Water Supply Engineering

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Lecture - 09
Population Forecasting

Welcome back friends. So we have been talking about water demand this week and so far we did discuss about how we what are the various components of the demand and then how we select appropriate per capita demand based on the statistical experiences and the guidelines given by the different agencies. In the last class, we talked about how the demand varies.

So what are the various fluctuations that we need to consider on the scale of monthly variations or seasonal variation what we may refer as and on the scale of daily variations and hourly variations. So all these leads to certain fluctuations and the average demand that we get on a yearly basis is not appropriate for designing the system, because demand is not constant at average demand throughout the year.

It varies, it fluctuates and that is the reason while designing the system we should select appropriate demand. Now when we are just talking about per capita demand, so how much water is consumed by a person or we did discuss earlier the different other types of demand as well. So what could be the institutional demands what could be the industrial demand and firefighting demand.

So the various concepts of demand we discussed so far, but when we eventually go to build a system, go to design a system, we need to get an overall quantity. The per capita demand is good for estimation on knowing purpose but you cannot design a system just based on the per capita demand. You need to know how much total water is to be withdrawn from the source, how much total water is to be treated, how much water is to be supplied through a distribution system.

Now this water has to typically reach the end consumers. So the quantity of water will eventually depend on how many consumers are to be fed with this water. So the per capita demand is one aspect but we must need to know how many persons we are going to feed the supply, water supply through our system and that is why it is quite important and essential to predict or forecast the population that we need to serve.

Why I am using predict the population or forecast the population because systems particularly like infrastructure projects, as such water supply systems are not done for a short span of time. If I am planning a system, I want that system to work for next 20, 25, 30 years or maybe larger period. So for that purpose, we must kind of have an idea of what population we need to serve during that period.

So it is not that population today, if we design a system for today's population, say today's population is x, but we want our system to work for 30 years. So it is not that population will remain constant for 30 years. So as the population increases, the demand will increase and if we have not had appropriate provisions for that, our system might fail.

So this is what we are going to discuss in this class mainly on the estimation of demand and the forecasting of the population. So the concepts that we will be discussing is the concept of design period and design population. We will talk about the various methods of population forecasting.

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Then what are the pros and cons of these methods and what is the suitability of these population forecasting methods.

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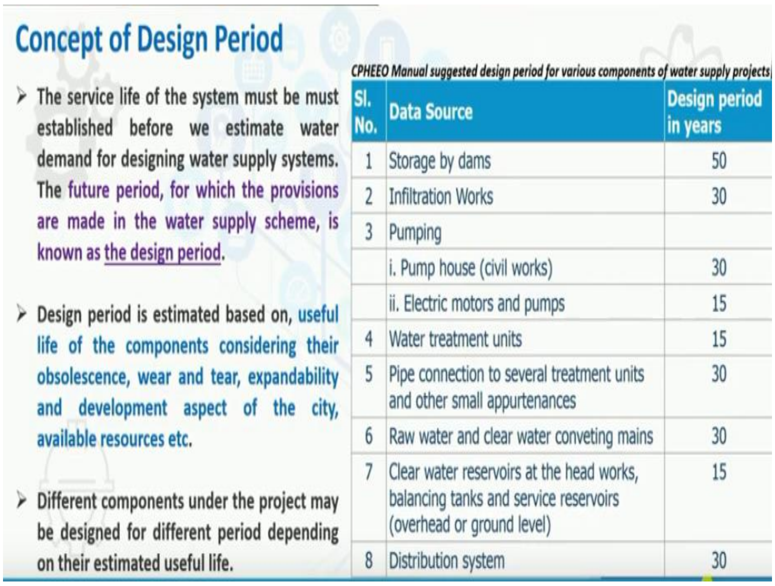

So firstly, before we go to the population forecast we need to know for how many years or how many decades we need to forecast the population and that depends on the design period. So the concept of design period is as such that whatever system we are putting in place, the service life of the system should be established before hand.

So that we can appropriately estimate the demand for designing water supply systems. And as just suggested that these systems are to cater in a future period. So there has to be adequate provisions for considering the requirements of that future period in which the system is to be served. And that future period or the service life of the system is typically known as design period.

So in fact time for which we plan a system or design a system. So design period is estimated based on the useful life of component considering their usual wear and tear, their obsolescence and there are other aspects related to the area or field where we are planning the system. So what is the expendability aspect of the area? What are the development aspects there, and what are the available resources there.

So these are some of the prime factors which governs the design period. Then it is not necessarily that each component of a water supply system will have same design period. Their useful life might be different and that may govern the different design period for different components of the system. Like as per CPHEEO Manual the design period for different components could be different.

Like pumpings typically pump house are designed the civil work is done for 30 years, but the electric motors and pumps design life is considered as 15 years. The water treatment units is typically maybe considered as 15 year, pipe connections for 30 years. If we are planning a storage dam or reservoir big systems like that, so the design period for that may be considered as 50 years okay.

So that way the design period may be different for different components. Importantly for treatment setups, treatment systems design period is taken. Overall treatment plant in fact is designed for larger period say 30 year 25 year that way, but some specific units may be designed for a shorter span of time. The distribution period is generally designed for a 30 year period.

