your region does not have a particular region in India, does not have adequate data, you can use these empirical relationships for making the hydrologic designs.

In the next lecture, then we will take this analysis further and see how from the intensities of the rainfall, how do we construct the hyetographs, design hyetographs and from the hyetographs how we move on to hydrographs because finally, hydrographs is what we need to use in our hydrologic designs.

So, thank you for your attention, we will meet in the next lecture.