Urban Land use and Transportation Planning
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Lecture – 22
Urban Land Suitability Assessment

Welcome back, in lecture 22, we will start with urban land suitability assessment.

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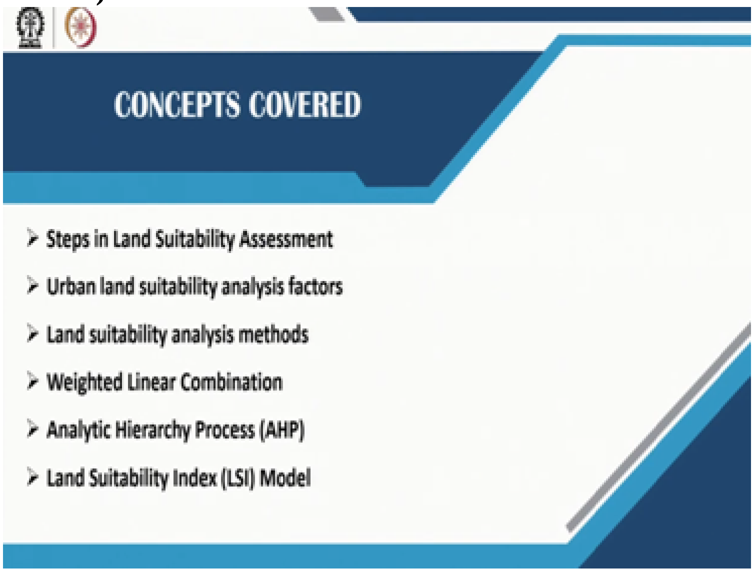

The different concepts that will be covered are, steps in land suitability assessment, urban land suitability analysis factors, land suitability analysis methods, weighted linear combination, analytical hierarchy process, and land suitability index model. The last 3 concepts are different ways to do land suitability analysis.

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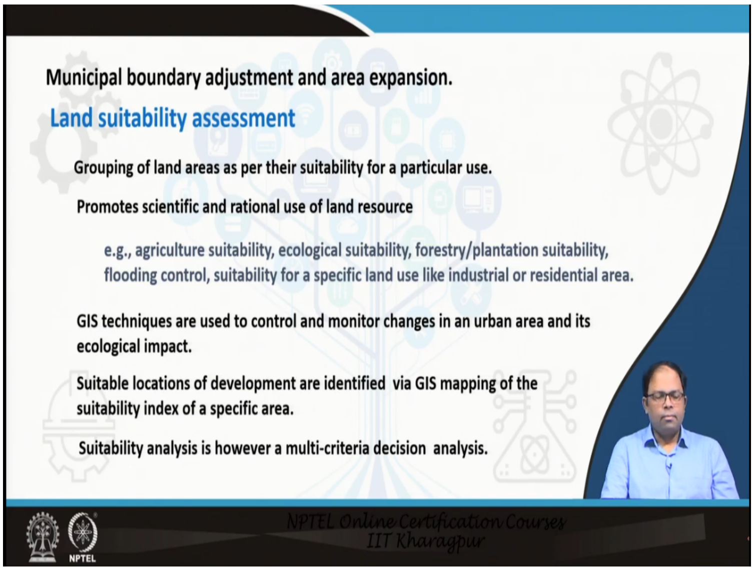

Land suitability assessment:

In the last lecture, we have covered municipal boundary adjustment, and area expansion. Broadly, we have talked about how to determine the new land area that is required based on the total population growth of an area or the carrying capacity of an area and then we also talked about how to expand the area, how much to grow within the existing urban boundary, and where to expand the boundary. Whenever an expansion takes place, a lot of surrounding areas are integrated into the municipal area which not only has residential areas, but also open lands and agricultural lands. The process of expansion takes place over 15- 20 years. For example: A municipal area might be willing to include an adjoining wetland to support its own urban drainage system; or it may go for some adjoining agricultural area that can be repurposed for urban agriculture, or a landscaped area, or plantation to act as a breather to the entire urban area. In order to determine the amount and type of land to be included, and the landuse/ activities to be allowed on any newly included area, land suitability assessment is carries out. Land suitability assessment is a scientific and rational exercise carried out to group areas as per their suitability for a particular use. For example: which land is suitable for agriculture, for ecological preservation purposes, for forestry or plantations. Areas demarcated to control flooding, during heavy rainfall, does not need to be at a central location and having a lot of transportation infrastructure or other kinds of development. So, in order to preserve the land required to control floods through water detention basins, and other measures, we need to carry out land suitability assessment.

Similarly, we can also have land suitability analysis conducted to determine land suitable for industrial purpose, land suitable for residential areas and so on.

When we conduct land suitability assessment, usually it is for some specific purposes which are needed to be reserved for an urban area, or for broader decisions like which areas to develop, and which areas to retain for future, or for uses like ecological areas, forestry plantation and so on. GIS is that the tool that is used to both control and monitor changes in an urban area through the generation of maps and databases. It also helps us to determine the ecological effects of certain factors on a particular area. As a decision support system, the maps of suitability index for various locations can be used to determine the suitable locations for different kinds of development.

Suitability analysis is a multi-criteria decision analysis in which the entire area is divided into smaller parts and then suitability is determined with respect to a particular objective, based on scores on various criteria. Each of these scores are used to come up with an index for each sub-division/criteria and is visualized in GIS for easy interpretation.

