Wastewater Treatment and Recycling
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Lecture – 08
Population Forecasting Methods

Hello everyone. So, last time we concluded the discussion, when we were talking about how important it is to know the future population when we tend to design sewerage systems or when we intend to estimate the design capacity of a sewerage system. So there were different forecasting methods, population forecasting methods and in this particular session, we are going to discuss those methods or many of those major methods which are typically used for the population forecasting purpose.

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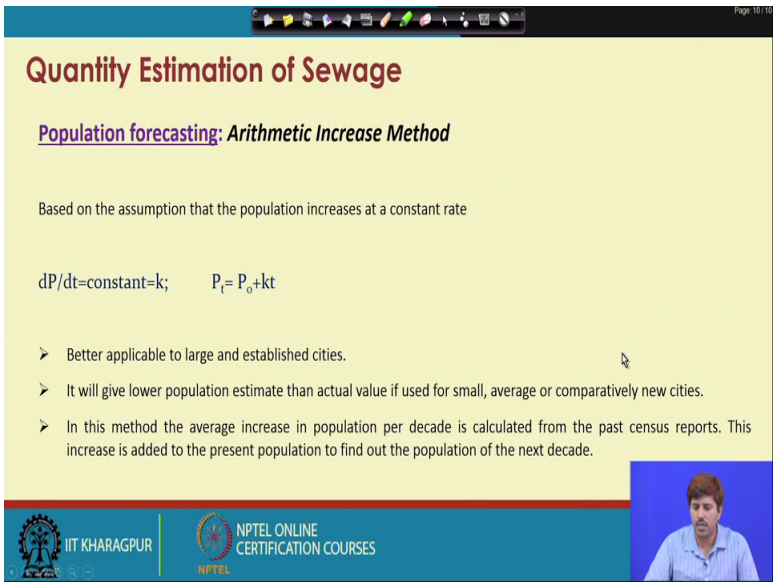

To begin with, one of the most primary method is Arithmetic increase method, which is based on assumption that population increases at a constant rate. So, if you see that change in the population in a unit time, dP by dt or rate at which the population changes is actually constant and this leads to equation that population at any time P t will be equal to population at any given time P o plus this rate into the time, that has been passed. So, this kind of method or this arithmetic increase method is better applicable to large and established cities only because those large cities which are near saturation, the population grows only by fixed number, almost fixed number each here, ok.

So, we can apply such arithmetic increase method over there. It will give lower population estimate than actual value. If we use it for a new city or a small city because smaller or newer city is tend, the population tend to grow very rapidly if there is a new town coming in and there is a lot of scope for people coming in. So, it is not only based on the death rate or birth rate, there is lot of your migration will be there.

So, with these kind of, with these setups, the population of such places grow very rapidly and then, arithmetic increase method will not be able to sort of estimate, that the estimates that will be provided will be lower by arithmetic increase method because it considered only a fixed amount of population is going to increase.

So, in this method, the average increase in the population per decade is calculated from the past sensex data and accordingly, the population is estimated. So, let us see an example for this, ok how it is done.

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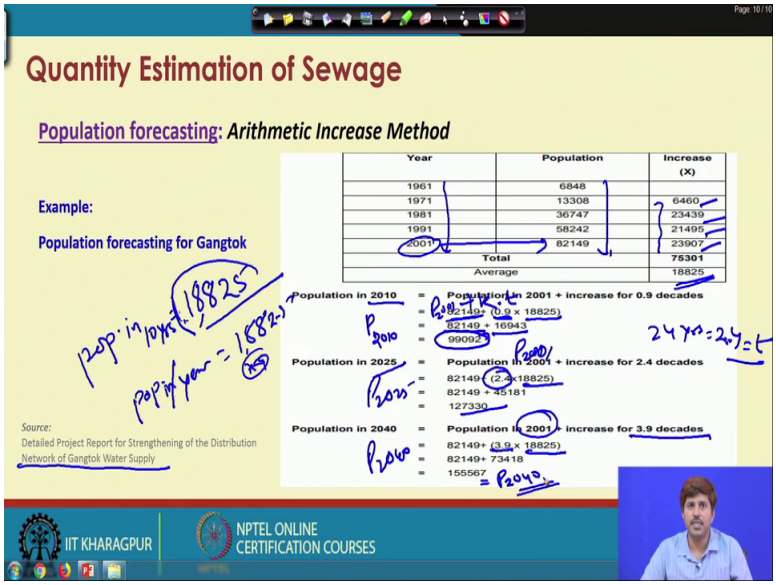

So, this is actually, this is an example from DPR of the strengthening distribution network of Gangtok Water Supply. So, for the purpose of Gangtok water supply system, this estimates were made, ok.

The sensex data out is available for various decades. So, since 1961 till 2001, these are the population. Now, if you see from 61 to 71, the population has turned 13308 from 6848. So, total increase was there of around 6460. Then, from 71 to 81 in next 10 years,

the population has become almost triple of this. So, the total increase was 23000. Now, this was very small cities of population got doubled, but you see here the increase is much larger. Then, further the population increased by 21000 and thereafter population increased by 23000.

So, that way for four different decades if you see, these are the estimates of the population increase and this is the total population increase and now, if you divided by 4, so in 10 years, average population increase in 10 years was obtained as 18825.

