Urban Landuse and Transportation Planning
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Lecture - 21
Urban Growth Assessment

In module 5, urban growth, land suitability accessibility and land price will be covered. In lecture 21, urban growth assessment is discussed.

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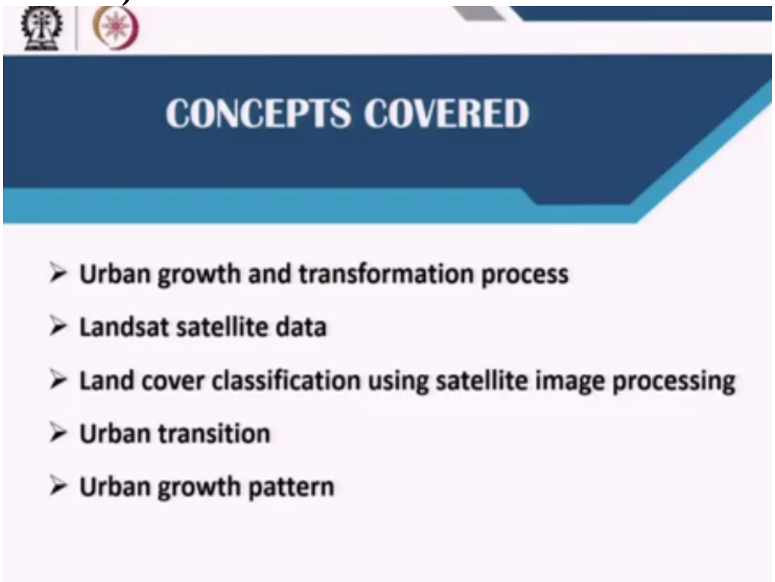

The different concepts covered in this lecture are urban growth and transformation process, Landsat satellite data, land cover classification using satellite image processing, urban transition and urban growth pattern.

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Urban growth and transformation:

Similar to urban population growth and transformation, urban land use/ landcover and land price goes through a transformation process. This further influences residential location choice, work location choice etc. Essentially all these transformation processes deal with land. So, land is a fundamental part of urban transformation.

There are several economic theories of land price and location choice. For example, Ricardo (1817) proposed that land prices depend on land quality. Von Thunen (1826) suggested that land use patterns and land prices depend on distance and transport costs. Alonso in Bid-rent theory, explored how rent changes at different distances from the central part of the city. Discrete choice models have also been used to predict choices between alternative locations. In spatial interaction theory, a gravity model is used to predict location of jobs and residences in an urban area. Similarly, accessibility based location models predict location choices based on accessibility of land. These theories help in determining the background processes or the fundamental reasons behind the transformations in urban land use and land cover. In an urban area, we have certain boundary and these theories also help in unraveling the changes in the urban area boundary. Accompanying these theories, are many models which helps in computing the kind of change that could be expected in the future or the kind of changes that are taking place. These can be also used to predict the change in the different components and how it varies among the agents. Agents can be anyone from an individual, a company, a real estate developer etc. The changes undergone by the agents lead to the overall change in the urban area and the modeling process is known as agent based simulation. Apart from agent based simulations, rule base simulations and micro simulations are also used. Thus, land use transportation modeling frameworks are used to determine the possible transformations of an urban area over a certain period of time. The urban area on the other hand neither has a fixed population, nor has a fixed area as it undergoes expansion in both the domains over time and has a characteristic pattern and direction to it. For an urban planner, it is very important to understand these before getting started with the landuse transportation modelling process.

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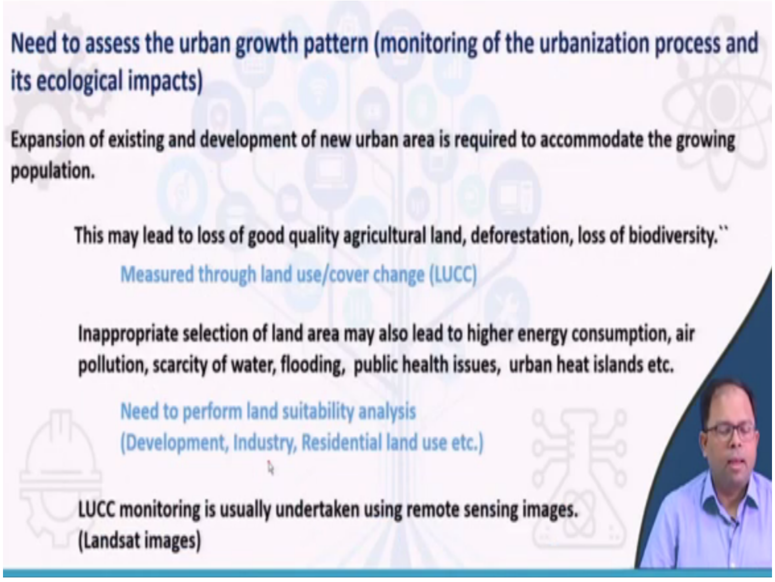

Need for assessment of urban growth pattern.