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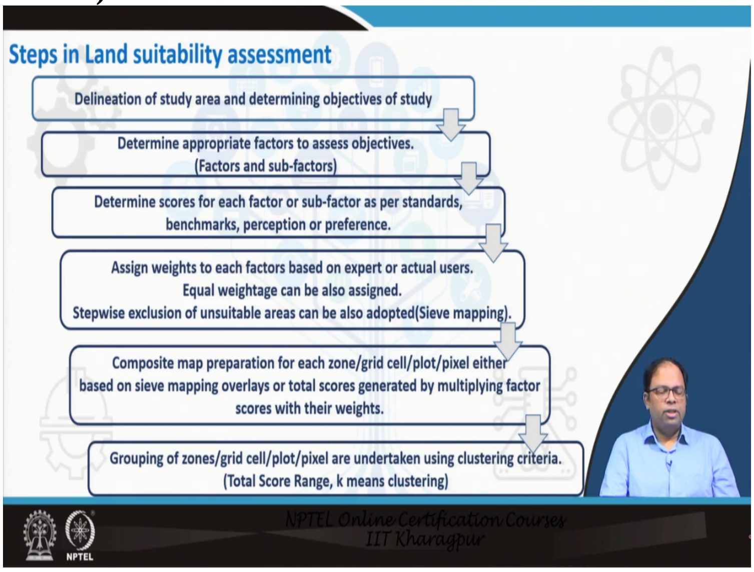

<u>Steps in Land suitability assessment:</u>

While performing a land suitability assessment, the first thing we need to do is, to delineate the study area and determine the objectives of the study. Based on the objectives, the second step is selection of factors and sub-factors through which the objectives are assessed. For example, if we consider determination of residential area, the selected factors would look into transport accessibility criteria, pollution criteria and so on; If we happen to deal with plantations, soil type, water availability, etc. would be evaluated.

The next step involves scoring for each of the selected factors and sub-factors, as per standards, benchmarks, perceptions, or preferences. Standards or benchmarks are certain guidelines which are set either by government bodies or by the actual assessor. For example, while considering assessment of an area for construction activities, an assessor will give a low score to the area if it has a high slope, medium score in case of a moderate slope, and high score in case the area is flat. Similar exercise has to be done for each factor and sub-factors, and they have to be normalized at the end to bring all the factors and sub-factors to a uniform scale

The next step is to determine the important factors or what weightage has to be assigned to each one of them. This is done either based on expert opinion or opinion of actual users. If actual users cannot be identified or they may not be the suitable candidates for making certain kinds of decision, experts are approached. Experts are usually, people who understand the reasons for choosing a given objective, the factors that have been chosen, and also understand how to score them. So, only domain experts in appropriate fields are asked about the relative importance of factors compared to others so that weights can be assigned to these factors. Sometimes it is very difficult to prioritize factors as all of them may seem to be equally important. In other cases, it may be difficult to compare two factors such as land price and pollution of a particular area. Even so, pollution can be attributed a cost in terms of health effects it may be difficult to do so. In such cases, all the assigned weights may be equal.

Stepwise exclusion of unsuitable areas, also known as sieve mapping, can be employed to reduce the number of alternatives to assess. In this process, maps are created based on each factor and certain threshold, or exclusion criteria is set to exclude the areas not suitable for the objective. For example, slope beyond a certain value may be considered as a threshold to exclude areas that are not suitable for construction. This exercise is repeated for each factor to exclude areas based on their unsuitability for any of the selected factors. After this exercise, the only areas left are suitable for the given objective considering all the selected factors.

The next step after assigning weights is to prepare composite maps of zones/ grid cells/ plots/ pixels, based on the level of detail of the analysis. Zones are based on administrative boundaries; Grid cells are units of urban area smaller than zones, (1 km x 1 km) or (500m x 500m) for instance, or even lesser; plots of various sizes can be taken as unit for analysis that gives a liberty to avoid scenarios where part of a unit is suitable and part is not suitable; pixels can also be allotted scores for each factor. Total scores are generated by multiplying factors with their weights and the scores are assigned to each of this pixel, zone, or grid. Using this a composite map can be generated by mapping those values using GIS.

The next step is to group the zones/ grids/ plots/ pixels by assuming certain range of scores. For example, if the total value ranges from 1 to 4, then ranges from 0 to 1, 1 to 2, 2 to 3 and 3 to 4 can be created and categorized as least suitable, less suitable, moderately suitable, and most suitable, respectively. This system often gives rise to ambiguities related to boundary conditions. For example, if 0 to 1 is least suitable, putting 1.1 and 1.9 in the same category is debatable. Techniques like k-means clustering can be an answer to such ambiguities where number of clusters are generated (or declared) and points are categorized based on their nearness to each centroid.

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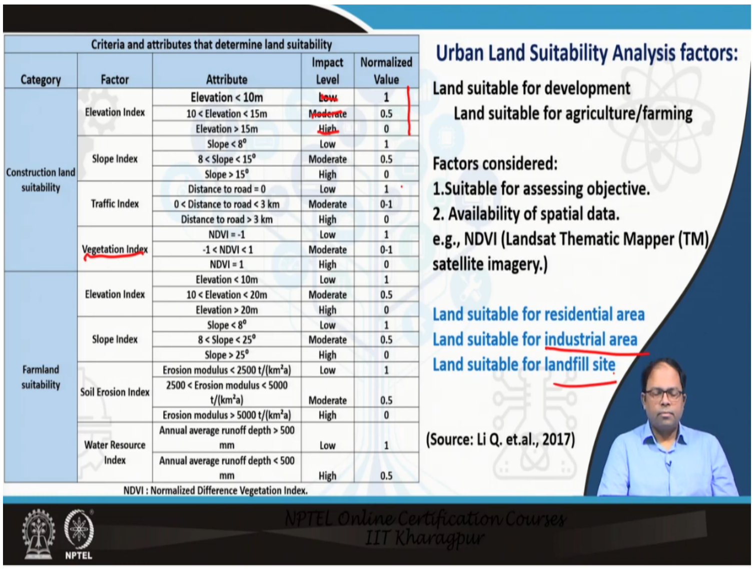

