Urban Utilities Planning: Water Supply, Sanitation and Drainage
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Module – 02
Urban Water Supply
Lecture – 06
Water Demand Prediction and Management

Welcome back. In module 2, we will cover Urban Water Supply and in lecture 6, we will look into Water Demand Prediction and Management.

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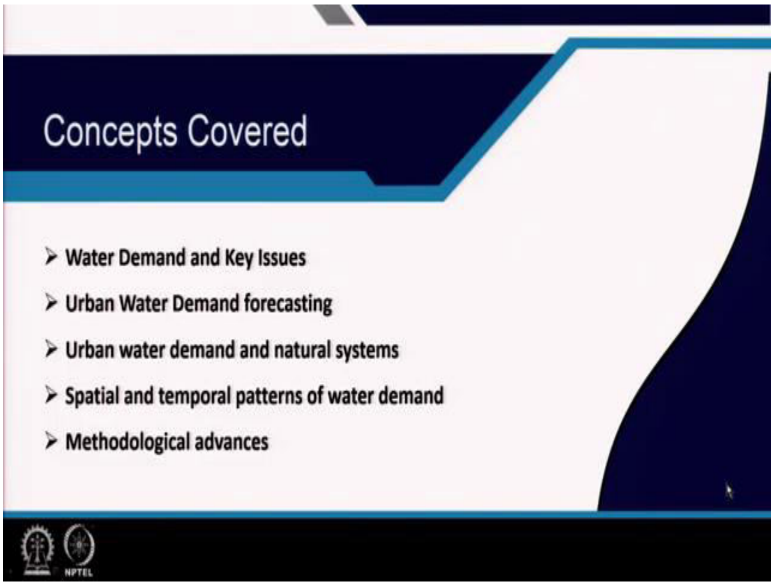

The different concepts that would be covered in this lecture are water demand and key issues, urban water demand forecasting, urban water demand and natural systems, spatial and temporal patterns of water demand and some methodological advances.

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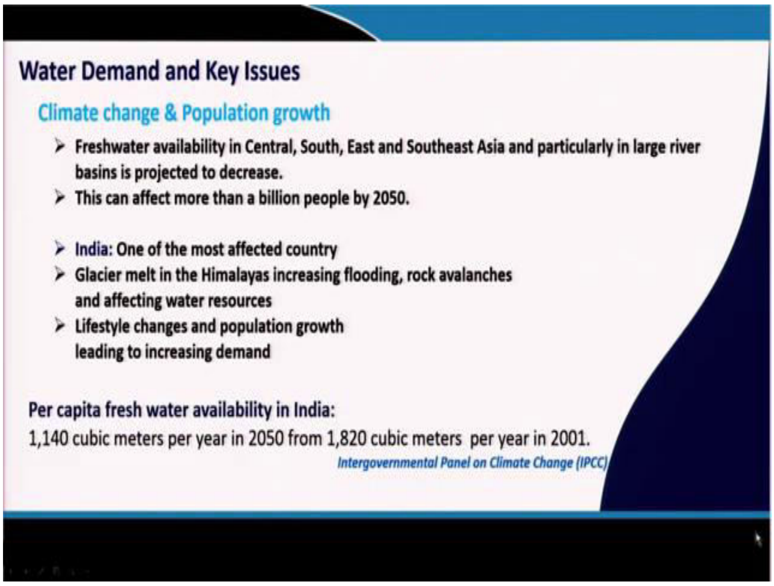

Water demand and Key Issues

We discuss the different issues that plague water supply in general and also estimation of water demand. Climate change and population growth are the two key issues that are posing the biggest concerns for all the scientists as well as urban planners. And as a result of climate change, we are likely to see billions of people being affected.

For example, freshwater availability in Central and Southeast Asia and particularly in the larger river basins are projected to decrease by 2050 and it is going to affect around a billion people.

As India is one of the tropical countries where we have a lot of glacier fed rivers, it is going to be one of the most affected countries. In a recent event in the Rishi Ganga river, flood resulting from melting of glaciers damaged the dam and bridges and led to a lot of casualties.