Understanding the growth pattern and direction not only helps in monitoring the urbanization process but also in assessment of its ecological impact. For example, sprawl developments i.e., where people shift away from the urban core area to the surrounding areas, results in better environmental quality in the residential areas, but at the same time it increases the travel time and travel cost significantly. From the administrative perspective, adequate resources need to be provided in terms of road and other infrastructures. So this kind of development does have an added ecological and environmental cost to it.

While planning for the growing urban areas, one need to consider the growth pattern and direction of existing growth. On the other hand, we also need to minimize the loss of valuable ecological resources like, agricultural fields, forests, biodiversity, etc. In order to track these kind of changes in an urban area, landuse land cover (LULC) change is monitored which essentially represents the change in the land cover within a selected boundary over time. For example, this method can trace the direction and quantity of increase in built-up area over a certain period of time in a certain region. This helps to delineate the proposals for future development while considering the LULC character of that particular region. Inappropriate selection of land area may lead to higher energy consumption, air pollution, scarcity of water, flooding, public health issues, urban heat islands etc. In order to select the appropriate land for development, land suitability analysis is carried out. For example, a site for solid waste management cannot be adjacent to a residential area; a residential township cannot be on the windward side of an industrial area emitting gaseous pollutants, etc.

LULC monitoring is usually done using remote sensing images, particularly Landsat images. Landsat is a US government satellite which takes images of the earth. These images are made available for analysis and can be utilized for LULC monitoring.

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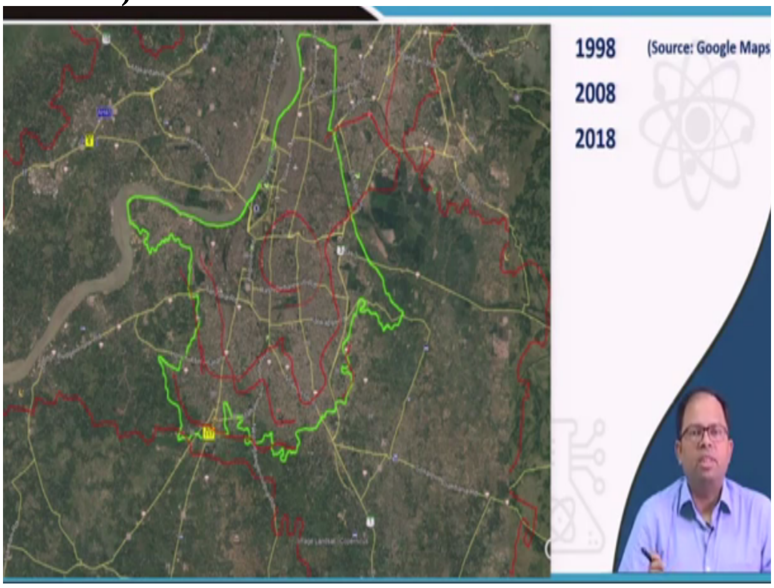

In the google map image of Kolkata Municipal Corporation (KMC) (in green outline; red outline is for Kolkata Metropolitan Area (KMA)) for the year 1998, the grey regions represent the extent of the built-up area. It is pretty evident that, the area under KMC is intensely developed whereas, the intensity reduces beyond the boundary of KMC where green areas seems to increase. In the map of 2008, intense development expanded to areas which were previously not that intense and in 2018, this expanded even further. These time series images can be used to infer about the growth direction but only at a qualitative level. Quantitative assessment of urban growth requires more tools which is covered in the consequent parts of the lecture.

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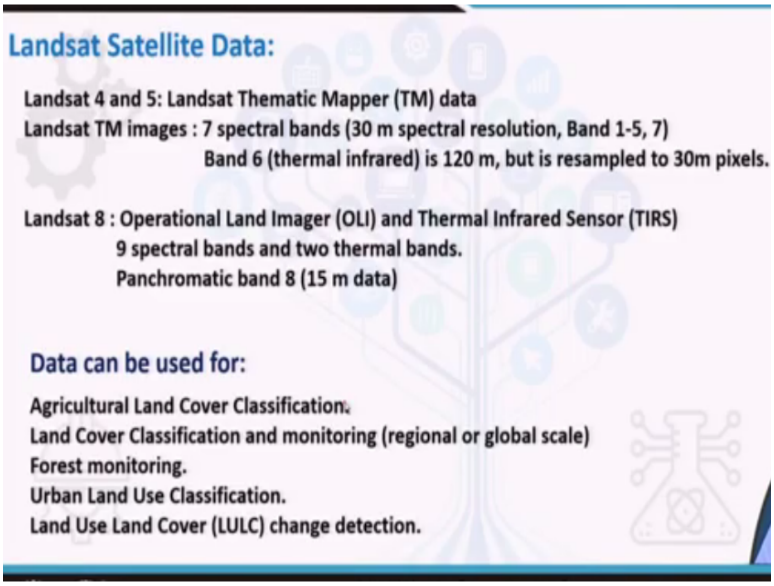