Criteria and attributes that determine land suitability				
Category	Factor	Attribute	Impact Level	Normalized Value
Construction land suitability	Elevation Index	Elevation < 10m	Low	1
		10 < Elevation < 15m	Moderate	0.5
		Elevation > 15m	High	0
	Slope Index	Slope < 8°	Low	1
		8 < Slope < 15°	Moderate	0.5
		Slope > 15°	High	0
	Traffic Index	Distance to road = 0	Low	1
		0 < Distance to road < 3 km	Moderate	0-1
		Distance to road > 3 km	High	0
	Vegetation Index	NDVI = -1	Low	1
		-1 < NDVI < 1	Moderate	0-1
		NDVI = 1	High	0
Farmland suitability	Elevation Index	Elevation < 10m	Low	1
		10 < Elevation < 20m	Moderate	0.5
		Elevation > 20m	High	0
	Slope Index	Slope < 8°	Low	1
		8 < Slope < 25°	Moderate	0.5
		Slope > 25°	High	0
	Soil Erosion Index	Erosion modulus < 2500 t/(km²a)	Low	1
		2500 < Erosion modulus < 5000 t/(km²a)	Moderate	0.5
		Erosion modulus > 5000 t/(km²a)	High	0
	Water Resource Index	Annual average runoff depth > 500 mm	Low	1
		Annual average runoff depth < 500 mm	High	0.5

NDVI : Normalized Difference Vegetation Index.

Li Q. et. al. (2017) performed land suitability analysis of an urban area where they tested the suitability for construction land and farm land. For construction land suitability, indices like elevation index, slope index, traffic index, and vegetation index has been used. For farmland suitability, indices like elevation index, slope index, soil erosion index, and water resource index has been used. After selection of factors, each area is scored based on their attributes on respective factors. For example, in case of developing elevation index, the actual elevation of the areas under assessment has been taken and has been graded based on their impact level as low, medium, high as per the elevation values of <10m, 10m- 15m, and >15m respectively. In this case, impact levels signify the degree of impedance to respective objective. For traffic index, the authors have taken distance from road, although other factors could have been taken like congestion, accessibility, etc. The ranges for impact level for this factor has been taken as low, moderate, and high for values of 0km, 0-3km, and >3km. The normalized values for low, moderate, and high are taken as 1, 0.5, and 0 for elevation index, and 1, 0 to 1, 0 for traffic index respectively, implying that better values have been given higher scores. Normalization is done to put both the indices on the same scale for evaluation. Similarly, farmland suitability is also determined.

NDVI, a Normalized Difference Vegetation Index, is used for determining farming suitability. NDVI indicates the amount of greenery in a particular area. NDVI maps are generated from Landsat Thematic Mapper data. Similarly, to generate elevation index, contour maps are required. If data like Landsat imagery or satellite imagery data and contour data is not available, both of these factors that have been considered for land suitability assessment cannot be evaluated. So, availability of data is very important when we create the list of factors that is used to evaluate land suitability. For different objectives such as land suitable for residential areas or for industrial areas and for landfill sites, different types of factors are considered. For example, for industrial areas, access to port, roads etc. is looked upon.

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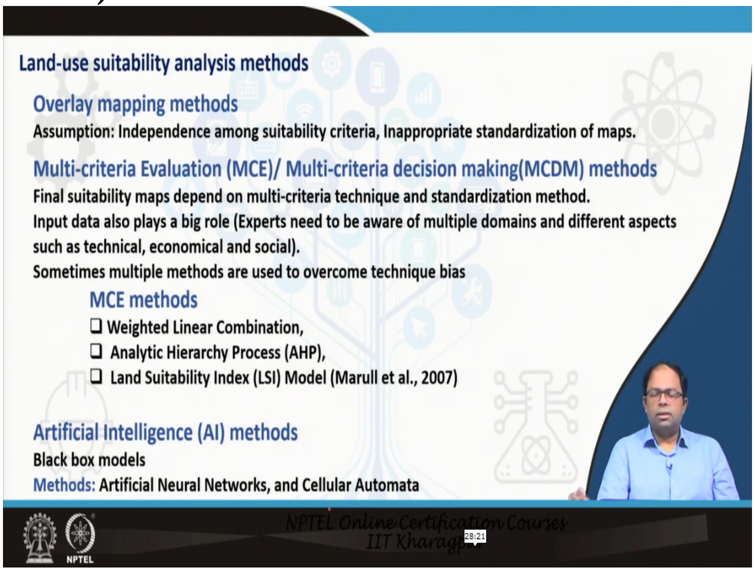

<u>Landuse suitability analysis methods:</u>

Broadly three methods have been discussed here:

1. Overlay mapping methods
2. Multi-criteria Evaluation (MCE) methods: Weighted Linear Combination, Analytical Hierarchy Process (AHP), Land Suitability Index (LSI).
3. Artificial Intelligence methods

Overlay mapping methods:

In overlay mapping methods, we assume that, the different factors or the maps that are under consideration, are independent from each other and if there is any correlation between any of them, they are not taken into consideration. In each of the individual independent maps, using exclusion criteria, unsuitable areas are eliminated. The final maps are overlaid to come up with a final set of suitable areas that fulfill the criteria of all the factors. Sometimes maps are not standardized which is a concern in this particular method.

Multi-criteria Evaluation (MCE) or Multi-Criteria Decision Making (MCDM) methods:
The final suitability maps depend on multi-criteria technique and standardization methods. The final outcome may change as per the standardization criteria employed. The input data also plays a big role. For example, the weightages may vary from expert to expert; the results may vary from one urban area to another.; different groups of people may assign different weightages for the same set of factors. While choosing experts, it should be made sure that they have a decent awareness about multiple domains and different aspects (technical, economical, and social effects) of the selected factors, so that they can understand the criticalities of the objective. This sometimes may result in the difficulty in getting weightages. Sometimes analysts employ multiple methods for evaluation and take the average from all the outcomes.