So, if we use arithmetic increase method let us say if you want to estimate the population in 2010. So, how many years we are now see the data. We have taken here is of decade. So, 10 years time frame is not 1 year. Here this needs to be clearly seen that the time frame we are working with is actually of 10 years, ok. So, this is the average population increase. The value that you have got 1800 18825 is actually population increase in 10 years, ok. It is not population increase in 1 year.

So, if we want we can basically divide by 10 and get a population increase in 1 year also. That is possible, ok. So, in that case it is going to be 1882.5,, but typically because the population estimation is done for a future year and 10 year or one decade is considered the unit time. So, that is the typical convention. Now, if you see that population by arithmetic increase method, so if you are, if you want to know a population in 2010, you know the population in 2001. So, your P o here becomes 2001.

So, you know that P 2001 is known to you plus what is the average increase into time. So, in 2001 the population was 82,149. So, 82,149 is the value of the population and then, your K is the average increase in 10 years is your 18000. This can be seen over here. It is actually your 18,825. So, this 18,825 is the average increase and what is the time frame since 2001 to 2010, there are 9 years and this is so in decade terms because if we considered as 10 years has 1 unit. So, 9 years is equal to 0.9.

So, we multiply this 0.9 with this alternatively population in population increase in 1 year if we see population increase per year. So, this is going to be 1882.5 and then, you can multiply this by 9 over here. So, either you multiply with 0.9 to 18,825 or 9 to 1882.5, you are going to get to the same figure that is your 16943 and if you add this to 82,149, you get a population estimate of 99,092 for 2010.

Similarly, we can do it for later years. So, for 25, P 2025 will be P 2010, that is your population and then, you have in 2001 and you need to know in 25. So, there is 24 years gap and 24 years is equal to 2.4 decades. So, your t becomes 2.4 that is your t ok. So, 2.4 into the average population will give you 1, 27,330 and similarly, for P 2040 again you have the population known in 2001. So, there are basically 39 years, you want to estimate population. After 39 years, make it 3.9 decades, ok.

So, your t becomes 3.9 here. So, you multiply 18,825 with 3.9 and that gives you a value of your 1, 55,567 as population in 2040. So, that is how the population estimates can be made using the arithmetic increase method which is one of the very simple method, which works based on the principle of average increase is constant.

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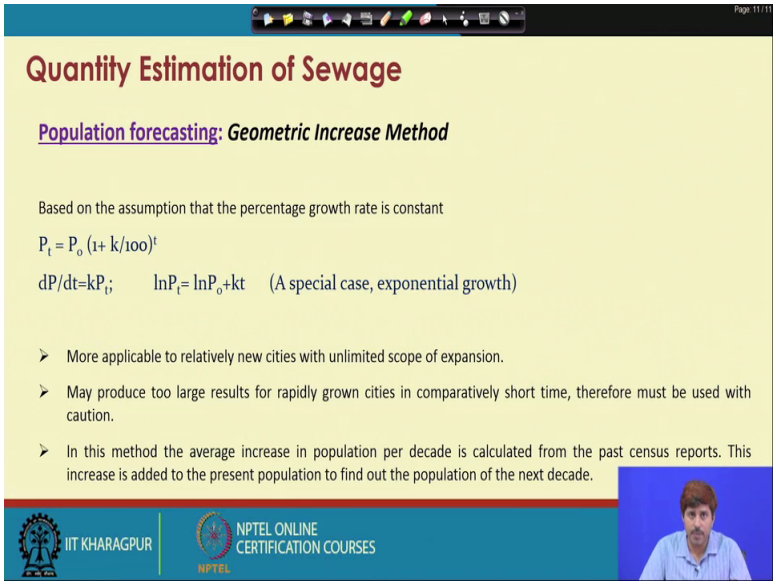

Then, there is Geometric Increase Method which is based on that the percentage growth rate is constant here, the rate or the number of persons increasing per year or the population increasing per is not constant, but the rate at which population increases is constant. So, our rate needs to be estimated and then, typical geometric expansion formula could be applied over here which is population at time t is population at time P 0 plus 1 upon k by 100 to the power t or we can refer is that r by 100 to the power t and exponential growth is actually one of the special cases of this Geometric Increase Method which is typically exponential in growth is not used for human population though, ok.

So, this is a Geometric Increase Method works best for the new cities, ok. When there is an unlimited scope of expansion, the population grows pretty rapidly, may produce very large result for rapidly grown cities in comparatively short time, ok. So, it must be used with the caution, and the typical rate of increase of population is estimated and an average value of that is taken and thereafter, this equation can be used for the estimation of the population.