Landsat Satellite Data:

Landsat satellite data can be used for land cover classification and monitoring both at regional and global scales. It is used for forest monitoring, urban landuse classification and detection of changes in landuse and land cover. Landsat are a series of satellites. Landsat 4 and 5 are deactivated now and currently Landsat 8 is present in the orbit, but the images of previous years from Landsat 4 and 5 are still available for analysis. Landsat Thematic Mapper (TM) data is the data acquired by the on-board sensor. The data has seven spectral bands; 1-5, 7 has a resolution of 30 m; and band 6, which is a thermal infrared band, has 120 m resolution which is again resampled to 30 m pixels. Landsat 8 is a newer version of the satellite, which has Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). There are a total of 9 spectral bands and 2 thermal bands, each with 30 m resolution. Band 8 is a panchromatic band which has a pixel size of 15 m. The following table shows the spectral characteristics of both Landsat 4/5 and Landsat 8.

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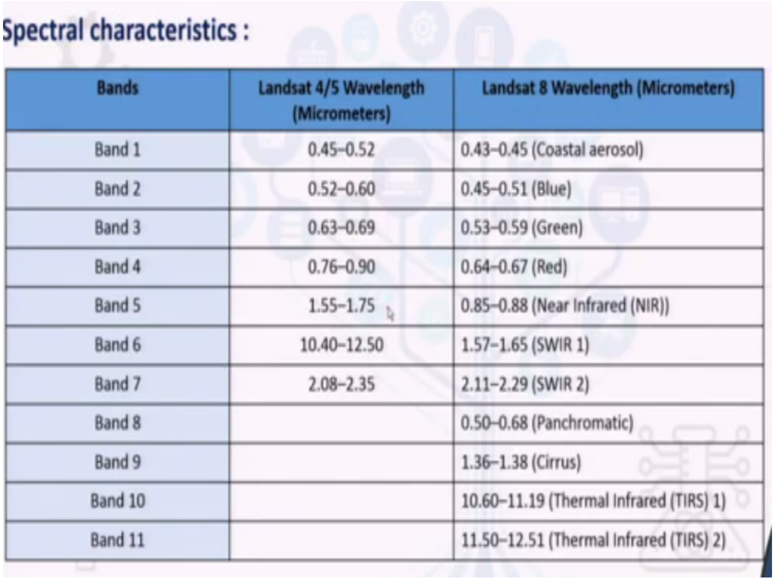

Spectral characteristics :

Bands	Landsat 4/5 Wavelength (Micrometers)	Landsat 8 Wavelength (Micrometers)
Band 1	0.45–0.52	0.43–0.45 (Coastal aerosol)
Band 2	0.52–0.60	0.45–0.51 (Blue)
Band 3	0.63–0.69	0.53–0.59 (Green)
Band 4	0.76–0.90	0.64–0.67 (Red)
Band 5	1.55–1.75	0.85–0.88 (Near Infrared (NIR))
Band 6	10.40–12.50	1.57–1.65 (SWIR 1)
Band 7	2.08–2.35	2.11–2.29 (SWIR 2)
Band 8		0.50–0.68 (Panchromatic)
Band 9		1.36–1.38 (Cirrus)
Band 10		10.60–11.19 (Thermal Infrared (TIRS) 1)
Band 11		11.50–12.51 (Thermal Infrared (TIRS) 2)

Bands	Landsat 4/5 Wavelength in µm	Landsat 8 Wavelength in µm
1	0.45-0.52	0.43-0.45 (Coastal aerosol)
2	0.52-0.6	0.45-0.51 (Blue)
3	0.63-0.69	0.53-0.59 (Green)
4	0.76-0.9	0.64-0.67 (Red)
5	0.55-1.75	0.85-0.88 (Near Infrared -NIR)
6	10.4-12.5	1.57-1.65 (SWIR1)
7	2.08-2.35	2.11-2.29 (SWIR2)
8		0.5-0.68 (Panchromatic)
9		1.36-1.38 (Cirrus)
10		10.6-11.19 (TIRS1)
11		11.5-12.51 (TIRS2)