Among the different MCE methods, weighted linear combination (WLC), analytic hierarchy process (AHP) and land suitability index (LSI) are the common ones. LSI is a specific model that is mostly used for ecological evaluations. It also provides a different perspective as compared to AHP or WLC.

Artificial Intelligence methods:
In addition to sieve mapping and MCE, we also have artificial intelligence methods like cellular automata, artificial neural networks. In cellular automata, the development that should take place in the next cell depends on many factors plus, the actual development in the nearby cell. So, there is a sort of simulation which takes place and based on various given criteria, we can determine what is going to be the land use in the next cell and accordingly we can also determine suitability as well. These are black box models, which means we cannot know what is the actual process going on while a decision is being made by the model. Various MCE methods are discussed in the next section.

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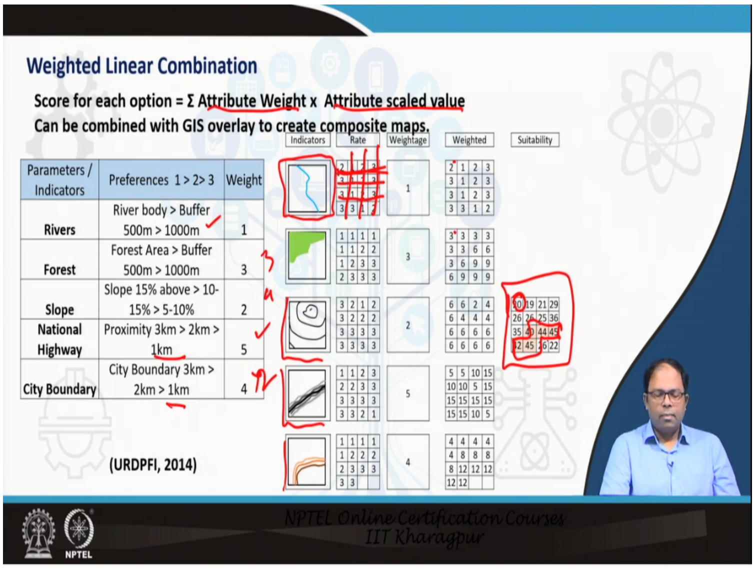

Weighted linear combination (WLC):

In weighted linear combination, there are three things, attributes (factors), alternatives (the various options that are present), and weights. Each alternative is given a score on various attributes, and these scores are normalized to bring the different attribute scoring to same scale. Each attribute is assigned certain weight and finally the weighted sum is calculated for each alternative. These weighted sums can further be combined with GIS overlays to create composite maps. This method can also be combined with some exclusion criteria at the beginning to filter out some of the unsuitable alternatives, and weighted sum can be calculated for the remaining few alternatives.

In the example shown, a large area has been shown with various maps showing features in it. These features are the parameters/ indicators that has been selected for a particular objective. One map shows the river passing through the area, another map shows the forest in that area, another map shows the contours of the area, another map shows national highway passing through the area, and the last map shows the city boundary in that particular area. The maps are divided into cells of equal size and each cell in each map is given a score based on the impact each indicator might have on the objective. In the first map, the cells which have a river in it are scored as 0, the ones which are 500 m away from river are scored 2, and the ones that are 1km away from river are scored 3. Similarly, the other maps are also scored base on the rule in the following table.

Parameters	Score	Weight
River	• Has river: 0 • 500 m from river: 1 • 1000 m from river: 2	1
Forest	• In forest: 0 • 500 m from forest: 1 • 1000 m from forest: 2	3
Slope	• > 15% slope: 0 • 15%- 10% slope: 1 • <10% slope: 2	2
National Highway	• 3 km away: 0 • 2 km away: 1 • 1 km away: 2	5
City boundary	• 3 km away: 0 • 2 km away: 1 • 1 km away: 2	4

After the scoring is done, each score is multiplied by the weights of the respective parameter (as mentioned in the table), and then they are overlaid upon one another to get the weighted sum of each cell. Finally, we can create clusters within the map based on the high score cells and demarcate them as most suitable areas for the given objective.

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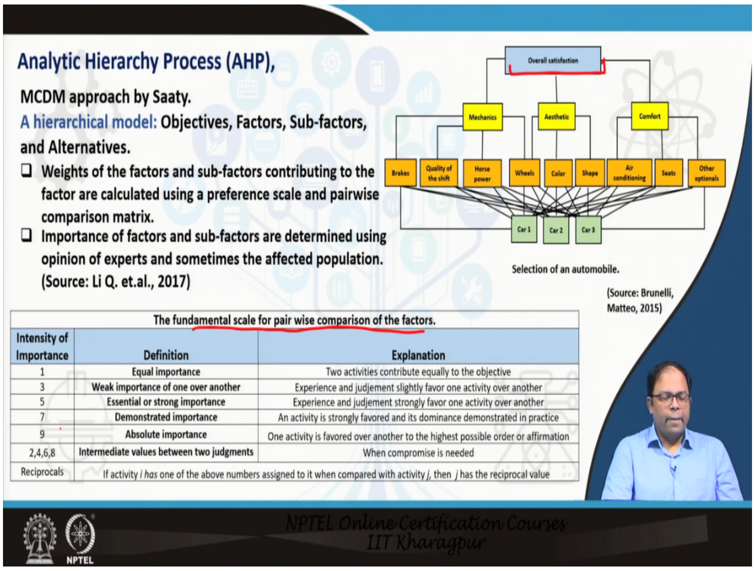

Analytical Hierarchy Process (AHP):