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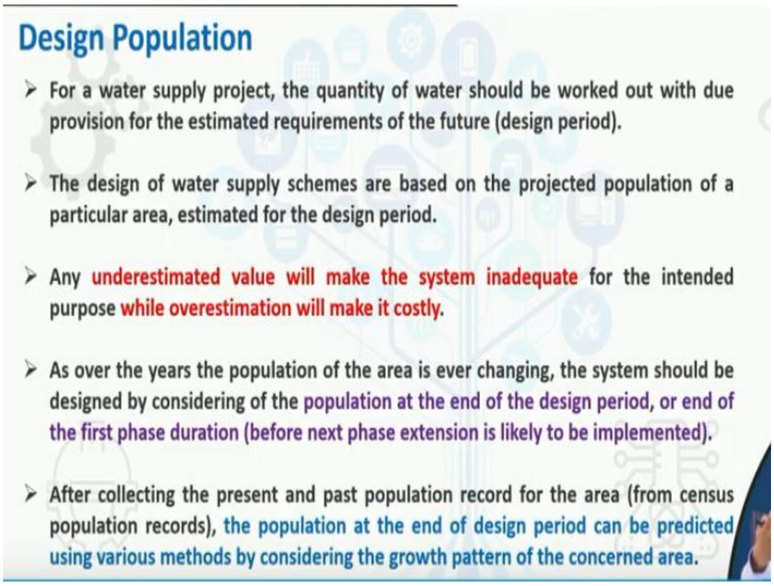

Now this design period gives us an idea of the design population, okay. Idea means it will not give us automatically but we will have to get an idea of the design population based on the design period. So whenever we plan a water supply project, the quantity of water that we should need to withdraw then treat and then supply is to be worked out for the meeting the provisions under the design period, the future period for which our system is supposed to work.

The design of these water supply schemes is that is why based on the projected population, okay. This projected population is typically of a particular area, so estimated for the future period or future design period. It is important like we discussed in the very first class also that demand estimation is important because underestimation or overestimation of demand will lead to problem.

And since our demand estimation will depend on the design population so similarly, underestimation of the design population or overestimation of the design population is also going to lead to certain problems. What problems this could be? The underestimation will kind of give us a lesser demand. So our system is going to remain the inadequate.

And if we go for overestimation so that probably we will put a system for larger capacity which is not actually needed. And that is why the system will not be hydraulically efficient as well as it will turn costly. So as kind of over the years, the population of the area keeps on changing and it is very difficult to precisely estimate the population in a future period.

So that is why there are certain set of methods most of them depends on several assumptions which may or may not hold true. In some case it does work in some case it does not work. So there are several methods based on certain assumptions. And that methods are used to forecast the population at the end of the design period. It is not necessarily always has to be at the end of design period.

In cases our design period is large, many times the development takes place in the phases. So we may need to estimate the population at the end of each phase projected population at the end of each phase also. So we will put a system based on the population either at the end of design period or at the kind of the population at the end of the next phase. In inception case it typically becomes the first phase.

So that is how the things are planned. Now for forecasting the population we need certain data. So the present and past population record of the area is collected from the population census data and that data is then used for extrapolation of the extrapolation **to** in order to get the population of the area that we are actually trying to consider.

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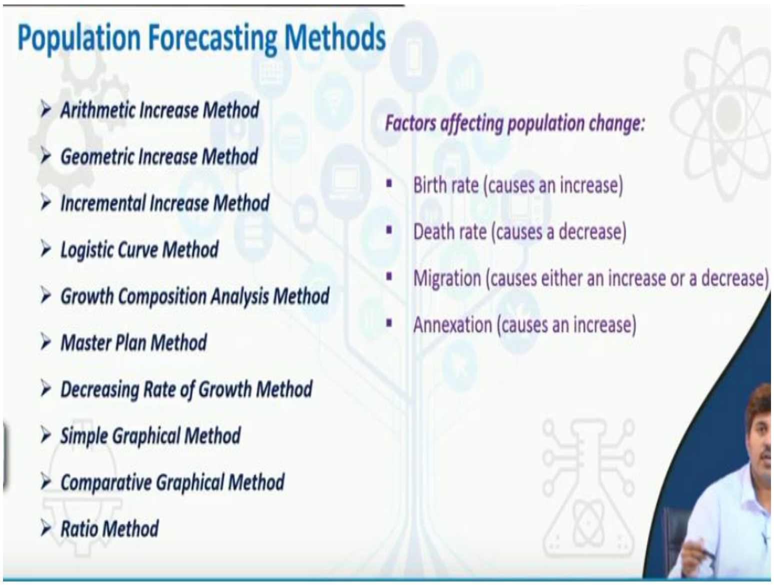

So there are several methods for population forecasting, okay. These are some of the most common methods which are typically used. There is arithmetic increase method which works on certain assumption that population increase is always a constant. Then there is geometric increase method which works on assumption of the percentage population change is constant.

Similarly, there is incremental increase method which works on the population change is not constant but it leads to certain increment and that increment is more or less constant. Then there are various other methods, growth composition based method, master plan method, then there are graphical methods, ratio methods. So there are variety of methods which are typically used.

However, the population of any particular region depends on several factors and the important factors are the birth rate. So basically which leads to increase in the population, the death rate which leads to the decrease in the population, migration this may increase or decrease depending on what kind of migration it is. Is it immigration or emigration.

So if people are moving in the area of the concern the population is going to increase. If people are moving out from the region that we are trying to forecast the population for, the population will decrease. So it may tend to a increase or decrease depending on whether it is immigration or emigration. And then annexation is another cause, which typically leads to increase in the population.