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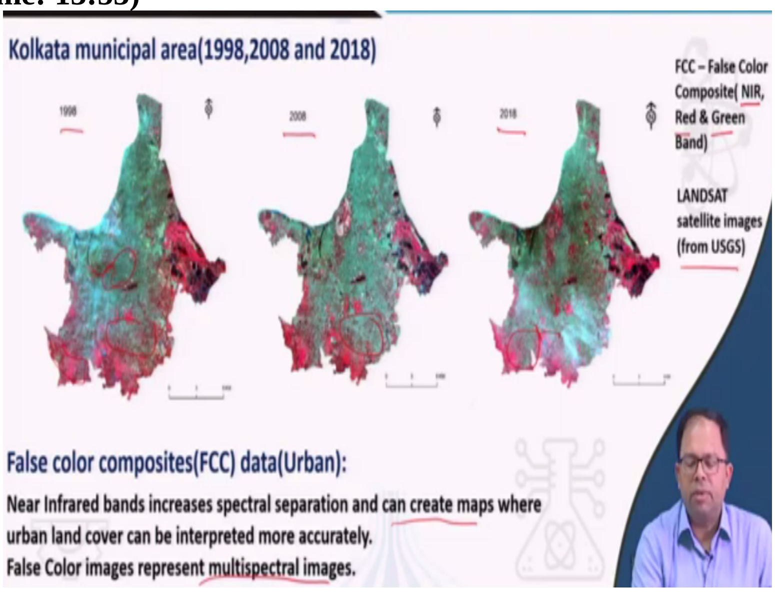

The different band data can be used to create composite or multispectral images, also called false colour composites (FCC). In the example, NIR, Red, and Green bands have been used to create the maps which look different from what is generally seen in Google Maps. The use of NIR increases the spectral separation that enhances the interpretability of the map. For example, the standard view of Google Map does not have distinct separation for the start and end of vegetation, but incorporating NIR enables such distinct separation. Hence, the significance of FCC images is that, multispectral images helps to determine the type of development in different pixels. In the shown example, the red colour indicates vegetation, green indicated development, and black indicates waterbody. The example shows that over the years 1998 to 2018, the intensity of development has increased towards the southern part and further moved towards south-western part.

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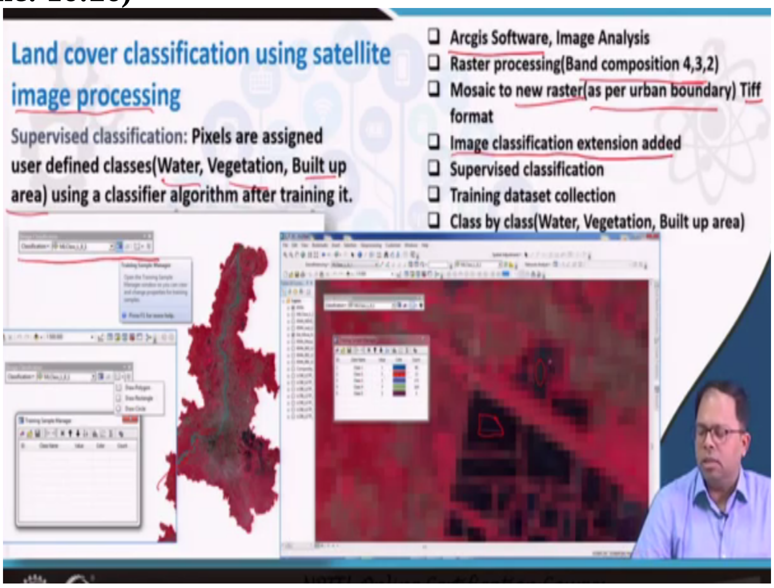

Land Cover classification using Satellite image processing:

In order to quantify the growth and type of development, satellite image processing is done which employs either supervised or unsupervised classification. The former is explained in this lecture. In satellite image processing using supervised classification, each pixel of the image is assigned a user defined class which can be a kind of land use or land cover. Water, vegetation, built up area are 3 classes that are shown in the example. If each type of pixel is assigned to a particular class, based on the selection of analyst or based on some examples, an algorithm is used to classify all the pixels of the image into various classes. The number of classes varies as per requirement and the quality of the data. In the given example, three classes have been used, and ArcGIS software has been used for classification. First of all, raw satellite image is obtained and a new raster map is composed using the bands 4, 3 and 2.

Raster image processing is used for creating a new mosaic as per the boundary under consideration. The image is finally saved in a tiff format. Image classification extension is then invoked and supervised classification is selected. This method requires the model to be trained in term of which type of pixels fall under which class. With the help of closed forms and polygons, certain pixels of the raster map are selected and assigned to the class which they are supposed to belong to. Next the same can be done for other classes.