AHP was developed by Saaty and is a hierarchical model. In the example, a decision is to be made to choose a vehicle based on the satisfaction from various selected factors like, mechanics, aesthetics, and comfort of the car. Each of these factors also have sub-factors; mechanics has brakes, quality of shift, and horse power; aesthetic involves wheel, colour, and shape; and comfort has air conditioning, seats, and other options. Weights of the factors, and sub-factors contributing to the factor are calculated using a preference scale and a pairwise comparison matrix is prepared. Within each factor, each sub-factor is compared on their importance with respect to every other sub-factor and is represented in a matrix. Scores from 1 to 9 is used, 1 implying both the aspects are equally important, and 9 implying one factor is absolutely important over the other. If A vs. B is ‘x’, B vs. A is represented as ‘1/x’ in the matrix. This is the fundamental scale used for pairwise comparison.

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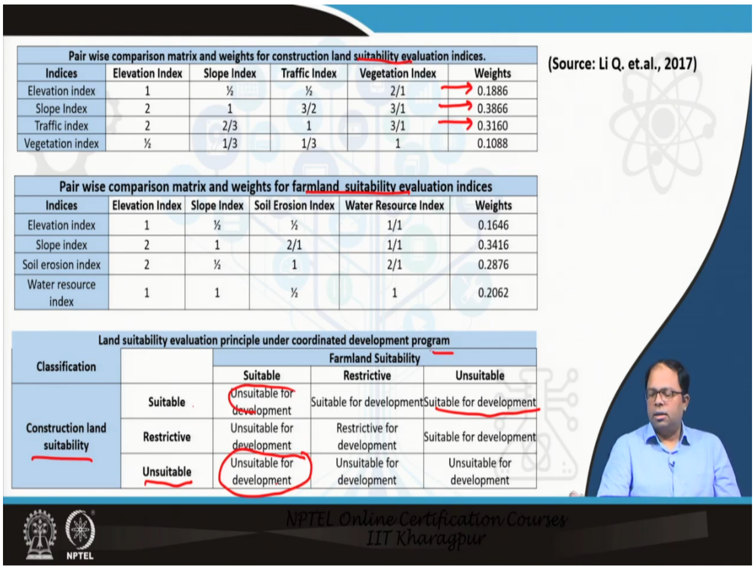

Considering the example in the paper by Li Q. et. al. (2017), each of the indices for construction suitability and farmland suitability are scored in pair wise comparison matrix separately, and the weights for each index is calculated by combining the scores horizontally (in this case/method). The method of combining depends upon the analyst and usually we go for average.

After the weights of all the indices are calculated, in order to find the areas deemed to be suitable for development, another matrix based on suitability, restrictive development, and unsuitability is formed. The areas that are suitable for farmland are not suitable for development; areas suitable for construction is suitable for development; areas suitable for both farmland and construction, are not suitable for development; areas that are neither suitable for farmland nor for construction are also not suitable for development and so on.

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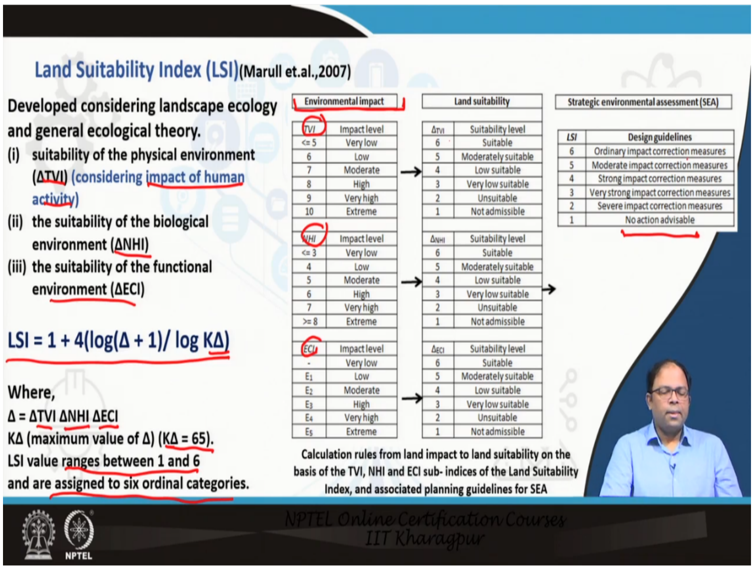


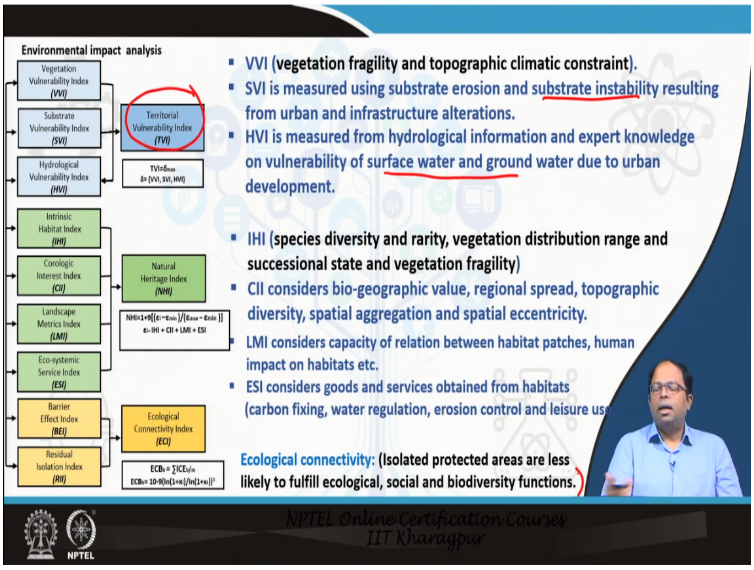
Land Suitability Index (LSI):