Means in our region of concern the annex another reason. So like in Delhi typically earlier it was just Delhi then we got to know the NCR, similarly in all the cities Mumbai we got a Navi Mumbai and then other areas are keep on adding. So when we do this kind of thing the population of the overall area increases, however density might increase or decrease depending on the population in the area which is being annexed to the original setup.

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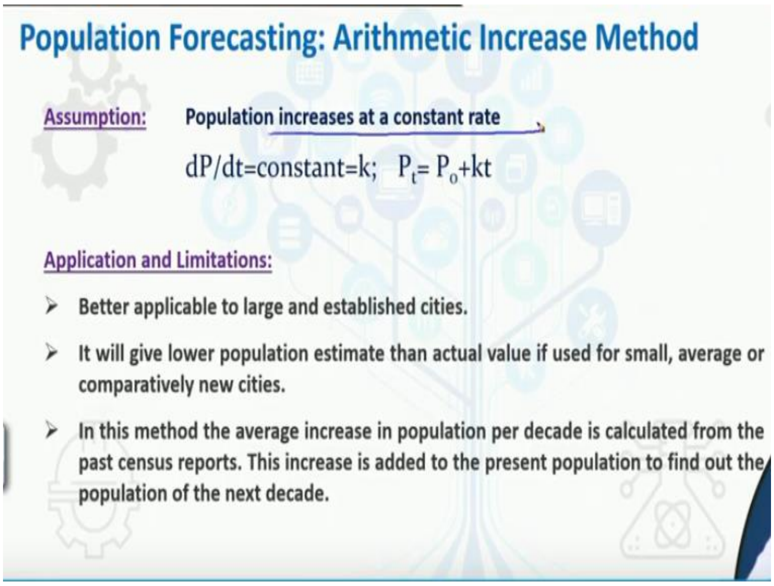

So some of the most common methods which are typically used for population forecasting is one of the very basic method is arithmetic increase method, which works on a assumption that population increase is at a constant rate, okay. So means let us say if population of the city or a town is one lakh next year it become 1.2 lakh. So 20,000 increase is there.

Again next year it will become 1.4 lakhs, next year it will become 1.6 lakhs, 1.8 lakhs. So each year or each time unit it is not necessarily has to be year, generally the population estimations are done in a decades period of 10 year and that is why that is primarily because the census data are available at a 10 years interval okay. So a population is not counted every year.

We have census data available say in 61, 71, 81, 91, 2001, 2011 that way. So similarly, the one decade might be used as a time unit. So the net change in the population over a unit time period whether if we are taking year as a unit time period, so then it is year or if we are taking decade as a time unit then it is a decade. So net change over a time unit is always constant.

So that is the arithmetic increase method. It is better applicable to large and established cities, the cities which are very large which is well established, population does not increase on a kind of exponential rate. So almost constant increment is there on each time unit and that is why this method could be available.

Generally it will give lower population estimate than actual value if used for small or average or comparatively new cities because new cities grows pretty rapid, okay and more so ever like if you are starting with a 500 people in one time unit the increment maybe just 50 or 100 okay. But it is not always remain 100. When the population has become 2000 so it is not that is still the increase will be only 100.

So newer cities grows at a much faster rate, okay. So method is simple.

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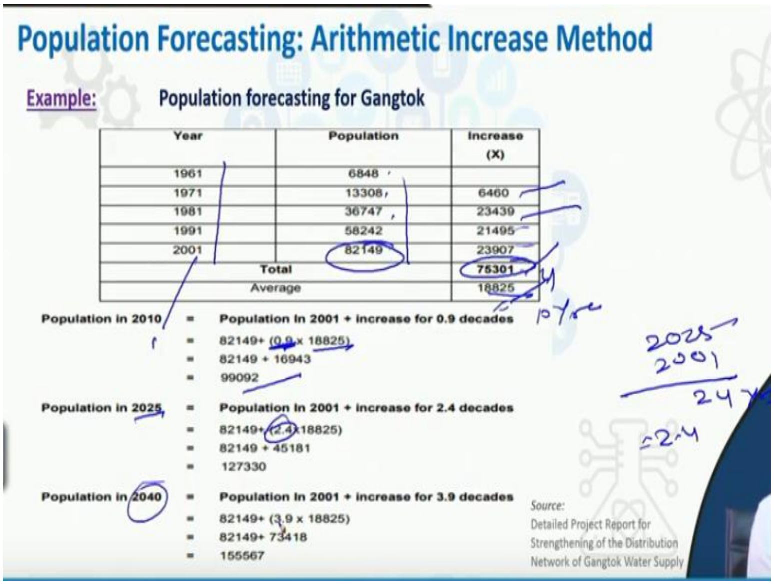

We kind of estimate the average increase in the population and then use the simple arithmetic equation for the estimation. So like this is an example for population forecasting from the Gangtok okay. The data available across different decades are like this from the populations Census. This is the population. So we can see how much increase is there.

So subtract this number from this, we got this increase this number from this we got this increase and that is where we get the increase. This is the total increase over the span of time. And since we have four values, so you divide this by four, you get the average increase, and then population let us say you want to estimate the population in 2010. So basically 9 year means, this average is per decade per 10 years.

As you see the change in the population is over a period of 10 years. So then when you are trying to estimate in 2010 so that is 9 year that means 0.9 decade. So your time units become 0.9 and the average increase you multiply this with time and add it to the last known population. So you get the number over here. Similarly, for 2025 your time gap would be you are talking about 2025 the last data available is 2001.