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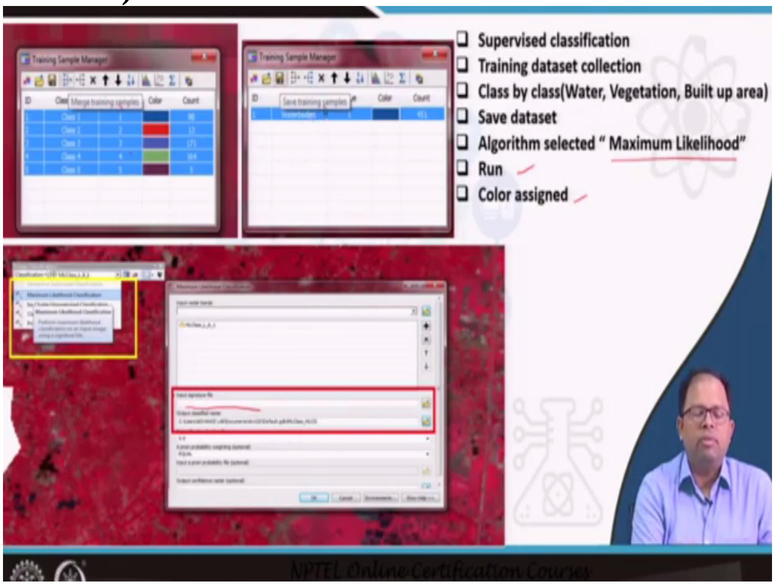

Once these steps are done, the data needs to be saved. After that the classification window is invoked where maximum likelihood classification is selected (other methods can be used as well). Then the signature file i.e. the file that was saved after training, needs to be passed as input and then the output location is also indicated. After that, the algorithm can be run and different colours can be assigned to various classes of landuse/ land cover.

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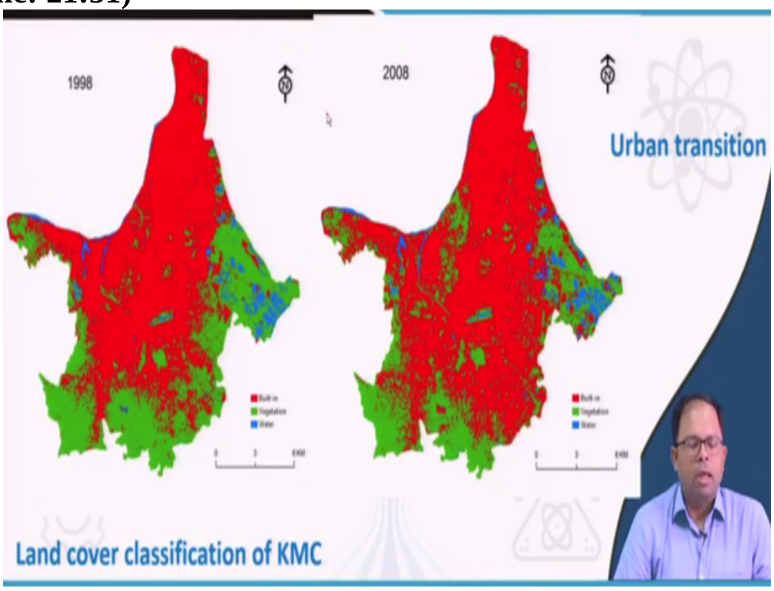

The images shown are the result of the analysis of land cover classification for KMC. Red represents the built-up area, green represents the area having vegetation, and blue represents water bodies. Once the classification is done by the algorithm, the colours can be chosen by the analyst. The images generated by this procedure is comparatively more clear and distinct than both FCC images or Google image. As evident from the images, lot of remaining green areas in 1998 have been converted to developed land by 2008, with small patches of vegetation in between which may represent the parks. The larger green areas may represent agricultural land or normal vegetation.   As coordinates are attached to this whole system, it is also possible to measure the amount of land (in sq. km for example) that has been classified under developed land.

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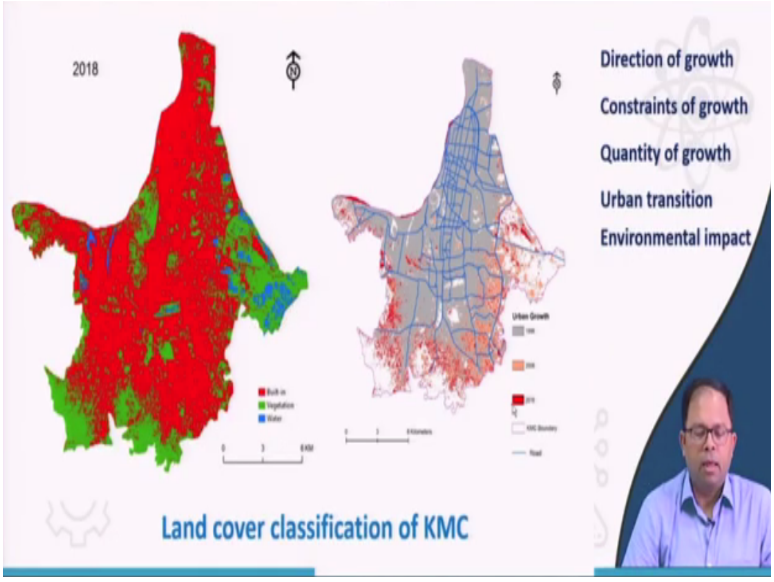