Thus, glacier melt in Himalayas is increasing because of climate change and because of this melting of glaciers, there is going to be increase in flooding and rock avalanches. It is also going to affect the water resources because if we cannot trap the water in our dams, we would not be able to use it.

In addition to climate change, the other bigger change is, lifestyle change and population growth. Particularly in India, we are going through lot of economic changes resulting in lifestyle change and population growth thus increasing the demand of water in urban areas.

Water Risk

IPCC (Intergovernmental Panel on Climate Change) estimates that the per capita freshwater availability in India is going to reduce drastically to around 1140 cubic meters per year in 2050 compared to 1820 cubic meters per year in the year 2001. It is a drastic reduction and our government is extremely concerned about this.

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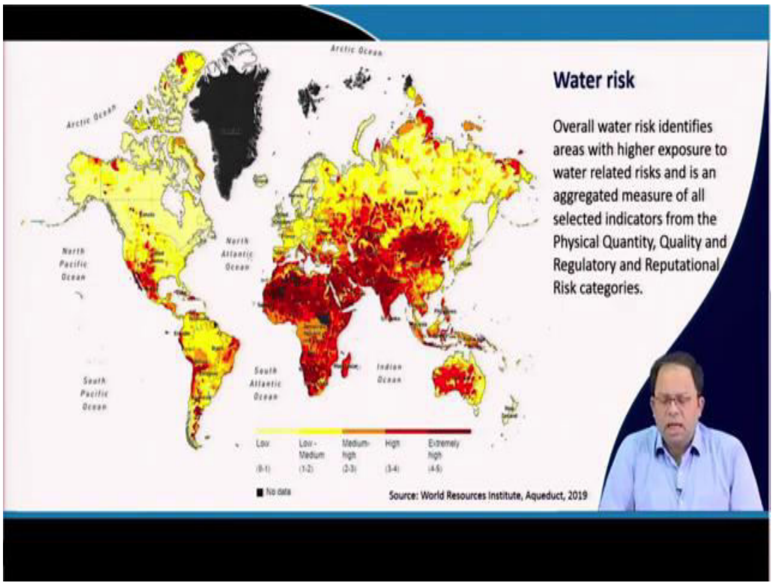

This map that you see is the water risk map, prepared by the World Resource Institute. It displays the different kind of risk associated with the physical quantity of water available and the different regulatory and the reputational risk categories.

For example, ability of the institutions in managing water plays a role in determining which are the riskiest areas in the world. And as you can see large parts of Africa and Asia are at very high-risk category and particularly, India is at severe risk category. Entire India is very dark red which is extremely high and we need to be cautious.

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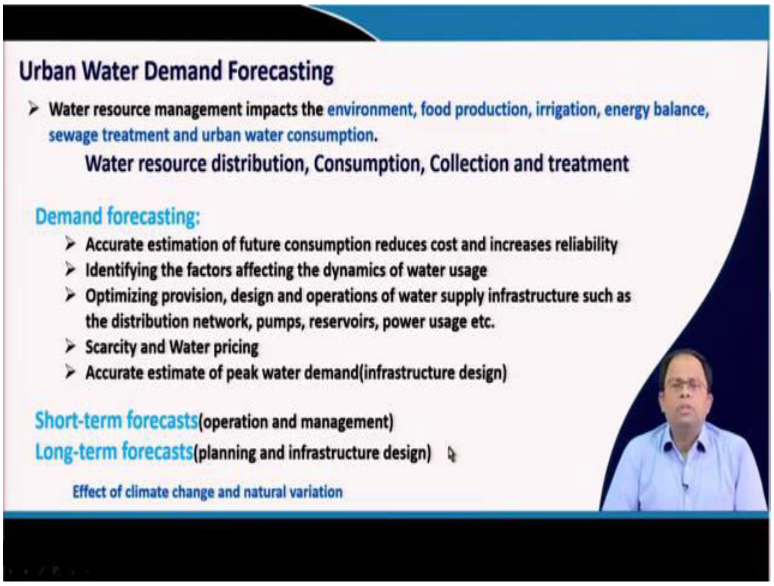

Urban Water Demand Forecasting

The first thing that we need to do is to understand how much water is required in the future and for that, we have to conduct urban water demand forecasting. Urban water demand is all about water resource management. This involves the overall water that is available in a particular area or a particular country. Water is a resource which has to be efficiently managed, failure of which will lead to sever consequences. It will impact the environment, food production, irrigation, energy balance and so on. For example, along a particular river using dams we can trap water and use the water for production of energy, irrigation and urban water consumption. All these are affected if we do not manage our water properly.