So that means 24 years which is actually 2.4 decades. So this becomes 2.4 and for 2040 similarly, this becomes 3.9 So it is a simple method okay. No complicated calculations are there.

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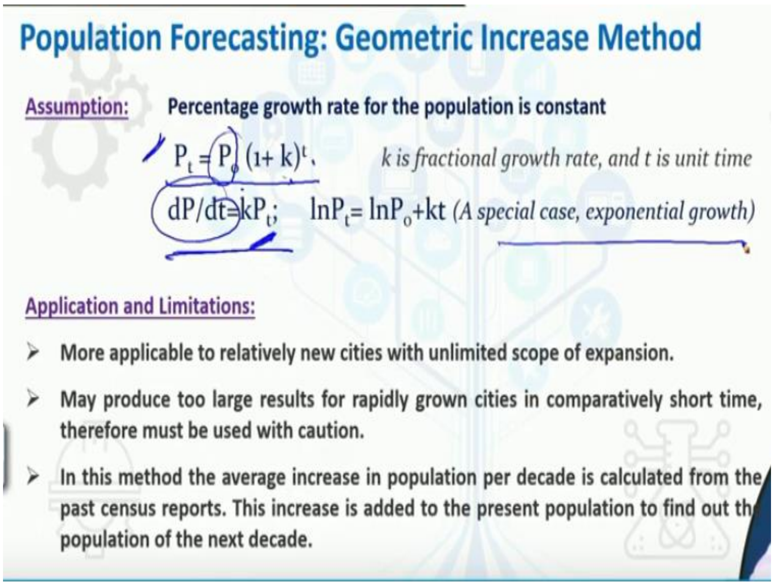

Then there is geometric increase method which works on a concept that percentage growth rate for the population is constant, okay. So percentage or fractional growth rate we can take anything if you want to take percentage growth rate we have to like use in terms of percentage and then eventually divide with 100 to get the fractional growth rate or it can be estimated in terms of fractions only, okay.

So this typically follows a geometric equation. So population at any time t will actually be initial population which is known to us into 1 plus the rate of growth into t, the time period whichever we are taking. This works very well for the new cities with unlimited scope of expansion, okay because it kind of follows exponential growth.

In fact, this model is derived basically from this concept that rate of change of the population is proportional to the population which is exponential growth model and it is kind of a special case of the exponential growth. And that is why works very well for newer cities with unlimited scope of expansion. It may produce large result for rapidly growing cities in comparatively short time.

So that has to be kind of considered okay. For estimation purpose, the average growth rate, percentage growth rate is estimated.

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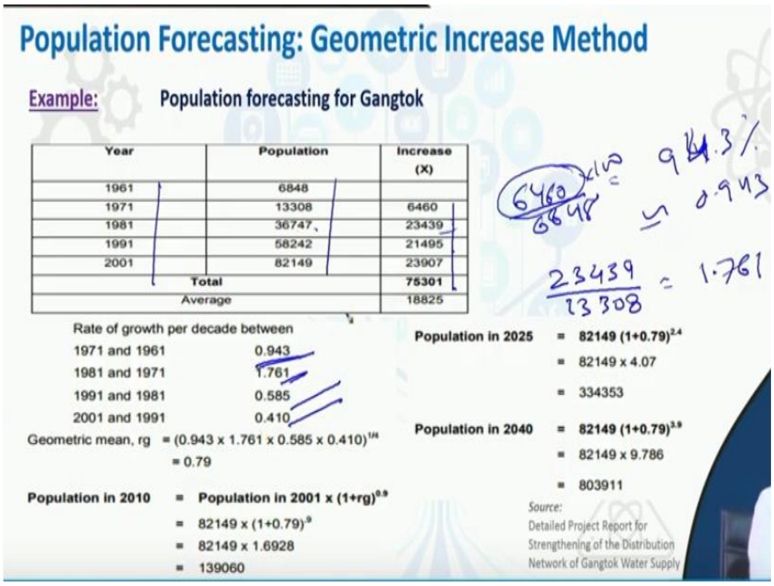

Average means not standard average or mean. It is the geometric mean which is estimated. So for the same example of the Gangtok city, this is the population data we had for different years. So this was the increase. Now if you see the rate of growth per decade between, so the population increase was 6460. From this much population increased.

So this is net increase and the baseline population was 6848 at the previous decade. So the percentage increase is this much, means in 200 if you say. So almost like that number comes to be 94.3%. So this is 94.3% or we can say 0.943 is the growth rate. So similarly, we can get the growth rate over here for next decade growth rate. Then we see that increase is 23,439.

So 23,439 is the increase and this number has increased from a base value of 13,308. So that way we can see that this number comes out to be 1.761 okay. So that is the growth rate or if we multiply it with 100, so we get 176% growth over here, okay. Similarly, when we move to the next decade, so the growth is 21495 as opposed to a initial population of 36747.

So the growth becomes 0.584 and then in the next decade it becomes 0.410. The geometric mean is to be estimated so we multiply all these numbers, all the four numbers we multiply and take fourth root of this. So we get a growth rate of 0.79. The problem of using geometric mean method for such system that we may see that in a latest scale, the growth is actually reducing, and it is barely around 0.4.

But we will be using 0.8 growth rate which is almost 80% increase in the population over a next decade, which is actually too high. So that is how basically done. For estimation purpose, the last known population is known to us. So we take that last known population and multiply it with 1 plus growth rate what we have got. So 0.059 into to the power the number of time units.