Land Suitability Index model is a very specialized model based on landscape ecology and general ecological theory. It has 3 Indexes, Territorial Vulnerability Index (TVI), Natural Heritage Index (NHI), and Ecological Connectivity Index (ECI). TVI deals with the suitability for different human activities; NHI deals with the biological environment; and ECI deals with the suitability of the functional environment. LSI is determined by combining the indices through the following formula.

$$\mathbf{LSI = 1 + 4(\log(\Delta + 1)/\log K_{\Delta})\ ;\ \Delta = \Delta_{TVI}\ \ \Delta_{NHI}\ \ \Delta_{ECI}}$$

$$\mathbf{K_{\Delta} = \text{max. value for } \Delta \text{ (assumed to be 65)}}$$

The values of LSI range from 1 to 6 which are assigned to 6 ordinal categories of suitability, ranging from ordinary impact correction, moderate impact correction, strong impact correction, very strong impact correction, severe impact correction, and no actions advisable measures for values of 6,5,4,3,2, and 1 respectively. For each of TVI, NHI, and ECI, the impact level is scored and categorized in six categories (very low, low, moderate, high, very high, and extreme). The impact levels are then converted into suitability levels by following the convention of very low impact corresponding to suitable, low impact corresponding to moderately suitable, moderate impact corresponding to low suitability, high impact corresponding to very low suitability, very high impact corresponding to unsuitability, and extreme impact corresponding to no admissibility. The scores are also assigned to suitability ranging from 6 for suitable to 1 for not admissible. **(Refer Slide Time: 32:43)**



Each of TVI, NHI, and ECI is constructed using various sub-indices which are given in the following table. The different sub-indices under these indices are listed in the table below.

Indices	**Sub-Indices**
TVI	Vegetation Vulnerability Index(VVI) Substrate Vulnerability Index (SVI) Hydrological Vulnerability Index (HVI)
NHI	Intrinsic Habitat Index (IHI) Corologic Interest Index (CII) Landscape Metrics Index (LMI) Eco-systemic Service Index (ESI)
ECI	Barrier Effect Index (BEI) Residual Isolation Index (RII)

VVI depends on vegetation fragility and topographic climatic constraints, SVI relates to ocean substrate instability resulting from urban and infrastructure alterations. HVI is measured from hydrological information and expert knowledge on vulnerability of surface water and groundwater. So, these sub-indices are water, erosion, and vegetation related which are the three major impacts that human beings can cause.

IHI refers to species diversity and rarity, vegetation distribution range, succession range and vegetation fragility, how new species or rather new generations are going to succeed etc.

Corologic index actually considers bio geographical values, the spread, the topographic diversity, spatial aggregation and spatial eccentricity and LMI considers capacity of relation between habitat patches, human impacts on habitats and so on.

ESI considers goods and services obtained from habitats like carbon fixing, water regulation, erosion control and other benefits that we can derive. And finally, ecological connectivity looks into isolated protected areas, which are less likely to fulfill ecological, social and biodiversity functions.

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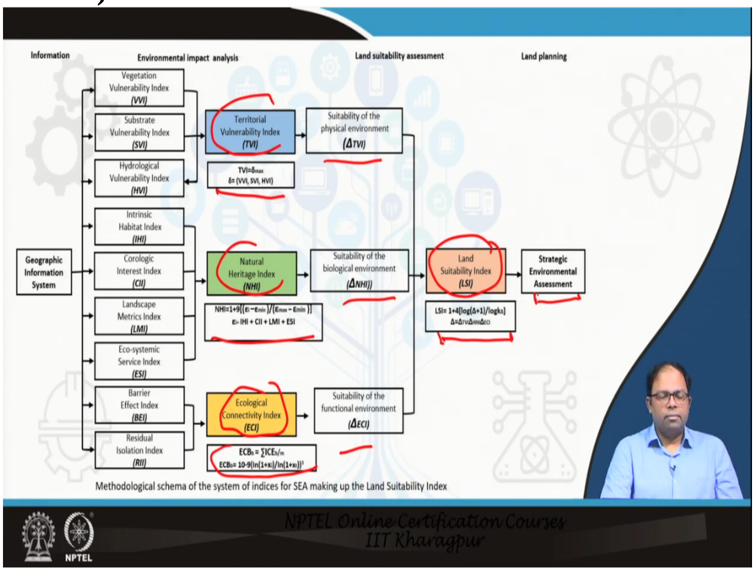
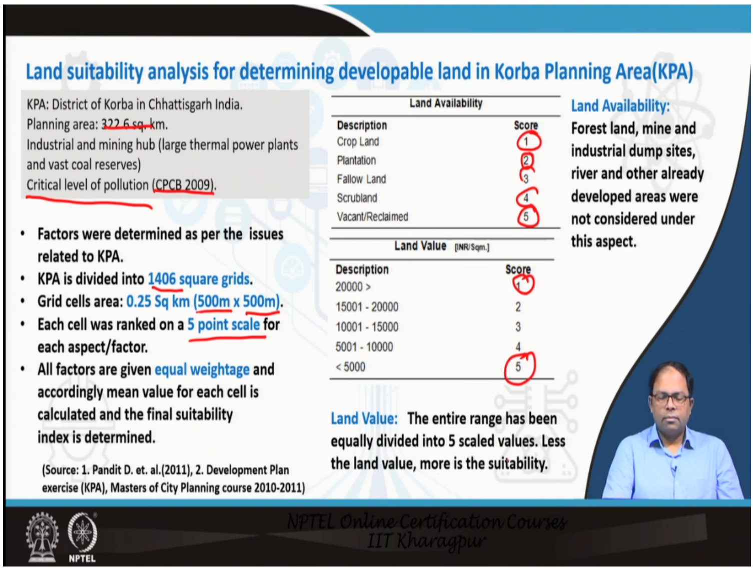