Water resource distribution includes the collection, distribution and the consumption part and finally, once it is consumed, the wastewater is collected and then it is treated and may be reused. So, the entire chain is actually being affected if we do not do proper water resource management.

The first thing is to estimate the future consumption of water and if we can do that, it reduces the cost and increases the reliability. For example, if we do not estimate the demand correctly, we may end up with wrong infrastructure which will need to be modified in future thus increasing cost. If we know exactly how much water is going to be available at certain time periods, at a certain year or during certain seasons, we can use the data to plan for the gaps or deficit.

We can then identify which are the factors which are affecting the dynamics of water usage and can introduce certain policies to bring about change in these factors so that it will reduce water usage.

Estimating future consumption helps in optimizing provision, design and operations of water supply infrastructure such as the distribution network, pumps, reservoirs, power usage and so on. Thus, we design the entire water supply network starting from the pipelines that takes the water from the treatment plant to the overhead reservoirs and then to the different buildings, the pumps that are required in the system to pump water, the storage reservoirs, and the power required to run all these have to be planned accordingly. We have to determine the size of pipelines, horsepower of pump and optimize the same. If we know the exact amount of water that needs to be supplied based on availability, we would be able to design the system for an urban area in a much better way. As we have already discussed, water is gradually getting scarce and scarce resources commands larger price. This is going to be a big issue in future.Finally, accurate estimate of peak water demand is required. Because the infrastructure, the pipe networks are all designed based on the peak water demand So, these are the different reasons why we need to do proper forecasting of demand of water for urban areas.

Types of forecasts

There are two kinds of forecast, one is the short-term forecast and the other is a long-term forecast. Short-term forecast is usually used for operation and management whereas, long-term forecasts are used for planning and infrastructure design. Long-term forecasts for the next 20 – 30 years are suitable for infrastructure planning because average life of pipes and other infrastructure varies from 20 to 30 years.

When we design infrastructure which would be there for 30 years, we have to know what kind of demand would be there 30 years down the line whereas, short-term forecast are mostly for operation and management like demand fluctuations during different time periods and so on.

In addition to this forecast, we also need to understand the variability in the demand. That means, mainly because of climate change, there are certain unpredictability and certain events will happen which we cannot predict.

Apart from this, we have the natural variation. Some of these variance is because of the natural cycles as there is higher rain fall, lower rainfall in some years while some of it is because of climate change which have to be understand.

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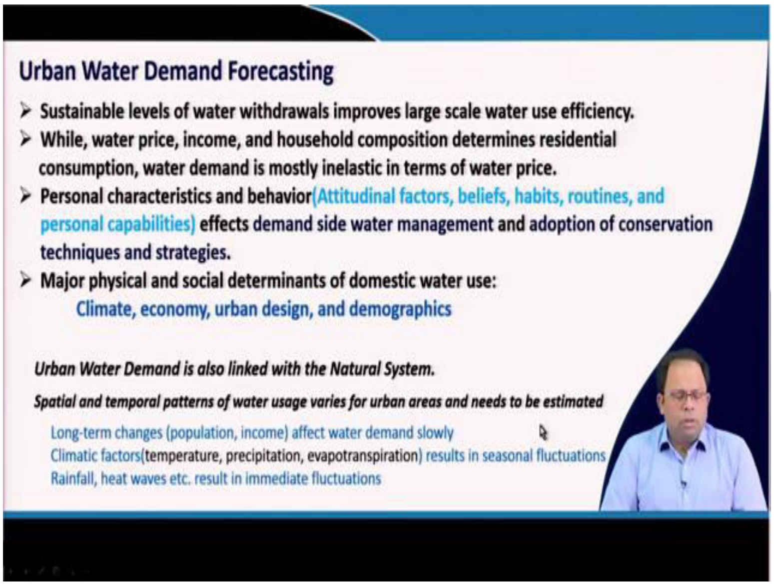

We need to maintain sustainable levels of water withdrawals. Water extraction should be such that we do not exhaust it completely. If we cannot control this, it will lead to other problems. This will be discussed in subsequent lectures. Ideally, if we can control it, then we can efficiently use and reuse and continue extracting in a sustainable manner.

