Medal for Research on Development

War on the Dream – How Land use Dynamics and Peri-urban Growth Characteristics of a Sprawling City Devour the Master Plan and Urban Suitability?

A Fuzzy Multi-criteria Decision Making Approach

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13th Annual Global Development Conference

Urbanization and Development: Delving Deeper into the Nexus

Organized by Global Development Network (GDN) in partnership with Central European University (CEU)

Budapest, Hungary

June 16-18, 2012

Theme 3: The Enabling Environment – Housing, Transportation and Infrastructure

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Abstract

This paper integrates fuzzy multi-criteria decision making approach represented by the fuzzy Analytic Hierarchy Process (FAHP) and GIS to study the spatio-temporal patterns of land use dynamics in urban and peri-urban areas of Lucknow – capital city of India's largest State Uttar Pradesh. Satellite pictures from past and present are used for evaluating urban growth in terms of carrying capacity, land suitability and resource constraints. Land capability and urban suitability analysis is performed from a landscape perspective with weighted factors and constraint threshold using Weighted Linear Combination (WLC) method. Land use conflict analysis is carried out to explore disagreements between urban suitability and Master Plan 2021. *The finding shows that patterns of urban growth do not follow Master Plan and even Master Plan deviate profoundly from the preferred land suitability.* Of the total area of the conserved, greenbelt, reserved forests and floodplain as per the defined land suitability class, 4.18% of the area has been converted into existing builtup/settlements whereas 46.36% of the total area is proposed under residential settlements, business districts and commercial land use under the Master Plan 2021. *Therefore, with the process of urban sprawl in the core and at the peri-urban interface, conserved area such as greenbelt, open spaces and floodplains are threatened and will be rendered fragile.* It will also create enormous infrastructure and resource crisis in the future, far beyond the capacities of governments and institutions. Project outcome would assist planners and land developers to evaluate whether development goals are in agreement with the intended land use objectives and if yes, how the resources should best be used to optimize city's enabling infrastructure and carrying capacity.

Key-words: peri-urban interface, master plan, land suitability, land use, urban planning, Fuzzy-AHP

1. Introduction

At the start of the 20th century, approximately 15 percent of the world's population was living in urban areas. In 2007 urban inhabitants surpassed rural population globally, and according to a recent UN estimate, by 2050 almost three-quarters of the world's population will live in cities and towns - with most of this increase occurring in the developing countries of the global south (United Nations, 2009; Martinez *et al.* 2008; Nijman 2008; UN-HABITAT 2006).

In India, urban growth rates in most of the major metropolitan areas show no signs of slowing. A rapid urbanization process with a simultaneous significant development in economy and industrialization has augmented considerable urban expansion in the latest decade. According to the 2011 Census, urbanisation in India has increased faster than expected. For the first time since independence, the absolute increase in the urban population was higher than that in the rural population. This has huge implications for providing infrastructure and other civic amenities in urban areas (Bhagat, 2011; Ahluwalia, 2011; Kundu, 2011). The fast pace of residential and commercial development is replacing agriculture and other undeveloped land around them. Urbanization affects land changes through the transformation of urban-rural linkages. A rapid urbanization process with a simultaneous significant development in economy, industrialization and tremendous immigration, has augmented considerable land use change in the latest decade. The problems of urban sprawl, loss of open vegetation and a general decline in environmental quality can be generally attributed to increasing population concentrating more people on less land even as the total land devoted to urbanization expands.

Many environment-development problem of a city is rooted in the way land use planning is made and governed as intended in the Master Plan. The uncontrolled urbanization pushes too hard in the direction of 'bigger cities' with inadequate enabling infrastructure. Consistent with the operation of a free market economy, people's and market responses to economic opportunities are mediated by private and public land owners which in turn drive land cover changes – often in a unscientific manner ignoring the long term environmental and aesthetic impacts (Lambin *et al.,* 2001; Brueckne, 2000). This can create externalities as land development agencies in the past have often neglected enabling resources and overall carrying capacity of a region in developing master plans for future growth.

Land use and land cover changes are so pervasive that, when aggregated they define the character of a city. They also define how major infrastructure such as transport, housing, commercial and market places, greenbelt etc will function in the future (Ding *et al.*, 1999). Urbanization becomes synonymous with frequent land use changes that have often negative impacts on the environment. Poorly regulated land governance which is rooted in inefficient intuitional regime leads to often unscientific urban development that do not conform well with the land suitability and carrying capacity of the region. This leads to complex policy challenges faced by planners and policymakers. This can also create externalities as land development agencies in the past have often neglected enabling resources and overall carrying capacity of a region in developing master plans for future growth (Frenkel and Ashkenazi 2008).

The present study has been carried out with reference to a rapidly growing city – Lucknow, which is the capital city of India's biggest and fastest growing State – Uttar Pradesh. It examines patterns of recent urban expansion and attempts to study how land use restrictions and modifications that respect land suitability can affect the future shape and character of the city in terms of enabling infrastructure and carrying capacity. Historical land use patterns, together with current trends, and several parameters such as groundwater, floodplains, forest cover, wastelands etc are used to define the land suitability and model future land use. These land use change models use simple parameters including present urban extent, major transportation routes, topography, geomorphology, protected lands etc. The primary focus of the modeling effort is to account for physical controls on land use and see how current trends of urbanization are in conflict with the land suitability and intended zoning as prescribed in the Master Plan.

The paper is divided into six sections – the first section gives general introduction and significance of the present study. Section two below provides a brief review of the literature and section three presents general characteristics of the study area. Study approach is outlined in section four with brief introduction to the models employed. Section five discusses specific findings of the study. Finally conclusion and policy implications of the study are discussed in section six.

2. Review of literature

2.1 Components of land use transformation and urban sprawl

Understanding the process of land use transformation in the urban core and along the rural-urban boundary is very important to guide the urban growth for future habitation. Understanding of urban growth and landscape characterization through historical and current land uses provides the data necessary to evaluate environmental impacts of land use change, to delineate urban growth boundaries or municipal service areas, to develop land use zoning plans, and to determine future infrastructure requirements. There are a number of environmental, socio-economic, political and historical factors that impact land use and land cover. These factors further interact dynamically resulting in diverse sequences and trajectories of landscape changes depending upon the specific context in which they arise. Given the complex nature of the feedback loops between pattern and process, it is difficult to separate correlation from causality, and distinguish effect from cause (Nagendra *et al.*, 2004). Urban sprawl is increasingly viewed as a significant and growing problem that entails a wide range of social and environmental costs (Bengston *et al.*, 2004).

An assessment of the relative contributions of various factors that causes unregulated spatial expansion is very important to understanding the dynamics of urban population growth (Bhagat, 2011). The natural increase, net rural-urban classification and rural-to-urban migration are some of the important components of urban growth. Economists believe that three underlying forces—population growth, rising household incomes, and transportation improvements—are responsible for this spatial growth (Mieszkowski and Mills, 1993). Brueckner (2000) describes three types of market failures which may lead to excessive spatial growth of cities. The first arises during the process of urbanization, when economic agents fail to take into account the social value of open space and greenbelt. The second type of market failure arises due to failure on the part of urban dwellers to recognize the social costs of congestion created by their use of the transportation network, which leads to excessive commuting and congestion. Finally, the third market failure arises from the failure of public and private real estate developers to take into account all of the public infrastructure costs generated by their development projects. Thus, development appears artificially cheap from the developer's point of view, but encourages excessive urban growth making enabling infrastructure to function below standards.

2.2 Peri-urban interface (PUI) and land use dynamics

Peri-urban interface (PUI) is the transitional zone between a sprawling city periphery and its rural surroundings. Lying between city and villages immediately adjoining the urban area, these extreme peripheries of urban areas suffer from a lack of definition. Yet, in most regions of the world, these areas are expanding rapidly and an increasing number of people are occupying them (McGregor *et al.*, 2005, Kayser, 1990). The context of such urban growth is situational and case specific. They provide little basis for a unified understanding of urban sprawl (Iaquinta and Drescher, 2001).

As is popularly understood, rural and urban are two broad land use categories, rural areas being dominated by agriculture, horticulture, dairy, etc. whereas, urban areas being primarily occupied by residential, commercial, manufacturing units and other user services. PUI can be perceived as the space between these two categories (urban and rural), marked by interaction of rural and urban forces, resulting in exchange of their individual resources. PUI is often described "not as a discrete area, but rather as a diffuse territory identified by combinations of features and phenomena, generated by activities within the urban zone (Nottingham and Liverpool Universities, 1998).

PUI along rural-urban boundary forms a dynamic semi-natural ecosystem, from where the intact natural resources of rural landscapes are sourced into the growing city, transforming the PUI in return. Peri-urban boundary is forever shifting, followed by extending urban areas engulfing the interface in route. Due to rapid urban growth, city periphery is subjected to multiple transformations – physical, morphological, socio-demographic, cultural, economic and functional (Dupont, 2004, Brook and Davila, 2000). These transformations cause this area to experience high spatial uncertainty resulting in undesirable, complicated land use/land cover (LULC) patterns. As the PUI emerges and tries to develop rapidly, there is a need for protecting common property resources that are diverted to other activities and purposes (Narain, 2009; Narain and Nischal, 2007).

It is increasingly being accepted that PUI of sprawling cities experiences significant land transformation, due to expansion of the urban core contained within their boundaries. The resources and energy required for the rapid expansion is actively supplied by peri-urban areas at the cost of its natural/semi-natural land-cover, which under this pressure gets disintegrated. Managing the environment of this interface has significant implications, for sustainability of urban and rural development, since the ecological, economic and social functions performed by and in the peri-urban interface affect both city and the countryside (Narain, 2009; Allen, 2003). Moreover, the current top-down policies for land acquisition by the land authorities in developing cities do not consider social equity and environmental integrity (Narain, 2007).

There exists a widely shared belief that the extensive building on the peri-urban interface not only consumes precious land resources, but is largely responsible for the high costs of infrastructure and energy, congestion of transport networks, the increasing segregation and specialization of land use, and also degradation of the environment. All these elements tend to draw a city away from the model of sustainable development, and undermine certain traditional features, such as its compactness and diversity (Camagni *et al.*, 2002). Accurate and timely information on the status and trends of peri-urban ecosystem has been attracting increasing attention recently (Díaz-Caravantes *et al.*, 2011; Yin *et al.*, 2011; Torres *et al.*, 2007). Unfortunately, due to the lack of basic knowledge and timely information of the urbanization process and its long term ecological impacts, urban and regional planners in developing countries have not been able to analyze consistently, much less manage and restore the ecosystems in peri-urban areas.

Understanding the complex dynamics of the peri-urban environment is often difficult at the spatial and temporal scales necessary to understand the processes controlling them. Remote sensing however provides ways to make indirect measurements as proxies for many of these quantities (Miller and Small, 2003). The application of remote sensing and GIS for urban studies has been valued greatly in various studies (Sarvestani *et al*., 2011; Taubenböck *et al*., 2009; Haack *et al*., 1997), as it is very useful for collecting data on suburban attributes with their spatial and temporal extents (Donnay *et al.*, 2001; Jensen and Cowen, 1999). The potential importance of this area is reflected in the growing emphasis on identifying new urban remote sensing applications for policy and management (Miller and Small, 2003). With increased availability and improved quality of multi-spatial and multi-temporal remote sensing data as well as new analytical techniques, it is now possible to monitor and analyze urban expansion and land use change in a timely and cost-effective manner (Wu *et al.* 2010; Huang *et al.*, 2009; Xu *et al.*, 2007; Alberti, M., 2005; Herold *et al.*, 2003).

2.3 Spatial analysis using Fuzzy AHP

Analytic Hierarchy Process (AHP) aid in complex decision making by comparing factors which are difficult to quantify. It is done by building a hierarchy (ranking) of factors and then making comparisons between each possible pair in each cluster (as a matrix). This gives weights for each factor within a cluster (or level of the hierarchy). The end result when integrated with GIS data is a continuous map of suitability. Criterion is a basis for a decision that can be measured and evaluated or queried. Criteria may be constraints or factors. Factor is a criterion that influences the suitability of the decision, according to its value, whereas, a constraint is a criterion that limits the alternatives under consideration. AHP has been used in a variety of contexts including land use suitability for deciding among the complex criteria structure in different levels (Prakash, 2003; Bouyssou *et al.*, 2000; Weck *et al.,* 1997).

Table 1: Scale for pairwise comparison in AHP (Saaty and Vargas, 2001; Saaty 1977)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate prevalence of one over another	Experience and judgement slightly favour one activity over another
5	Strong prevalence	Experience and judgement strongly favour one activity over another
7	Very strong and demonstrated prevalence	An activity is strongly favoured and its dominance is demonstrated in practise
9	Extremely high prevalance	The evidence favouring one activity over another is of highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is required
Reciprocals	For inverse comparison	

All elements/criteria are compared pairwise with respect to objective, and results are arranged in the matrix. The normalized principal Eigen vector of the matrix is computed and the criteria are ranked according to their relative importance. The ranking shows the relative weightage of the utility of settlement over the given land use as per the preferred land suitability class (Cropland, Horticulture, Forests, waterbodies). This also indicates how much effort it would require (i.e. feasibility) to convert the given land use (Cropland, Horticulture, Forests, waterbodies) into settlement as outlined in the Master Plan.

AHP fails to incorporate uncertainty or vagueness in expressing preferences of the experts during the pairwise comparison of criteria. This drawback led to inclusion of fuzzy logic in the AHP (Jeganathan, 2003; Deng 1999; Buckley, 1985; Laarhoven and Pedryez, 1983). A fuzzy set is a class of elements or objects without any definite boundaries between them. In the FAHP approach, triangular fuzzy numbers are used for the fuzzification of the crisp pairwise comparison matrices (PCM). The basic concept of fuzzy extent analysis is to obtain the criteria importance and alternative performances by solving the fuzzified reciprocal PCMs. Once fuzzy performances are obtained, final results are derived in the crisp form. Therefore, the fuzzy performance matrices are transformed into the interval performance matrices using the alpha-cut concept. Thereafter, to obtain the crisp output, the concept of optimism index is introduced. For a detailed discussion, please see Prakash (2003).

3. About the study area

India, with the second largest population in the world (1.21 billion), having some of the fastest growing mega-cities, seems ideal for examination of the LULC dynamics in its metropolitan peripheries – where the challenges of urban expansion echo the current demographic pressure. Among its vastly populated world of towns and cities, the state of Uttar Pradesh is the largest sovereign national jurisdiction (state) in the world, having a population of 199.6 million (Census of India, 2011). It is the second largest state-economy in India contributing 8.17% to India's total GDP between 2004 and 2009.