So in this case, it is a decade because we have estimated it for a decade. So decade as we discussed, it will be 0.9, 2.4 and 3.9. So 1 plus 0.79 to the power 2.4 for 2025 and 0.9 for 2010. So this will give us the population forecasting okay predictions. Now it is interesting to see that the method has forecasted a population close to 804000 in 2040 whereas as the arithmetic increase method did that just 1.5 or 1.6 lakhs.

So that is the difference that could be the scale of difference between a geometric mean method and arithmetic increase method.

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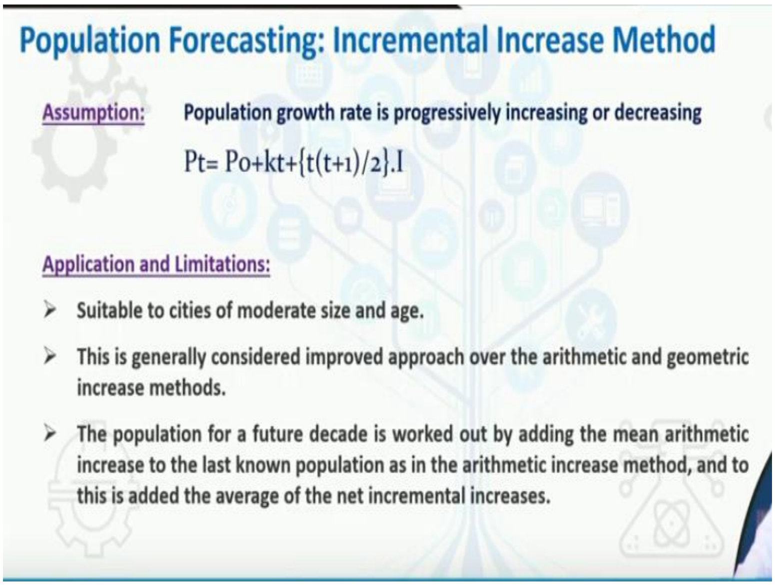

Another popular method is incremental increase method which is basically considers that increase is not constant but it is progressively increasing or decreasing, okay. So population the net increment in the population change is estimated. This is suitable for moderate sized cities and it kind of considers an improved approach over both the methods for moderate type of cities okay.

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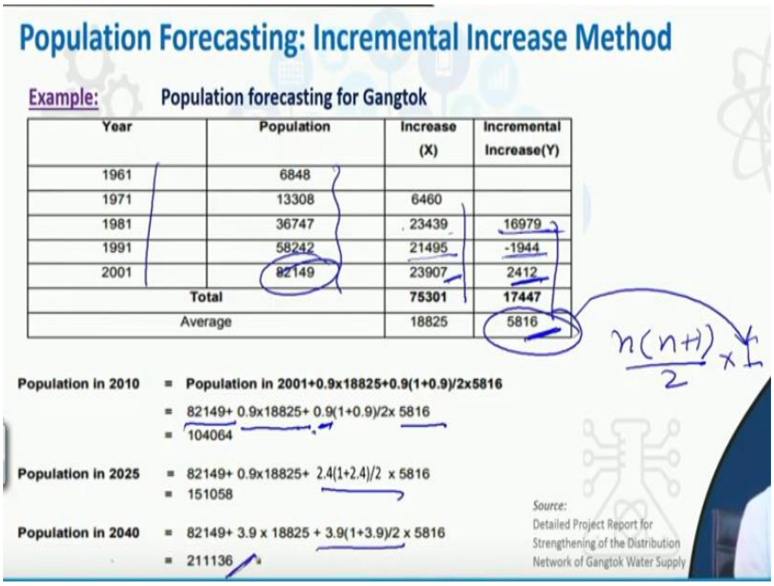

So with the same example we can see that we had a population data for these many years. So this was the increase. Now this was the incremental increase. So like in one decade the increase was 64, next decade increase was this. So what was the incremental increase? If we subtract this number from this, so we get this much was the incremental increase which was positive.

While next decade the population increased only 21,000 as opposed to the earlier increase 23,000. So in fact, there was a close to minus 2000 change which is in a negative side, it did not grow to that much. Again next decade earlier decade it grew to 21 this decade it grew to 23,000 around 24,000. So net increment was 24. So we add these and take an average value of this increment and then use this standard formula.

So the population on the earlier known time, so let us say this population that is known to us and then it is actually similar to the arithmetic increase method. So net increase as simple to arithmetic increase method. This additional incremental increase we have another term which is n (n+1) by 2 into the increment, which is actually increasing. So for 2010 we have 0.9 time unit as the earlier cases.

So 0.9 into 1 plus 0.9 by 2 into the incremental increase. For 2025 it is 2.4 and for 2040 it is 3.9. So the arithmetic increase method was giving a population forecast in 2040 as 1.55 lakhs. The geometric increase method was giving close to 8 lakhs whereas incremental increase method gives close to 2.1 lakhs, okay. So that is how kind of different results we may get.

And we have to be judicious enough to see which method we want to use. And that depends on the past data that we have. If you see that actually, it is constant increase, you can go for automatic increase method. That was not the case here, the increase was actually not constant, it is increasing from 6, 23, 21, 23. In fact, in a later it becomes more or less constant.

So that is why the increment is not that high and even incremental increase methods are more close to the arithmetic increase method as opposed to geometric increase method. Geometric increase methods such as that the percentage growth rate percentage growth rate, as we discussed, that it is not that high, it dropped from 1.8 to say around 0.4 only.