While water price, income and household composition determine residential consumption, water demand is mostly inelastic in terms of water price which means, even though we change the price of water, we expect people to consume less water, but usually it is not the case. That is why we say that water demand is mostly inelastic in terms of water price.

Then we have personal characteristics and behavior such as attitudinal factors, beliefs, habits, routines and personal capabilities. These affect the demand side management and affect the adoption of different conservation techniques and strategies. That means there are certain people who are willing to conserve water and others who aren’t interested in conservation based on their attitude, their beliefs and habits. This plays a big role.

And finally, there are major physical and social factors which actually play a large role in determining the domestic water use. In an urban area, the amount of domestic water use varies as per its climate, the economy, the urban design and the demographics. For example, in a particular urban local body, water is used for beautification. Thus, there would be more demand for water and in general, more affluent societies will need more water for their lawn maintenance. So, that is how economy plays a role in determining the total amount of water.

The urban water demand is also linked with the natural system. Natural system includes the rainfall that is generated, the water that goes back into the streams, the amount of water that percolates inside the ground followed by extraction of groundwater again. So, this is the overall way the natural system works and the groundwater demand depends on the natural system as well.

The spatial and temporal patterns of water usage will vary as per the different urban areas. The patterns vary based on different demographic and urban design characteristics of those areas. To summarize, we can say that long-term changes like population growth, income growth of an area effect water demands gradually. Climatic factors such as temperature, precipitation, evapotranspiration results in seasonal fluctuations. That means, in summer, the water requirement is higher, rainy season, water requirement is lower and so on.Also, rainfall, heat waves and so on results in immediate fluctuations.

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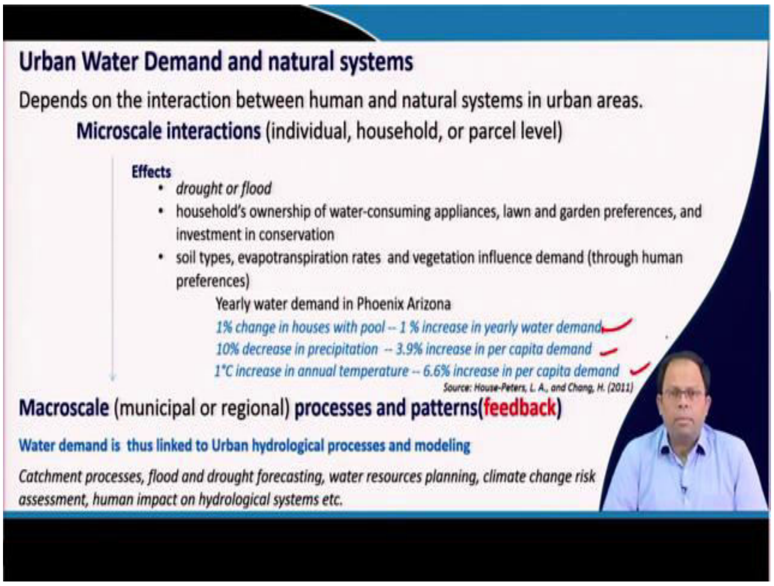

Now, when we talk about urban water demand and natural systems, there are lot of microscale interactions in an urban area at individual households or at the building or parcel level. People actually consume water and take different decisions depending on if they have a lawn or a swimming pool and other factors. These microscale interactions affect the overall macroscale which is the municipal or regional processes and patterns of water use. The individual uses sum up and they affect the overall processes and patterns in an urban area. From these overall patterns we can find the effect of microscale interactions on macroscale patterns.

Macroscale processes and patterns affects a larger area. Thus, we have to look into the different urban hydrological processes and other activities. The amount of water that is recharged in this particular urban area and the amount of run-off depends on the built-up area. So, water demand is thus linked to urban hydrological processes, and we need to model it.