Lucknow is the capital city of Uttar Pradesh with a population of 4.5 million and a geographical area of about 2525 sq. km out of which the city occupies about 300 sq. km (Figure 1). Lucknow has changed from small, isolated population center in early 1990s to large, interconnected urban complex today having diverse economic, physical, and environmental features. The temporal and spatial dimensions of the land use changes that shaped urbanization are little known. The city has seen a steady increase in population arising from natural growth, incorporation of peri urban areas in 1980's and large-scale migration. The population growth projected in the Master Plan 2021 varies between 3.51 to 4.37 per cent per year over different 5-year periods until 2021, somewhat higher than for average growth rate of cities of similar size in the country and state.

Table 2: Urban sprawl and population growth in Lucknow starting 1901

Year	**Area**		**Population**		**Density/ sq.km.**
	sq.km.	**% growth/ year**	**(000)**	**% growth/ year**	
1901	44.03	-	256	-	5814
1973	80.00	1.13	857	3.26	10712
1988	143.32	5.29	1224	2.50	8540
1992	159.26	3.99	1723	10.19	10819
1997	196.50	7.45	2012	3.36	10239
2011	303.63	3.89	3200	4.21	10539
2021*	414.34	3.65	4500	4.06	10861

(Source: compiled from various historical maps, survey of India toposheets and census data, *projected in the Master Plan 2021)

As any other fast growing developing Indian mega city, Lucknow faces an uncontrolled urban sprawl. The rapidly growing urban population in the city and high rate of migration spills into the peri-urban and rural areas surrounding the city boundaries. Lucknow is growing at unprecedented rates, creating extensive urban landscapes. Many of the agriculture and horticulture fields, wetlands, and forests that formed the Awadh's Capital of 1900 have been transformed during the past 100 years into human settlements. Every one of us has seen these changes to some extent but without a clear understanding of their impacts. It is not until we study these changes from a spatial perspective and the time scale of decades that we can begin to measure the changes that have occurred and predict the impact of changes to come.

The city apparently represents a typical urbanization process taking place throughout India as it has witnessed swift urbanization in recent years, leading to multifold increase in employment opportunities but a rapid degradation of basic natural resources like land and water (Dutta *et al.*, 2010). Once dominated by agriculture, the region is fast converting into a mosaic of interspersed rural-urban landscape with depleting natural land covers and increasing paved surfaces of urban land use.

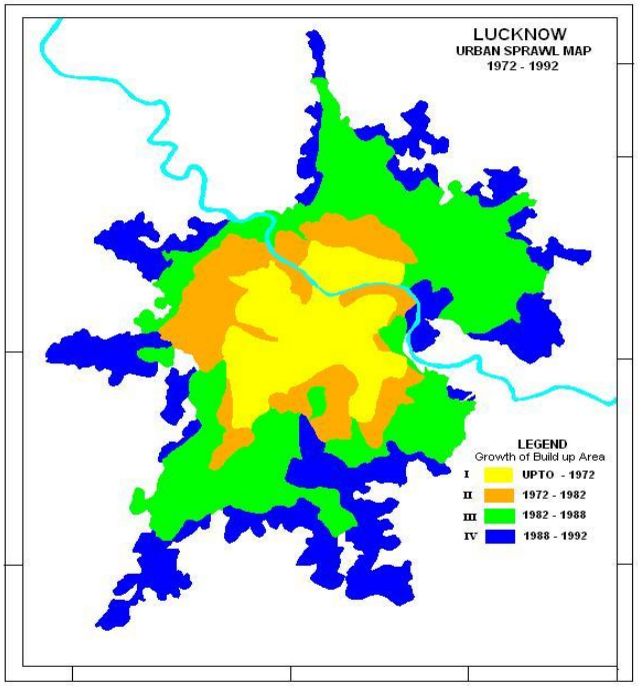

Figure 1: Urban sprawl in Lucknow from 1972 to 1992 (drawn from older maps and toposheets)

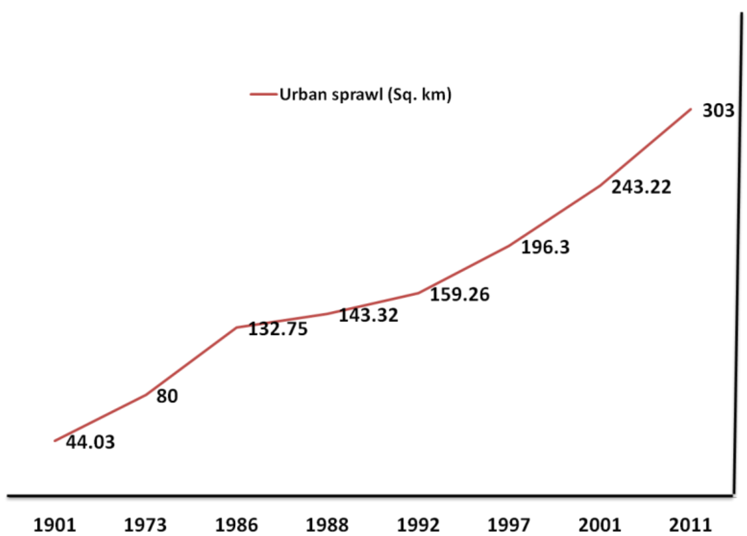

Figure 2: Urban sprawl (in sq. km.) in Lucknow since 1901 based on historical maps, survey of India toposheets and satellite pictures

The peri-urban sites of interest in present study were located at distances ranging from 14 km to 17 km from the centre of Lucknow city in different directions. The main consideration for including a location in the PUI was presence of abundant cropland in competition for land from non-agricultural uses outside the demarcated urban territory of land development authority. Four study sites were chosen in the transitional area on the periphery of city, well distributed spatially such that they represented all four directions of the city's expansion. The areas were chosen along major roads - State and National highways, which are well known for initiating the urbanization process by increasing accessibility (Figure1).

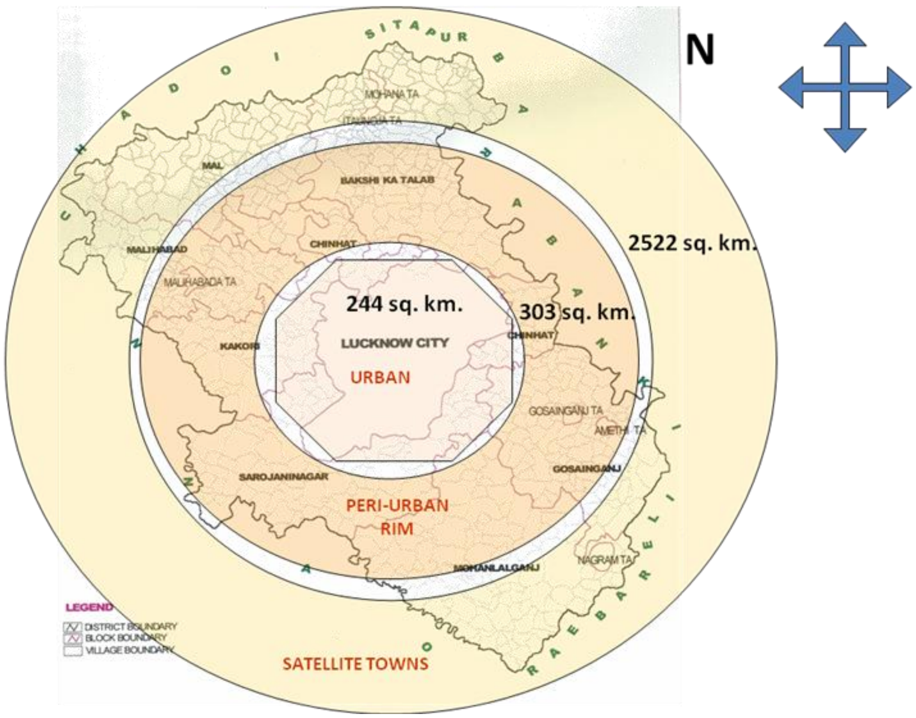

Figure 3: Urban sprawl is in all directions – peri-urban rim is transitional and it gets engulfed in urban core as urbanization proceeds

4. Methodology and data

4.1 Land use land cover mapping and land transformation analysis: The temporal land use / land cover maps for three periods viz. 1997, 2002 and 2009 were prepared using satellite data from following sources:

(i) Year 1997 Satellite data (PAN Sharpened IRS-1C, LISS III) : Required for land use /land cover map was procured from National Data Centre, Hyderabad (NRSC)

(ii) Year 2002 satellite data was replaced by interpreted land use/land cover map from UP Remote Sensing Application Centre's (UPRSAC) NRIS database. The database was reclassified to include relevant classes into aggregated level and to remove insignificant classes.

(iii) Year 2009 satellite data was used online from 2009 Google Earth image (GeoEye satellite) and interpreted using Google Earth KML features

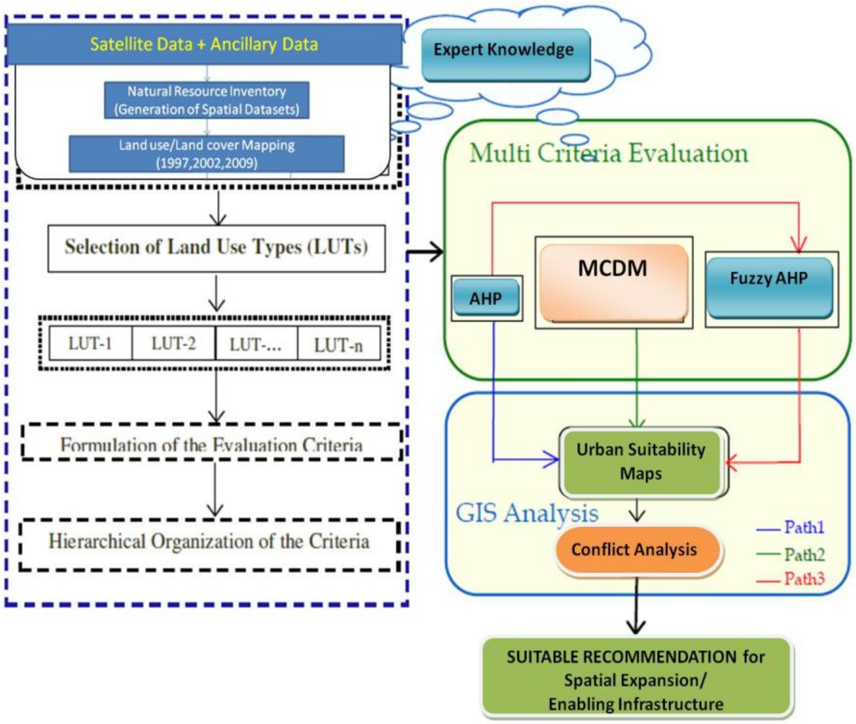

Figure 4: Project approach adopted for predictive modeling and land suitability in the study area

Mapping for temporal land use/land cover for the three time periods was done using visual interpretation at 1: 25,000 scale. Land use ground reconnaissance was carried out to develop a general understanding of land use situation in the month of March and June 2010. Land use change detection comparison was performed on multi-temporal land use/land cover maps using the classic post-classification change detection algorithm. Land transformation analysis was carried out to examine major drivers of these changes.

Classification of urban land use has been attempted using both traditional and advanced automatic techniques in the literature. Automated techniques are usually based on pattern recognition which provides areas with similar spectral and textural pattern (Zhan *et al.*, 2002). In contrast, traditional visual interpretation approaches follow the concepts of “analytical areas” or “photomorphic units and regions” (Haack *et al.*, 1997; Peplies, 1974). This study uses the traditional approach of visual interpretation in mapping the peri-urban areas.

Based on the information which could be obtained from satellite images, 12 major LULC categories were identified, delineated and classified using a classification scheme adapted from the NNRMS project (Committee report on NNRMS standards, 2005). Each class has a definition as explained in Table 3. Generalizations have been done wherever it is not possible to separate two types of land uses with insignificant differences.

After the identification and delineation, vector land-use maps of peri-urban sites were prepared using standard GIS software – ArcGIS 9 and IGIS. The area falling under each major category of LULC was calculated for three time periods and simultaneously, the change in land use area statistics over the study period (1997-2009) was derived and recorded.

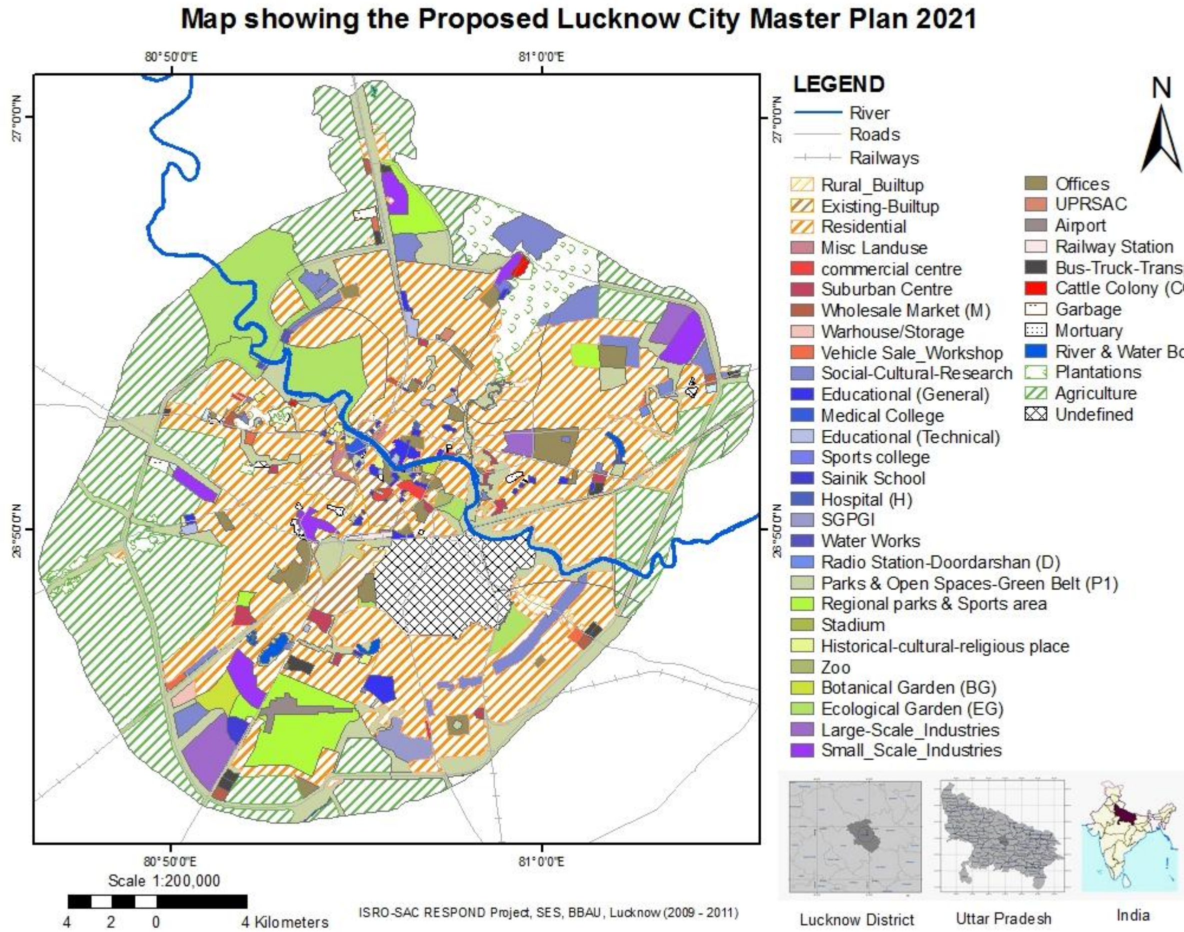

Figure 5: Lucknow Master Plan 2021 prepared by Lucknow Development Authority (LDA) – the public land regulatory agency

Temporal mapping of LULC was followed by post-classification method of change detection, using comparison of two independent land cover classifications (Mas, 1999) to detect bi-temporal urban land use change. Post-classification comparison is a comparative analysis of images obtained at different moments after previous independent classifications. It is the most obvious method of change detection, which uses a comparative analysis of spectral classifications for time periods t1 and t2 produced independently (Singh, 1989) with area changed being extracted through direct comparison of classification results (Jensen, 1983). Post classification approach provides "from-to" change information as the end result which can be used to derive the kind of land use transformations that have occurred in study area (Bauer *et al.*, 2005).