Similarly, a map can also be generated for the year 2018 with the same features. Overlaying all the three maps and giving them different colours (grey for 1998, orange for 2008, red for 2018) as demonstrated, can show the direction, and the change in direction of transformation over the years. For example, during 1998 to 2008, growth was towards the eastern part of KMC, but due to the presence of wetlands on the eastern part of Kolkata, and the river Ganges on the western flank, the growth direction during 2008 to 2018 was towards the southern part. The restriction of growth on eastern and western flank throws a light on the constraints of growth as well. As mentioned above, the quantity of urban growth can be estimated by measuring the area developed in various time periods which also gives an idea about the urban transition happening over the years. If adequate information of any adjoining environmentally sensitive area like agricultural land, forest, etc., is available, inferences on environmental impact can also be drawn from these kind of analysis.

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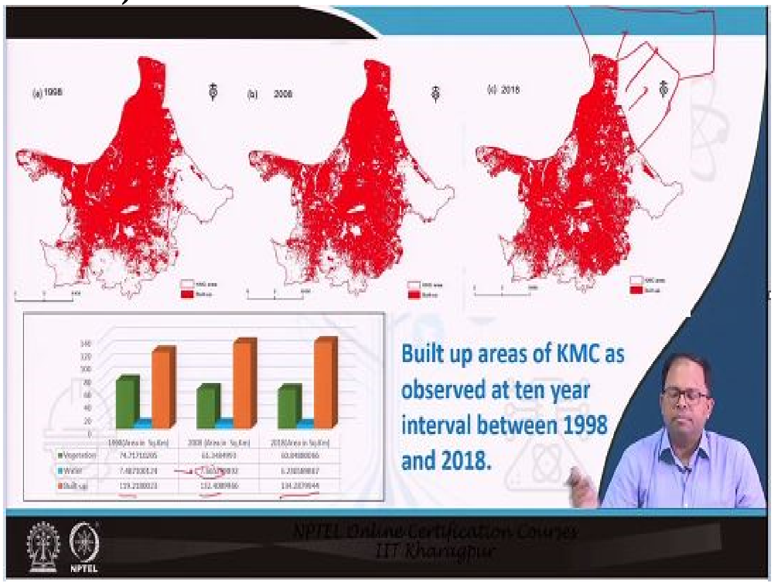

Summarizing for these 2 decades, 1990 to 2008, and 2008 to 2018, it was found that vegetation reduced from 74.7 sq.km. to 61.3 sq.km., and then from 61.3 sq.km.to 60.8 sq.km.; and waterbodies increased from 7.48 sq.km. to 7.66 sq.km., and then reduced to 6.2 sq.km. over the two decades. The increase in the area of waterbody over the 1st decade seems to be counterintuitive. These kinds of inconsistencies may occur due to some inaccuracies during training the model. It may be also due to heavy rainfall and water logging resulting in the increase in area covered by water on the day the satellite image was taken. The reason behind the reduction of waterbodies over the 2nd decade might be due to encroachments around the wetlands. The built-up area increased from 119 sq.km. to 132 sq.km., and then from 132 sq.km. to 134.28 sq.km. over the two decades. This implies that, the growth has stalled in KMC area, but since it is a part of the larger Kolkata Metropolitan Area, growth may just have extended to the adjoining municipal bodies like Bidhannagar Municipal Corporation (BMC) and 'New Town, Kolkata'.

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Urban Growth Pattern

After getting to know about the amount of growth along different directions, it is necessary to be able to understand the kind of growth pattern. Sprawl development, compact development are the qualitative categories of development. According to Hoffhine Wilson et. al., (2003), there are three quantitative categories of urban growth pattern based on Landsat imagery; Infill, Expansion, and Outlying. Outlying is further divide into three categories, isolated, linear branch, and clustered branch. Knowing the pattern of growth can serve as a decision support system to determine the ways to control the future growth of that area. The classification mentioned above depends on the relation of new area with existing developed area in terms of adjacency. It is worth mentioning that even though certain conclusions can be drawn from this kind of analysis, satellite imagery analysis is incapable of explaining spatial temporal details, unless images over a period of time are analyzed.