In these models, we look into catchment processes, floods and drought forecasting, water resource planning, climate change risk assessment, human impact on hydrological systems etc. These are the different aspects that usually hydrologists study and sometimes urban planners also look into some of these aspects.

For example, droughts or floods actually affect the microscale interactions of individuals. Take a household's ownership of water consuming appliances. If the household buys appliances which does not use that much water, then it will reduce the water demand. If the household has got a lawn or garden, their preference to invest in some conservation measures like rainwater harvesting impacts the overall water demand for that urban area.

This also depends on the soil type of that area, evaporation, evapotranspiration rates, and vegetations which again depends on human preferences. In Phoenix Arizona, in the US, 1 percent change in houses with pools resulted in 1 percent increase in yearly water demand. Then, 10 percent decrease in precipitation led to 3.9 percent increase in per capita demand. This is where you can see that natural systems also play a role. Similarly, 1-degree centigrade increase in annual temperature resulted in 6.6 percent increase in per capita demand.

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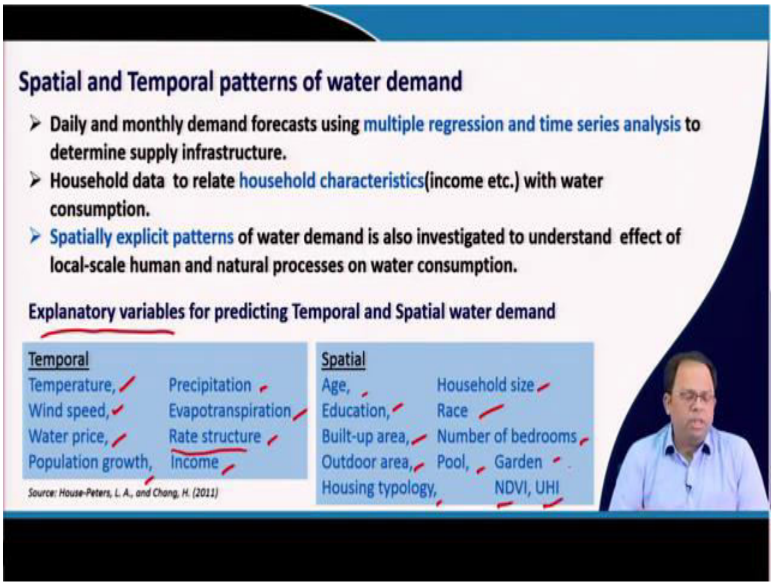

Spatial and Temporal patterns of water demand

When we look into the spatial and temporal patterns of water demand, we need to investigate how at different time periods or at different zones, the water demand varies in urban area. Daily and monthly demand forecast can be done using multiple regression and time series analysis.

Regression model is where we have a set of explanatory variables, and we have a decision variable. In this case, the decision variable is the amount of water that is consumed. It could be either per capita water consumed or it could be a total water consumed for that particular area. This is actually being predicted by many factors such as the climate, the soil type, income pattern. So, that is how multiple regression models can help. Time series analysis can also help where we can analyze these changes over a time period as well.

In addition to that, household data related to household characteristics such as income, household size help us to predict the varied consumption patterns. And spatially explicit patterns of water demand is also investigated to understand effect of local-scale human and natural processes on water consumption. So, this is where we are talking about the spatial variation of water demand. Local-scale human and natural processes of a particular urban area influences the demand for that particular area.

And when we talk about the different explanatory variables for regression, there can be some variables which are related with the temporal changes and some variables related with the spatial changes, and we can use both of them together to predict the future water demand in a particular area for a particular time period.

So, let us see what which are the variables that actually are used for this purpose. 1 degree increase in temperature leads to an increase in the per capita demand by a certain percentage. Wind speed of an area influences water consumption. Other factors are water price, population growth, income, pricing of water of that particular area, evapotranspiration, precipitation, and so on. These variables are related with temporal changes.

For spatial part, we consider the age profile, the education profile, the household size, what kind of race lives there, ethnicity, built up area percentage, number of bedrooms, outdoor area, pools, gardens, housing typology, NDVI which is the vegetation index that determines the number of trees present in that particular area, and UHI which stands for Urban Heat Island. These are the different variables which are used to determine the likely demand for water in a particulate area for a particular time period.