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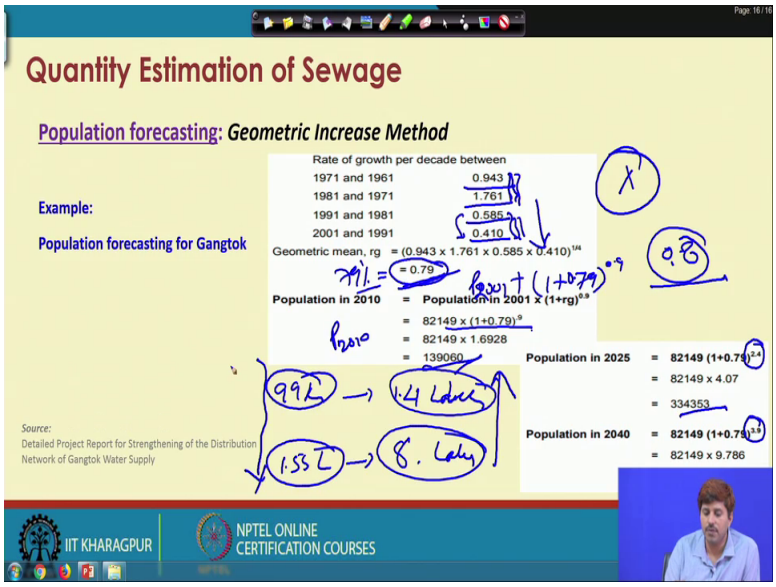

So, it will be cleared from this example. It is the same example ok, the same data that we used earlier we predicted earlier with the Arithmetic Increase Method. Now, if we use Geometric Increase Method for the purpose, so the rate of growth of the population per decade between 71 to 61 was 0.943.

Now, how you can get this rate of rate of decade? If you see the problem earlier, so your increase is here. So, when your initial population was 6,848, this was an increase of 6460, ok.

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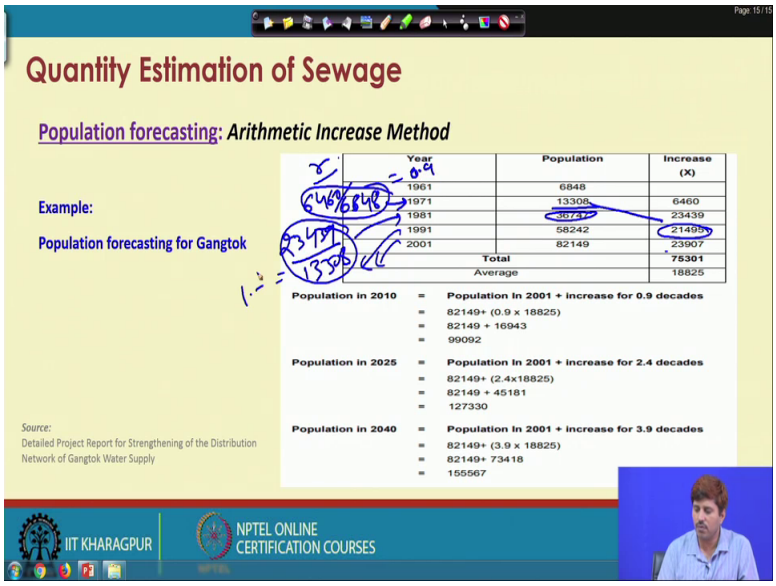

So, your rate of increase if you want to let say if you want to estimate the rate of increase over here, so that is your total increase was 6460 of initial population 6848. So, that becomes your rate of increase for 1. Then for next, your total increase in the population was 23,439. So, 23,439 divided by the population back at that time was 13,308.

So, from 13,308, the population increased the net population that increased to 23,400. So, that becomes another estimate of the rate. Similarly, 21,495 divided by 36,747 will be another rate of estimate and 23,907 divided by your 58,245 will be another rate of estimate for this. So, that way we will get these four different estimates for r and when we want to apply the Geometric Increase Method, we will have to consider like if you see. So, this number is going to be close to 1 point, a little less than 1 actually. So, 0.9 something this is almost around 1.8 or 1.9 something like that, ok.

So, it is one point something. Similarly if you divide this number 21,400, this by 36, so again it is less than 1 and similarly, again 23,907 by 58 so, it is closed loop 0.6 or so. So, we will get 0.9, 1 point something, 1.8 or so. Then, 0.7 or 0.6 something, this kind of estimates we will get and we need to take the average of those estimates here. So, these are those values what we are talking about. So, one was 0.943, one was 1.761, another was 0.585 and the next one was 0.410,. So, these were the rate of growth.

Now, we will take a geometric mean in Arithmetic Increase Method. We take this simple average, but here we are talking about the rate. So, we will take a geometric mean of this.

So, this multiply all four into to the power 1 by 4 will give us rate of increase as 0.79, ok. So, now we can use that formula. So, population in 2010, P 2010 is your P0 which is your P 2001 say plus 1 upon r by 100. So, if it is per in percentage, it is actually equal to 79 percent.

Now, if it is decimal fractions, so it is 0.79. So, that becomes 0.79 to the power time, and time as we discussed for this, its time is 0.9 because we have been working in decades. These rates are estimated for decade, so 0.09. So, this is what we get and this is the estimate of the population. Similarly, for 25 we got this estimate because everything remains same only. The decade changes, ok. It becomes 2.4 and then, for 48 becomes 3.9 and we got this population.

Now, if you compare the results of the Arithmetic Increase Method and Geometric Increase Method, this is very interesting. You will see that in 2010, the Arithmetic Increase Method population was something like 99,000 or so and here you got 1.4 lakhs ok. Then, in 25 it was 1 lakh something, in 2040 it was around 1.55 lakhs and here you have reached to 8 lakhs. So, this the prediction through Arithmetic Increase Method is fairly low as opposed to the prediction through the Geometric Increase Method, ok.