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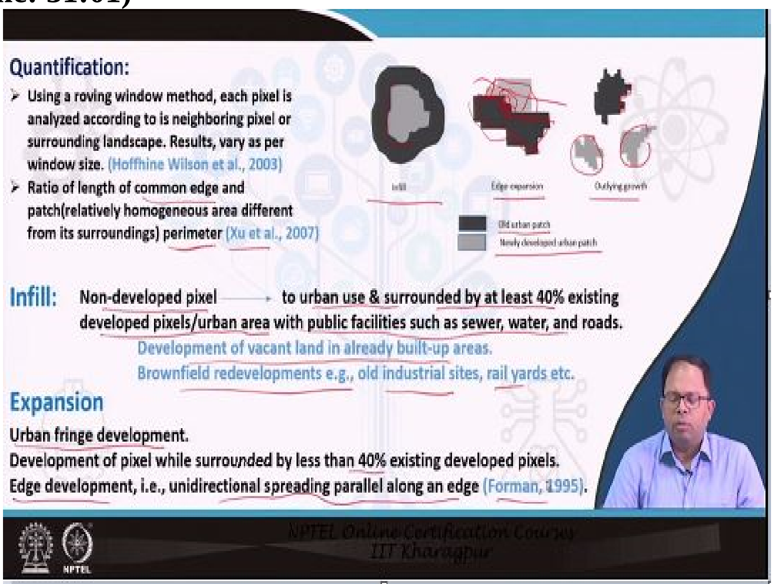

According to Hoffhine Wilson et. al. (2003), a new development(gray in figure) encircled by old development(black in figure) is called infill development; a new development adjacent to an old development is called edge-expansion; and isolated new developments away from old developments within a spatial area is called outlying growth. In order to quantify the growth pattern, the authors used a roving window method in which a window of desirable size is selected and each pixel is analyzed according to its neighboring pixels or surrounding landscape. For example, 60% of the perimeter of a single pixel may be surrounded by old area, and 40% by new development. Results of this kind of analysis changes with the change in window size. Alternatively, Xu et. al. (2007) used the ratio between the length of common edge shared by new an old development to the total perimeter of the combined patch of old and new development to predict growth patterns.

In **infill development** pattern, non-developed areas/pixels are converted into urban use and is surrounded by at least 40% existing developed areas/pixels. In other words, development of vacant land in already built up areas could be quantified as infill development. Brownfield redevelopment of old industrial sites, rail yards or repurposing sites which has lost economic significance can also be categorized under this pattern. **Expansion development**, also referred as urban fringe development has newly developed pixels surrounded by less than 40% of already developed pixels. Forman (1995) termed this type of development as edge development or unidirectional spreading of development parallel to an edge.

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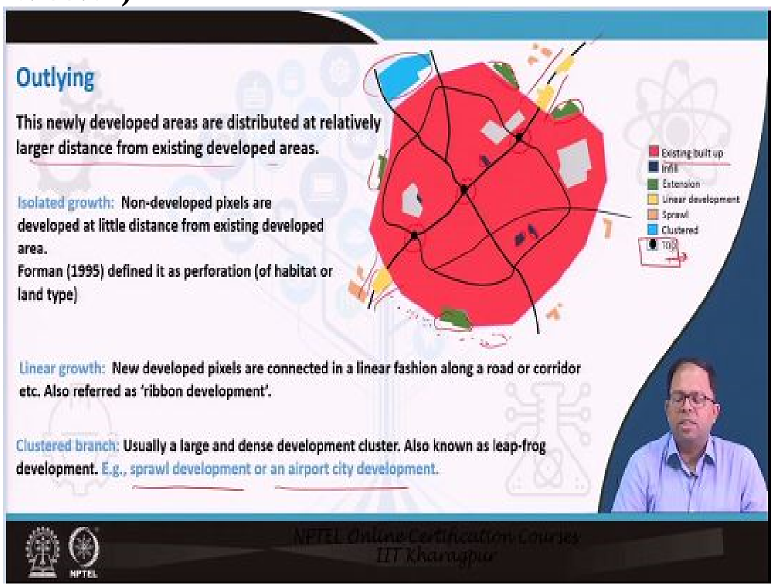

Outlying development is the kind of development pattern in which newly developed areas are distributed at relatively larger distances from existing developed area.

In the image shown, red color represents existing built-up area, deep blue represents infill development and green represents extension development. There are possibilities of a pattern where the development takes place near the existing development boundary but not in a continuous manner or at a little distance. Such patterns are categorized as **isolated growth** which is a sub-category of outlying growth pattern. Forman (1995) defined it as perforation (of habitat or land type). Other sub-categories of outlying development are; **linear growth**, in which newly developed pixels are connected in a linear fashion along a road or corridor; and **clustered branch**, in which large and dense development clusters like sprawl, or airport city are formed. Clustered branch development is also called leap-frog development. In addition, transit oriented development (TOD) is also important in today's context where existing transit station areas are developed intensively which may seem to be similar to infill development.