And the average value of the incremental growth rate of the geometric growth rate was also very high leads to the highly overestimation of the population.

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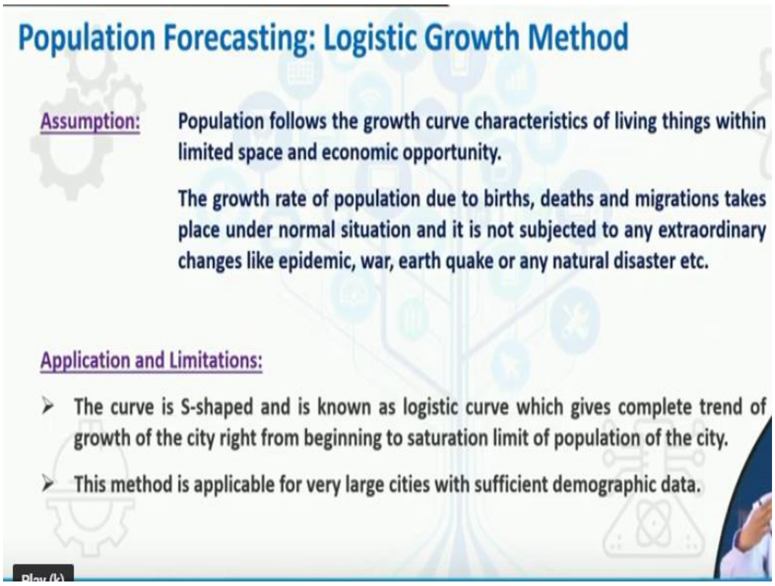

This is the logistic growth method, which works on a concept of that there is actually the capacity, carrying capacity of a city or town and it can only accommodate that much of population, okay. So that is the logistic behind this logistic growth method. It typically gives a kind of S-shaped curve which is known as logistic curve and it gives a complete trend of the growth of the population from the beginning to the saturation limit of the population of the city.

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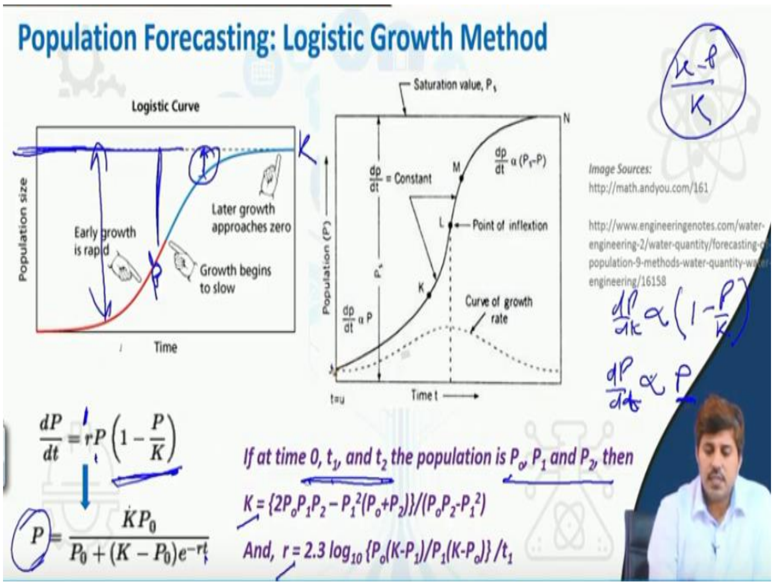

This method can be applied when we have sufficiently large city with the sufficient demographic data like it considers like in exponential growth rate we consider that rate of change of population is per unit time is proportional to the existing population whereas that will lead us to exponential growth, but this method does not only consider that.

It also consider that, that rate of change of the population growth is also dependent on the carrying capacity of the system or what is the deficiency from the carrying capacity. So this model suggests that population whether you start from anywhere cannot exceed this number. So maximum population the city can attain is this, okay. And after this the growth becomes in fact zero.

So that is how the maximum growth you can achieve. Now, if you start from a place say here, the deficiency is quite high. So rate of population change will depend on this deficiency. If you start from this place, so only few number of people can be accommodated and that is why the rate of growth will also reduce. So rate of growth does not only depend on P, it also depend on 1 minus P by K where K is the carrying capacity.

So K is this population and P is abruptly population at any point of time, right. Now the idea is that the K - P will actually give you the deficiency. So or if you divide it with the K it will give you the relative deficiency. So it is the same number and population is also proportional to that. So when we mix them, we get dP by dt is equal to P into 1 minus P and some proportionality constant r.

And this is the typical population that comes from using this method and we need at least three data points. So initial time t 1 and t 2 if we know the population P 0, P 1 and P 2, then we can estimate K like this r like this and use the K and r here in order to get the population, okay. So that is how the logistic growth method is used, okay. It is typically in the early stages.

This nature of the curve is S-shape. And that is why it is known as S curve. The early stage the growth is very rapid and then there would be a point of inflation from which beyond which it will actually the rate of change of the population or growth rate of the population will reduce. So that is the logistic growth method.