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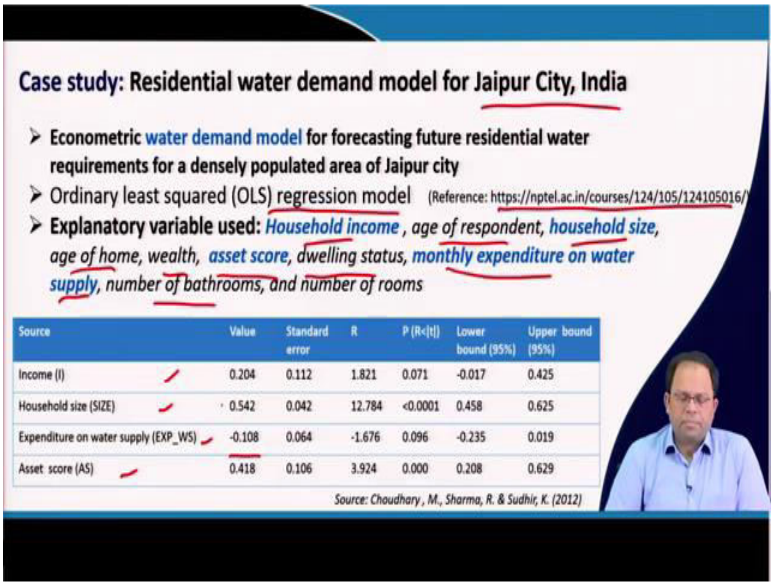

Consider this case study from Jaipur City for a residential water demand. The authors have used ordinarily least square regression, multiple regression model. If you are interested to learn multiple regression in detail and you can follow this particular lecture.

This is the lecture from one of my different courses where we have explained how to do a regression model.

Coming to the example, the residential water requirements for a densely populated area of Jaipur city has been predicted and the explanatory variables used are household income, age of respondents, household size, age of buildings, wealth, asset score which is related to amount of different items that are present in the household. It includes television, refrigerator and such things that influences the usage of water. It also includes the dwelling status, monthly expenditure on water supply, number of bathrooms and number of rooms.

These are the parameters the researchers used, and they found that the four parameters, vis-à-vis, income, household size, expenditure on water supply and asset score really determined residential water demand for this particular urban area. The other parameters were not found to be significant. So, all the parameters have got positive signs except for expenditure. This implies that if expenditure increases, then the demand decreases.

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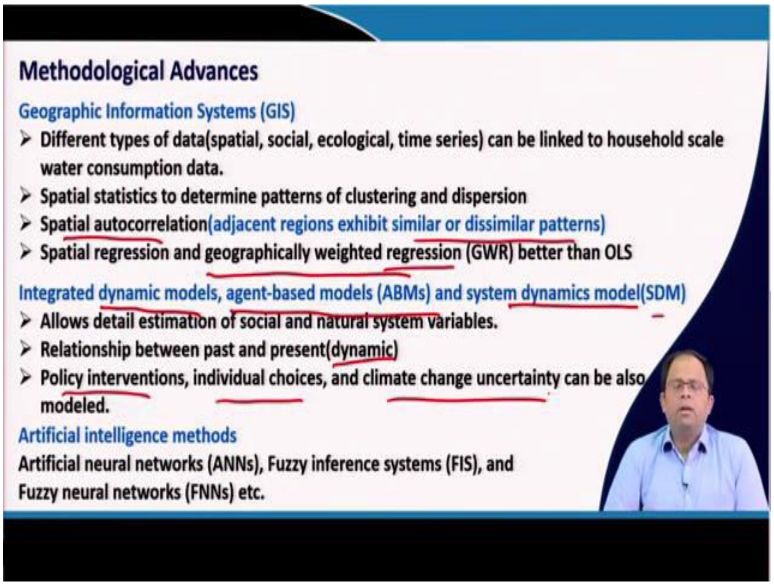

Methodological Advances

Coming to the different kinds of research that is done and the different methodological advances, we can say that introduction of GIS has really influenced this particular field. Government of India is looking to incorporate different remote sensing and GIS applications to determine water demand.