Table 3: Land use/land cover classes delineated (adapted from NNRMS classification Scheme)

S. No.	Class name	Detail / Definition
1	Area_Under_Construction	Area currently under land use transition into urban
2	Agriculture (Double Crop)	Area cropped during both rabi* and kharif* seasons
3	Dense Forest	Forest area with canopy cover range greater than 40%
4	Open Forest	Forest area with canopy cover range 10-40%
5	Horticulture Plantations	Area that refers to cultivation of fruits, mostly under irrigated conditions, associated with cropland and built-up areas.
6	Water bodies	Area with surface water, either impounded in form of ponds, lakes or flowing as streams, rivers etc.
7	Abandoned fallow	Cropland area left uncropped for many consecutive agriculture seasons.
8	Wasteland	Degraded land which can be brought under vegetative cover with effort and is currently unutilized and deteriorating for lack of water, soil management or other natural causes
9	Scrubland	Land generally prone to deterioration due to erosion. Possess sparse shrub vegetation.
10	Rural-Built-up	Smaller built-up area associated with agriculture and non-commercial activities with population size less than 5000.
11	Urban-Built-up	Notified town area of intensive use with much of land covered by structures with min. population of 5000, at least 75% of which is non-agricultural
12	Urban-Vegetated	Area dominated by vegetation cover midst urban areas.
*Rabi : Cropping season extending between November/December – February/March *Kharif : Cropping season extending between June/July – September/October		

A simplistic interpretation of the land use transformation via change detection method may persuade scientists to focus only on the largest transitions e.g. from cropland to urban which account for major part of landscape change, but a glance into the detail reveals other understated transitions which though not as large, are equally significant for sustainable urban planning. When aggregated, LULC changes significantly convey insightful data on the natural resources degradation. This study proposes employing the initial *'from-to'* information derived from change-detection to obtain a comprehensive natural resources status information by aggregation and reclassification of "from-to" change statistics into transformation categories. This process reveals the configuration of present landscape and captures the trends in land use dynamics, from which a future scenario can be perceived. The process of aggregation and reclassification of the multi-temporal *'from-to'* change detection information is relevant for prioritization of urban development in the human modified landscapes.

Prior to integration of temporal land use maps derived from visual interpretation, the mapped land use classes were aggregated into intermediate classes of Natural, Rural, Transitional and Urban to facilitate an expansive representation of natural resources degradation; with Transitional class containing degraded natural land use modifying into urban.

Temporal land use maps were integrated via post classification comparison procedure to achieve the 'from-to' land use change maps. A total of 64 no. of 'from-to' change classes were detected, examined and subsequently reclassified into four major *Transformation* classes of prime interest: *Gain, Loss, Loss-recoverable and Critical* as detailed below (Table 4).

Table 4: Four major land use/land cover transformation classes

"From" Class	"To" Class	Transformation class
Natural (*Dense Forest, Open Forest, Water-bodies*)	Rural	Loss-R
	Transitional	Critical
	Urban	Loss, Loss-R*
Rural (*Cropland, Plantations, Abandoned fallow*)	Urban	Loss
	Transitional	Critical
	Natural	Gain
Transitional (*Wasteland, Scrubland, Urban-vegetated*)	Urban	Loss
	Natural	Gain
	Rural	Gain
Urban (*Urban-builtup, Rural-builtup, Area_under_construction*)	Rural	Gain
	Transitional	Not Applicable
	Natural	Gain

*(in case of transition of Water-bodies or Forest into Manmade Grassland)

The transformation classes: *Gain, Loss, Loss-recoverable and Critical*, denote the significance of the individual land use change to the status of natural resources degradation and sustainable development of the landscape (Figure 6).

The class *Gain* indicates natural resources restoration e.g. forest regeneration on the fringes of protected forests or conversion of abandoned fallow / scrublands into croplands. *Loss* denotes degradation due to change of Non-urban to Urban land uses.

Loss-Recoverable class represents the currently modified non-urban land cover, which retains its recoverable quality despite of its urbanization and can contribute to sustainable city on being restored. Most of such conversion has been of water bodies on the city fringes into other manmade categories. This class can be recovered .e.g. natural depression of the lakes being used for agriculture and other land uses can be dredged to convert it back into lakes.

Special emphasis is on detecting the *Critical* category, which represents the natural and rural land cover converted into transitional land cover classes, on the verge of being modified to urban land use. These land cover (e.g. cropland, forest) have degraded over time and are under threat of being permanently converted into urban land use, after being marked unproductive by commons. This process has been popularly observed in case of the highly productive croplands which after being abandoned for long; convert into long fallow, then into wasteland and scrubland, which being considered unproductive is declared suitable for urban development.

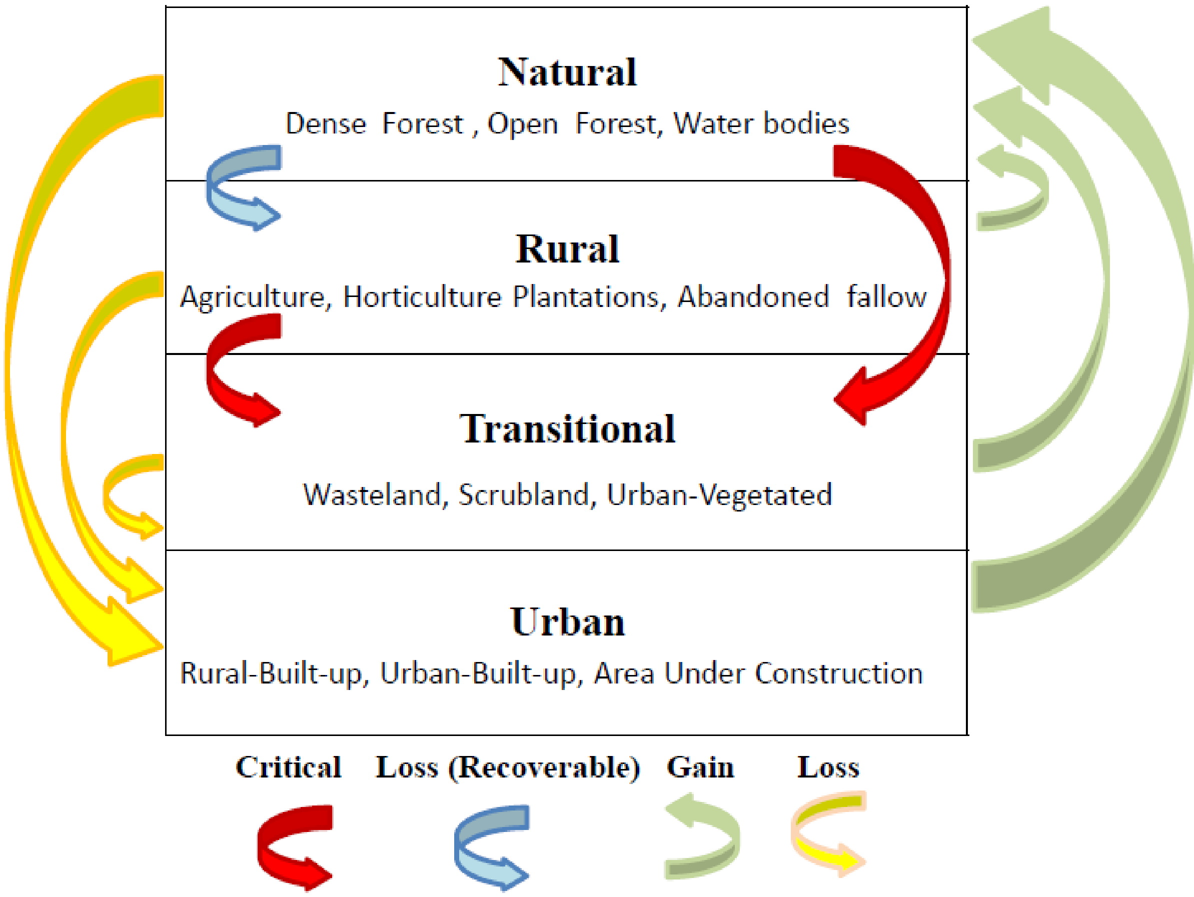

Figure 6: Four major land use/land cover transformation classes

4.2 Ancillary data collection: Ancillary data was collected from various sources and converted to GIS format. Following datasets were converted into separate thematic layers:

(i) Base maps of study area e.g. District Map, Road Map, Railway Map, Canal Network, Drainage Map were obtained from NIC (Uttar Pradesh)

(ii) Groundwater quality and quantity data from the regional office of the Central Groundwater Board (CGWB) located at Lucknow

(iii) Geomorphology and Soil texture layers were obtained from NIC (UP)

(iv) Digital Elevation model of the study area was downloaded from SRTM website and topographically analyzed to produce relevant layers

(v) Master Plan 2021, City Development Maps, Water Supply Sources, Slums locations, Sewer Trunk line locations etc. were obtained from several sources (Lucknow Development Authority, UP Jal Nigam, Urban Planning Department) and converted into referenced GIS thematic layers to be used for overlay procedures

4.3 Land capability and urban suitability analysis: In this technique, multi-criteria evaluation is used to combine a set of criteria to form a single suitability map using ARC GIS software. Land uses are grouped into designated number of classes according to their potentialities and limitations. The technique involves multi-criteria decision analysis (MCDA) using Weighted Linear Combination (WLC) method on relevant spatial layers of the area. A number of relevant soil and landscape criteria were identified through a review of the literature and their weights specified as a result of discussions with the experts. For the present study, Analytic Hierarchy Process (AHP) and Fuzzy Analytic Hierarchy Process (FAHP) has been used for obtaining weights which reflects the relative importance of various factors from matrix of paired comparisons. Resulting composite intersector capability map has some limitations but forms a useful physical base for decision making in land administration and planning. The purpose is to let the land indicate its inherent capability of use. In the present study LCA was used as an elimination tool for restricting the usage of class I agriculturally capable land for urban development depending on inherent characteristics e.g. soil, landscape parameter, groundwater and irrigation.

Land suitability analysis aims at providing a scientific basis for land-use planning, to achieve maximum socio - economic benefits at a minimum environmental impacts. For each spatial layer involved in the analysis, a set of relative weights for influential factors are developed. The suitability assessment for urban development focuses on identification of land suitable for future urbanization, in such a way that it does not adversely impact the environment and the impacts from land use change are minimum. The identification of potential sites involves the following broad categories of criterion:

Factors:

1) *Physical and Socio-economic characteristics:* Considers the physical and socio-economic suitability of a site in terms of urban development. Involves evaluation of soil, landscape and population factors critical to urban development.

   i.e. Agricultural Capability, Soil Group Texture, Existing Land use, Altitudinal Gradient, Ground water level, Geomorphology

2) *Spatial Infrastructure:* Considers the site's ability to provide services for sustainable urbanization. Measured in terms of distance to existing service centers and networks.

   .i.e. Road Network Buffer, Railway stations Buffer, Existing City Boundary Buffer

Constraints

1) *Natural Resources Sustainability:* Considers the effect of urbanization on environment, involves identification of environmentally sensitive zones .i.e. areas with fragile natural resources within reach of urban environment.

   .i.e. Proximity to conserved/protected forest, urban greenery, wetlands

2) *Urban Environment Sustainability:* Considers the long term sustainability of urban population in terms of public health and environmental safety, involves identification of hazardous zones .i.e. areas with public health or public safety hazards.

   .i.e. Proximity to solid waste dumps, Proximity to toxic/industrial areas, Proximity to flood plain

3) *Heritage conservation:* Considers preservation of historic and contemporary heritage sites, involves identification of heritage zones .i.e. areas with declared heritage structure

i.e. Proximity to heritage sites

Suitability score of a land use alternative for a defined land use goal is based on standardized criterion score x and priority weight W assigned to that criterion on basis of the chosen land use goal (urbanization). For a given set of priority weights, the best alternative land use is the one with highest final evaluation score of urban suitability value.

Table 5: Hierarchical structure for urban suitability with criteria and factors

Objective	Criterion	Factors
To select most suitable site for urban development	C1: Soil suitability	F11: Group texture
		F21: Agriculture capability
		F31: Sodicity
	C2: Landscape suitability	F12: Geomorphology
		F22: Slope/attitudinal gradient
		F32: Groundwater (depth and quality)
	C3: Infrastructure suitability	F13: Road connectivity
		F23: Rail stations and suburban railways
		F33: City development boundary
		F43: Sewerage systems
		F53: Water supply networks
	C4: Morpho-land use/ land use	F14: Greenbelt
		F24: Wetlands, floodplains and water bodies
		F34: Wasteland
		F44: Existing settlements
		F45: Open space

To select most suitable area for future urban development, a weighted linear combination method is used in combination with AHP and Fuzzy AHP for weighing of factors. In this study, factors are combined in weighted linear combinations. With a weighted linear combination, factors are combined by applying a weight to each, followed by a summation of the results to yield a total suitability map (Eastman and Jiang, 1995) for an individual land use category, i.e. Each land parcel is evaluated based on the degree to which its characteristic metrics [$t_{n,j_k,k}$] satisfy urban suitability/desirability on the measures of effectiveness of each metric [$m_{i_{j_k},j_k,k}$]. Then, the suitability values [$V(t_{n,j_k,k})$] are factored with the relative importance of factors associated with each criterion [$f_{j_k,k}$] and the relative priority of criteria on the objective [w_k]. With this approach, urban suitability is evaluated on the semi-absolute values instead of the relative values. The mathematical model supporting the evaluation of urban suitability is shown below.

$$\boxed{USV_n = \sum_{k=1}^{K} \sum_{j_k=1}^{J_k} w_k \cdot f_{j_k,k} \cdot V\left(t_{n,j_k,k}\right)}$$

where

USV_n : Urban suitability value of land parcel (n) determined according to land's capability

w_k : Relative priority of criterion (k) with respect to the urban suitability

$f_{j_k,k}$: Relative importance of factor (j_k) with respect to criterion (k)

$\sum_{j_k=1}^{J_k} w_k \cdot f_{j_k,k}$: Relative importance of factor (j_k) with respect to the objective

$t_{n,j_k,k}$: Land use suitability (n) along with factor (j_k) for criterion (k)

$V(t_{n,j_k,k})$: Desirability value of the land use (n) along factor (j_k) for criterion (k)

The weighted linear combination is repeated for each land use category separately to create a suitability map with a standardized value range per cell. For each suitability map, a five equal interval classification (cell range : 0 - 4) between the minimum and the maximum cell values calculated is employed i.e. assigning the five ranges in an increasing order to very low, low, moderate, high, and very high, respectively. The resultant raster maps are thus received.