Finally, the authors created LSI which is based on TVI, NHI, ECI using a formula, where each of TVI, NHI, and ECI depends on various sub-factors mentioned above and are tied together by another set of formulae. Overall suitability is determined form LSI, based on which the decision to take some corrective measures can be made. **(Refer Slide Time: 35:52)**



<u>Case Study: Land suitability analysis for determining developable land in Korba Planning Area.</u>

Korba is in the district of Chhattisgarh and is an industrial and mining hub. There are a lot of thermal power plants, and vast coal reserves in this area. The objective was to find suitable areas to propose future residential/ commercial developments. Factors were determined based on the prevailing issues in the planning area. For instance, pollution was a major issue as it had already been declared a critically polluted area in 2009 by CPCB; although undeveloped land was available, most of it was agricultural land; land value was also a problem in the area. The unused/ vacant land parcels available in the Korba Planning Area were identified along with their assigned landuse. The whole area of 322.6 sq. km was divided into 1406 square grids of (500 m x 500 m). Each cell was assigned a score based on a 5-point scale for each factor of equal weight.

Land availability was the first factor which was scored based on the type of available land; 1 for cropland, 2 for plantation, 3 for fallow land, 4 for scrubland, and 5 for vacant/ reclaimed land. Forest, mines and industrial dump sites, river, and already developed land were excluded from the selection.

The second factor was land price which was also categorized into 5 ranges and scored using a 5-point scale; lower land value had higher score, and higher value had lower score.

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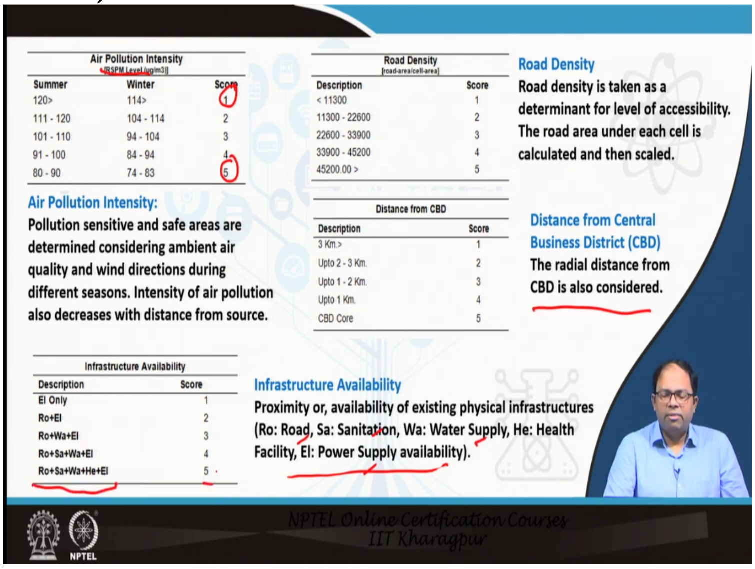

Air pollution intensity was the third criteria which was measured by the presence of respiratory suspended particulate matter (RSPM) in ambient air in both summer and winter seasons. It was found to be decreasing as distance from source increased. The RSPM levels found were categorized in 5 levels. In a 5-point scale, lesser score was given to higher values of RSPM, and higher scores for lesser values of RSPM.

Infrastructure availability was the fourth criteria which was assessed based on the proximity or availability of road, sanitation, water supply, health care facility, electricity supply. Electricity supply was common for all the 5 categories into which this factor was categorized. If only electricity was available, the cell was scored as 1; if road and electricity was present, 2 was allotted to the cell; similarly, if all the infrastructures mentioned above were present, 5 was allotted to the cell.

Road density was the fifth criteria that was assessed using the area of road in that particular cell and further scaling the area to convert it into ranges of 5 categories. Higher the area of road, higher score was allotted to a particular cell.

Distance from CBD was the sixth criteria in which the radial distance from CBD was taken to categorize each cell into 5 categories. If a cell lied in the CBD core, it was scored 5; if it lied within 1 km, 4 was allotted; between 1-2 km, 3 was allotted; between 2-3 km, 2 was allotted, and beyond 3 km, 1 was allotted.

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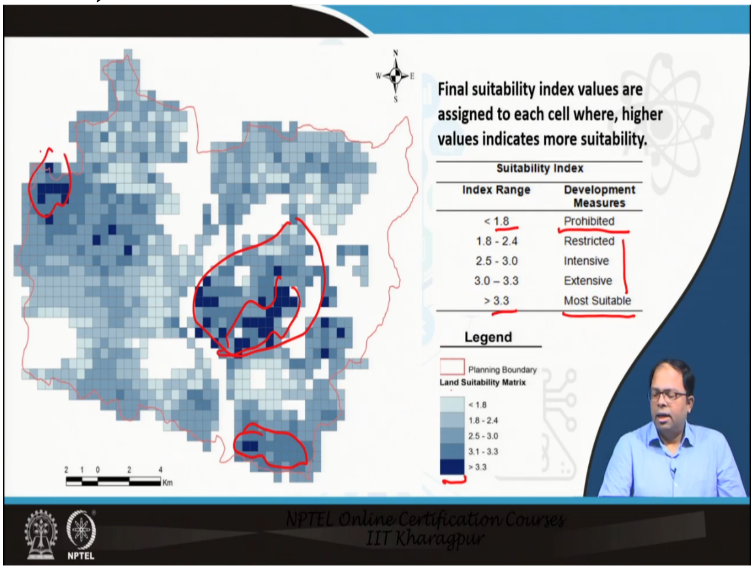

A map was created using the LSI calculated based on the scores on the factors and the equal weights of each factor. The ranges of the LSI were found to be >3.3, 3-3.3, 2.5-3, 1.8-2.5, and less than 1.8, for which the assigned development measures were most suitable, extensive, intensive, restricted, and prohibited respectively. These ranges were colour coded with the darkest colour as most suitable, and fading towards prohibited areas.