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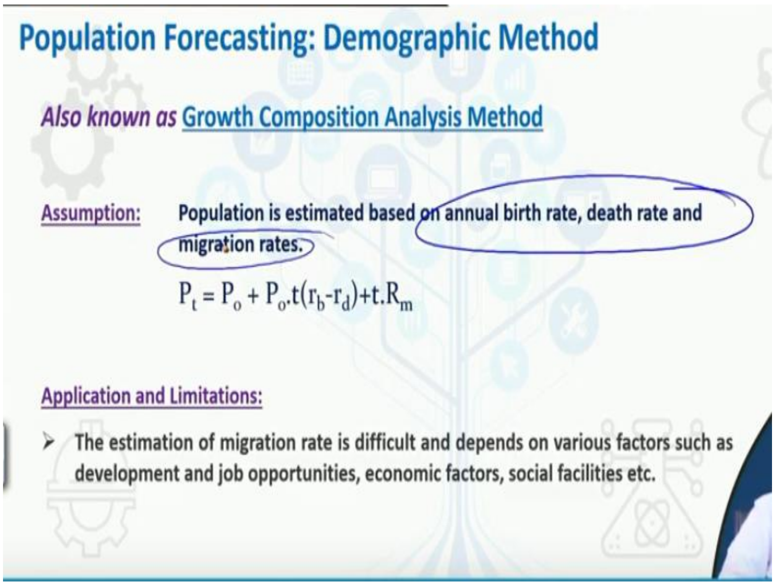

Then there are a few more methods. There is a growth composition analysis method, which says that, we need to get the birth rate death rate and migration rate and using those rates we can estimate the population. So the existing population plus we apply the death rate and birth rate and migration rate within the given time frame to the population and we get the number.

So this can be quite accurate, but the problem is that it is very difficult to get these rates. It is very difficult to get the death rate, birth rate and migration rate and for the time being death rate, birth rate can still be estimated because the municipalities holds the record of deaths and birth, but the rate of migration is extremely difficult to get okay.

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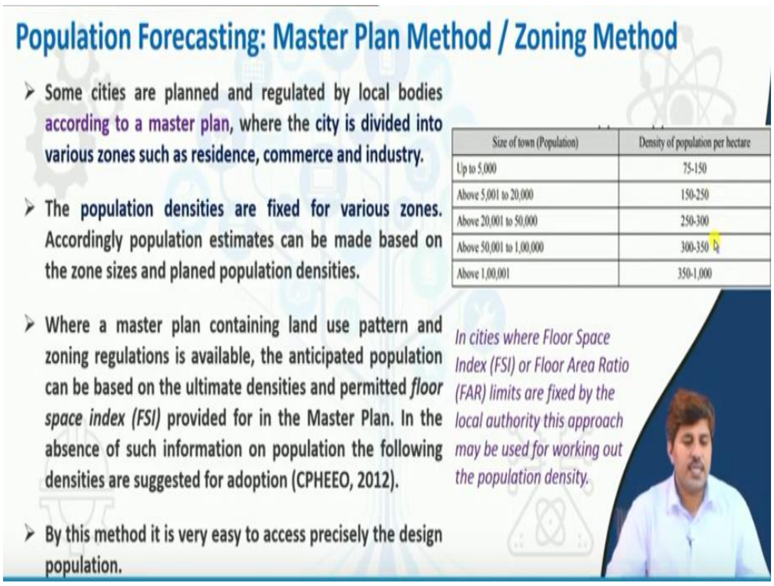

Then there are a master plan and zoning method. So this is this is a method applicable to these cities which are being developed under certain type of master plan okay. And this is by far the most accurate method for these kind of cities. So what happens when the master plan is built, there are different zones built and the population densities under the different zones are kind of kept constant.

So it is planned that okay this is going to be my industrial sector and the population density in this sector is going to be around this. This is going to be the residential sector. These many flats are going to be built. So we will allow these many families to come and stay in here. So all those things are fixed and it is done based on a master plan.

So population densities are fixed for various zones and accordingly we can get the population estimate, because if it is being done under master plan so abrupt growth is not permitted. It is not that anyone can come and settle in there. So those aspects are not there and that is why the population estimates are quite accurate. So it is very easy to kind of assess precisely the design population in these cases.

If the densities are not fixed, the manual recommends certain densities like depending on the size of the population and density of the population per hectare, which can be used as per the manual.

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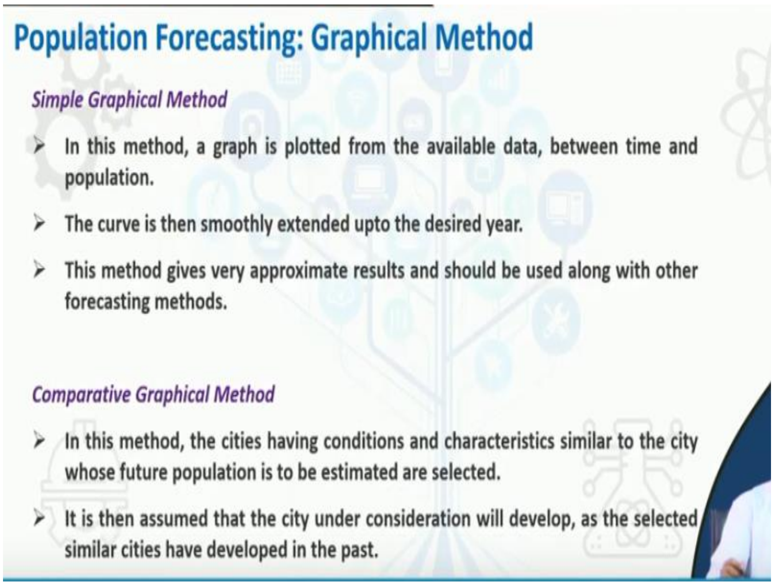

Then there are graphical methods. Under this we have a simple graphical method and comparative graphical method. So graphical methods are based on extrapolation. So like in the arithmetic increase, geometric increase also we do extrapolate following a fixed equation. So arithmetic increase a constant equation, geometric increase a kind of geometric equation or simplified exponential equation.