4.4: Conflict Analysis: Conflict analysis explores the disagreements between derived urban suitability and city Master Plan 2021. The urban suitability maps (using AHP and FAHP) are overlaid with city Master Plan 2021 using summary function, which produces cross-tabulation statistics that compare class value areas between two thematic layers. The conserved / restricted area map when overlaid on digital layer of Master Plan 2021 of the Lucknow city highlighted various conflicts between planned future development and restriction preferences recommended in the study. Potential zoning conflicts included planned residential areas and supporting infrastructures (transport network, greenbelt and open spaces, agricultural areas etc.). Urban suitability maps are used as zone layers, with individual suitability classes acting as analysis categories. Statistics for each of these categories is calculated on the basis of the occurrences of classes from the 'class' layer, in this case the Master Plan 2021 layer.

5. Results and discussions

5.1 General urbanization patterns

Pattern of urban growth in Lucknow city as explored by the study is not linear or nodal. Urbanization seems to spread radially in all the directions and influence of transport infrastructure is minimal. Drivers of such changes are many and very site specific. Some areas have developed out of older city core, but others developed out of new industrial zones. In the study area two major land use/cover trends between 1997 and 2009 can be discerned: *(i) Intensification of urbanization in central/core areas where a few remaining open areas and water bodies were occupied and landfilled to accommodate residential developments; (ii) Urban expansion in peri-urban/ suburban areas, where the extension of urban core increased at the cost of permanent crops and pastures.*

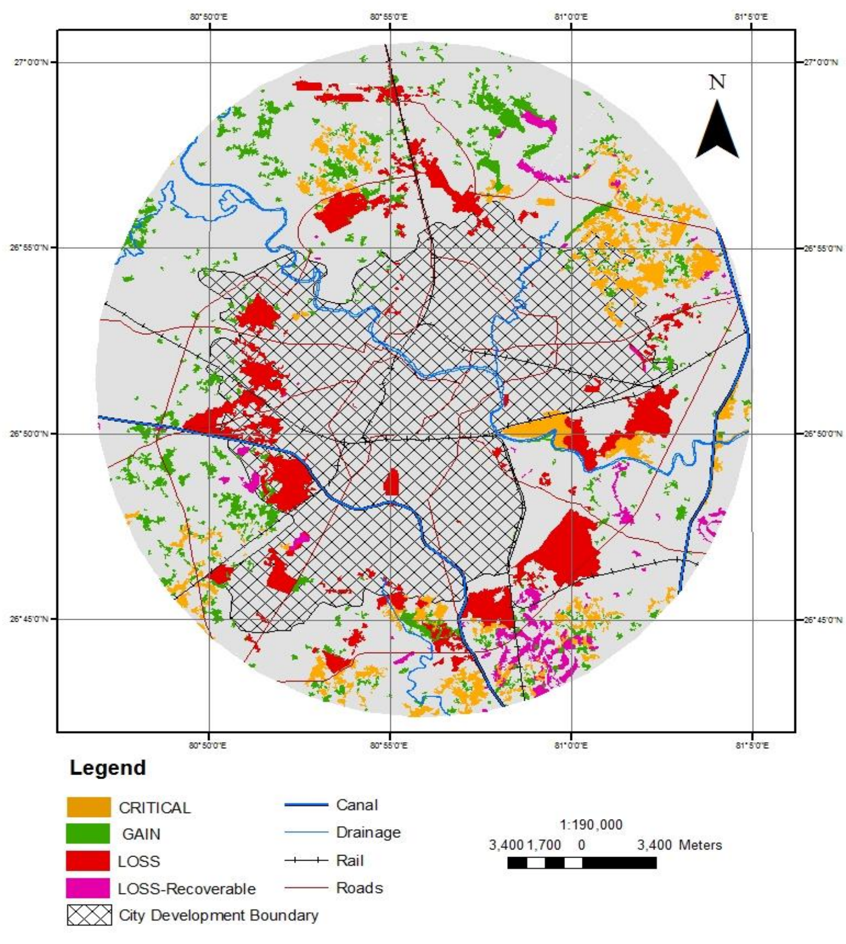

Figure 7: Spatial occurrence of land use transformation categories – from 1997 to 2009

Due to peri-urban land takeover by urban development agency, competition for land between real estate developers and nonurban users, mainly farmers and other agricultural users, have increased tremendously in the last decade. For the city to grow spatially, public and private developers bid away additional land from agricultural users in the peri-urban areas. Increased demand for housing and commercial space means that land is worth more in urban use than in agriculture, thus reflecting greater economic benefits in its developed state. According to Brueckner (2000), land conversion in such situations is guided by the 'economist's "invisible hand," which directs resources to their highest and best use'. In this process productive agricultural land is often converted into urban land use. As the value of agriculture output is fully reflected in the amount that agricultural users are willing to pay for the land, a successful bid by public and private developers means that society values the houses and other structures built on the land more than the agriculture output that is forgone.

As the city's population expands, it must grow spatially to accommodate more people. In addition, people's rising incomes and quality of life concerns affect urban growth because residents demand better housing conditions and more living space as they become richer over time. The greater demand for space causes the city to expand spatially as the population increase. This effect is further reinforced by the 'urban-social-aspirations' to expand and buy additional lands for their housing needs in a location where land price is cheap, mainly the peri-urban areas. Therefore, the spatial expansion due to rising incomes and quality of life concerns among the residents is strengthened by a price incentive favoring urbanization along the city's periphery.

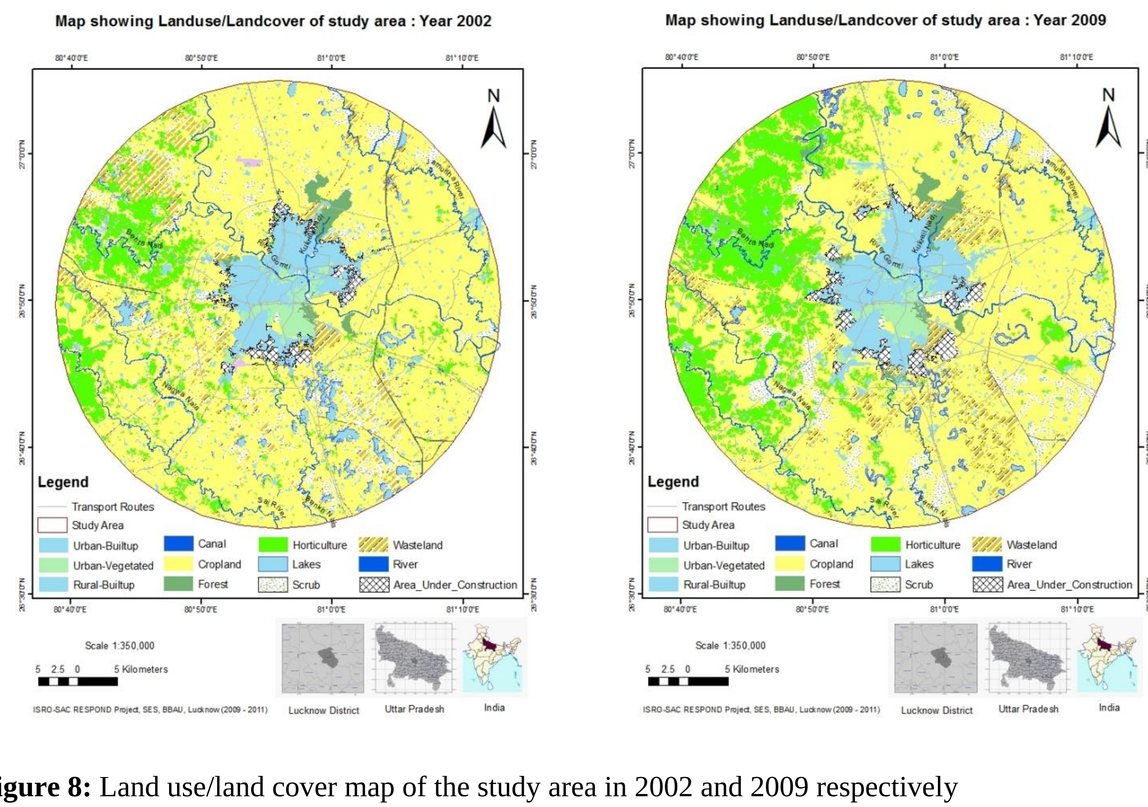

Figure 8: Land use/land cover map of the study area in 2002 and 2009 respectively

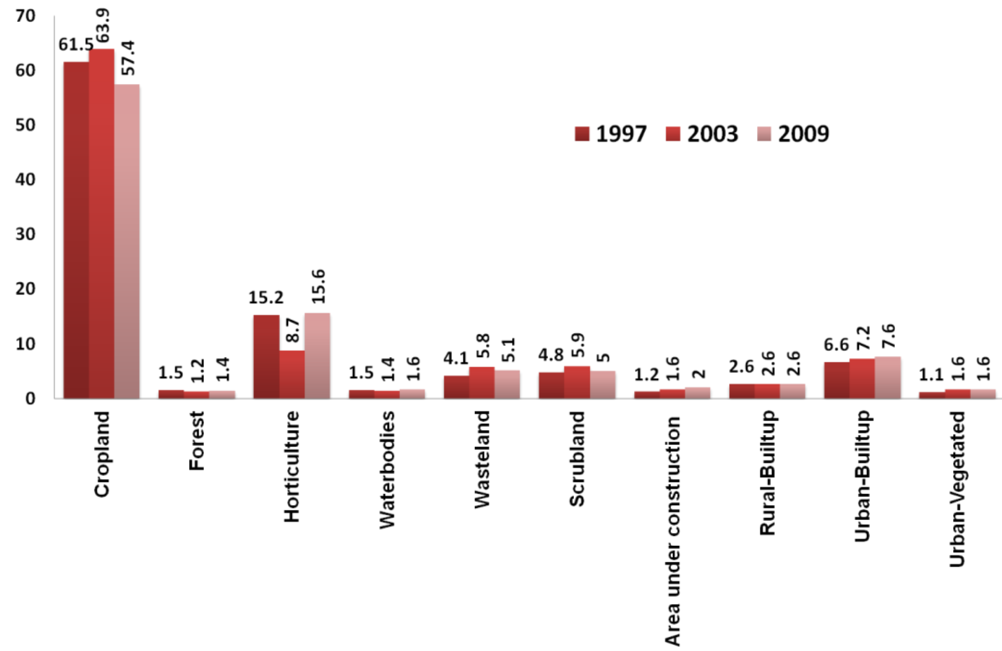

Figure 9: Percentage share of different land use categories in the study area from 1997 to 2009

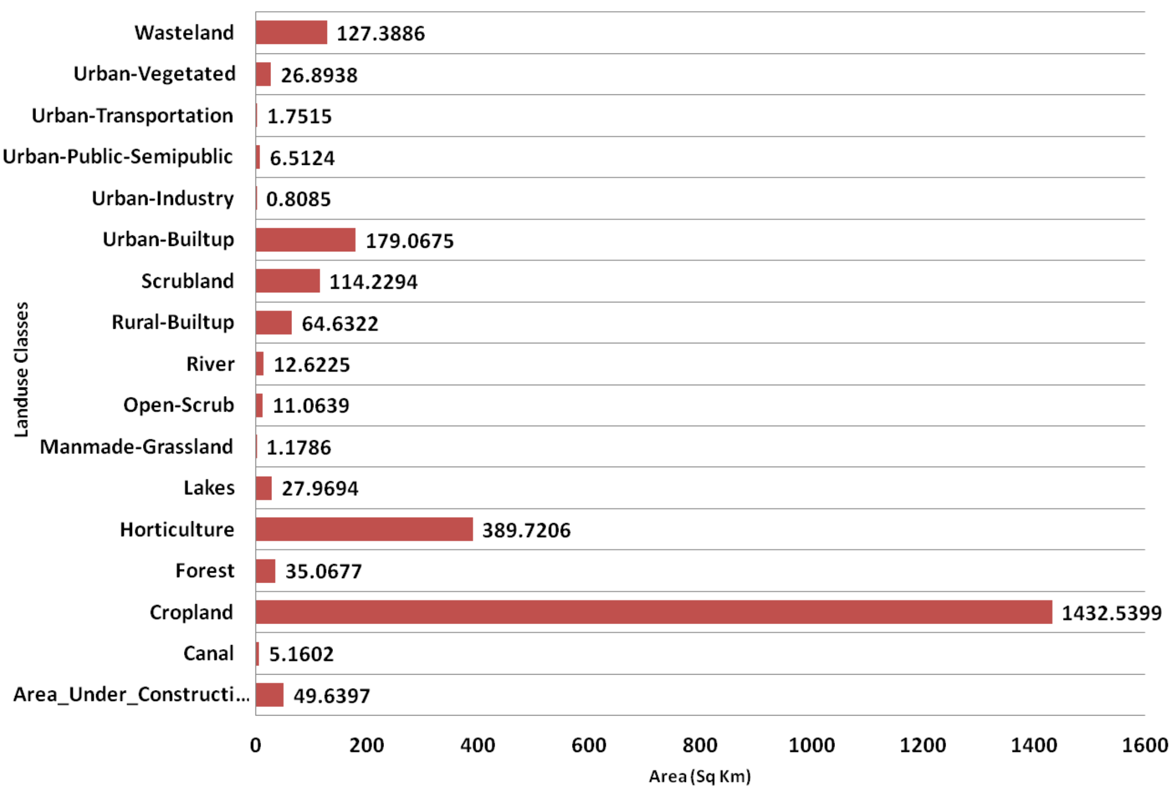

Figure 10: Land use statistics in the year 2009

5.2 Spatial expansion of peri-urban sites

Within the vast peri-urban area, study focuses on sites located in four suburban areas which differ in their individual demographics and economics, resulting in dissimilar land use mosaics. These four sites are: Bakshi ka talab in North, Chinhat area on North East, Uterethia on South and Dubagga in Northwest. All the four sites, falling on the periphery of the city contain a mix of rural and urban land use, along with some land uses like quarrying/mining which are particularly associated with PUI and land transformation activities. The LULC changes of these test sites were observed from year 1997 to 2009 and relative differences of individual sites were analyzed to unveil the change pattern and ultimately link these patterns to land transformation process. A short description of these sites is provided below:

(a) ***Northern site*** is located in Bakshi Ka Talab, a suburban town in Lucknow district, connected to Lucknow City via National Highway 25 which further leads to the neighbouring Sitapur City. The area has been primarily agriculture-intensive and has been experiencing significant urban development with increasing number of educational and research institutions coming up in the area.