So, that is how we can get very wide range of predictions and we must be very sure that which method to choose from, ok. Now, if you see that rates here have actually been very high. Initially it was 0.9 close to 2 in fact and then, later on the rate has pretty decreased, but if you see it is actually further on decreasing also, but if you see the average or the mean increase rate, it is close to 0.8 which is very high. So, if your existing rate is 0.41, the trend is decreasing, ok. So, in the next decade, your rate will further be lower, however you are using a rate of 0.8 and that is why these exorbitant estimates are coming in, ok.

So, that is probably not a good idea to use Geometric Increase Method for this place, ok. On the other hand, Arithmetic Increase Method the rates if you see were, initially it was very low. So, that lead to a very little number for the prediction whereas, later on the rates were pretty stabilized, but on a higher side as around 23,000 20,000 25,000 in that range. The increase in the population was in that range, but because of 6000 increase in the first decade, our average value was pretty low. So, probably these are the underestimates and these are the overestimates.

So, none of the method may be very workable over here, ok.

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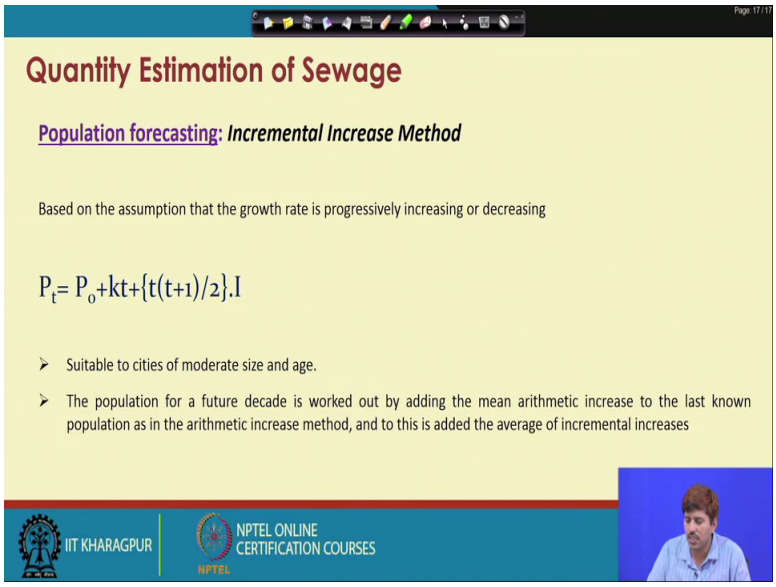

However, this is how these methods are used. Then, there is an Incremental Increase Method which is based on the assumption that growth rate progressively either increases or decreases which as we have seen, ok. So, in the previous example we saw that growth rate was initially very high close to 1 and then we saw close to 2 and thereafter, it actually started decreasing. So, growth rate can increase or can decrease depending on if it is a newer city, new town, growth rate is likely to increase. If it is an older town, growth rate may actually likely to decrease also.

So, there is a possibility of increasing progressive increase or decrease in the growth ate and that is considered in the Incremental Increase Method which is suitable for a moderate sized cities and age.

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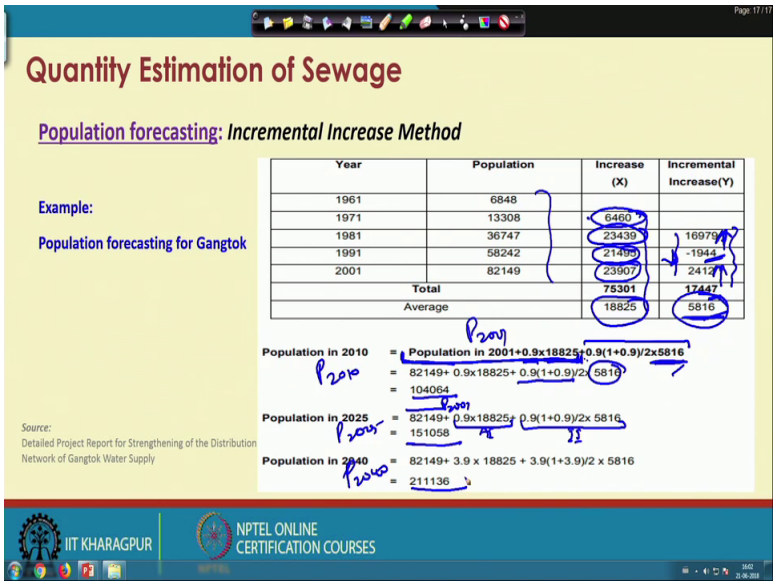

So, let us see through an example how the Incremental Increase Method is done. We will take the same example again, so that it becomes more clear. This is the same data and while estimating Arithmetic Increase Method, we estimated these numbers, ok. Now, if you see the Incremental Increase, so the increase in the first decade was 6,460 while increase in the second decade was 23,439.

So, there was an additional 16,979 increase was there. This becomes our incremental increase. So, close to 17,000 were incremental increase because in our Arithmetic Increase logic in the next decade also population should have increased by 6460 what has increased with a much higher value and there was a close to 17,000 more increase in the population as opposed to the basic Arithmetic Increase Method concept, but when we move to the next decade, you see the population increase by 21493 now.

