An Algorithm Development Using Agent-Based Modeling and Simulation for Land Use Land Cover Change under Geospatial Framework

Thesis submitted to the Andhra University in partial fulfilment of the requirements for the award of

Master of Technology in Remote Sensing and Geographic Information Systems

Submitted by

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Under the Supervision of

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CERTIFICATE

This is to certify that this thesis work entitled — *An Algorithm Development Using Agent-Based Modeling and Simulation for Land Use Land Cover Change under Geospatial Framework* is submitted by Mr. Vivek Kumar Singh in partial fulfillment of the requirement for the award of *Master of Technology in Remote Sensing and GIS* by the Andhra University. The research work presented here in this thesis is an original work of the candidate and has been carried out in Geoinformatics Department under the guidance of Mr. Ashutosh Kumar Jha, Scientist/Engineer 'SD' and Mrs. Kshama Gupta, Scientist/Engineer 'SE' at Indian Institute of Remote Sensing, ISRO, Dehradun, India.

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Abstract

Urban planning is one of the most important areas which widely incorporate Remote Sensing and GIS technologies. The advent of very high resolution satellite images has made it possible to view and analyze urban settlements at micro level. This has revolutionized the planning process where decision makers plan the expansion of cities, construction of roads and railway, development of industrial and commercial areas, establishment of educational institutions, etc. Most, if not all, of these decisions depend on the demographics of the area under consideration. Simulation of these factors is used to predict the future settlement which gives a good basis for the planning and urban expansion. This study focuses on the effects of different socio-economic factors on the planning process, and the modeling of these parameters for future predictions. For these predictions, three modeling techniques – CA-Markov model, ISRO IGBP LULC model and Agent-based modeling are used. CA-Markov model works only on spatial data, whereas ISRO IGBP LULC model works on spatial as well as non-spatial data. These two models are used to identify the spatial and non-spatial drivers responsible for expansion of the city, and also the area of expansion.

Socio economic factors and geographical factors are considered for modeling urban settlement in the city. In this study, agent based modeling, with dynamic approach in identifying settlement pattern based on socio-economic, demographic and commercial factors that are affecting the housing market in relation to income, is used. Proximity rules are designed to influence the households' decision to build a house in the area of their choice. The entire set of rules has some limitations because of the agent's heterogenetic nature to interact with the environment and also because of the influence of the land market representation. Parameters studied during preparation of the proximity rules are: the agent's preference to stay in his known area or search for an area where the neighbourhood factors are more to his satisfaction and convenience; resource constraints that define the buying capability of the agent; competitive bidding that indicates the agent's capacity to own a land of his own choice. Agent is defined in terms of households. During simulation household is categorized in terms of low income residential, medium income residential and high income residential where categorization is done on the basis of land occupied. There is an increase in the housing options for household agents because of increase in expansion of the city or the households moving away from the city center. Socio economic status changes with the demand of land so as to accommodate the increased population. Change in diversity is monitored to study the urban settlement pattern over time.

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Chapter-1

Introduction

Geo-computational or geo-simulation modeling such as agent based modeling is emerging as a new area for predicting land use land cover change. Models are of different approaches like deterministic and stochastic models, simulation and optimization models, reductionist and integrated models, linear and non-linear models, one-agent and multi-agent models, and so on (Janssen 2014) (Crooks and Heppenstall 2012).

Computational modeling techniques give unique approach to view the urban phenomena and spatial processes (P. M. Torrens 2003) whereas classical urban models result in collective dynamics of multiple objects in urban scenario.

1.1 Characteristics of geo-simulation modeling approach

The characteristics of geo-simulation modeling approach are explained below.

Intellectual roots **-** Geo-computational modeling techniques have intellectual roots that are not in classical urban models. This is due to implementation of different socio-economic factors that are integrated with engineering concepts of spatial processing.

Spatial units - Geo simulation modeling approach takes discrete and spatially non modifiable (P. M. Torrens 2003) objects like house, car, land parcels, etc. that are not incorporated in traditional urban models.

Spatial interaction **-** Interaction of spatial objects with discrete time, distance delay, distance between spatial objects results are contrast in the models. In case of classical urban models it was observed that main focus is to describe the flow and information of different spatial units. User defined rule plays an important role in the spatial interaction of the spatial object. These rules are defined on the basis of socio-economic status, physical and environmental status of the spatial units.

Time **-** Interaction of spatial objects with time is dynamic in nature in geo-computational modeling but in case of classical urban models it is static. Decision making behaviour of the spatial units or objects depends on what kind of environment they exist in. The behaviour of spatial objects changes with discrete time periods, so dynamic interaction between the spatial objects takes place when the model is used to predict growth expansion.

Attitude **-** The Attitude approach differs in classical and geo-simulation models. Classical urban models work spatially but have limited input parameters. These models fail to predict the growth as it doesn’t take variations and socio economic factors into account which are responsible for urban growth. Geo-computational models have parameters based on scenario generating factor like distance to road, distance to commercial area, land demand, basic income group living in the area, availability of land, etc.

1.2 Urbanisation in India

According to Pranati Datta et al 2006, “Urbanisation is an index of transformation from traditional rural economies to modern industrial one”(Datta 2006). Urbanisation means increase in urban population which are grouped together to acquire lands to live and have economic support(Pathak 2014). A basic difference between rural and urban settlement is the size of population, number of households, migration and basic urban services. Settlement patterns in and around metropolitan regions become all the more important when considering the pace with which the urban settlements are increasing, both in number and size(Mahavir 2004). In addition, in developing countries, there is a new category: increasingly large numbers of spontaneous human settlements are coming into existence on the urban fringes. According to Table 1.1, there is an increase in the number of towns from 2001 to 2011. In 2001, the number of statutory towns was 3799 which increased to 4041 towns in 2011. The number of census towns increased from 1362 in 2001 to 3894 in 2011. This increase in the number of towns was observed due to increase in urban population. This indicates that a large number of people are migrating from rural to urban areas.

Table1.1: Number of Towns from 2001 to 2007.

Class	Population Size	No. of UAs/Town 2001	No. of UAs/Town 2011
Class I	1,00,000 and above	393	465
	Out of above, more Than 10,00,000	35	53
All Classes		5161	7935
(i) Statutory Towns		3799	4041
(ii)Census Towns		1362	3894

Source : Census of India -2001 & 2007

Geo-computational modeling approaches are used to predict new urban fringes based on the current urban scenario. The effects of increased urban population with changing socio economic factors are studied by planner and policy makers to take decision. Geo-computational modeling techniques such as agent based modeling, cellular automata are dynamic in nature and most successful modeling approaches used to study the urban settlements. Both these approaches are combined and studied at different spatial scales for prediction modeling.

1.3 Cellular Automata

Cellular Automata is a modeling approach is a combination of cells arranged evenly on a tessellated grid-space, cell states, neighbourhoods, transition rules, and time (D. P. M. Torrens and Benenson 2014).

In urban scenario, cellular automaton operators might be considered as environment, a landscape, or a territory. Cell Space in cellular automaton is consider as regular in structure just like chess board and infinite in extent i.e. by describing the cell space as a torus(Benenson and Torrens 2004).In an urban area, the cell state will be defined as any attribute of urban entities like land use (residential or commercial), population density (high density or low density), land cover (forested or concrete), etc (P. M. Torrens 2004). Cellular automata models to urban systems: realism, spatiality, resolution, presentation, and links with geographic information systems, object-oriented programming, and remotely sensed data (Benenson 2014). Simulation techniques are applied to study urban phenomena, including regional growth, urban sprawl, gentrification, Pareto equilibrium, residential growth, population dynamics, economic activity and employment, historical urbanization, land use evolution, and polycentric city to name a few (D. P. M. Torrens and Benenson 2014).

Limitations of Cellular automata are the rules defining the change in its state. Cellular automata work using transition probabilities and it was observed that rate of change of one class to another is fixed, so dynamic nature or heterogeneous nature of the state does not depend upon the socio-economic factors or demographics of the area.

1.4 Agent Based Modeling

Agent Based Modeling is a combination of macro level programming which is applied in many real time applications like forestry, water, urban, survey areas, etc. (Benenson and Torrens 2004). This modeling approach is heterogeneous with multiple numbers of agents and their interaction. Agents are the elements of socio-ecological environment; it may be individuals, households, firms, nations, depending on the application ("Agent Based Modeling" 2014). According to M. Batty, "A class of models developed based on representing objects and populations at an elemental or individualistic level which reflects behaviours of those objects through space and time" (Batty 2009). Agents with heterogeneity properties are derived from social elements of the application in which the model is designed; it may have location difference with knowledge of wealth, social connection, cognitive processes, experience, etc. Interaction between the agents and environment shared information depending upon the action or behaviour of the agent with the environment. Agent based models are implemented on many platforms like Swarm, Starlogo, Netlogo, Mason, Cormas, Repast(“Agent Based Modeling” 2014), etc. The validation and calibration depends on human decision making.

System dynamics is described based on differential equations which are numerically solved in user-friendly packages like Stella and Vensim. Using these packages agent based modeling is implemented with a fixed topology of interaction with environment. The problem related to urban scenario has attracted many researchers who are now focusing to find out the parameters based on which individuals make decisions of settlement. Agent based modeling approaches allow to simulate individual action based on decision of individual and decision making ability of other agents.

Different agent based models are proposed to provide prediction model for urban land use change. It provides ability to make decision based on individual behaviour and environment interaction of agents with multiple agents. Many theoretical and geo-computing models are developed to identify the urban residential problems like identification of mono centric pattern of the cities and segregation of residents (Huang 2013). Agent based modeling is a goal oriented modeling approach. Spatial statistics by and large tend to perform the same sort of task, but in a more abstract way, allowing us to make generalizations about what we see in the data, to extract hypotheses from it, or, to use it to test hypotheses. But the data that is stored and processed in a GIS contains, so to speak, the seeds of its own destruction. The patterns of land use land cover, social, economic, and demographic characteristics, constantly change, both because the spatial structures are themselves inherently unstable, and because they are typically exposed to external phenomena that also force to change. This problem is dealt with by programmes for periodic data collection and updating, but such a response is not suitable for all purposes, since at best it gives us only a regularly updated picture of current conditions. Planners and decision makers need to know not only the current state of affairs; they also require some idea of future conditions. Ideally they would like to be able to see the possible consequences of the plans and policies they may have under consideration.

1.5 Problem Statement

In Indian cities, lack of state intervention and failure in planning policies in settlement has encouraged the informal sale and distribution of land by private individuals and the subsequent construction of housing. Planners and decision makers need to know not only the current state of affairs; they also require some idea of future conditions, which depend on the human behaviour and the interaction of humans with spatial and non-spatial environment. Modeling techniques that take into consideration these aspects of human behaviour need to be employed to predict the future settlement pattern. This helps any decision making body to take decisions based on impact, present trend of the economic and social conditions, and to identify required level of services.

1.6 Research Objective and Research Question

1.6.1 Research Objective

An algorithm development using agent based modeling and simulation for land use land cover change under geospatial framework.

1.6.2 Research Sub Objective

1. Development of framework for proximity rule based algorithms by incorporating agent-based and cellular automata models.
2. To identify urban growth pattern indicators.
3. To model settlement growth pattern using significant spatial and non-spatial drivers and agents.
4. To find out the suitable area for future development.