(b) ***North-Eastern site*** located in Chinhat Area is situated on National Highway 28, around 15 km from Lucknow city connecting it to Faizabad city. The site is situated between the National Highway and River Gomti and has a railway route running through it. The area has been agriculture- intensive with very fertile croplands due to proximity to river Gomti and presence of canal network. Owing to its numerous industries, the area has is the industrial hub of city and has been experiencing significant development since a decade owing to establishment of new industries and some higher-education institutions.

(c) ***Southern site*** located in Uterethia-Amausi area is situated 15 km from Lucknow city centre and is surrounded by National Highway 25 connecting to Kanpur city on one side and National Highway 24B connecting to Rai Bareilly City on other side. It is a transportation hub due to the presence of Amausi international airport. The area has been historically marked by presence of numerous ponds/ lakes, vast scrublands and numerous sporadic clusters of plantations. The area is currently experiencing rapid development due to several real-estate development plans under implementation.

(d) ***Northwestern site*** located in Dubagga-Alamnagar area is situated 12 km from the city centre and has two major roads and northern rail route passing through it. State Highway 40 connects Lucknow to Kannauj, finally leading to Agra and State Highway 25 connects Lucknow to Hardoi via Malihabad. The area though being dominated by agriculture has a significant amount of plantations on private lands which have been steadily increasing.

Results from the change detection analysis reveal that urban land use increased post 1997 in the peri-urban areas over with an average annual rate being 13% (Figure 11). This observation can be supported by the following table which shows major land use transformations marked in bold – Rural to Urban being 41.91% of total change. As indicated by the figures below and Table. 6, Rural to Urban and Transitional to Urban are the main transformations observed by the study, which is quite obvious given the rapid urbanization of area. *Although the allocation of land is governed by competition between urban and agricultural uses, the outcome has increasingly tipped in favor of urban use, leading to substantial spatial growth in peri-urban areas.*

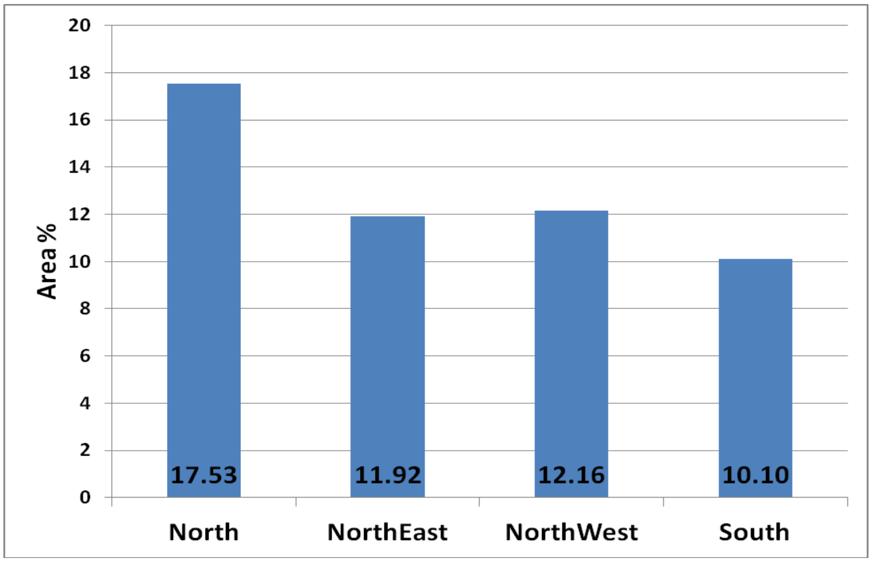

Figure 11: Growth rate of urban land use in peri-urban areas between 1997 and 2009

Table 6: Land transformation from 1997 to 2009 at four peri-urban sites showing transformation classes

"From" Class	**"To" class**	**Change (2002-2009)**	
		Area	**%**
Natural	Rural	0.22	*0.63*
	Transitional	1.46	*4.24*
	Urban	1.43	4.16
Rural	Urban	14.46	**41.91**
	Transitional	4.36	*12.64*
	Natural	0.29	0.84
Transitional	Urban	9.47	**27.45**
	Natural	1.29	3.74
	Rural	1.35	3.90
Urban	Rural	0.02	0.07
	Transitional	0	0
	Natural	0.14	0.42

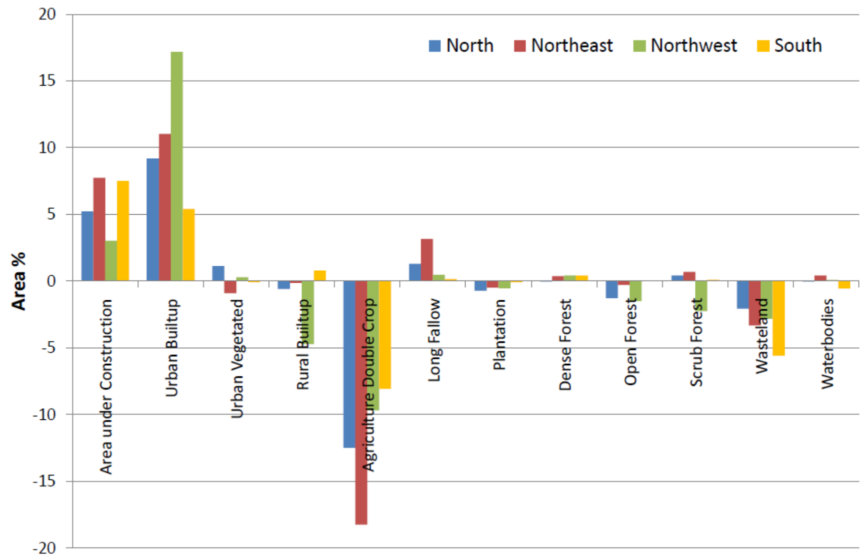

Figure 12: Change in land use (%) in four peri-urban sites of the study area

Of importance to the study are *other* categories (marked in italics in the Table 6), specifically the *rural to transitional* and *natural to transitional* which together contribute a fair 16.84 % to the LULC change and are placed in the transformation category of *Critical*. This *Critical* category is generally the result of land cover degradation and is prevalent in peri-urban areas on brink of being urbanized. With existing open areas in city core and a possibility of giving vertical expansion to urbanization, this category can be saved and reconverted to its original state of sustainable land cover.

Also important is the observation of a small but significant amount of change (7.64%) from *transitional to natural* and *transitional to rural*, mostly observed in the study as conversion of wastelands into croplands, which confirms that above reconversion is possible and takes place naturally also, although at much smaller percentage than required.

Detailed results from the study reveal that urban land use for all four sites has increased over the study period (year 1997 to 2009) with the largest growth of 17.5 % being observed for Northern site and lowest of 10% for Southern site. On an average, more than 70% of the total land use /land cover change has been towards the transformation category of *Loss* towards urban land use, there has been practically negligible amount of *Gain* and an insignificant amount of *Loss-recoverable*. Only the *Critical* class holds some hope especially for Northern and North Eastern sites where more than 20% of the total land use is in *Critical* stage.

4.2. Spatio-temporal patterns of land transformations during urbanization

When considered individually, the land use change statistics of study sites reveal important details about current socioeconomic processes dominating the area and their drivers. As is revealed from the statistics, there are four classes displaying significant land transformation; *Agricultural cropland shows major decrease, urban built-up shows major increase, wasteland shows moderate decrease and area under construction shows significant increase; all other land use classes exhibit relatively insignificant change.*

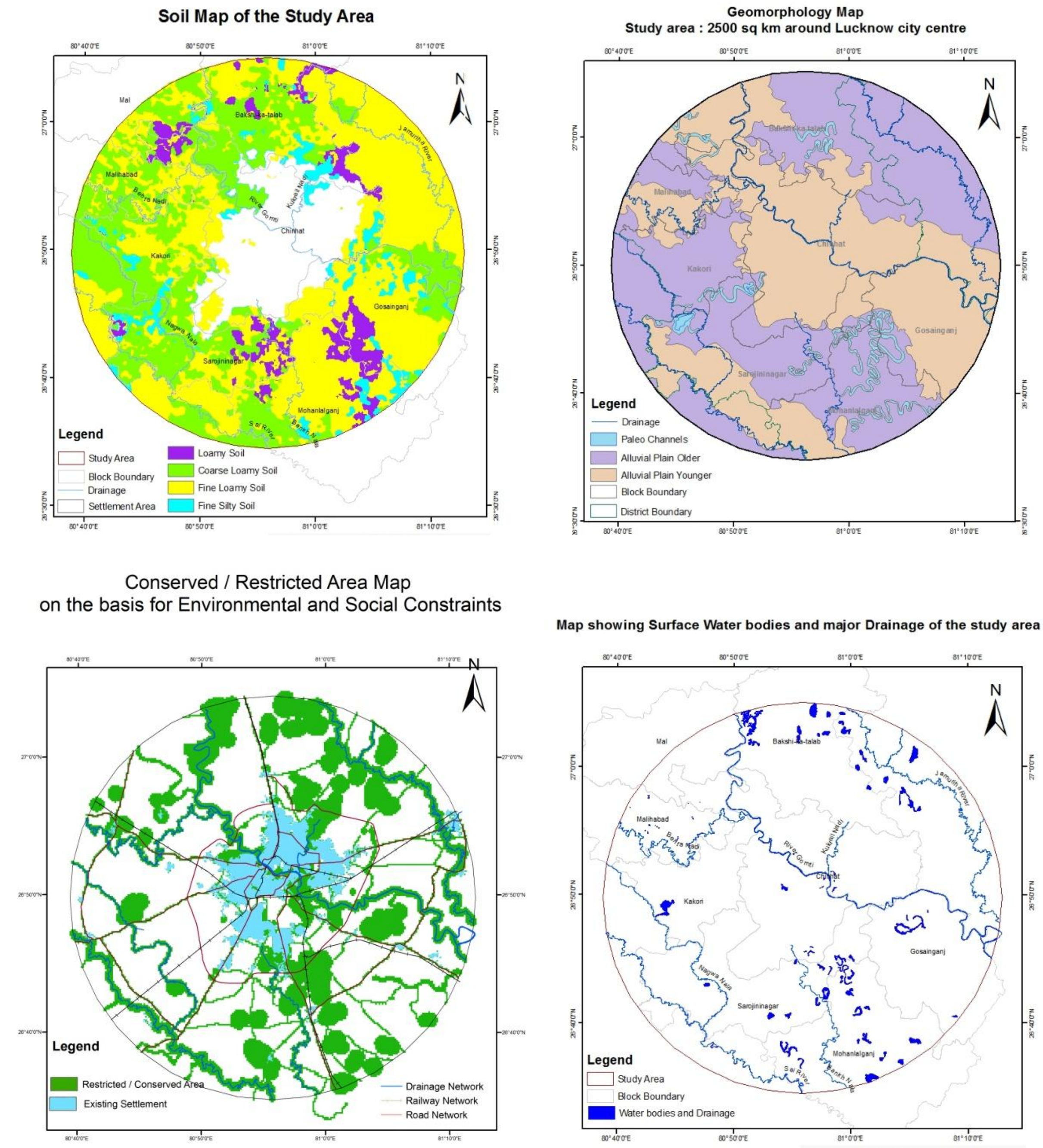

Figure 13: Thematic layers of soil, geomorphology, greenbelt and conserved areas and drainage used for overlay analysis

It is observed that site along the Northwestern direction (enroute to suburban Malihabad town) has experienced maximum amount of relative increase in urban built-up (17.18%), with a simultaneous decrease in rural built-up (4.71%), wherein the latter seems to have merged with extending urban land use. This finding is unexpected, as it was anticipated that this area would experience least urban growth due to its location along state highways, as opposed to location of other sites along national highways and absence of adjacent major industrial town as opposed to North east (adjacent to Barabanki) and South (adjacent to Kanpur). The site also shows a significant decrease in cropland (9.68%) and wasteland (2.82%), indicating the conversion from these classes to urban land use. Surprisingly, this site displays minimum area under construction (3.04%) amongst the study sites; indicating a reduction in rate of future urbanization and pointing towards occurrence of a probable land speculation prevalent in recent past which may have spurred the observed urbanization.

Decrease in cropland area (18.25%) is observed to be maximum in North-eastern site, which falls along the Lucknow-Barabanki national highway. The area is intensely industrialized, with increasing number of unplanned factories/industries. Capacity of existing environmental infrastructure in the area for sewage, industrial and solid waste management is inadequate, spelling serious environmental deterioration. The site displays maximum amount of area under construction (7.72%), a significant increase in urban built-up (11.02%) and fair decrease in cropland. The area also shows a significant amount of area under long fallow (3.15%), indicative of a trend where farmers leave their cultivable land fallow, waiting for urban development opportunities and in event of selling their land towards urban development, gain compensation used to develop farmlands further from city. For these farmers, the uncertainty of when exactly the land might be taken over by urban structures is too great to make it worthwhile continuing with serious, intensive agricultural production. This explains the widespread abandoned fallow or unutilized land found around many expanding cities (Berg *et al.*, 2003).

Southern site, falling on Lucknow-Kanpur route, displays a marked decrease in wasteland (5.59%) and cropland (8.08%), with a simultaneous increase in area under construction (7.51%) indicating an increased rate of future urbanization. A careful observation of initial (1997) and final (2009) images of the site, reveals that most of the defined wastelands are being used for real-estate development. *Southern site alone shows a decrease in water bodies, owing to the fact that this area was marked by presence of numerous big and small water bodies in past, which have been transformed to agricultural uses or land filled for real estate development.*

Northern test site displays significant decrease in most rural land use classes; Cropland (12.50%), Wasteland (2.07%) and Open Forest (1.28%) with a simultaneous increase in urban built-up (9.17%) which is understandably due to urbanization (Fig. 4). *The transformation class of area under construction (5.21%) also shows significant increase indicating a continuous urbanization in future.*

4.3. Relating spatio-temporal patterns to ecological processes

As per the highlights of transformation statistics (1997 to 2009), 95 % of *Critical* category comprises change from croplands to wasteland/scrubland. Also observed is an insignificant for now (0.04 %) conversion of forest into urban vegetated wherein *open forest patches on city fringes degrade rapidly as expanding settlement approaches them*. These open forests are soon converted into urban-vegetated class which is vegetation interspersed with urban built-up, feared to be quickly engulfed by densification of the city. Also, 75 % of *Loss-recoverable* category accounts for change of lakes into cropland and horticulture, wherein water bodies have been landfilled and are being used for agriculture or plantations.