In the earlier decade, the population increase was 23,439. So, by that logic the population should have increased by the same number, but it increased only 21,000. So, there was a little decrease in this time. So, there is sort of incremental in increase if you see is actually negative as there was a decrease in the population by close to 2000. So, minus 1,944 population. So, population increase was 1,944 less than the previous decade.

Again, when we move to the next decade, we see that population increase was 23,940 and in the previous decade, it was 21,493. So, compared to the previous decade, again the population increase was higher by 24,012 numbers, ok. So, that way if you see that

there is an incremental increase or decrease in the population and our incremental increase, decrease, Incremental Increase Method says that this also needs to be accounted and we can consider this as an, we can get an average value of the incremental increase or decrease and apply to the population.

So, that way we will see that the average value of this is coming out to be around 17,447, right. The total incremental value and the average value per decade is 5,816. So, this says that whatsoever is the average increase over here which is 18,825 is fine, but there is an average incremental increase as well of 6,000 ok. So, if you start from first decade, you should add this number and then, if you start go to the second decade, you should add this number plus this number. So, that way this incremental increase number should also be added and then, the population can be estimated similarly in 2010. So, population in 2001 plus time number of decades, the average increase the arithmetic.

So, up till this point it is actually an Arithmetic Increase Method, ok. So, in Incremental Increase Method, we have an extended term, then incremental increase Arithmetic Increase Method. So, in Arithmetic Increase Method only considered up to this, but Incremental Increase Method further moves ahead and considers one more term due to incremental increase which is t into 1 plus t by 2 into the average incremental increase, right. So, that is how if our average incremental increase is this, so we get this third term over here as 0.9, that is our t in the terms of decade. So, 0.9 into 1 1 plus 0.9 by 2 into incremental increase method,. So, this gives an estimate of 1, 04,064.

Similarly, for 2025 this is our population in 2001, then this is your arithmetic increase component and this is my incremental increase component. So, this gives a population of 151 and then, similarly P 2040 is 2, 11,136. So, now, if you compare this estimate is far more appears far more reasonable. Arithmetic Increase Method predicted lower, the Geometric Increase Method predicted much higher while this Incremental Increase Method predicts a much better numbers that way, and Arithmetic Increase Method often lies between, sorry Incremental Increase Method often lies between Arithmetic Increase Method and Geometric Increase Method. So, this number was some 99,000 in Arithmetic Increase Method which has increased to this. This number was some 1, 55,000 which has increased to 2, 11,000 in Incremental Increase Method.

So, that is how the different methods can be used for the estimation of the population. So, these three are the more common and more popular methods. Of course, there are similarly other methods.

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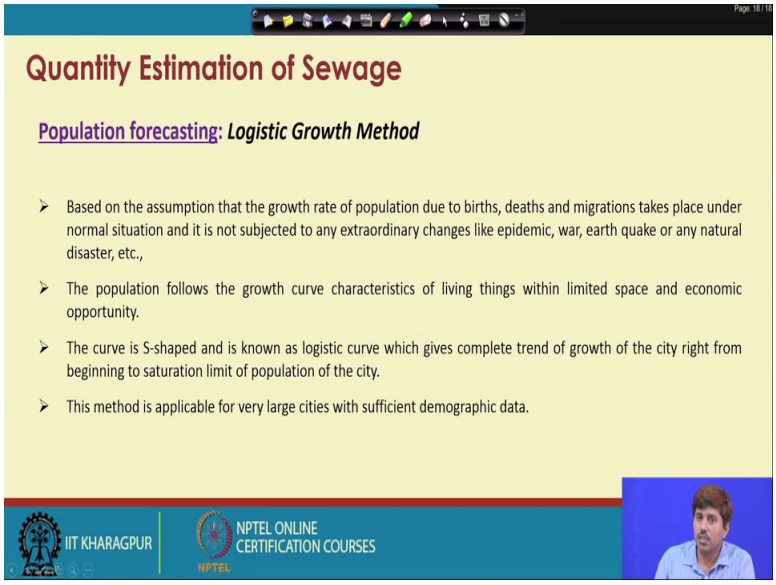

There is this Logistic Growth Method, ok. So, this is based on assumption that population due to birth, death or migrations take place under normal situation and is not sort of subjected to any extraordinary changes like epidemic war, all these things. The concept of logistic growth is that a ecosystem or an environment or a city have limited space and opportunities.

So, if such happens let us say you have, you consider any town for say let us talk about Lucknow. So, population of Lucknow is now say if there is a population 55 lakh for say, ok. Now, if population is increasing, it is fine. How much people can Lucknow accommodate? From 50 lakh, it will be able to, it will increase let say 20 say 70 lakh, 80 lakh, 1 crore, but is it possible that Lucknow can accommodate 50 crore people. It is not possible, right. So, a city has a carrying capacity. It can accommodate a maximum. There is an upper limit of the population that it can accommodate beyond which probably it will not be able to accommodate and the growth takes place according to this carrying capacity.