1.6.3 Research Questions

1. What are the proximity rules which can be implemented in the proposed modeling process?
2. What are the drivers and agents that are significant in controlling the settlement growth pattern and how do they affect the growth pattern?
3. How can the direction of growth be shown based on the different drivers and modeling agents?
4. How are these parameters used to evaluate the suitable areas for future development?

1.7 Scope and Limitation

This is study, three modeling approaches are discussed. These modeling approaches are CA-Markov model, ISRO IGBP LULC model and agent based modeling. CA-Markov and ISRO IGBP LULC models work on the principal of cellular automata. ISRO IGBP LULC model is designed by Indian Institute of Remote Sensing, ISRO. The limitations in the study are mentioned below:

1. Socio economic data is collected from Census of India was available which is present at ward level.
2. Modeling is done at Dehradun municipal boundaries, hence the output growth beyond municipal boundaries is not considered.
3. Scale of mapping is 1:5,000.
4. Accuracy of the models depend the accuracy of the ground survey data.
5. Sizes of the land defined in the modeling are set according to expert views of the planners and real states experts.

Chapter-2

Literature Review

2.1 Urban Models

Studying and understanding of human decision making process has influenced many government policies which create a topic of research to find out the reasons how and when social elements of society influence the decision making ability of a human. Many urban land use land cover change model has been introduced in the recent past to understand the behaviour of human decision making while settling in area of their own interest. The models have been categorized in two categories: a) classical urban models (b) computational urban models.

2.1.1 Classical Urban Models

2.1.1.1 Bid Rent Theory (Alonso 1964)

According to Leory (1983) in Bid Rent Theory, "In this case our model predicts that rich will live on the [City Center] side of the boundary. The historical records from [the mid-1800s] indicate that, as predicted, household income declined with the distance from the center. In 1849, for example, an observer wrote that "nine-tenths of those whose rascalities have made Philadelphia so unjustly notorious live in the dens and shanties of the suburbs." (Trussell 2010).The study is based on Single Street as a point of departure (Narvaez, Alan Penn, and Sam Griffiths, 2013). This theory explains value of land for different purposes as in urban cities, land in the centre of the city is the most expensive land because of public transport easily accessible ("Settlements2.pdf"). It calculates the distance in three different approaches: as fewest numbers of turns, by measuring the segment length within a street (metric) and least angle change path in urban system (Narvaez, Alan Penn, and Sam Griffiths, 2013). According to the three different sectors describes in the model: retails, manufacturing and residential are prepared to pay for land. Main focuses of these sectors are accessibility with city center. Due to this there is increase in the cost of land and different sectors are ready to pay high price for land from CBD. As distance from the CBD increases availability of land increases and it is affordable for residential and even agricultural use. One major limitation of this model is its complex infrastructure related to road connectivity.

2.1.1.2 Burgess concentric model

Burgess concentric model was developed by Earnest Burgess in the year 1920 (Brown). The model depicts the use of urban land form in the form ring structure(Brown). The concentric ring model is divided in to zone of multiple layers where each layer describes the formation of urban land use pattern within the city (Bishi and Olajide 2014). The inner most ring or zone describes about the central business district, then after zone of transition, zone of independent workers home, zone of better residences and zone of commuters (Bishi and Olajide 2014). The study explain the existence of social problems like unemployment, crime(Brown). The model was implemented with the socio-economic status of the city to implement and understand the effect of policy related to taxation. Focus of the model in to understand positive correlation of socio-economic status of households with distance from the CBD(Bishi and Olajide 2014). The status of different sections of society based on the location from the CBD. Limitation of this model is the lack of proper planning of streets, road connectivity and demographic structure.

2.1.1.3 Sector Model

Hoyt's sector model describe a shape of a pie from which are cut at random(Riley 1958). Hoyt observed that the value of many cities were having consistent pattern, with understanding the concentric model. The model describe income household pattern of settling along the rail road line as well as near to commercial establishment (Bishi and Olajide 2014). Hoyt modified the Burgess model of concentric zone. In the modified model, Hoyt explains about the model based on major road networks available in the city. It was observed in the structure of settlement in major city are clustered around several important transport facilities such as railroad lines, sea ports, and trolley lines. According to Hoty, "cities would tend to grow in wedge-shaped patterns, or sectors, eminating from the CBD and centred on major transportation routes. Higher levels of access translate to higher land values" (Bishi and Olajide 2014). For example, sector model in Tulsa, central business District consider as the focal point for the intra city structure (Riley 1958). Residential land use pattern grow around the transport routes. This means high class residential areas are located in south east of the central business district divided into three sub class: low-high class residential, middle high class residential, high class residential (Riley 1958).

2.1.1.4 Multiple Nuclei Model

In year 1945, Chauncy Harris and Edward Ullman came up with new modeling approach known as multiple nuclei model which overcome the traditional concentric zone and sector model (Bishi and Olajide 2014). This model evolved due to failure of concentric zone and sector model. In the model, "Chauncy Harris and Edward Ullman suggested that specialized cells of activity would develop according to specific requirement of certain activities, different rent paying abilities, and tendency for some kinds of economic activity to cluster together" (Bishi and Olajide 2014).

2.1.2 Comparison of Burgess, Hoyt, and Harris and Ullman's models of urban structure

2.1.2.1 Implicit Assumptions

All the models have variation in characteristics with limited space leading to higher land value which leads to maximum number of employment in city center assuming hub of commercial and industrial base(Maretto, Assis, and Gavlak 2010).

2.1.2.2 Common Features

Models main focus was accessibility with residential segregation (Maretto, Assis, and Gavlak 2010) (Bishi and Olajide 2014). All the models take input as the distance from CBD and land cost value. Boundaries of all the input parameter were clearly mentioned.

2.1.2.3 Comparsion

According to concentric model, circular pattern land use is considered while in sector model is of sectorial pattern of land use. Land use pattern of sector model developed along transport routes and emphasizes on repelling force of land use while in case of concentric model invasion succession forces on the pattern of land use is considered with no transport development. While comparing the different models, it was observed that mono-centric approach in both concentric and sector model was followed but in case of multiple nuclei polycentric approach was applied with more emphasis on land use zone with respect to suburbanization, transport development and outward growth of city (Bishi and Olajide 2014).

2.2 Computational Urban Models

2.2.1 Cellular Automata model

Combination of many generic algorithms result in the development of cellular automata which is based on the global coordination. Cellular automata models are model with discrete cell space having states of different land use land cover classes. Values may be binary (urban or non-urban), qualitative (different land use) or quantitative eg: household density (Li, Sato, and Zhu 2003) or degree of development (Yeh and Li 2002) or the value of buildings (Cecchini and Rizzi 2001), or a vector of several attributes (Portugali and Benenson 1995). In cellular automata model, cell changes its state to other state using transition rules. These transition rules are depend on time and may vary from time to time.

Transition rules are derived using below formula (Yeh and Li 2002)

$$S^{t+1} \approx f(s^t, N) \tag{2.1}$$

Where t= time period from t to t+1, N = neighbourhood cell and S= cell states. Function f describes the transition rule from time period t to t+1 (Yeh and Li 2002). In CA, neighbourhood and transition rules are associated with each other. Eight adjacent neighbourhood cells are surrounding the automata.

The most common attribute of CA models (Santé et al. 2010) requires in the cellular automata to simulate urban scenario are:

1. **cell space**

   Cell space is defined in term of regular and irregular cell spaces. Regular cell space is a grid structure that is used in cellular automata(Santé et al. 2010). Square and hexagonal grid structure was proposed to have more homogeneous neighbourhood (Iovine et al. 2005). It was assumed that the cell space is having 3 dimensional matrix that is used to represent growth in urban area(Santé et al. 2010).It is observed that the homogeneous structures of the cells are identical and defined by their state(Santé et al. 2010). It is assumed that cell space where non uniform cell space are used then it indicates that they are suitable for certain land use patterns(Santé et al. 2010).

2. **Neighbourhood**

   In cellular automata, urban system has neighbourhood with same extended so that it may be under the influence of neighbouring cells located(Santé et al. 2010). In spaces composed of irregular units, the neighbourhood can be defined as the adjacent units, as the units within a specified distance or using the Voronoi spatial model (Shi and Pang, 2000).The neighbourhood are defined differently for each cell in term of space(Santé et al. 2010). Such a relaxation is widely acknowledged (Couclelis, 1985), but seldom implemented (Santé et. 2010). Models in which each cell receives a weight according to its state (Santé et. 2010) and location within the neighbourhood (White and Engelen, 1993) allow for the application of neighbourhoods of different sizes and shapes by introducing weights equivalent to zero(Santé et. 2010).

3. **Transition rules**

   Developing transition rule are based on the present state of the cell and surrounding neighbours cells. Cellular automata consider the external factors that are used to formulate the rule which reflects many urban theories (Santé et. 2010).Rules are static and depend upon the input parameter on which they are applied, dynamic change in the rule parameter based on space and time will affect the transition rule therefore it is necessary to adapt the rule based on specific inputs. Example of input parameter is distance to roads, demand of land, population density.

4. **Growth constraints**

   In cellular automata, transition rule define the change from one state to other state. The demands based on social, economic, demographics (Santé et. 2010) are the factors influencing the overall urban growth.

5. **Time steps**

   Urban cellular automata assume that cells having different cell size will have different time (Stevens and Dragicevic, 2007). A less frequent relaxation is using variable time steps (Couclelis, 1997) to simulate specific events of different lengths of time(Santé et. 2010). Cecchini and Rizzi (2001) (Santé et. 2010) have two types of rules: structure rules and conjunctures rules; structure rule defines each time iteration and conjuncture rule is applied on specific event.

2.2.2 Review of some CA Models

1. According to (Almeida et al. 2003), (Almeida et al. 2005) , cell size should be 100m with function describing the weight of different classes in LULC and probability of change from one class to other class. The model has 8 land uses class with two different modeling approaches: descriptive approach and multiple land use approach to calculate the annual growth rate for urban land use land cover. Validation of the model is done by using curve fitting method for finding the relationship between the demand of land based on different social or economic and demographic factors of urban area with respect to time.

2. According to (Barredo et al. 2003) (Barredo et al.(2004), the model has 22 land use classes with 9 active class. These 9 active classes are defined as the classes based on demographic and social factors that are used to indicate the urban growth pattern in the city. Grid size is 100 m cells with neighbourhood are defined in circular radius of 8 cells. The model has stochastic disturbance because of the parameter considered for the model.

3. (Caruso et al. 2005) defines the model in term of descriptive approach. The model in the descriptive approach use mathematical equation for urban growth expansion, the results shown growth in the residential pattern and conversion of agriculture land to residential pattern due to increase in demand of the land. The factor influencing the model is demographic. It indicates the neighbourhood using a circular radius of 3 or 5 cells. Validation of the model is done using fragmentation index.

4. Kappa index is used to validate model proposed by He et al. 2006 and He et al. 2008. Descriptive modeling techniques are discussed in the models. Model proposed by He et al.2006 did not neighbourhood effect. However in He et al. 2008 neighbourhood effect was proposed with a cell size 5 with circular radii. Earlier Model in 2006 has system dynamic nature to calculate the urban area but in 2008, linear regression method was applied in the urban growth.

2.2.3 Agent based and micro-simulation models

Micro simulation model is the modeling techniques that operate on individual units like persons, households, vehicles and firms (Huang 2013). Every entity or unit in the model contains attributes that are used to define behavioural rules and interact with multiple units with same attributes. Simulation of micro simulation models and agent based models define the heterogeneous attributes of the agents in the model. Agent based modeling is a combination of inductive and deductive simulation of pattern based individual behaviour with emergent effect(Filatova 2014) (Axelrod 1997, Nolan et al. 2009).