Site specific observation of *Critical* land transformation category, reveals that at Northern site, *Critical* category is being formed by conversion of four rural land use classes, out of which conversion from cropland is maximum (63%), followed by a substantial 28% being formed by conversion of forest to urban-vegetated. *This observation is alarming, making this site fragile, since presence of forest on a city periphery is already rare and its being lost to urban land use means extensive loss of natural habitation with severe threat to the remaining areas of core natural forest.*

Other sites cannot boast of such strong natural land cover class but the presence and hence loss of water bodies in Southern site is also alarming, making it a fragile area as well. Decreasing croplands have their own serious implications as unnecessary loss and degradation of prime agricultural land through urban expansion can be deteriorating. As observed, North Eastern area exhibits the change of maximum amount of cropland into transitional category.

4.4 Relating urban accessibility, spatio-temporal land use patterns and developing urban form

In studying interactions between human and ecological processes, considering solely the aggregated interactions cannot help explain the outcomes. A complex set of social, political, economic, and biophysical factors drive urbanization and affects when, where, how, and at what rate urban development proceeds (Alberti *et al.,* 2003).

The environmental and social problems associated with peri-urban sustainability initiates the idea of possible influence of urban accessibility on spatio-temporal land use patterns and the ensuing urban form. Initially, urban accessibility seems to be a consequence of population and employment geographical distribution, whereas in long term, accessibility turns out to be an important factor in determining urban form (Miralles, 1997).

The present study observes that the relationship of urban accessibility with spatio-temporal patterns and ensuing urban form exists but is relative and not the only causal factor. This fact has been explored by relating the statistics of spatio-temporal LULC the transport infrastructure of area.

LULC change does not follow a general pattern across all the sites. The spatial expansion appears to be very complex, depending upon not one or two but a number of varying factors. In North Eastern site, the change (mostly *Loss and Critical*) appears to be closer to and along City Development Plan (CDP) boundary, not much dependent on National Highway passing through just middle of the site. In Northern site too, National Highway does not apparently play the only important role as the change (*Loss, Critical and Gain*) appears to be radially extending outside along the CDP. The influence of transport routes is also absent in the Southern site which is bounded in two sides by important highways. The change (mainly *Loss*) appears to be along the third boundary collinear to the existing urban zone and extending outwards.

In North Western site, the influence of state highways is visible, as the change (mostly *Loss*) is concentrated along the two major roads, towards Malihabad and towards Kannauj with more urbanization noticeable along the road to Kannauj. The reason seems to be the presence of lucrative horticulture-enterprises along the Malihabad road, which might stop the marginal farmers who sell their lands to real-estate and other urban developers.

Two main physical processes seem to be driving urbanization in the study sites at the peri-urban interface:

- Urban growth in three peripheral sites (N, NW and S) is occurring through *Envelopment*: annexation of surrounding landscape through the growth of existing urban areas (Seto and Fragkias, 2005). *Since the study area is primarily dominated by agricultural land, urban growth through 'envelopment' is happening mostly at the expense of such cultivable lands.*

- Urban growth in North Eastern site is occurring through '*Attainment*' – occupation of small built-up clusters (mostly rural) dispersed in landscape by extending urban areas. Attainment seems to be the direct result of improvement in accessibility due to development of transport infrastructure. Rural settlements located amidst predominantly agrarian areas are urbanized when major roads pass through them and the urban development along these routes intensifies to engulf them. Along with the economic development and ensuing urbanization, an impetus on improvement of major transport routes is obvious. Accessibility to the far flung townships and villages have led to development of hitherto underdeveloped areas on fringes of the city, which welcome the conversion of rural land for upcoming industries and educational institutions requiring vast unutilized land resources and spelling major financial gain to marginal farmers.

Thus, pattern of urban growth in Lucknow city as explored by the study is not linear or nodal. Some areas have developed out of older city core, but others developed out of new industrial zones. In the latter case, the lack of transport infrastructure has not inhibited the development and nor is the direction of development controlled by presence of transport routes as observed in earlier studies (Taragi, 1997). A large chunk of urban middle class prefer cheap housing in the suburbs even when there is not enough transportation infrastructure. Many people buy land in such areas from investment point of view as they know that land price would go up substantially once the area is earmarked for housing in the future. As a result, peri-urban locations look increasingly investment attractive, which leads to spatial growth of the city.

It is evident from the conflict analysis that the Master Plan 2021 is conflicting from the zoning restrictions recommended by suitability analysis, the restricted/conserved areas recommended by the study are certainly in conflict with the planned future development. Of the total area of the conserved, greenbelt, reserved forests and floodplain as per the defined land suitability class, 4.18% of the area has been converted into existing builtup/settlements whereas 46.36% of the total area is proposed under residential settlements, business districts and commercial land use under the Master Plan 2021, 11.84% under transportation network and 5.11% under agriculture. Therefore, with the process of urban sprawl in the core and at the peri-urban interface, conserved area such as greenbelt, reserved forests and floodplains are threatened and will be rendered fragile.

It is evident from the analysis that the majority of area (more than 80%) has weak or very weak suitability for future urban development primarily because of the high conservation and agriculture suitability and incompatibility of physical land use to enabling infrastructure. As per the land use statistics of 2009, high value class I agriculture land and horticulture fields form 57% and 15% of the area respectively. Therefore, converting them to urban land use will affect future food sustainability badly. Around 20% of the area, i.e. 500 sq. km. has moderate suitability whereas about 2% (50 sq. km.) of the area has high suitability for urban development. Since out of the 2500 sq. km, about 303 sq. km. has already been under active urban land use including the denser urban core, *any future urban land transformation should be done very carefully taking into account the zoning regulations and importance of open space, greenbelt and class I agriculture land.*

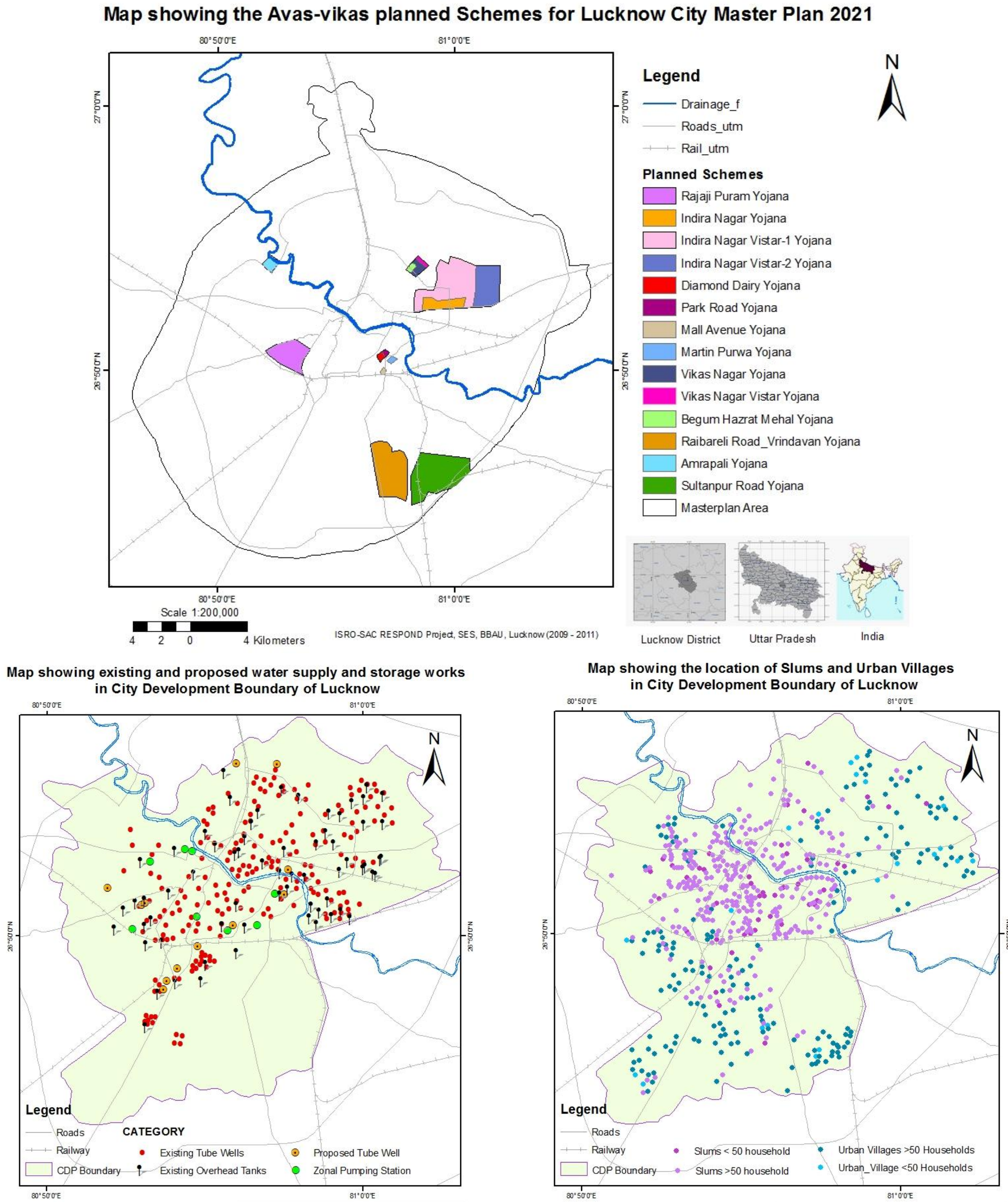

Figure 14: Maps showing planned housing schemes, existing and proposed water supply networks and slums and urban villages in the city development boundary

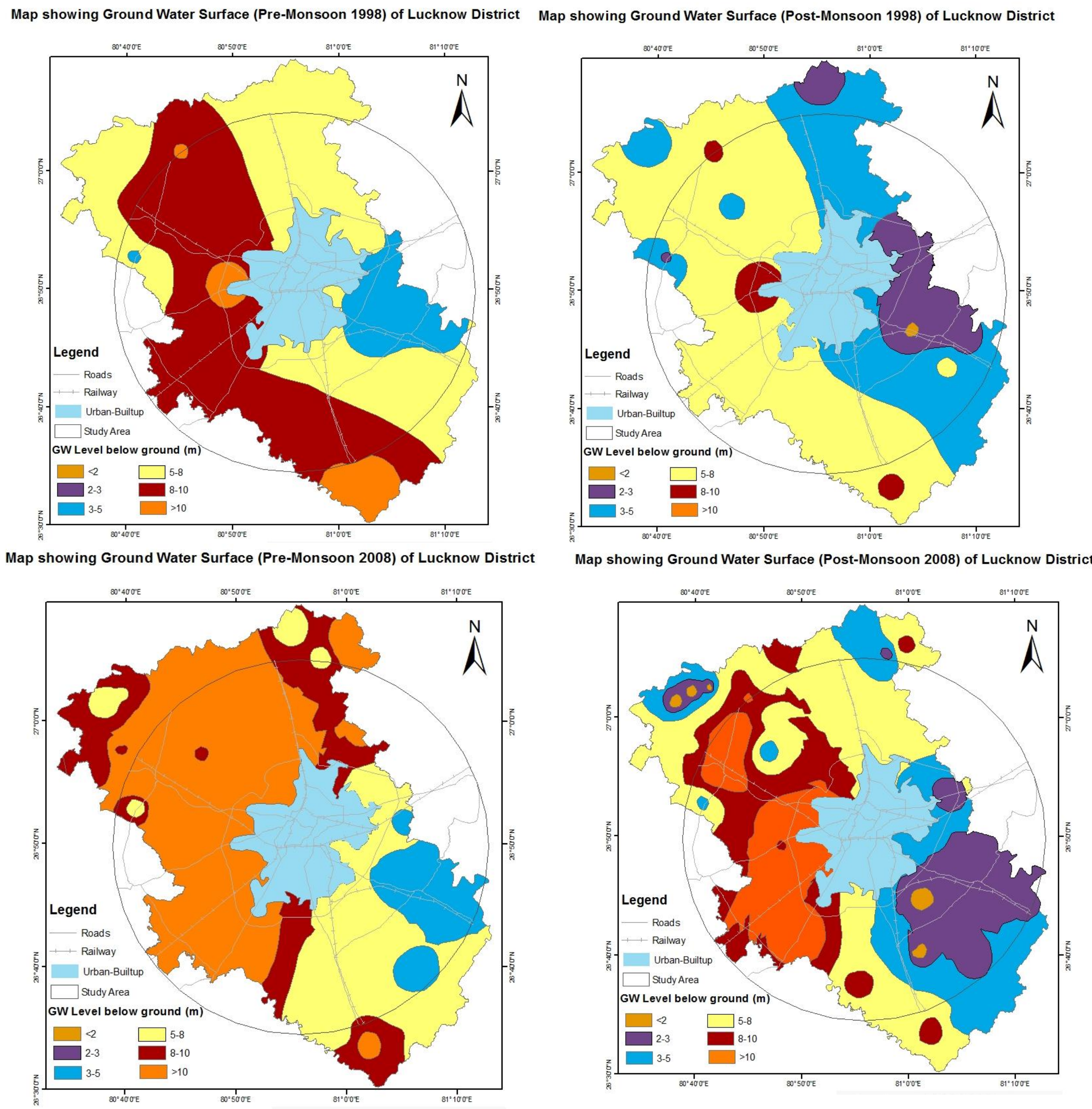

Figure 15: Maps showing decline in groundwater table during 1998 – 2008 in the study area