So, that is what is the logistic growth method. So, it is kind of S-curve in this also known as S-curve method and then, there is a S-shaped curve which sort of signifies the growth

pattern of the city, and this method is applicable for very large city when there is a sufficient demographic data because one need to see how the growth is taking place over the different decades or over the different years. So, as to what happens that when the population approaches carrying capacity, the growth rate reduces. If I have a city which can accommodate say 1 crore people and right now there are only 10 lakh people. So, there are resources available for 1 crore people, there are space available, there are food, water, job available for 1 crore people, but there are only 10 lakh people.

So, there will be a lot of migration and there will be a rapid growth actually, ok. So, that way the city will grow pretty past, but if it can maximum let us say accommodate 1 crore people, what happens when there are already 90 lakhs people already there. So, then because there is most of the resources has been consumed, there is not much resource available, there is not much space available, there is no jobs available as such. So, the growth will be fairly slow, ok. So, initially there growth is pretty rapid and then, it tends to slow as the system reaches near carrying capacity and that is what is called the Logistic Growth Method.

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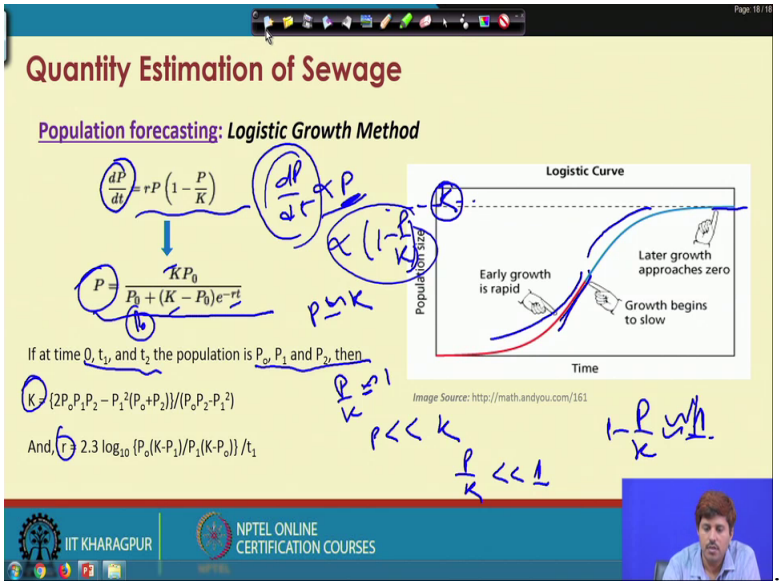

So, it is something like this. You will see that initially the early growth is pretty rapid and then, growth becomes slow down and there is a maximum population size which is typically referred as carrying capacity. So, this carrying capacity is fixed and if population reaches there, it may tends stabilize. So, the further growth is not practical,.

Conceptually it says that the rate of growth of the population dP by dt. So, if you see your Geometric Increase or Exponential Increase Method typically, so your dP by dt is proportional to P, in your Exponential Increase Method. In Logistic Growth Method, there is one more term which control is actually 1 minus P by K and here K is the carrying capacity, ok.

So, as the population approaches K, when P becomes almost equal to K, so this P by K becomes almost equal to 1 and then, 1 minus 1 is almost 0 and then, the change in the population becomes 0. Rate of numerically or mathematically rate of change in the population becomes 0. On the other hand, when P is very small as compared to K as I was giving example that if it can accommodate 1 crore people and there are only let us say 10 lakh people. So, in that case P is 10 lakh, K is 1 crore and P by K becomes 0.9, ok.

So, if P is very small, then K, so P by K is actually very less than 1 and then, 1 minus P by K 1 minus P by K will actually approximately be equal to 1, and if it is equal to 1, so your rate of population almost grows exponentially. So, you will see very rapid increase in there in the population. So, that is the basic model and that is the equation which is used for estimation of parameters, ok. So, if at three different times the population is this, then we can estimate K based on this and r as using these equations and once we know r and K, so the initial population P0 is known to us. So, then you can estimate P after time t using this equation.

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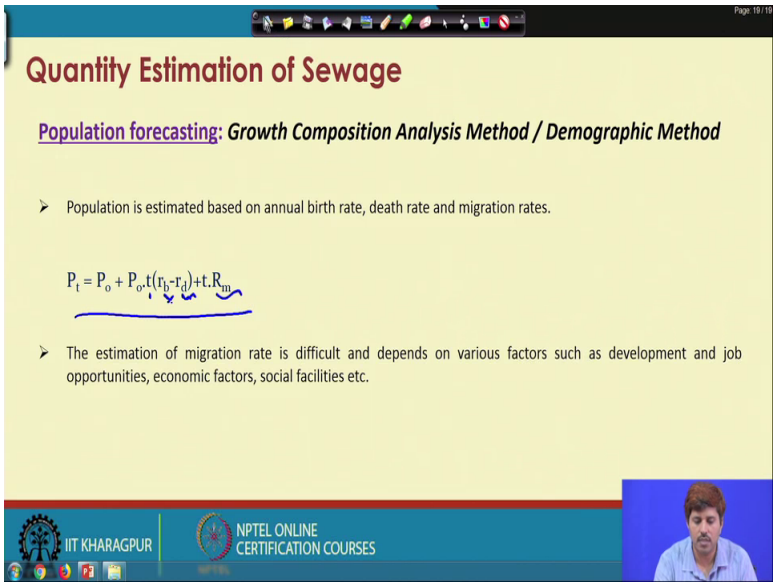

So, that is Logistic Growth Model, one of the method of the population estimation. There are few more methods. There is a Growth Comparison Analysis Method or Demographic Method which is also known as. So, this considers estimation of the birth rate, death rate and migration rate because it says that the population typically changes due to birth, death and migration rates, excluding other factors. So, if we know all these rates, so based on the time decade period what we are using, so rate of birth and rate of death will be dependent on the initial population while rate of migration is independent of that. So, we can use this equation in order to get the population estimation.