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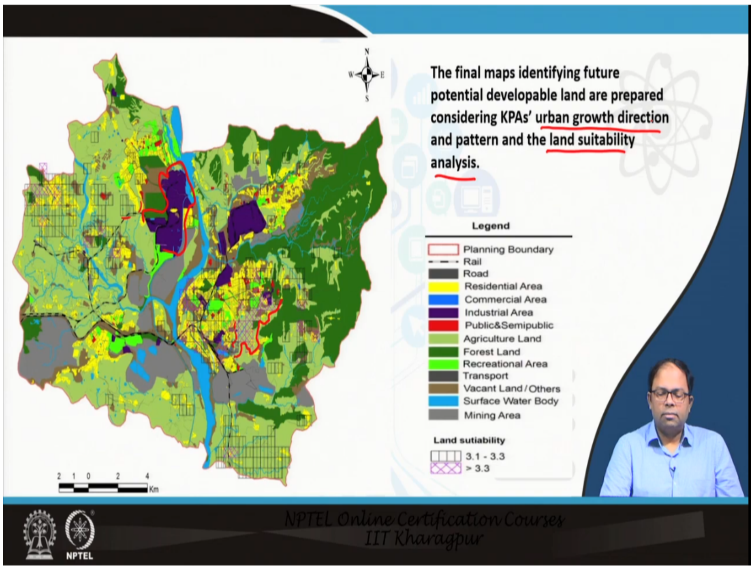

In the actual landuse map of Korba Planning Area, the areas identified for future development have been marked with hatches. The final map identifying future potential developable land also considers KPA's growth direction and pattern.

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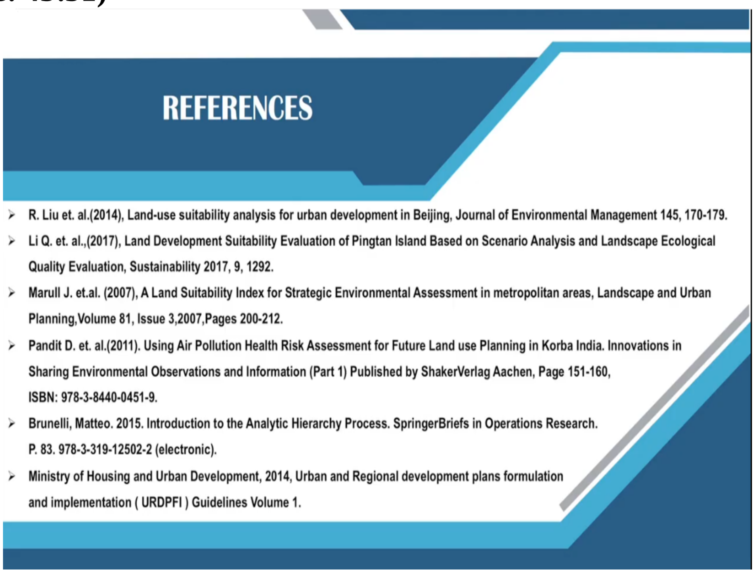

The references to the books, papers, guidelines and reports referred are given

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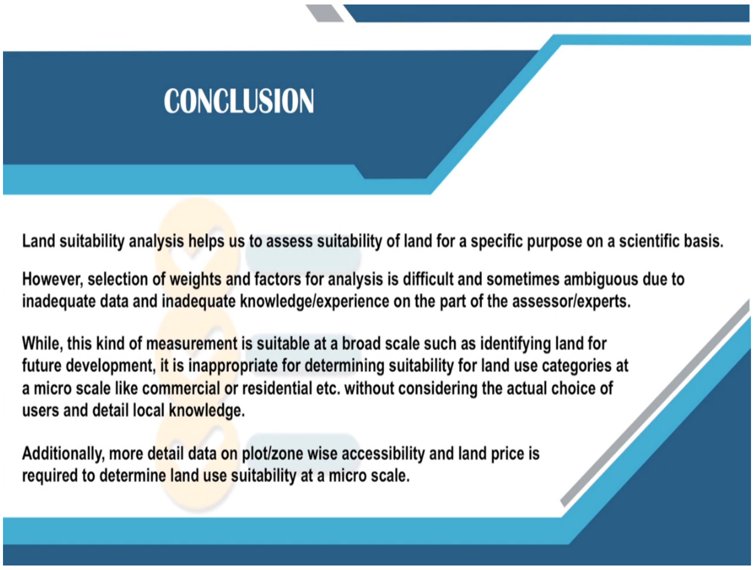

To conclude it can be said that, land suitability analysis helps us to assess suitability of land for a specific purpose on a scientific basis. However, selection of weights and factors for analysis is difficult and sometimes ambiguous due to inadequate data and inadequate knowledge experience on the part of assessor or experts, for which utmost care needs to be taken. While this kind of measurement is suitable at a broad scale such as identifying land for future development, it is inappropriate for determining suitability for land use categories that are micro scale, like commercial or residential etc., without considering the actual choice of users and the detailed local knowledge. While determining the suitability of a land for commercial development, we need to take into consideration other factors and also the behavioral factors of the people as they are the potential users of these areas, and they are the ones going to make decisions on land purchase or the construction in a particular area. Additionally, more detailed data on plots zone wise accessibility and land price is required to determine land use suitability looking at a micro scale. So, these are the things that also need to be considered when we develop our land suitability index for a particular area.