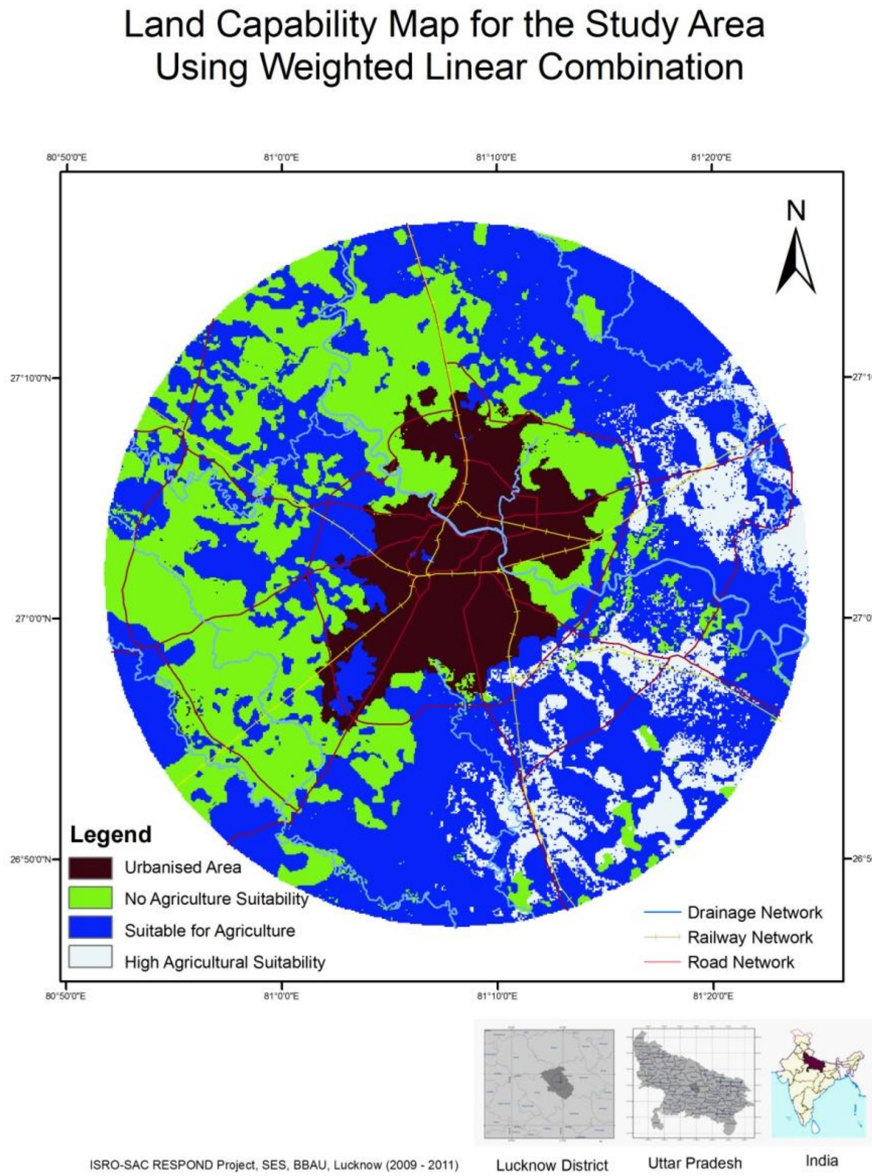

Figure 15: Land capability map of the study area using weighted linear combination method

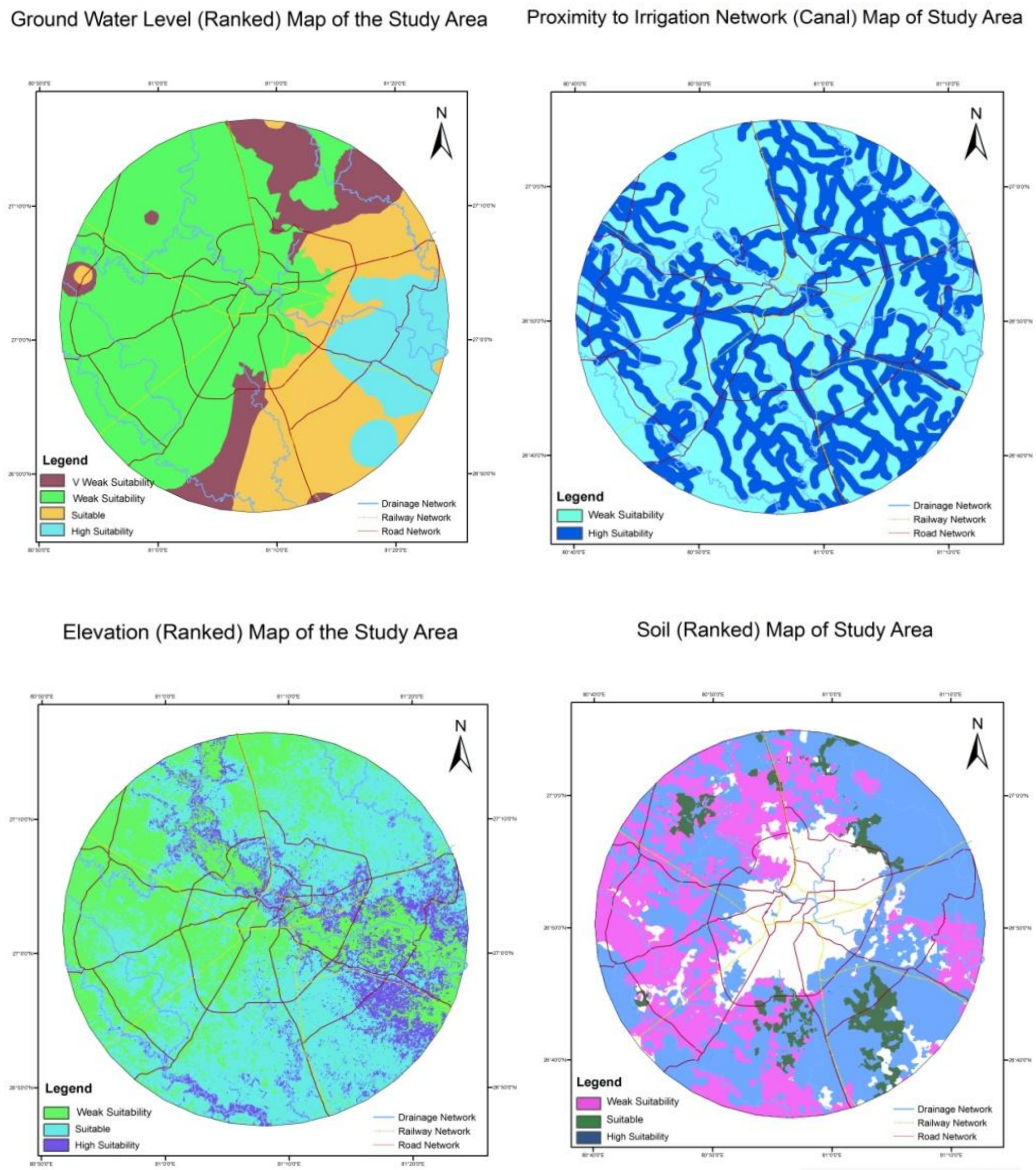

Figure 16: Ranked maps for groundwater level, irrigation network, gradient profile and soil for the study area

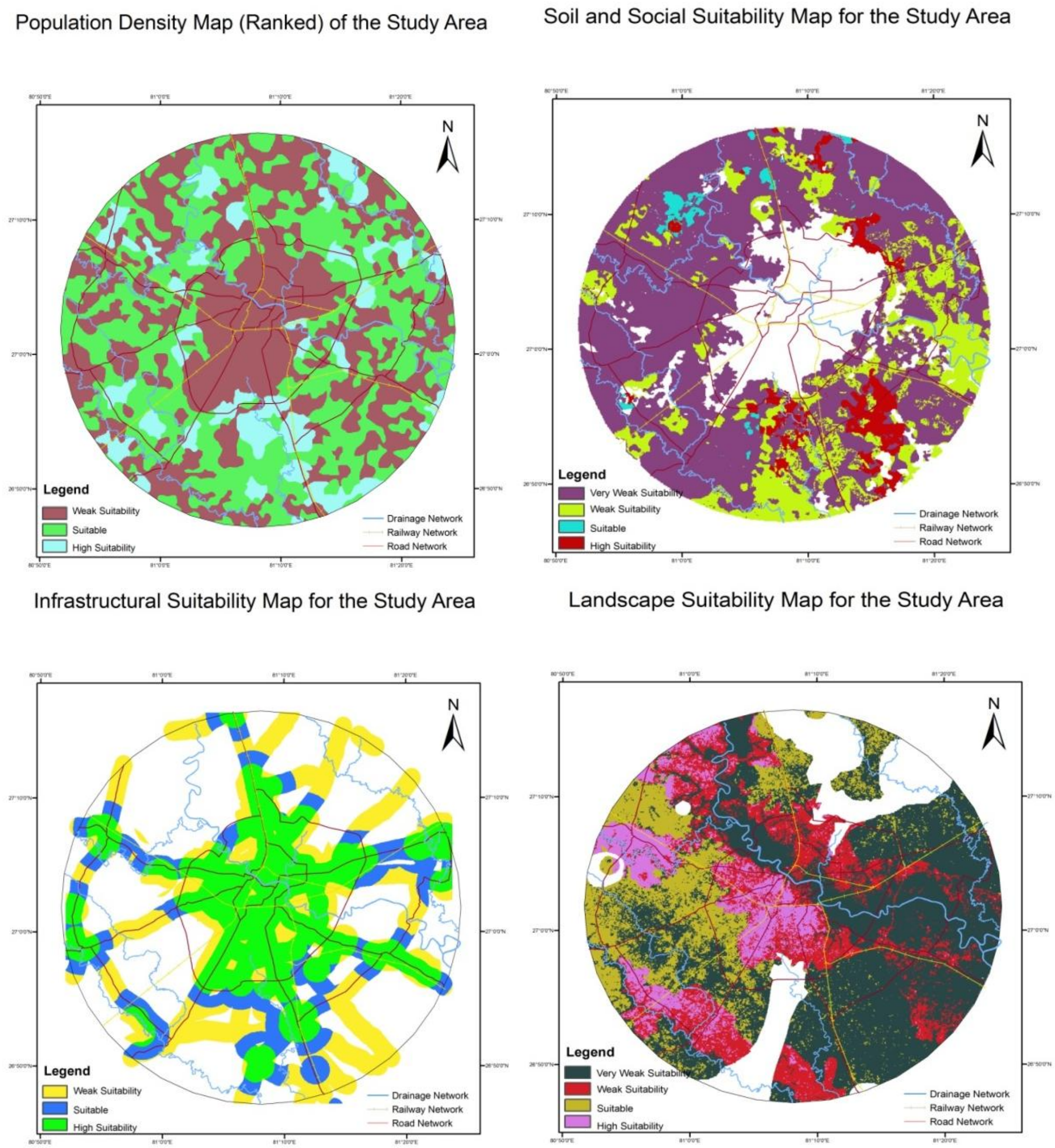

Figure 17: Maps showing population density, soil, infrastructure, and landscape suitability in the study area

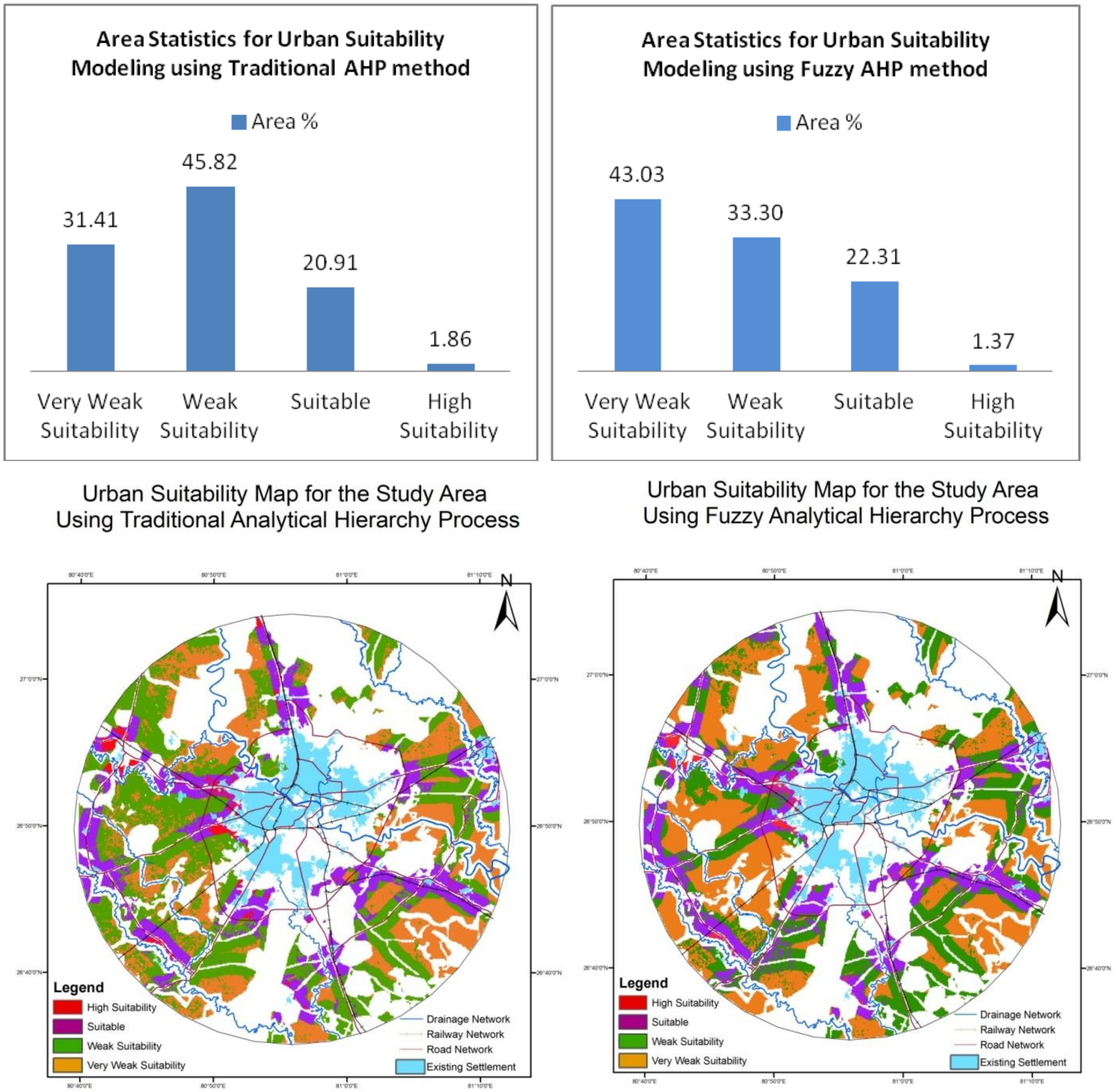

Figure 17: Urban suitability maps and their corresponding area using traditional AHP and Fuzzy-AHP method

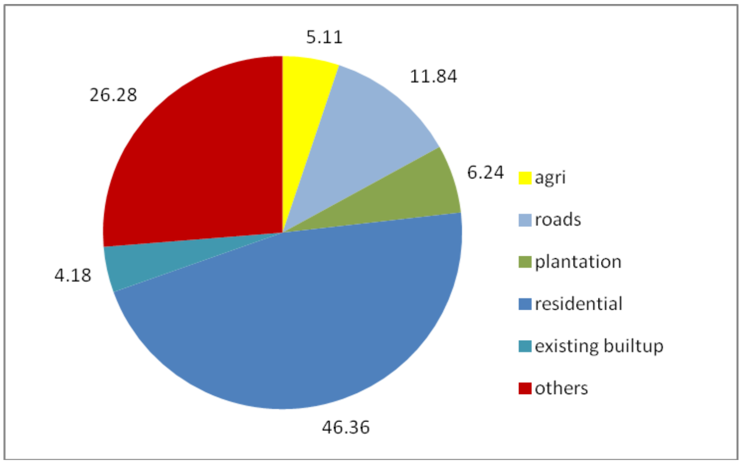

Figure 18: Conserved, Greenbelt and Reserved Forests Conflict Statistics with the Master Plan 2021

6. Conclusion and policy implications of the study

This paper quantitatively explores the spatio-temporal patterns of land use/land cover transformations in the core and along the city periphery of Lucknow city, the capital of India's largest state, in addition to observing nature and form of urban expansion resulting in a complicated urban landscape. Conflict analysis is carried out to explore disagreements between urban suitability, enabling infrastructure and Master plan 2021 proposed by the land authorities using satellite imageries, Fuzzy AHP and sub-models. The paper also investigates significant and broad-based trends of land use/land cover change in urban and peri-urban areas and focus in particular, on the degradation of the preferred land use types, brought about by these changes. The methodology provides a cost effective rapid land evaluation framework which may help policy makers, urban and regional planners and researchers working in developing countries to understand the dynamics of urban growth.