2.2.3.1 Agents

Agents are collection of small programs designed to perform actions depending upon the need of the application. They can store information regarding different interactions with multiple agents and with the environment. Agents have states, and they can change from one state to another through these interactions. (MadhanMohan et al. 2014).

Features that are most common in agents are mention below (See and Batty 2012):

- **Autonomy:** Agents are not governed by centralised control; they are capable to interact with other agents with properties to exchange and process information with decision making abilities(Crooks, See, and Batty 2012)(See and Batty 2012).
- **Heterogeneity**: Agent are permitted to develop autonomous person or element or actor means agent representing an individual with attributes like sex, age, job etc.
- **Active:** Activities or work assign for an agent which describe the proximity rule derived from environment where the agent interact with multiple agents and environment.
- **Proactive/ goal –directed**: agent should be goal directed so that they can achieve their goal with respect to their behaviour.
- **Perceptive-** Agents are known to their surrounding and interact happen based on the environment set for the agent to interact.
- **Bounded Rationality-** Agents can be configured using heterogeneity.
- **Interactive / Communication-** Agent can interact other agent.
- **Mobility-** Motion of agent varies with space and time.

- **Adaptation/Learning-** Agents are designed on the basic of their complex adaptive systems which describe the state to alter from the previous states with properties to access full memory(Heppenstall et al. 2012).

2.2.3.2 Agent looks, Rules, Behaviour and Relationships

An agent can be an entity like a car, house, person, a piece of land, insect, etc. Behaviour and relationships between agents to multiple agents will be used to create rules which are used as an action for agent. For example, retail shop agent will be operating on same set of rules that is how to have maximise profit in limited time (Heppenstall et al. 2012).

Rule is made from conditional operator (if-else) which drives the agent to take action based on the input parameter of the model environment. For example, in three discrete time periods, we observe that for the first time period, we have people staying in areas having low, middle or high income but when we are predicting for the next five years, we observed that sample of low income group people are becoming middle income group and middle income group people become high income group but this is not in case of every group. High income group people remain in high income group for every time period but there is a probability that low income group will convert to middle income and middle income to high income. Using this assumption, we predicted the settlement of people in different areas based on income. The model takes income as an input and should show past, current and future scenario using modeling approach.

2.2.3.3 Urban Residential choice model based on agent based modeling

Agent based modeling differ from system dynamics model i.e. cellular automata because of the ability to make decision based on pattern of urban growth and behaviour of individual agents when they are interacting with each other. According to Huang 2013 major feature that differ agent based modeling approach to other model is: agent heterogeneity, land market representation and measurement of outcome.

1. Agent Heterogeneity
   Modeling urban scenario using agent based modeling is to study the effect of different parameters used while prediction such as socio economic factors or parameters. Heterogeneity of the agent is applicable in 1D landscape, 2D land scape with maximum of two attributes is incorporated in the agent. Rules can be based on demographic characteristics, households and personal experiences.
   Based on behaviour, agents are categorised into several types:

Type 1: agents are identical, attributes and decision making rules remain same. Schelling's segregation model is one good example.

Type 2: agents are grouped in agents with similar attributes. It was observed that the attributes remain same but modeling rules were changed. For example Segregation model of Jayaprakash et al (2009), the black residents do not resided near to white residents but vice-versa is not same that means white residents do settle near to the black residents.

Type 3: agents attribute change with time and interaction with multiple agents and environments. For example, circle rate predicts what type of agents will residence in the area. So circle rate attributes change with time and environment.

Type 4: Decision and attributes of the agents vary with time. During the interaction of agents with environment, it was observed that attribute of some agents does not change, they remain constant.

2. Land market representation

Incorporating land market spatially in urban LULC, to understand the urban residential pattern in the cit. The factors that affect the cost of the land based on market value for settlement are:

i. Preferences

Preference to settle in an area of known depend upon the utility measurement or suitability measuring function(Filatova 2014). Agent with heterogeneous properties changes their preference according to the property of neighbourhood and their socio economic status.

ii. Resource constraints

Resource constraints mean the cost or income to buy a piece of land to build a house within budget i.e. Affordability to buy a house.

iii. Competitive bidding

Competitive bidding means bidding to buy a piece of land to build the house. The Income attribute is most important attribute to buy a piece of land.

iv. Relocation

Relocation is process in which the agent decides to stay in the current location or change to another location. This factor is mostly affected by economic status of the agent. The agent generally decides on the basis of economic and distance from the service center.

3. Measurement of outcome

Agent based modeling add another new dimension of analysis based on decision and behaviour of the individual agents and consequent emergent patterns(Huang et al. 2013). Combining all the dimension introduced in the modeling process has increase the challenge for measuring model outcomes.

2.2.3.4 List of some urban residential model based on agent based modeling:

- OBEUS- According to Benenson, 1998; 1999; Benenson et al, 2002; 2005; Omer, 2005, OBEUS is model based on segregation approach. The agents are identified as residential agent that describes the ability to buy land for settlement. Based on the availability of land and economic status of the agent, using these as input parameter agent decides to relocate or not. Degree of heterogeneity is more than 3% for the agents. Spatial distribution of land use and segregation index is calculated using spatial autocorrelation for accuracy assessment of the predicted model.
- MASUS- MASUS is a segregation model designed by Feitosa et al, 2011, based on empirical data having resource constraints and the model is designed for household agents. The location of households do not changed with respect to time. Degree of heterogeneity is more than 3% of the agents.
- Barros**-** This model is implemented when landscape scale is large, the modeling is done on clustered data to identify the effect of urbanization in area that are near or going to be called as new towns. This model is proposed by Barros, 2012. Residential agent are considered for modeling based on empirical relationship between income of the agent to build house and distance of agent residence from the service center. The availability of land is an important factor in this model. Agent takes decision based on the resource constraints and income to afford the price of the land. Degree of heterogeneity is 1% of the agents. Similar model was proposed by Tian (Tian et al, 2011) but the number of agent were more due to that interaction between various agents could not be fully implemented.
- (Jordan et al, 2012) proposed a new modeling approach, combination of segregation and social approach in large landscape. Considering the effect on large urbanisation, agent tend to move to the area where land is available and agent can afford the price of the land. The areas near to the main town are not considered being the part of the town. The area may be a village or small town where all the facilities are available. Modeling is done on residential level so agents are considered as residential agent with degree of heterogeneity more than 3%. On the basis of affordability and availability of land, agent can takes decision to relocate.

Chapter-3

STUDY AREA AND DATA USED

3.1 STUDY AREA

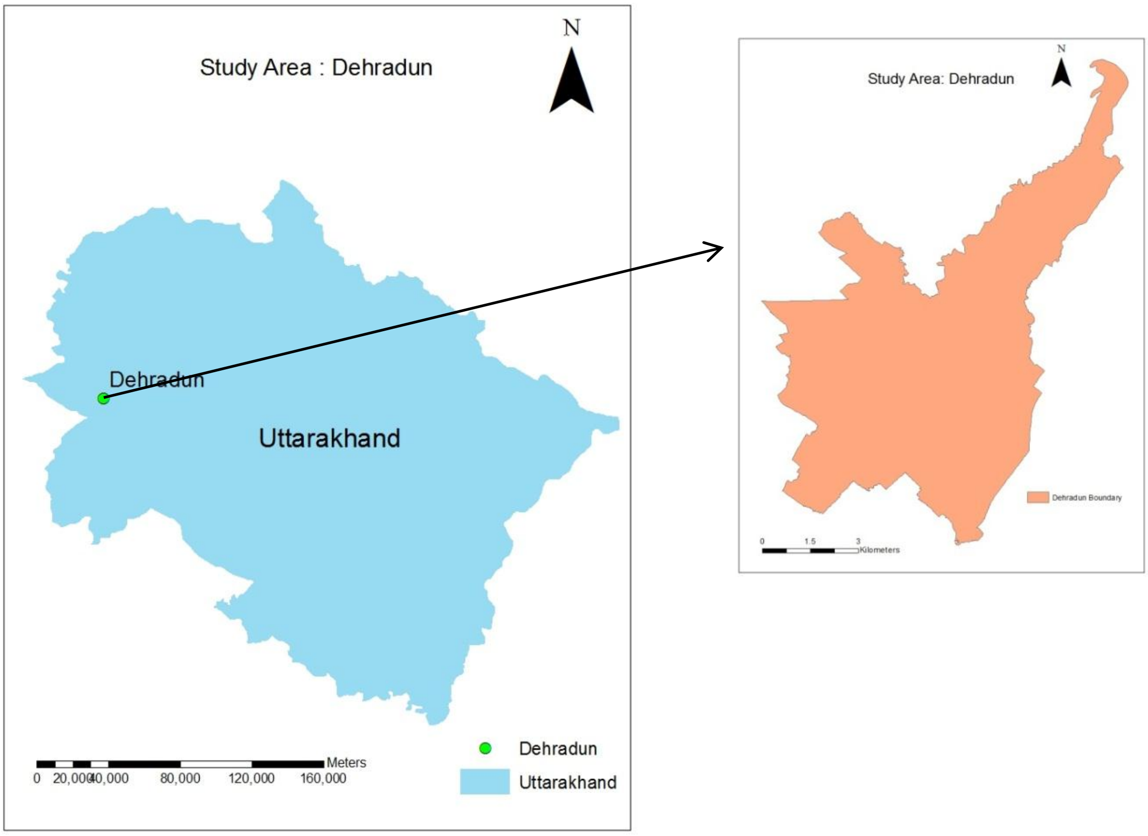


Figure 3.1 Study Area - Dehradun

Dehradun city, the capital city of Uttarakhand state in India has been chosen as study area for present study. The location map of Dehradun City is shown in Fig. 3.1. The town lies in the Dun valley, on the watershed of the Ganga and Yamuna rivers. Dehradun City lies at $30^{o}19^{'}$N and 78^{o} $20^{'}$ E. 38.04 sq. km is the area under the control of Dehradun municipal board. According to 2011 Census, the city has been divided in 60 wards. Two intermittent streams viz. Rispana river and Bindal river, on the east and west respectively mark the physical limits of Dehradun municipality.

Dehradun is situated at an altitude of 2,200 feet above sea level. Dehradun enjoys a salubrious climate due to its location in the hilly part of the state. During the summer months, the temperature ranges between 36°C and 16.7° C. The winter months are colder with the maximum and minimum temperatures touching 23.4°C and 5.2° C respectively. Dehradun experiences heavy to moderate showers during late June to mid-August. Most of the annual rainfall of about 2000mm in the district is received during the months from June to September, July and August being the rainiest months in the season.

3.1.1 Urban Settlement and Urban Form:

Dehradun is hub of prestigious educational and research institutions which are situated outside the city (Banerjee, Reddy, and Paul 2002). The city is divided into four zones to understand the settlement pattern: the Western zone, the Central zone, the Eastern zone, and the Southern zone. Some important establishments like the cantonment area, Oil and Natural Gas Corporation, Forest Research Institute, Wadia Institute of Himalayan Geology and Indian Military Academy lie in the Western zone. The Central zone consists of the old city with colonial vestiges and private residential areas. The canal in the Eastern zone (Rajpur area) serves the need of water for drinking and agriculture. The Southern zone is predominantly industrial area(According to City Development Plan, Dehradun (2007)),.