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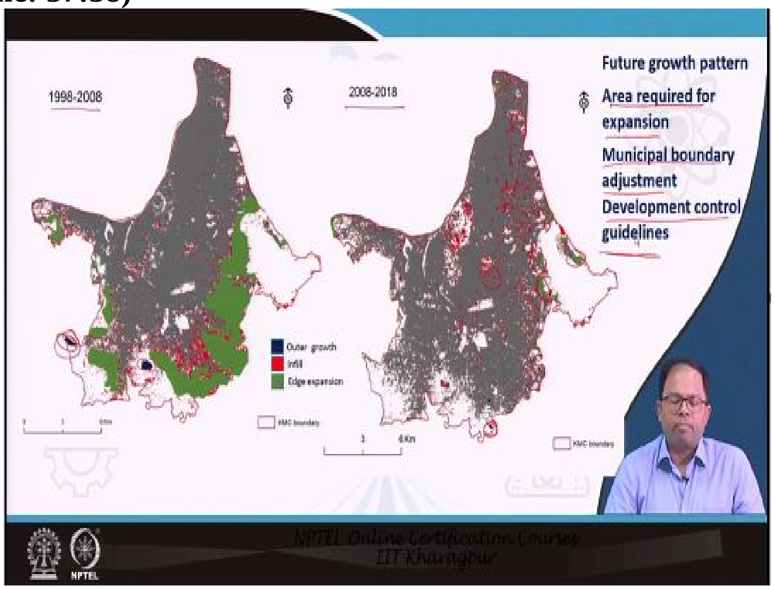

Considering the example of KMC and LULC transition between 1998 to 2008, and from 2008 to 2018, conclusions can be draws based on the urban growth patterns. Between 1998-2008, there has been a lot of edge expansion (represented by green colour) and a substantial amount of infill development (represented by red colour) towards the southern an eastern part of KMC. Few outer growths (represented by blue colour) are also observed towards the south and south western parts. Between 2008-2018, only a few edge expansion instances towards the eastern part of KMC is observed along with substantial amount of infill development in the central, northern and north eastern parts of KMC.

Apart from being able to determine the future growth pattern, the total area required for expansion in future needs to be understood. For example, if an urban area is going to experience migration (due to some proposed attractions), demand of new land is generated in order to accommodate the immigrants as well as to accommodate the natural growth of the urban area. From the past trends of development patterns, the share of infill development, edge expansion, and outlying growth can be estimated for each time period. Looking at the amount of developable area left in the city, decision can be made on the future growth locations or the need for municipal boundary readjustment which is a very crucial step while developing a landuse transportation plan.

This type of assessment also facilitates in development of development control guidelines. For example, in KMC a lot of encroachment can be seen around the wetlands. This is not desirable considering the importance of the wetlands for the urban area. Policies can be framed in order to restrict these kind of developments.

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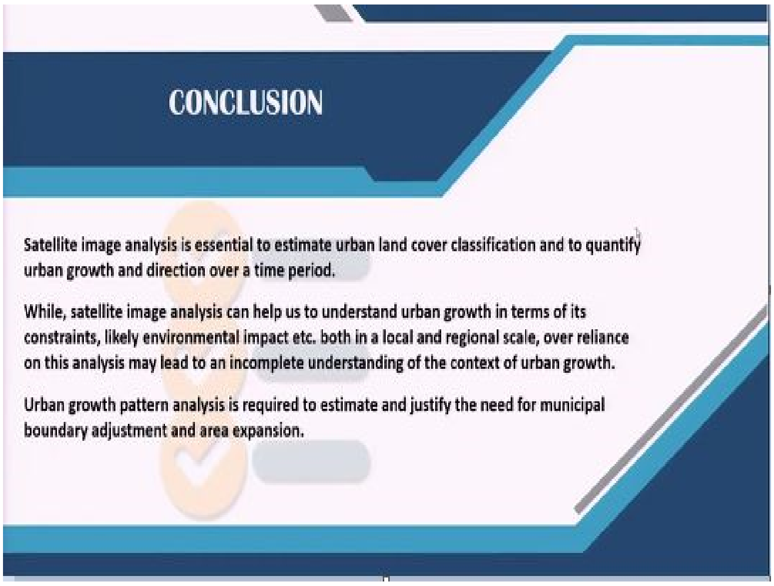

The references to the literature used to prepare this lecture are given. To conclude it can be said that, satellite image analysis is essential to estimate urban land cover classification and to quantify urban growth and direction of growth over a time period. While, satellite image analysis can help us to understand urban growth in terms of its constraints, likely environmental impacts, etc. (both in local and regional scale), over reliance on these kind of analysis may lead to an incomplete understanding of the context of urban growth. Thus, we need to have other information as well to really understand the reason for the growth to be taking place in a certain direction. But the initial information derived from satellite image analysis is worth acknowledging. Urban growth pattern analysis is required to estimate and justify the need for municipal boundary adjustment and any expansion which is the starting point of land use transportation model.