Here in graphical method, we do not follow any such specific guideline. Whatever is the trajectory of the past data we just simply extend it. So in simple graphical method a graph will be plotted between the available data in time and population and then it is smoothly extended to the desired year. A comparative graphical method is cities chosen which has grown in a similar fashion.

And whose future population kind of is known to us or has been estimated earlier. And then the similar comparative graph is extended and we get the population.

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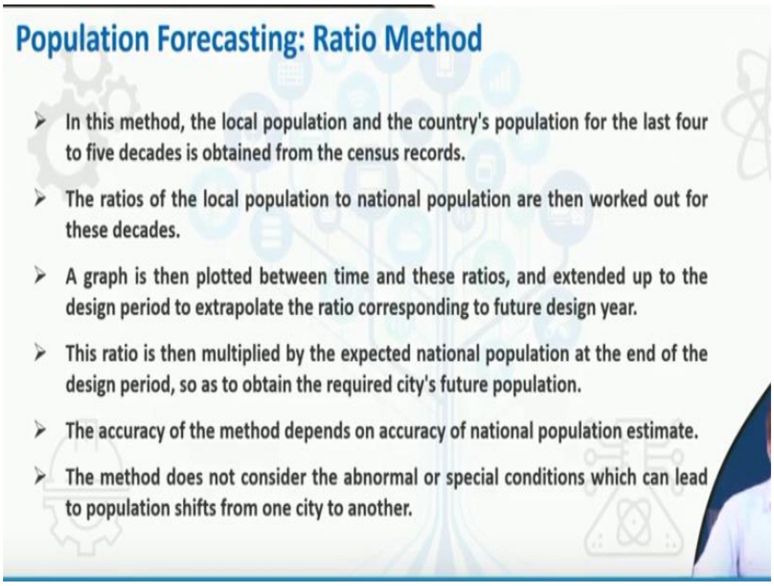

Then ratio method is again of a similar nature. So we in ratio method we take the ratio of the population of a place from where we need to forecast the population. So let us say we want to forecast the population for a city of Lucknow. So what is the population ratio of the city of Lucknow versus a larger territory? Generally, let us say National population can be taken.

So the ratio of the population of Lucknow to the population of India or to the population of the entire UP and that ratio is worked out over a period and then the kind of the ratio, average ratio and those kind of thing can be determined. And since national population forecast is available, so let us say if we use this ratio and we know that what is the National population forecast for 2015 or 2040 so and we know the ratio so we can get the population forecast of the Lucknow city using the ratio, okay. So that is one simple method.

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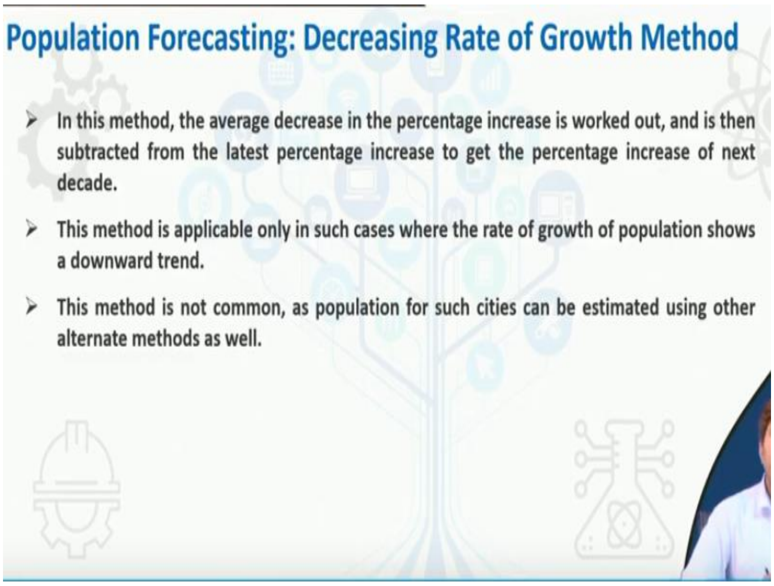

It also does not consider abnormal or special conditions, disasters and those kind of thing. There is a decreasing rate of growth method. This is the method where the, it is believed that the percentage increase in the population is decreasing, okay. So it is not constant as in the case of geometric increase method we considered.

So we determine that decrease in the percentage increase and then subtract that from the latest percentage increase to get the percentage increase for the next decade. So like the Gangtok example we are seeing, so percentage, average percentage increase was very high and the percentage increase was decreasing subsequently. So probably this kind of method can be more suitable instead of the geometric increase method for those places.

However, this can be applied only in such cases where the rate of growth of the population shows a downward trend and there are other methods available for such cities, and that is why this decreasing rate of growth method is very rarely used. So these were some of the method for the population forecasting, which gives us the population forecast.

And then this forecasted population can be further used for estimation of the total capacities and the design kind of design capacity of the various unit and system or overall the total demand that needs to be met from the supply system. So how do we do that we will discuss in the last class of this week, okay and thank you for joining and see you in the next class.