3.1.2 Demographic Aspects

To examine the socio-economic profile of the city, secondary data (from various sources, including the Census of India) were collected .

3.1.2.1 Population and Population Growth

According to census result of 1981 and 1991, the decadal change in Dehradun population was 21.33% and 21.85% respectively. Due to formation of new capital city, there was a sudden jump to 39.73% in the population in census year 2001. In 2011, the decadal change in the population was 43.23% with an expansion of 3.5% growth rate from 2010 to 2014 (According to City Development Plan, Dehradun (2007)), refer Appendix Table A.1.

3.1.2.2 Literacy

Literacy rate has important effects on demographic characteristics and participation in modeling. According to census 2001 and 2011, literacy rate in urban Dehradun is 90.3 for males in 2001, 89.3 for males in 2011 and 81.1 for females and 85.3 for female. Overall literacy is 96.7 percent in decade change, refer Appendix Table A.2.

3.1.2.3 Occupation

Data on occupation shows that 28 % are in service, 11.6 % are self-employed, 29.8 % are students, 25.4 % are housewives, 0.1 % are farmers, and 4.2 % are retired. Only 0.9 % is unemployed (According to City Development Plan, Dehradun (2007)).

Table 3.1: Occupation by age

Category	Age Group (in years)		
	18-24	25-44	45-59
Student	56.3	3.2	
Service(Worker)	12.8	32.7	37.3
Self Employed	8	17	15.9
Unemployed	2.3	0.9	0.2
Farmer	56.3	3.2	
Housewife	13.1	38.3	35.0
Retired	0.1	0.2	5.5
Total	100	100	100

Table 3.1 shows in percentage, the occupations of people in different age groups. In the age group of 18-24 years, 56.3% are students, 12.8% are workers, 8% are self-employed. This indicates that maximum income comes from students who are living in the city.

3.1.2.4 Income and Expenditure

More than 50% of the population of Dehradun falls in medium income group, while 8% lie below poverty line. Mean per capita income is Rs. 2372 and mean household income is Rs. 10461 (According to City Development Plan, Dehradun (2007)) as mentioned in Table 3.2.

Table 3.2 Income Expenditure Table

Income	In Rs.	Households (%)
Per Capita Income		
Below Poverty Line (BPL)	Up to 562	7.6
Poor	563-1999	46.8
Lower-Middle	2000-3499	28.0
Upper-Middle	3500-5999	11.6
High	6000+	6.0
	Mean Income	**Rs.2372.4**
Household Income	Upto 2999	14.9
	3000-5999	26.7
	6000-9999	26.4
	10000-14999	15.8
	15000+	16.2
	Mean Income	**Rs.10460.6**

3.2 Satellite Data and Data Properties

Temporal satellite products used in the study are Ikonos, Quick Bird of time period 2001, 2007 and 2013. The following are the data properties of the satellites used.

i. **Ikonos** – The model data has been prepared using Ikonos image of year 2001 having spatial resolution of 0.8 m in panchromatic band and 4m in multispectral bands with swath of 11 km and orbit repeat cycle of 16 days.

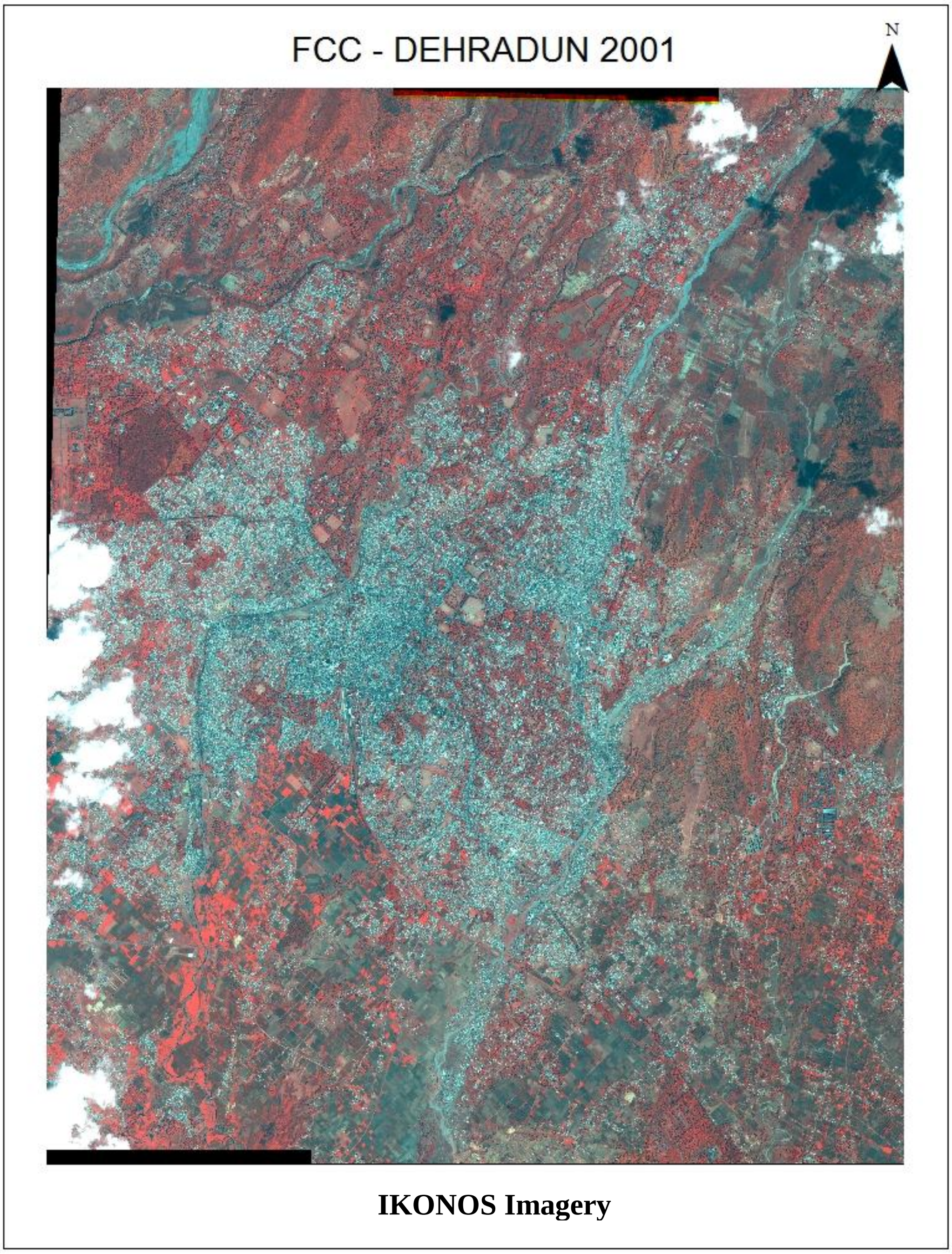


Figure 3.2: FCC of Dehradun city - 2001

ii. **Quickbird -** The model data has been prepared using Quickbird image of year 2007 and 2013, having spatial resolution of 0.6 m in panchromatic band and 2.4 m in multispectral bands with swath of 16.5 km and orbit repeat cycle of one day.

iii. **Aster Dem-** The ASTER GDEM covers land surfaces between 83°N and 83°S and is composed of 22,600 1°-by-1° tiles. Tiles that contain at least 0.01% land area are included. The ASTER GDEM is in Geo-TIFF format with geographic lat/long coordinates and a 1 arc-second (30 m) grid of elevation postings. It is referenced to the WGS84/EGM96 geoid. Pre-production estimated accuracies for this global product were 20 meter at 95 % confidence for vertical data and 30 meter at 95 % confidence for horizontal data.

Chapter-4

Methodology

4.1 Methodology workflow

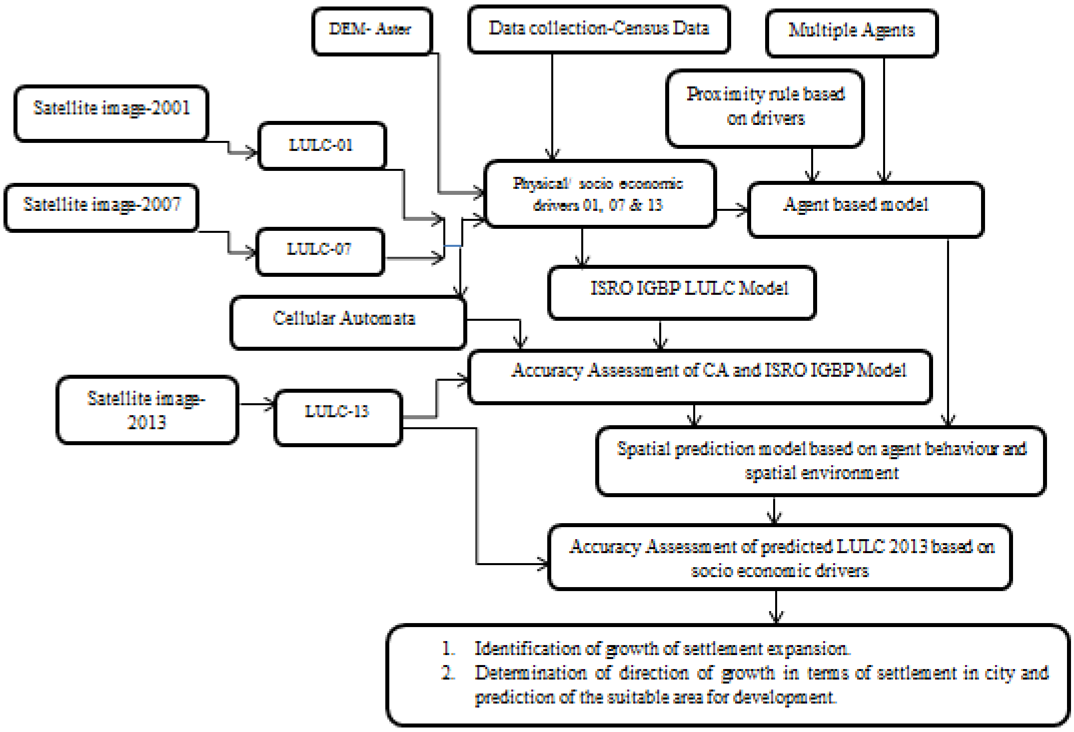


Figure 4.1: Methodology Workflow Diagram

Methodology of this study mainly focuses on prediction of settlement pattern in the city using agent based modeling approach. Figure 4.1 explains the complete flowchart of the methodology. Methodology also involves creation of new software modules for simulation i.e. interaction of agent with multiple agents and with environment. Methodology is divided into 3 Phases. First phase is the data preparation phase where LULC and physical and socio economic drivers of different times i.e. for 2001, 2007 and 2013 are prepared for the simulation. Second phase is the identification of spatial and non-spatial drivers used for simulation process. In this phase, cellular automata model and ISRO IGBP LULC model are used. Third phase is the phase where agent based modeling and simulation is used for the prediction of future settlements based on socio-economic factors supporting the growth in the city.

The data planning and acquisition is the first step to start a project. Urban Land Use Land Cover map is prepared using two approaches: first is the visual interpretation technique which involves digitization of various features e.g. builtup, vacant land, urban agriculture and urban forest. Digitization technique involves line, point and polygon that are drawn to prepare land use land cover map. The second approach is the object based feature extraction technique which is a rule based technique to extract objects e.g. buildings, vacant land, urban agriculture, urban forest.