It is observed that due to rapid economic development, the city has expanded in size and structure, becoming increasingly more complex, heterogeneous and irregular in shape. Development has been muddled in peri-urban areas, causing natural and rural land cover to degrade over time and the trend suggests more such degradation in coming years. The land developers tend to be disconnected from the realities of resource limitations and largely inattentive to the long-term impacts of land use modifications. Natural land covers like forest and water bodies are experiencing major deterioration rendering some of the PUI sites as fragile. Each of these impacts is linked to changes in the extent of urban, agricultural, and forest lands, and (or) transportation, housing and other critical infrastructure systems. This process will continue with time if not checked through proper intervention and strict planning measures and can adversely impact the quality of life of urban and peri-urban dwellers.

Although urban sprawl cannot be stopped in a rapidly developing city, a remedy for this problem lies in strict zoning regulations based on land suitability and carrying capacity, which allow land use to be channeled toward more sustainable outcomes. Detailed observations of transformation category statistics reveal that although the pace of urbanization will grow up in the future, a significant amount of recoverable land cover presently under transformation (denoted by *Critical* class) can be restored and focus of development can be shifted on underutilized areas within the city development boundary. It is also suggested that older urban areas with dense horizontal urbanization can be considered for urban redevelopment using vertical urbanization methods. Primarily, unplanned and unfocussed urbanization, not considering the suitability of land cover or its environmental impacts/aesthetics should be discouraged in order to promote healthy and livable cities. Results from urban growth models can be used by land use planners and policy makers to anticipate and plan for future spatial expansion to ensure growth along the lines of city development plans and enabling infrastructure.

Acknowledgements

Funding support from Space Application Centre, Indian Space Research Organization (ISRO-SAC) under RESPOND project is greatly acknowledged. Late Dr. S. K. Pathan, Dr. Jayaprasad and Prof. M. Yunus are acknowledged for helping me at various stages of the analysis and for providing generous feedback and suggestion in improving the outcome of the project.

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Annexure 1

Table: Fuzzified values of pairwise comparison matrix (PCM)

Crisp PCM Value	Corresponding Fuzzy PCM value	Crisp PCM Value	Corresponding Fuzzy PCM value
1	(1,1,1) if diagonal; (1,1,3) if otherwise	1/1	(1,1,1) if diagonal; (1,1,3) if otherwise
2	(1,2,4)	1/2	(1/4,1/2,1)
3	(1,3,5)	1/3	(1/5,1/3,1)
4	(2,4,6)	1/4	(1/6,1/4,1/2)
5	(3,5,7)	1/5	(1/7,1/5,1/3)
6	(4,6,8)	1/6	(1/8,1/6,1/4)
7	(5,7,9)	1/7	(1/9,1/7,1/5)
8	(6,8,10)	1/8	(1/10,1/8,1/6)
9	(7,9,11)	1/9	(1/11,1/9,1/7)

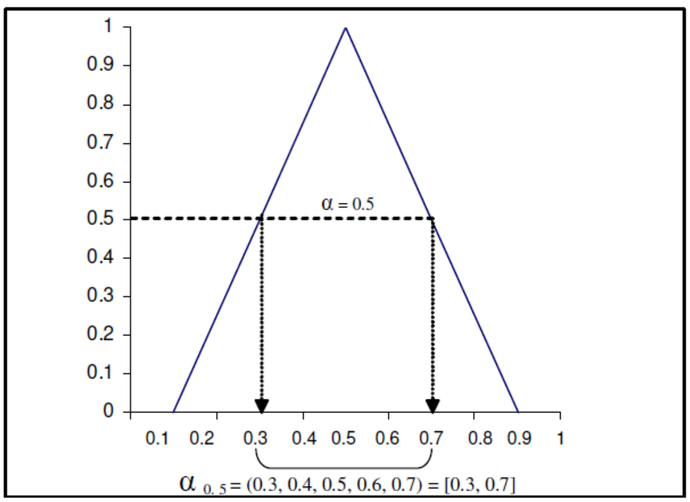

Figure: Alpha cut operation on triangular fuzzy number

Pair wise comparison matrix for criterion classes (worked example):

Table: The fuzzy weighted values of the criteria

Criteria	Fuzzy weighted values	Ranking
Soil suitability	0.08	3
Landscape suitability	0.50	1
Infrastructure suitability	0.09	2
Land use	0.07	4
CI=0.049 CR=0.044		

Urban development suitability (Expert 1)

	C_1	C_2	C_3	C_4
C_1	1	5	6	7
C_2	1/5	1	4	6
C_3	1/6	1/4	1	4
C_4	1/7	1/6	1/4	1

Urban development suitability (Expert 2)

	C_1	C_2	C_3	C_4
C_1	1	4	6	7
C_2	1/4	1	3	4
C_3	1/6	1/3	1	2
C_4	1/7	1/4	1/2	1

eigenvector (Expert 1)

0.61
0.24
0.10
0.05

eigenvector (Expert 2)

0.62
0.22
0.10
0.06

λ_{max} = 4.39, C.I. = 0.13, C.R.= 0.14

λ_{max} = 4.10, C.I. = 0.03, C.R.= 0.03

Table: The fuzzy weighted values of the second level

Objective	Criterion	Factors	Fuzzy weighted values	Ranking	Tests
To select most suitable site for urban development	C1: Soil suitability	F11: Group texture	0.16	3	CI=0.084 CR=0.093
		F21: Agriculture productivity	0.56	1	
		F31: Sodicity	0.28	2	
	C2: Landscape suitability	F12: Geomorphology	0.29	2	CI=0.069 CR=0.088
		F22: Slope/attitudinal gradient	0.56	1	
		F32: Groundwater (depth and quality)	0.15	3	
	C3: Infrastructure suitability	F13: Road connectivity	0.21	3	CI=0.067 CR=0.086
		F23: Rail stations and suburban railways	0.05	5	
		F33: City development boundary	0.36	1	
		F43: Sewerage systems	0.10	4	
		F53: Water supply networks	0.28	2	
	C4: Morpho-	F14: Greenbelt	0.16	3	CI=0.073

	land use/ land use	F24: Wetlands, floodplains and water bodies	0.06	5	CR=0.084
		F34: Wasteland	0.10	4	
		F44: Existing settlements	0.37	1	
		F45: Open space	0.31	2	

Annexure 2

Difference in pairwise comparison matrices in AHP and Fuzzy AHP

Analytic Hierarchy Process

$$\boldsymbol{W} = \begin{array}{c} \\ w_1 \\ \vdots \\ w_i \\ \vdots \\ w_n \end{array} \begin{array}{c} \begin{array}{ccccc} w_1 & \cdots & w_j & \cdots & w_n \end{array} \\ \begin{bmatrix} w_1/w_1 & \cdots & w_1/w_j & \cdots & w_1/w_n \\ \vdots & & \vdots & & \vdots \\ w_i/w_1 & \cdots & w_i/w_j & \cdots & w_i/w_n \\ \vdots & & \vdots & & \vdots \\ w_n/w_1 & \cdots & w_n/w_j & \cdots & w_n/w_n \end{bmatrix} \end{array} \begin{bmatrix} w_1 \\ \vdots \\ w_j \\ \vdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ \vdots \\ w_i \\ \vdots \\ w_n \end{bmatrix}$$

$$\boldsymbol{Ww} = n\boldsymbol{w} \Rightarrow (\boldsymbol{W} - n\boldsymbol{I})\boldsymbol{w} = \boldsymbol{0}$$

In real situations, w_i / w_j is unknown, but $a_{ij} \cong w_i / w_j$ and $a_{ij} = 1/a_{ji}$ (positive reciprocal), and let $\boldsymbol{A} = [a_{ij}]_{n\times n}$.

a. $\boldsymbol{Aw} \cong n\boldsymbol{w} \Rightarrow (\boldsymbol{A} - \lambda_{\max}\boldsymbol{I})\boldsymbol{w} = \boldsymbol{0}$, find $\lambda_{\max}$ and find $\boldsymbol{w}$ with $\lambda_{\max}$, and calculate $C.I. = (\lambda_{\max} - n)/(n-1)$

$$\Rightarrow \boldsymbol{w} = (w_1, w_2, \ldots, w_n)$$

b. $\min \sum_{i=1}^{n} \sum_{j=1}^{n} (a_{ij} - \frac{w_i}{w_j})^2$

s.t. $\sum_{i=1}^{n} w_i = 1$

c. $r_i = (\prod_{j=1}^{n} a_{ij})^{1/n} \Rightarrow w_i = r_i / \sum_{i=1}^{n} r_i$ (normalization) $\Rightarrow$ $\boldsymbol{w} = (w_1, w_2, ..., w_n)$

d. When $\boldsymbol{Aw} = \lambda_{\max}\boldsymbol{w}$, then $\lambda_{\max}$ can be estimated by $\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(\boldsymbol{Aw})_i}{w_i}$

- **Fuzzy AHP**

(1) Fuzzy $\tilde{\boldsymbol{A}} = [\tilde{a}_{ij}]_{n\times n}$ $\rightarrow$**Fuzzy** $\tilde{\boldsymbol{w}} = (\tilde{w}_1, \tilde{w}_2, ..., \tilde{w}_n)$

a. $\tilde{\boldsymbol{A}}$ $\rightarrow$solve $\tilde{\lambda}_{\max}$ $\rightarrow$solve $\tilde{w}_i$, i.e. $(\tilde{\boldsymbol{A}} - \tilde{\lambda}_{\max}\boldsymbol{I})\tilde{\boldsymbol{w}} = \boldsymbol{0}$

b. $\tilde{r}_i = [\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{in}]^{1/n} \Rightarrow \tilde{w}_i = \tilde{r}_i \otimes [\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n]^{-1}$

Inverse operation of triangular fuzzy number: $(a,b,c)^{-1} = (1/c, 1/b, 1/a)$

(2) Fuzzy $\tilde{\boldsymbol{A}} = [\tilde{a}_{ij}]_{n\times n}$ $\rightarrow$**Crisp** $\boldsymbol{w} = (w_1, w_2, ..., w_n)$

c. $\tilde{\boldsymbol{A}} = [\tilde{a}_{ij}]_{n\times n}$, $\tilde{a}_{ij} \cong \frac{w_i}{w_j}$, $l_{ij} \tilde{\lesssim} \frac{w_i}{w_j} \tilde{\lesssim} u_{ij}$, $i = 1, 2, ..., n-1$; $j = 1, 2, ..., n$; $i < j$

$l_{ij}(\alpha) \tilde{\lesssim} \frac{w_i}{w_j} \tilde{\lesssim} u_{ij}(\alpha)$ in level α, then fuzzy constraints:

$$\begin{aligned} w_i - w_j u_{ij}(\alpha) \tilde{\lesssim} 0 \\ -w_i + w_j l_{ij}(\alpha) \tilde{\lesssim} 0 \end{aligned} \quad \Rightarrow \boldsymbol{Rw} \tilde{\lesssim} \boldsymbol{0}$$

where, the matrix $\boldsymbol{R} \in \mathrm{R}^{m\times n}$, $m = n(n-1)$

then $\mu_k(\boldsymbol{R}_k\boldsymbol{w}) = \begin{cases} 1 - \frac{\boldsymbol{R}_k\boldsymbol{w}}{d_k}, & \boldsymbol{R}_k\boldsymbol{w} \le d_k \\ 0, & \boldsymbol{R}_k\boldsymbol{w} \le d_k \end{cases}$

$\lambda = \mu_D(\boldsymbol{w}) = \max_{\boldsymbol{w}}\{\min_{k=1,2,...,m}[\mu_1(\boldsymbol{R}_1\boldsymbol{w}), ..., \mu_m(\boldsymbol{R}_m\boldsymbol{w})] \mid \boldsymbol{w} \in Q^{n-1}, \ w_1 + w_2 + \cdots + w_n = 1\}$

The max-min prioritization problem:

$\max \quad \lambda$

s. t,

$$\lambda \leq 1 - \frac{\boldsymbol{R}_k \boldsymbol{w}}{d_k}$$

$$\sum_{i=1}^{n} w_i = 1,\ w_i > 0,\ i = 1, 2, ..., n; k = 1, 2, ..., 2m$$

(3) Crisp $\boldsymbol{A} = [a_{ij}]_{n\times n} \rightarrow$ **Fuzzy** $\tilde{\boldsymbol{w}} = (\tilde{w}_1, \tilde{w}_2, ..., \tilde{w}_n)$

$\boldsymbol{w}^{\boldsymbol{k}} = (w_1^k, w_2^k, ..., w_n^k),\ k = 1, 2, ..., K$ **;**

$\tilde{\boldsymbol{w}} = (\tilde{w}_1, ..., \tilde{w}_j, ..., \tilde{w}_n)$ **;**

$\tilde{w}_j = (l_j, m_j, u_j)$;

where, $l_j = \min_k \{w_j^k \mid k = 1, 2, ..., K\}$; $m_j = \frac{1}{K}\sum_{k=1}^{K} w_j^k$ or $m_j = [\prod_{k=1}^{K} w_j^k]^{1/K}$;

$u_j = \max_k \{w_j^k \mid k = 1, 2, ..., K\}$.