With the help of GIS, different kinds of data such as spatial data, social data, ecological and time series data could be linked to the household scale water consumption data in a map. This helps us visualize the amount of water being consumed by one particular household. We can link other available data sets to this similarly and perform spatial statistics to determine patterns of clustering and dispersion. Spatial auto-correlation can also be done where you can understand and identify the similar and dissimilar patterns in any particular neighborhood. Spatial regression and geographical weighted regression is another tool where we carry out the regression for local areas with same explanatory and varying coefficients. So, the effect of different variables or the weight of different variables will vary in each of these local areas. This makes a geographically weighted regression better than a standard regression. So, these are the different advances in terms of GIS.

Agent-based models ABMs or system dynamics models SDMs are the two kinds of modeling that is gradually being undertaken. System dynamics relates to different kinds of relationship between different entities via different processes. If you change one aspect or input, everything changes and that could be tracked. Water use is not a simple process because it is linked with many events natural as well as manmade events. So, if you change certain parameters, you see changes in all the other things and it will show an overall change in the water demand. Agent-based models are similar where you have different agents which can be individuals or processes interacting with each other based on which we determine the overall demand.

This allows a detailed estimation of social and natural system variables and how the different processes are related with each other. Relationship between what happens in the past and present and how it is linked to the water demand can be explored which is why it is called a dynamic model.

And we can also test different policy interventions, individual choices and climate change uncertainty into these models. That is, if we change certain policies what will be the likely effect on water demand? So, these are the things that could be also tested using these models.

In addition, artificial intelligence methods are also gaining traction in this field. If you are able to store large amount of sensed data for different indicators or factors such as water moisture content, humidity patterns, weather temperature patterns and so on, this long-term data helps us to carry out regression to predict water demand or consumption. We can go for artificial intelligence methods employing artificial neural networks, fuzzy inference systems and fuzzy net neural networks for predicting or determining total water demand in an urban area. It is similar to regression, but it depends on patterns based on the existing data sets. So, these are the different methodological advances which are happening in the particular field of forecasting water demand.

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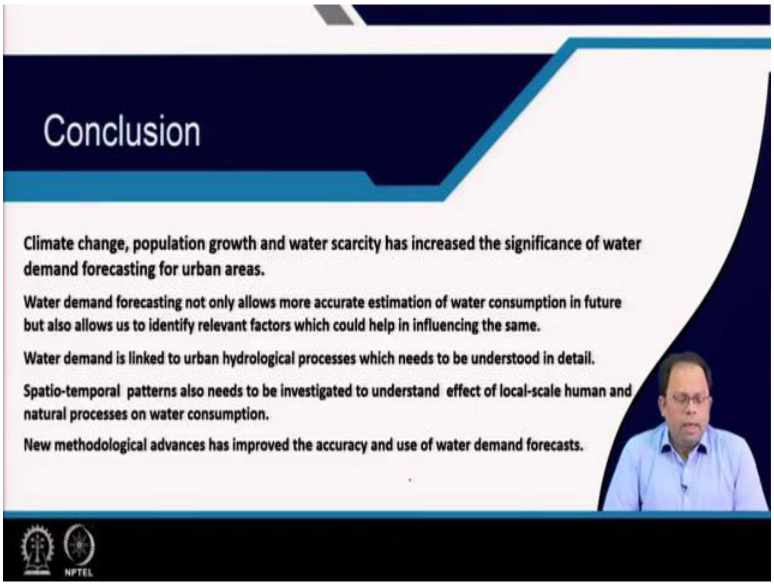

So, to conclude, climate change, population growth and water scarcity has increased the significance of water demand forecasting for urban areas. Water demand forecasting not only allows more accurate estimation of water consumption in future, but also allows us to identify relevant factors which could help in influencing the same.

Water demand is linked to urban hydrological processes, which needs to be understood in detail. Then, spatio-temporal patterns also need to be investigated to understand the effect of local-scale human and natural process on water consumption. And finally, new methodological advances, has improved the accuracy and use of water demand forecast.

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So, these are the references you can use.

Thank you.