The digitization technique was used to prepare LULC of 2001, 2007 and 2013 which consist of classes institutions, recreational area, transportation, urban agriculture, forest area, low density residential areas, medium density residential areas and high density residential areas. Road network and commercial areas are also digitized.

Various point data like schools, colleges, parks, bus station, railway station and hospitals were prepared through GPS points collected during ground survey.

4.2 Object Based Feature Extraction

Object based feature extraction is a rule based technique to extract objects for data preparation. These objects can be roads, buildings, forest area, agriculture area and water bodies. These rules work on the principles of spectral values, texture values and spatial values. The three different techniques used for extracting objects are as follows:

1. **Spectral based rules for extraction**

   According to spectral based rules for extraction, spectral values of each input band of the image are compared. The attribute values of the cluster pixels are computed from the input band where the segmentation of the image has the same value i.e. attributes was calculated based on the contribution of the entire clustered pixels having same value.

2. **Texture based rules for extraction**

   Texture values are computed for each input band of the image. Two-step process is involved in computing the texture attributes. Firstly, pre-defined square kernel is passed to the input image band, and then the attributes are calculated for each pixel in the band based on the kernel window size and referred to the center kernel pixel. Secondly, the average results of all the pixels are clustered to create the attribute values.

   The values of texture attributes are computed from a range where it defines the region inside the kernel (Based on kernel window size) computing mean by estimating average value of the region inside the kernel, variance, entropy mean calculating the statistical measure of randomness which was used to describe the character of the input image based on texture so texture entropy was calculated for each pixel in the region.

3. **Spatial Attributes rules for extraction**

   The boundary of the clustered polygons having same value was computed using object based extraction in spatial rules. Spatial rules were based on the input parameters like shape, size, elongation which are required to form cluster polygon of same values.

In object based feature extraction techniques, there are two important factors to be considered. First is the scale factor that indicates the size of the object. Size of the objects is defined by the DN (digital number/grey scale values) values in the image. For defining the size of an object, a cluster of pixels that have same DN values was formed. These clusters are denoted as an object in the image. Second is the merge factor that is used to merge all the objects that are having same DN values. Extraction of objects (e.g. building, vacant lands, urban agriculture and urban forest) is done by setting scale level at 30 and merge level at 90. After setting the scale and merge level, segmentation process is applied. After segmentation, individual objects were extracted using rules. Extraction of urban and recreational areas is done from satellite image of 2001, where texture range rule value is lies less than 1.42592 for urban and 0.73231 for recreational whereas spectral mean rule value is between 1537.78871 to 1538.74679 for urban agriculture and between 618.26275 to 619.9203 for vacant land. Similarly for year 2007, same rules are applied for urban, urban agriculture, recreational area and vacant lands. Analysis values are mentioned in Table 4.1:

Table 4.1: Rules for object-based feature extraction

Year	Classes	Texture Range	Spectral mean
2001	Urban	Greater than 1.42592	-
	Urban Agriculture	-	Between 1537.78871 to 1538.74679
	Recreational area	Lesser than 0.73231	-
	Vacant land	-	Between 618.26275 to 619.9203
2007	Urban	Greater than 1.32289	-
	Urban Agriculture	-	Between 1725.80238 and 1726.48019

	Recreational area	-	Lesser than 1726.4809
	Vacant land	-	Between 1726.54475 and 1729.44965

Second Phase in the methodology, is the identification of spatial, non-spatial drivers and future area for expansion and area for future development. Two approaches: Cellular automata and ISRO IGBP LULC model are considered for the modeling.

4.3 CA-Markov Chain Model

In CA-Markov chain model, LULC of 2001 and 2007 were prepared using visual interpretation techniques. Visual interpretation techniques are size, shape, texture, colour, height, shadow and pattern. Using these techniques, LULC was prepared. LULC consisting of three different urban classes – residential, open space and industrial - are generated. Each of these classes is divided further classified according to second level of classification in urban land use: Residential - low density residential, high density residential and medium density residential; open space - urban forest, urban agriculture, recreational**,** vacant land; Industrial - government institution, public and semi-public, and transportation. Houses in low density residential areas have the characteristics of low density of development, varying pattern, variable size and large amount of green spaces adjoining the built-up structures. Vegetated areas separating two adjacent houses tend to be big. In case of medium density residential areas, less vegetated area exists, areas have semi compact settlement. Medium densities residential have medium density of development, less varying pattern. In case of high density residential areas, the areas have large clustered settlement; less open space is available around the settlement. Institution areas are identified by their surroundings. Institutions building have fixed boundaries with large vegetation around building structures or group of buildings e.g. playground, garden. Building structure are defined in term of shape and size of the institutional area is large. Transportation like railway station, city bus stand is identified by the spatial arrangement as well as by ground survey. Usually transportation class occupy large area. Recreational areas are open areas where construction is not allowed. The areas are parks which are taken care of by the government e.g. central parks. Recreational area are easily interpreted from satellite image as they appear red in color. Ground survey is done for validation. Similarly Urban forests are those forest areas which are reserved forest areas present in the outskirt of the city having fixed boundaries as well as it has texture and pattern. Public Semi-Public is identified by ground survey and these are NGOs, public help centres.

In CA-Markov prediction model, the transition area matrix is calculated for all the classes for LULC 2001 and 2007. Transition area matrix explains how many pixels are residing in the same class and how many pixels of one class are converted to other classes e.g. some pixels of urban agriculture class are converted to low density residential class in predicted LULC of 2013.

A transition probability describes the probability of change of state of one class to other class. It was observed that sum of all the classes in one row is equal to 1. All the elements in the matrix are non-negative values. After calculating the transition area matrix and transition probability matrix for time period of 6 years for LULC 2001-2007, these matrices are considered as input to the CA-Markov model for the prediction of LULC 2013. Predicted LULC 2013 was generated and accuracy assessment is done by comparing the predicted LULC 2013 and actual LULC 2013.

4.4 ISRO IGBP LULC Model

ISRO IGBP LULC Model is a "macro scale model defined on a set of regions that interact with each other on the basis of classical spatial interaction equations which allocate activity among the competing region" (White, Uljee, and Engelen 2012). Allocation of land for use is based on the parameter affecting the demand in the competing region. Demand for the land is based on Markov transition probability or it can also be defined directly by the user. The socioeconomic parameters like population density, number of households, income and literacy rate, and physical parameters like distance to road, distance to commercial area, land rate or parcel area and distance to the service centres are other factors that influence demand of the land. They are used to generate the suitability of the area shown as a grid. The cells of this grid are then allocated to that class which corresponds to maximum suitability.

Grid structure is used to give suitability weightage to the cells of different classes based the formula:

- Suitability of class k in year (N_o)

$$S_{ij}(k)_t = P(Lulc_{ij}(k) \times W_t(k)) \tag{4.1}$$

- Suitability of class K in year (N_1)

$$S_{ij}(k)_{t+1} = P(Lulc_{ij}(k) \times W_{t1}(k)) \tag{4.2}$$

- Maximum Number of cells required for each class for prediction

$$N^k{}_{t+1} = N^k{}_t + \frac{d(N^k)}{d(t)} \tag{4.3}$$

where

$$LULC_{ij}(k) = K{\sim}D_i(i = 0 \ldots . n, j = 0 \ldots . n) \qquad (4.4)$$

D=Drivers, W=Weight, t= Time Period, N_o=First time period, N_1=Second time period, P=Probability, LULC=Land use land cover, d (N^k)/d (t) = Rate of change of cell, N^k_t=Number of cell located for each class.

In ISRO LULC modeling, Regression techniques are used to find the empirical relationships between dependent, independent and continuous variables (Jokar Arsanjani et al. 2013). Regression framework is designed to access spatial dependency using two basic approaches: first, developing models that are complex and second, calculating the distance between various sample points. The approach of regression is used to generate the suitability of each cell in the grid. The model supports linear, logistic and non-linear neural network based approach for this purpose.

ISRO IGBP LULC model consists of a combination of three modeling techniques of regression: Logistic Regression, Linear Regression, and Neural Regression. In this study, the Neural Regression technique is used, because it is a knowledge-based model which takes decisions based on the inputs given in the study, i.e., the socio-economic data like household densities, population density, literacy rate, etc.

The objective of this model is to predict the LULC map using physical and socio-economic drivers which affect the land use pattern. All the LULC maps and drivers should have the same spatial extents and cell counts.

Following are the list of drivers generated for the model and it was observed that all the drivers have the same extent and equal cell count:

Distance to Built-up

This driver is generated using Euclidean distance (calculating distance for each cell from the closest source). Residential objects are considered in this model.

Distance to Hospitals

GPS locations of all the major hospitals in the city were collected. The GPS points are converted into shapefile format with the attributes name and coordinate locations so as to calculate the distance of hospitals from each cell in the image.

Distance to College/School

The approach used to create this driver is similar to that used to create the driver 'Distance to Hospitals'.

Distance to Road

Roads are extracted from the satellite images, and the distances from these roads to each cell in the image are calculated using Euclidean distance.

Elevation

Aster DEM is resampled to 5 meter. Elevation of each cell is extracted using zonal statistics.

Socio Economic Drivers

Socio economic parameters (Source: Census of India) such as population density, households and literacy rate are difficult to predict spatially.

Circle rate

City circle rate is the minimum rate of the property that can be bought or sold, and is defined by all state governments.

Population Density, Household and Literacy rate

Population density, household and Literacy rate from describe in the Census Data which are collected at ward level.

Implementation of ISRO IGBP LULC model

Urban land use is considered as active land use which is associated with activities i.e. residential land use is associated with socio economic factors e.g. literacy rate, population density and household density. Physical drivers e.g. elevation, distance to road and socio economic drivers are implemented on LULC 2001 and LULC 2007. Drivers and LULC of 2001 and 2007 are of 5 sq. meter resolution. Software module is created to work on three different regression models- linear regression, logistic regression and neural network. All the drivers are placed over the LULC 2001 and LULC 2007. If the selected model is logistic regression model then logistic model is implemented for prediction. First neighbourhood effect is calculated to understand the effect of socio economic drivers and physical drivers on each class using eq.4.4.

Neighbourhood effect:

$$NE(d_t) = K.d(t)^i \tag{4.4}$$

where d(t) is the Euclidean distance of each driver, t is the driver class, K is proportional constant and i [-1,1].

Neighbourhood effect is inversely or directly proportional to the distance to drivers. Probability of one class is multiplied with its neighbourhood effect. Similarly, probability of each class is calculated. Suitability map of each class is generated for the year 2001 and 2007 using eq. 4.1 and eq. 4.2. Suitability map of each class is associated with each driver defined in the ISRO IGBP LULC Model e.g. low density residential area is interacted with distance to road, distance to school, distance to hospitals, elevation, distance to built-up and socio economic drivers like population density, literacy rate and household density. In the model, pixels of low density residential class are clustered into different sample area in year 2001. Similarly all the pixels of low density residential class in 2007 are also clustered. Difference in the clustered pixels of 2001 and 2007 are considered. These clustered pixels are then considered for calculating the probability of low density residential. Probability of low density residential is multiplied with its neighbourhood effect. Suitability map of low density residential is generated using eq.4.1. Similarly model will generate for every class in the LULC. After generating suitability maps for each class in year 2001 and 2007, the model generates LULC 2001 and LULC 2007 based on socio economic and physical drivers. LULC 2001 and LULC 2007 are combination of all the suitability maps generated for 2001 and 2007. Using LULC 2001 and LULC 2007 transition area matrix and transition probability matrix is calculated. Using transition area matrix and transition probability matrix, the LULC 2013 is predicted and accuracy assessment is done.