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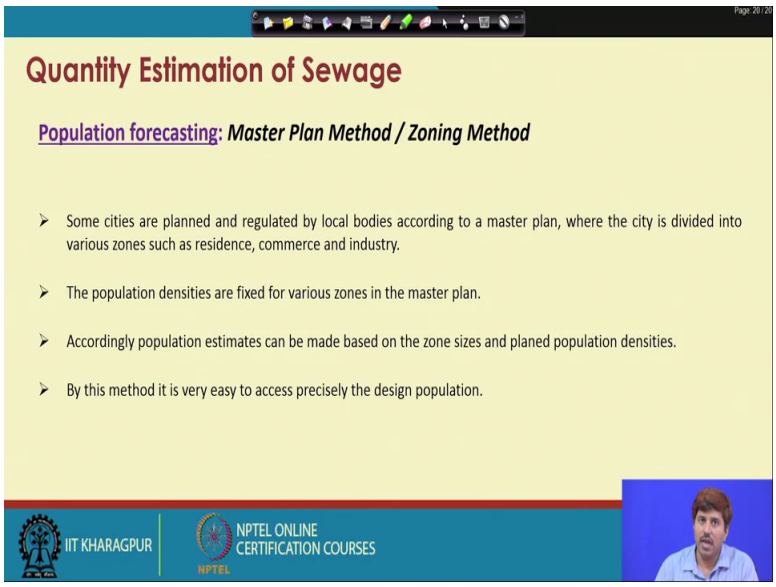

There is a master plan and zoning method which is very widely used for new cities. So, with the cities which are newly being developed in a planned and regulated way by local bodies according to a Fixed Master Plan or according to a zone, so there are zones divide, this is commercial area, this is residential area. We are going to build these many apartments over there, only that many people can accommodate their, ok.

So, if city is divided in the different zones, such as residence, commerce, industry and the population densities are fixed for these different zones based on the masterplan, say that this is my residential area and I want to have let us say 500 people per hectare at max, so then based on the area of that zone, we can have a idea of the possible population when the cities fully established.

So, these cities which are laid according to a master plan, their population is also controlled by the master plan or based on the master plan because beyond that people will not get the permission to build a new house, to build a residence, to get accommodated. So, since these kind of criterias are there that way according to the sort of rules and regulation and the policies of the cities, this population sizes can pretty easily be estimated because as they more or less remains based on the density and which is fixed.

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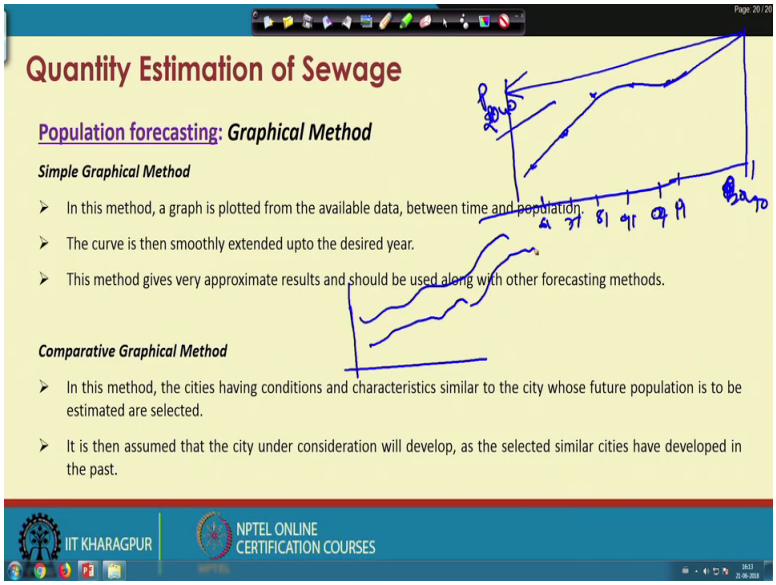

There are Graphicalethods. So, there are Simple Graphical Methods and Comparative Graphical Methods. So, in a Simple Graphical Method, the historic data for a cities population is plotted and that is, then again extended. So, whatsoever curve it is forming, that curve will be extended till the desired year and accordingly the forecast will be done. So far say if I am having this is my set time. So, for say 61 71 81 91 01, so that way 11, if I am having this data, let us say population was here, population was here population was here, population was here. So, kind of a curve is drawn and if I need population here, so I can extend the same curve over here and then, get the idea of the population. If let us say this is 2040, so I can get an idea of the population in 2040. This is called Simple Graphical Method.