Third phase is the phase where agent based modeling and simulation is used for the prediction of future settlements based on socio-economic factors supporting the growth in the city.

4.5 Agent Based Modeling

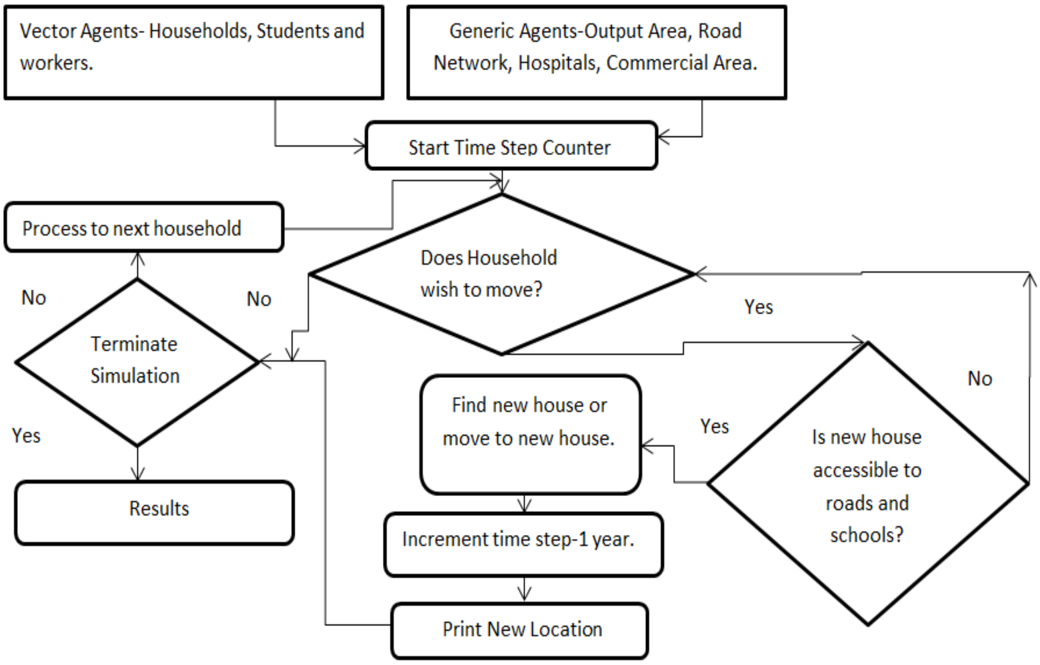


Figure 4.14: Workflow of Agent Based Modeling

In the Agent based modeling approach, socio-economic data of 2001 and 2011 are interpolated to 2007 and 2013. The socio-economic parameters, like income, number of houses, etc. are used to model the future settlement of agents, i.e., households. Output area, income, road, building, circle rate, hospitals, schools, colleges, residential area, vacant land agriculture land are in the form of vector data, and the final output is obtained in the form of a raster image. Figure 4.14 explain the methodology of the agent based modeling.

Agents are defined in terms of vector agents and generic agents. Generic agents are non GIS agents. Vector agents are those agents that are used to take decisions. Generic agents help the vector agents to take decisions based on the parameters or factors available to the agents for decision making in space and time. In this simulation process, household is a vector agent that is used to take decisions based on the conditions laid by the different rules defined to predict the LULC for 2013. Generic agents are the outcome of the different rules implemented to take the decision. For example, if land cost is less than 40000 rupees, then the available land will be allocated on the basis of the size of land occupied by the three classes (low, medium and high income residential). Land cost is generic agent. It is assumed that the area of a house in low income residential area is between 100 sq. meter and 120 sq. meter, in medium income residential area, it is between 120 sq. meter and 300 sq. meter and in high income residential area, it is between 300 sq. meter and 400 sq. meter.

Input Parameters:

(a) Raster Data

1. Circle rate 2012, Distance to commercial, Distance to road.

(b) Vector Data

1. Hospitals, commercial, roads, colleges, schools and ward-wise data of the number of households.

4.5.1 Rules for agent based modeling

The following rules are used to describe the interactions of agent with multiple agents and agent with environment.

1. Households build a house where the size of the house is adequate.

   According to this rule, agent should search for an area where the agent can build a house with the desired number of rooms. Size of the house depends on the income level of the agent (See and Batty 2012).

2. Households move to areas where schools and hospitals are easily accessible.

   If the household has school going children, the proximity of school should be around 2 to 5 miles, and hospitals should be in the range of 4 to 5 miles.

3. Neighbourhood qualities play a role in influencing household choice.

   Neighbourhood defines amenities or facilities available to the household in the area where the agent is planning to settle. Shops, green spaces, schools, hospitals, security are the elements which a household searches for before building a house.

4. The socio-economic status of area influences the type of house chosen.

   Socio economic status is an important factor used in decision making. Households take decision on the basis of their economic status. Cost of the land is less in highly populated area if the area is far from city center but if household settles in highly populated area near to the city center then cost of the land is high .Due to unavailability of land; agent has to decide to stay or relocate to new area where the agent finds similar condition for settlement according to his economic status.

5. Households will move to areas where transport routes are accessible.

   Connectivity is an important factor that is used to find a suitable land for settlement. Decision to stay near to school, work place, hospitals or city center depends upon the time taken by the agent to move, so every households check the road connectivity from his location.

4.5.2 Steps for Simulation

The flow followed for the methodology is as follows:

1. Preparation of LULC 2001, 2007 and 2013.

2. Implementation of CA-Markov model to predict the LULC of 2013.

3. Accuracy assessment using kappa statistic to find out the accuracy of predicted LULC 2013 with respect to the actual LULC 2013.

4. Implementation of ISRO IGBP LULC model on LULC 2001 and LULC 2007 using physical and socio economic drivers.

5. Comparison of predicted LULC of 2013 obtained from ISRO IBGP LULC model and the result of CA-Markov model. Kappa statistics of both the models are compared. The best result outcome is used in agent based modeling.

6. In agent based modeling, scenario of 2007 is setup. For each tick (a tick is one time instant during the simulation process, and its duration is user-defined), a new household is created in a suitable location. This suitable location is determined on the basic of rules defined in the model

7. Decision making rules are implemented based on priority. Based on the income of household, the household will decide to relocate. Before moving to new location, agent should fulfil some conditions. These conditions are:

   i. Agent should check the socio economic status of the area where he wants to relocate. Circle rate is used as input parameter that defines the cost of the land as it is set by government authority. If the circle rate is affordable to the agent then he will search for a suitable area with proper road connectivity, otherwise, the search continues. Agent finds a suitable land to build a house. Size of the house is defined in the model. After identifying the area, the agent checks for the nearest school or college in the area to send his children and hospital for any kind of emergency.

ii. The modeling for LULC 2013 will be done on ward basis.

8. Outcome will be raster image of predicted household locations in the year 2013.

Chapter-5

Results and Discussions

5.1 Generation of LULC Maps

Visual interpretation techniques are used for the preparation of LULC 2001, 2007 and 2013. These LULC maps are prepared from satellite image of 2001, 2007 and 2013. Before preparing the LULC maps, all the satellite image of different times are first geo-referenced. After geo-referencing all the satellite image, visual interpretation techniques are implemented. LULC 2001, LULC 2007 and LULC 2013 are shown in Figure 5.1, Figure 5.2 and Figure 5.3 respectively.

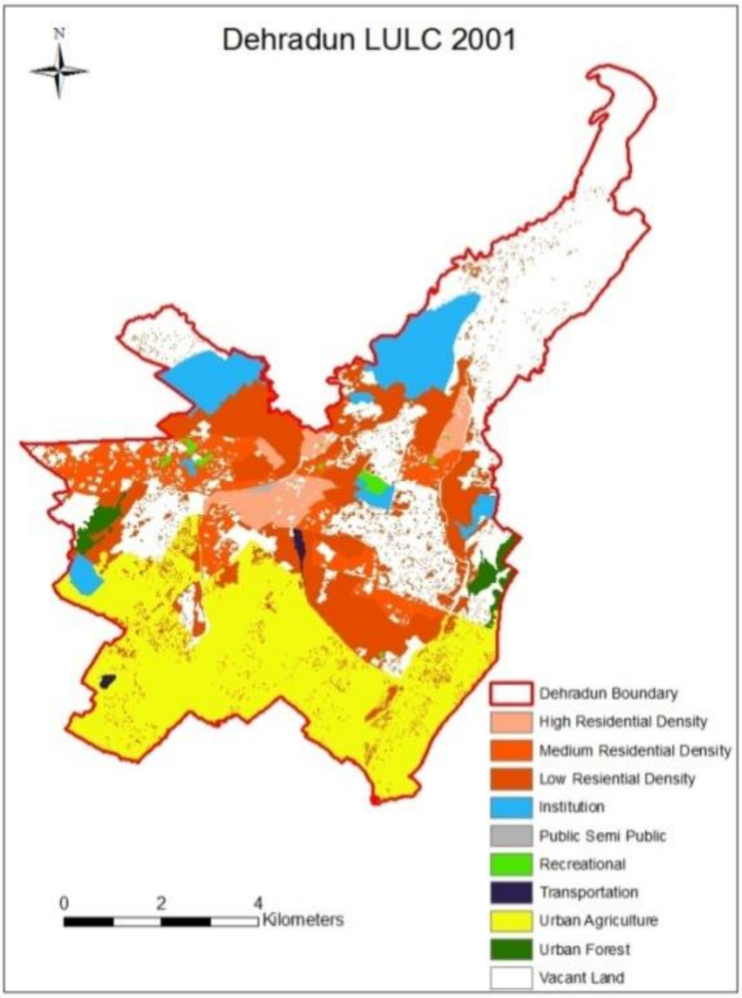


Figure 5.1: Dehradun LULC 2001

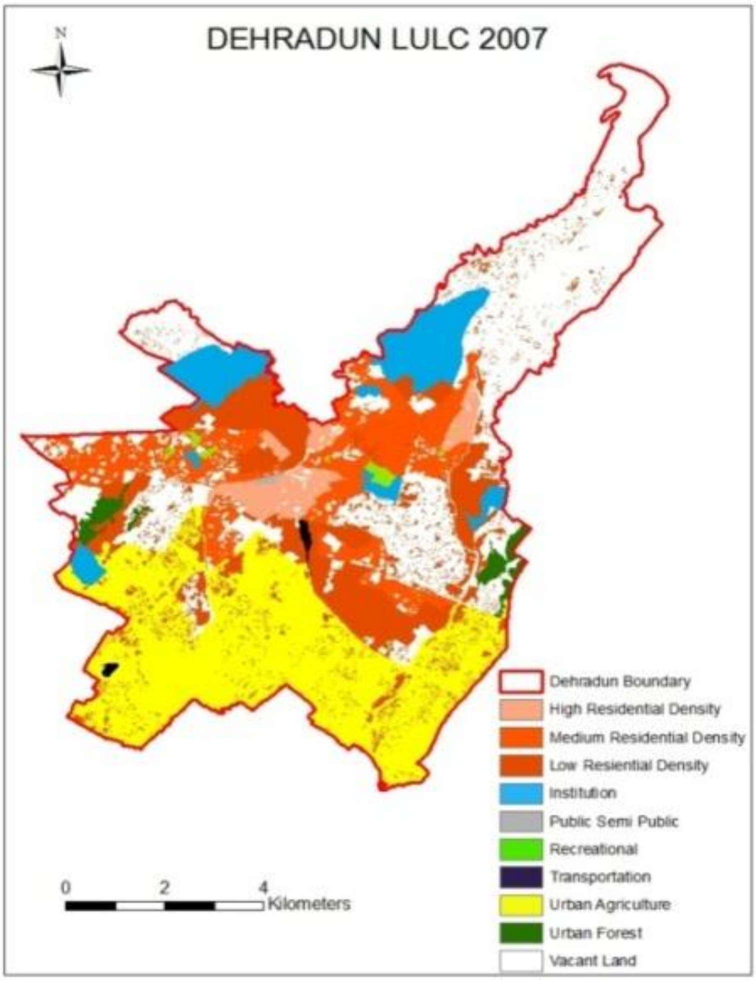


Figure 5.2: Dehradun LULC 2007

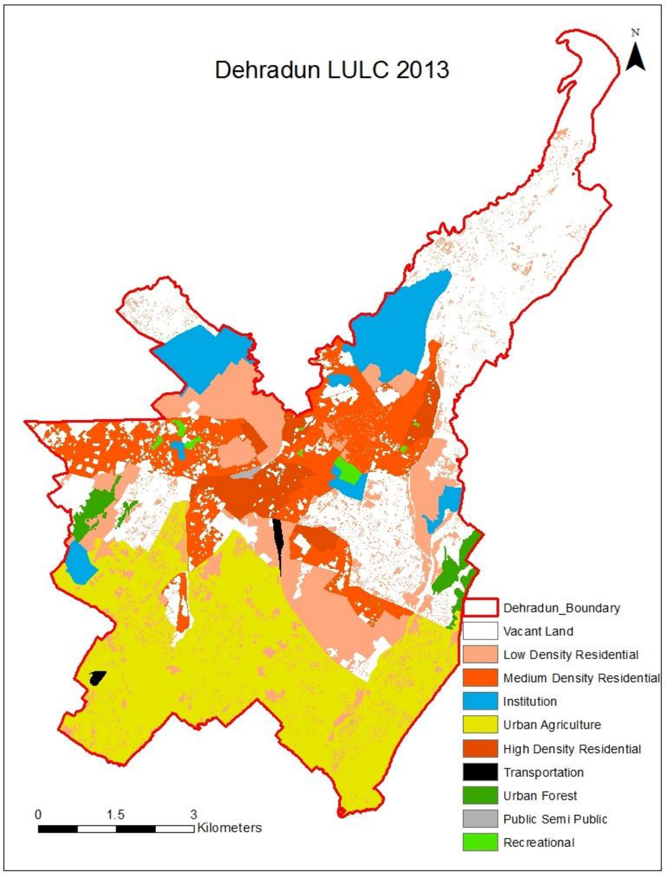


Figure 5.3: Dehradun LULC 2013

5.1.1 Accuracy Assessment of LULC maps

It is observed that in LULC 2001, 2007 and 2013, high density residential and medium density residential areas are present in the center of Dehradun city. Low density residential area is present in the outskirts of the city where lot of area is under urban agriculture and vacant area and development is in starting phase.

Accuracy of LULC classification for 2001, 2007 and 2013 is calculated in terms of kappa coefficient for each class. This is shown in Table 5.1. Accuracy assessment is done using 2001 satellite image for LULC 2001, 2007 satellite image for LULC 2007 and 2013 satellite image for LULC 2013. Signature files are prepared for each class then supervised classification is done. For accuracy of each class, random points are generated. For example for calculating accuracy of urban agriculture class, 200 points are generated. Convert all the classes to null value except the agriculture class. Then points are marked only on the urban agriculture class to calculate the accuracy of urban agriculture class. Similar process is carried out for all the classes. It is observed from Table 5.1 that 95 % accuracy is obtained for urban agriculture class in 2001 which is less in 2007 i.e. 93% for urban agriculture class. In 2013, accuracy of urban agriculture class is 91 %.Similarly 91 % accuracy is obtained in low density residential in 2001 while in 2007 it is 96%. It is observed that 94% accuracy obtained in year 2001 while in year 2007 and 2013 it is 91% and 89%.

Table 5.1: Kappa Coefficients for individual classes for years 2001 and 2007

Land Use Categories	Kappa Index 2001(%)	Kappa Index-2007(%)	Kappa Index-2013(%)
High Density Residential	95%	95%	95%
Medium Density Residential	93%	96%	95%
Low Density Residential	91%	96%	94%
Institution	98%	98%	98%
Public Semi Public	98%	98%	98%
Transportation	98%	98%	98%
Transportation	98%	98%	98%
Urban Agriculture	95%	93%	91%
Urban Forest	98%	98%	98%
Vacant Land	93%	87%	83%
Total Accuracy	94%	91%	89%

5.2 Cellular automata

In CA-Markov model, Table 5.2 shows transition area matrix which is created using LULC 2001 and LULC 2007 for a time period of 6 years.

Table 5.2: Transition Area Matrix for LULC 2001 –LULC 2007

Classes	1	2	3	4	5	6	7	8	9	10
High Density Residential	87388	0	0	0	0	0	0	0	0	0
Medium Density Residential	0	322161	0	0	0	90	0	0	0	0
Low Density Residential	0	71767	379617	0	0	0	0	0	0	0
Institution	0	0	0	190115	0	0	0	0	0	0
Public Semi Public	0	0	0	0	2823	0	0	0	0	0
Recreational	0	0	0	0	0	12315	0	0	0	0
Transportation	0	0	0	0	0	0	6674	0	0	0
Urban Agriculture	0	0	20401	0	0	0	0	730964	0	0
Urban Forest	0	0	0	0	0	0	0	0	730964	0
Vacant Land	0	33136	9623	0	0	0	0	0	2282	769111

Where

1. High Density Residential
2. Medium Density Residential
3. Low Density Residential
4. Institution
5. Public Semi Public

6. Recreational
7. Transportation
8. Urban Agriculture
9. Urban Forest
10. Vacant Land

Transition area matrix shows how many pixels of each class are converted to other classes between 2001 and 2007. For example, 33136 pixels of vacant land are converted to medium density residential area, 9623 to low density residential area, 2282 to urban forest and 769111 pixels remain as vacant land. A graphical representation of area covered by each class in 2001 and 2007 is shown in Figure 5.3.

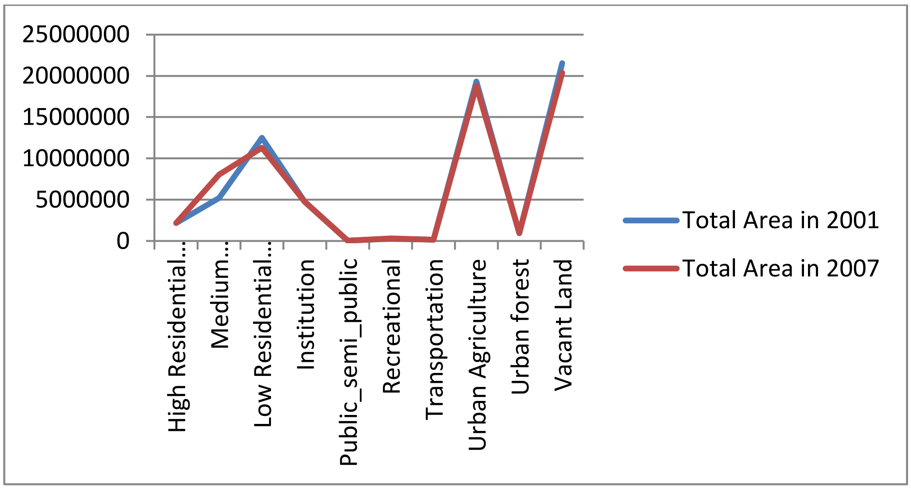


Figure 5.4: Graph showing change in the area covered by different classes from 2001 to 2007

Table 5.3 explains the transition probability matrix generated using LULC 2001 and LULC 2007 for a time period of 6 years. Transition probability matrix gives the probability of one class changing into another. So, all the values in the transition probability matrix lie between 0 and 1. The sum of all probabilities in any single row is 1. For example, vacant land class has a probability of 0.0407 to change into medium density residential area class, 0.0118 to change into low density residential area and 0.02 to change into urban forest.

Table 5.3: Transition Probability Matrix for 2001-2007

Classes	1	2	3	4	5	6	7	8	9	10
High-Density Residential	0.9957	0	0	0	0	0	0	0	0	0
Medium-Density Residential	0	0.9997	0	0	0	.003	0	0	0	0
Low-Density Residential	0	0.159	0.841	0	0	0	0	0	0	0
Institution	0	0	0	1	0	0	0	0	0	0
Public-Semi-Public	0	0	0	0	1	0	0	0	0	0
Recreational	0	0	0	0	0	1	0	0	0	0
Transportation	0	0	0	0	0	0	1	0	0	0
Urban Agriculture	0	0	0.272	0	0	0	0	0.9728	0	0
Urban Forest	0	0	0	0	0	0	0	0	1	0
Vacant Land	0	0.0407	0.0118	0	0	0	0	0	0.028	0.9447

where

1. High Density Residential

2. Medium Density Residential

3. Low Density Residential

4. Institution

5. Public Semi Public

6. Recreational

7. Transportation

8. Urban Agriculture

9. Urban Forest

10. Vacant Land

Using transition area matrix and transition probability matrix, LULC 2013 is predicted and its accuracy is found to be 89.06 %. The predicted LULC 2013 is shown in Fig 5.5.

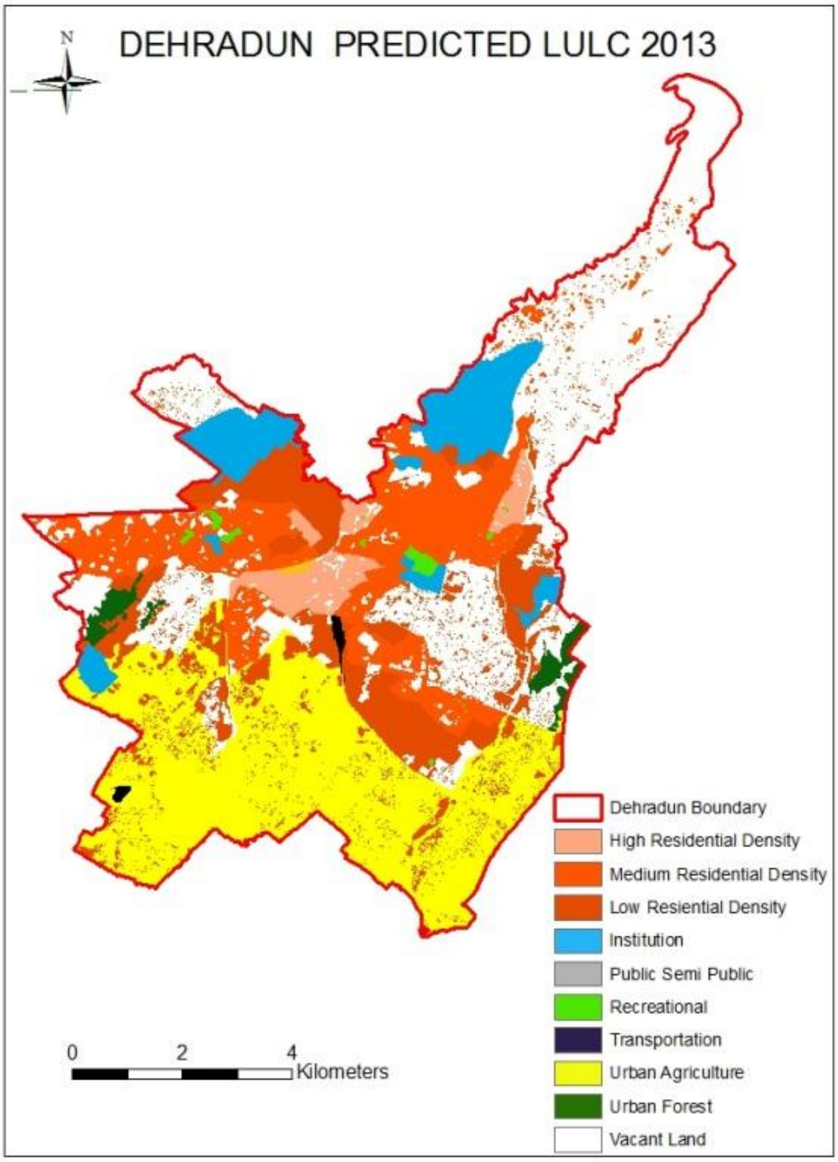


Figure 5.5: Predicted LULC 2013 for Dehradun

Table 5.4: Kappa Coefficients for individual classes for actual LULC 2013 and Predicted LULC 2013