There is a Comparative Graphical Method, where the graph is not extended for the same city, but it is actually compared to a similar city where future population is already

estimated, ok. So far say if you are having, if you are trying to extend new this thing in Mumbai zone, or Navi Mumbai side, you have already done some estimation for similar expansion of Delhi NCR. So, both are the equally urban areas, residential system or whatsoever is there.

So, you can use one population prediction. So, if my Delhi NCR population prediction is like this and my Mumbai is going like this, so I can estimate it similar way, extended similar way and find out the population. So, in Comparative Graphical Method, it is compared with the other city, other town.

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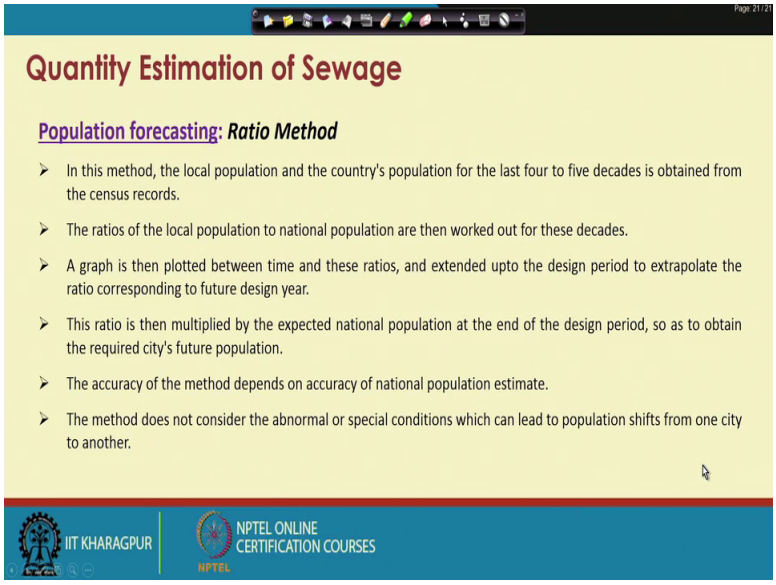

There is a Ratio Method, where the population of a city, the ratio of a population of a city with larger entity either of State or of the Country National population or the State population is obtained from the sensex data, ok. So, for say if I want to forecast the population of Patna, what is the population of Patna? What is the population of total Bihar? What is the population or what is the population of Patna as opposed to the population of total India, ok?

So, the ratio of population of Patna with the population of India will be obtained for 4-5 decades and then, if there is a forecast available for the population of India, I can use the same ratio to obtain the forecast for the population of Patna. If the population of Patna is let us say 0.05 times of the population of India and population of India is predicted to be

1.5 billion in say 2040. So, then in 2040, the population of Patna will be 1.5 billion into 0.5.

So, that way this population is estimated. So, we can say that for reference we can use the countries population, we can use the state population.

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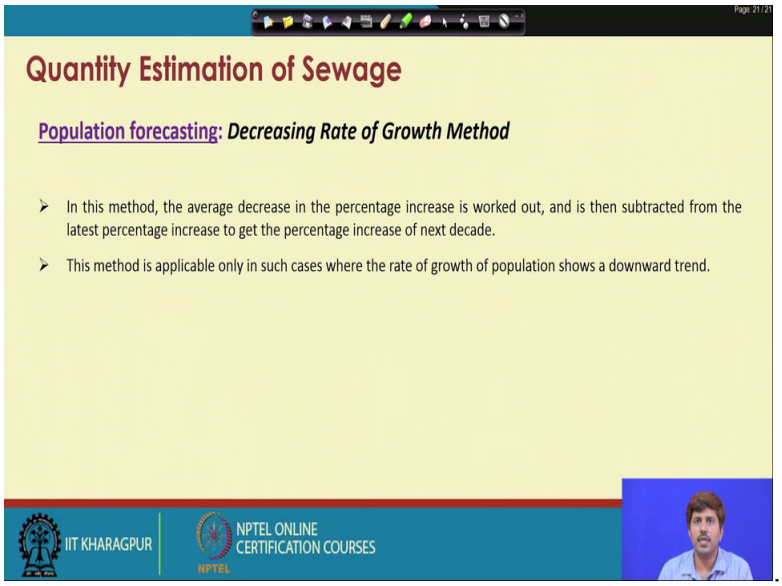

So, those kind of things can be obtained, we can do it through graph, we can do it through simple means. There is a Decreasing Rate of Growth method also. So, this is again the method for the cities where population has the downward trend which can be actually estimated through Incremental Increase Method as well because that also considered positive or negative increment, but if the cities are towards a downward system, so like in case of the average decrease in the percentage, increase is estimated and then, is subtracted from the latest percentage increase to get the percentage increase in the next decade, ok. So, those kind of estimation can be made using the Decreasing Rate of Growth Method. So, these are the major methods for population estimation population forecasting which are used to forecast the population of a city and then, based on that we can design the amenities including the sewerage system.

So, we will end this session here and in the next session, we will further discuss how we like earlier we talked about the design period, now how the population is forecasted for the design period, and we will move towards the next steps for the estimation of the

quantity of the sewer generated. So, this session will end here and see you in the next session.

Thank you.