Land Use Categories	Kappa-Index LULC 2013(%)	Kappa-Index LULC 2013(%)Predicted
High Density Residential	95%	90%
Medium Density Residential	95%	89%
Low Density Residential	94%	86%
Institution	98%	98%
Public Semi Public	98%	98%
Recreational	98%	98%
Transportation	98%	98%
Urban Agriculture	91%	86%
Urban Forest	98%	98%
Vacant Land	83%	81%
Total Accuracy	89%	85.06%

Table 5.4 gives the kappa coefficients for individual classes as well as total accuracy of LULC of actual 2013 and predicted 2013. In Table 5.4, it is observed that kappa value varies in case of medium density residential, low density residential, urban agriculture and vacant land. Graphical represented is shown based on the value obtained from Table 5.4 in Figure 5.6.

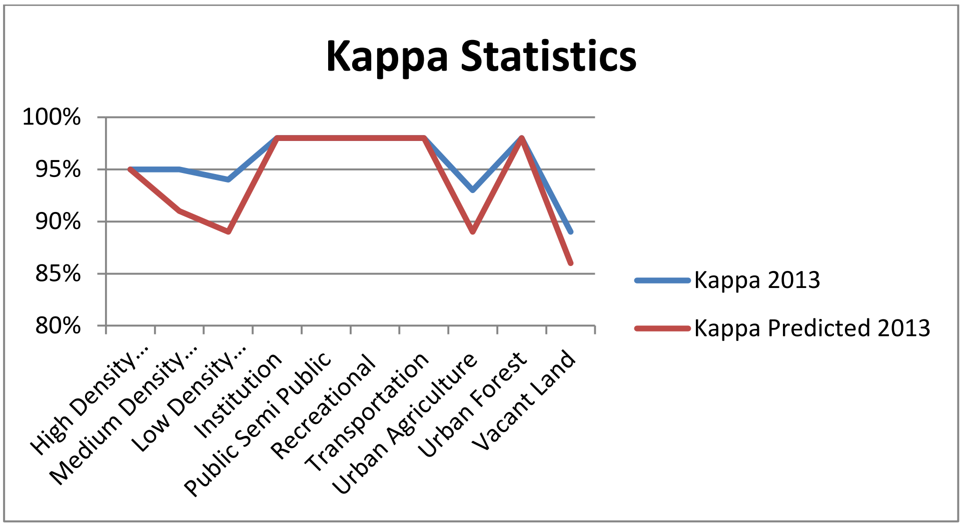


Figure 5.6: Kappa Statistics for actual LULC 2013 and predicted LULC 2013

5.3 ISRO IGBP LULC Model

5.3.1 Database Generation for Various Drivers

ISRO IGBP LULC model is a modeling technique which incorporate physical and socio economic drivers for the prediction. Complete description of all the drivers are mention in section 4.4. All the drivers are shown below in Figures 5.7(a) to 5.7(m):

Distance to built-up

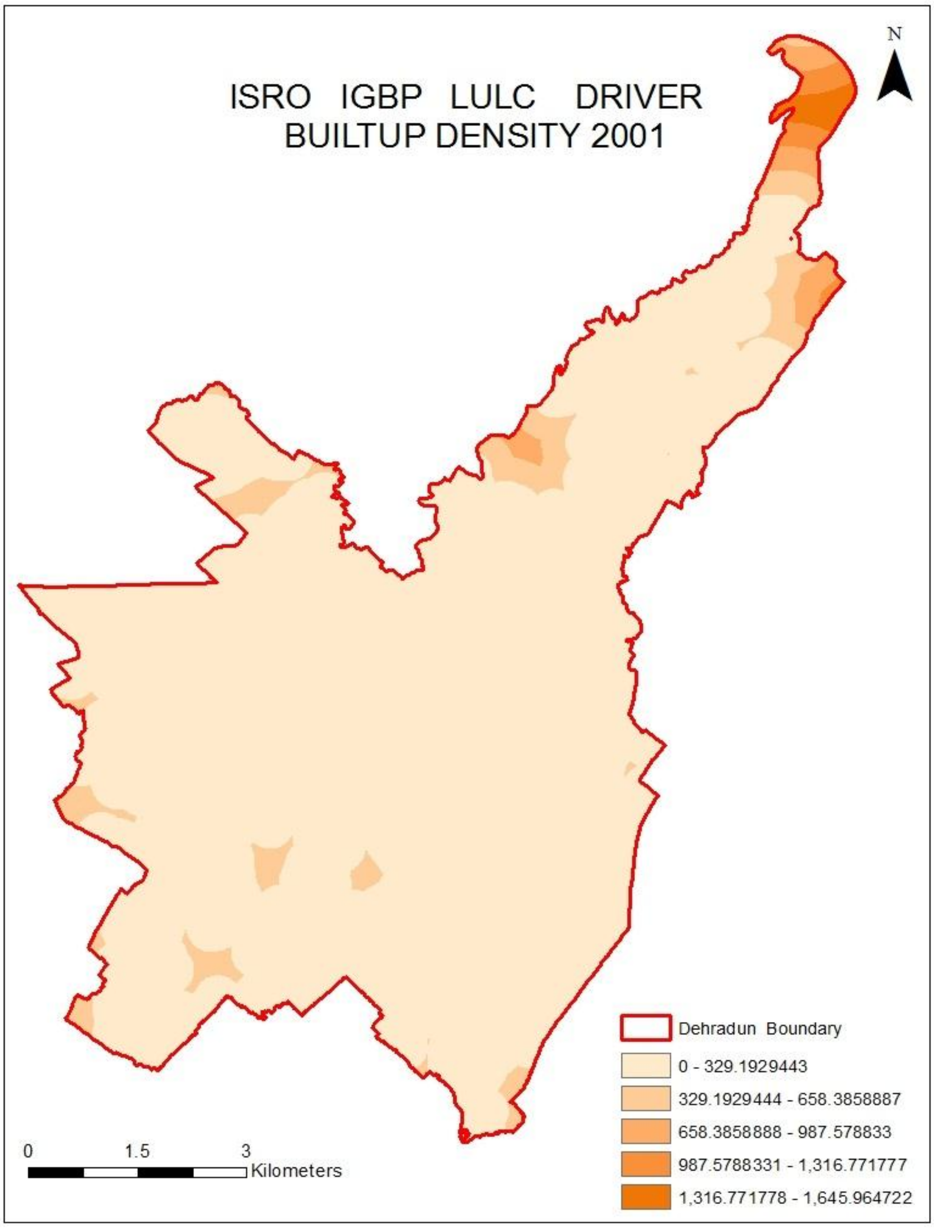


Figure 5.7 (a): Built-up density 2001

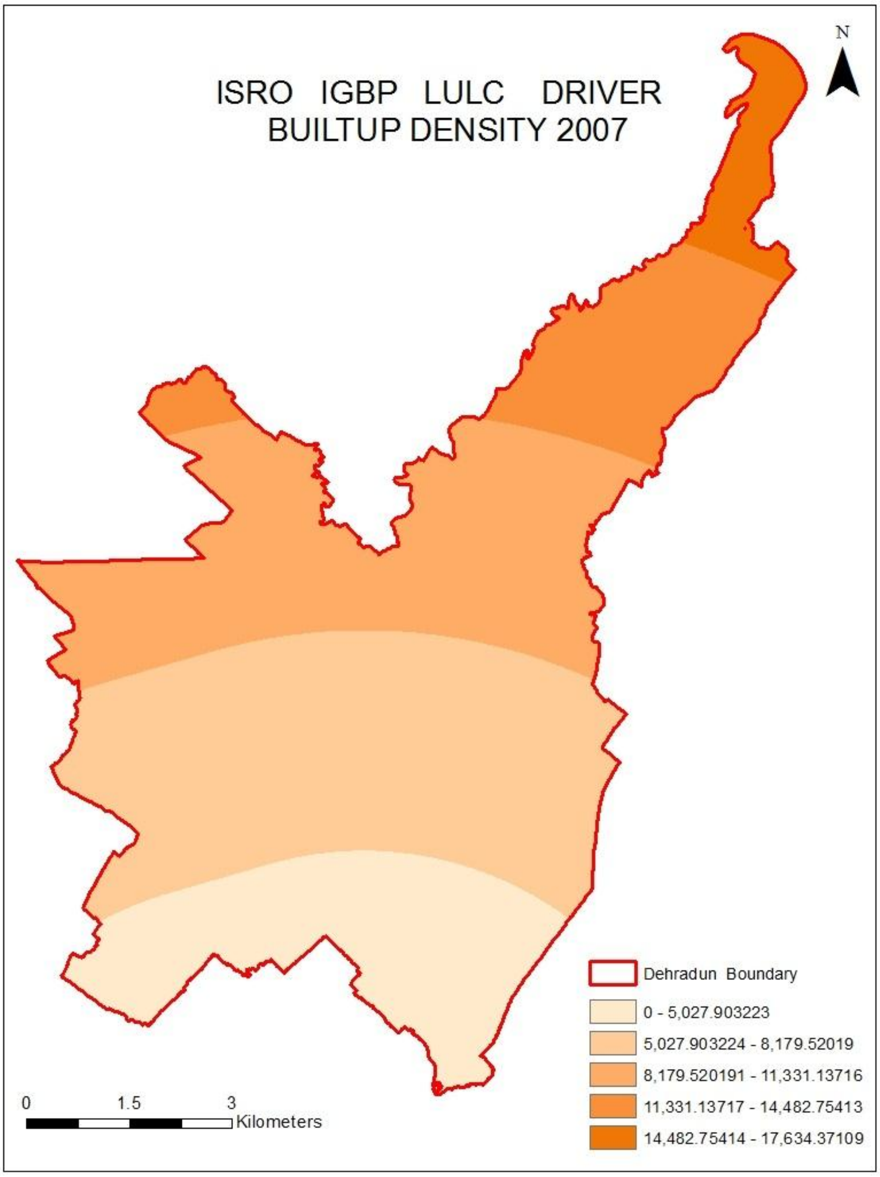


Figure 5.7 (b): Built-up density 2007

4. Distance to road

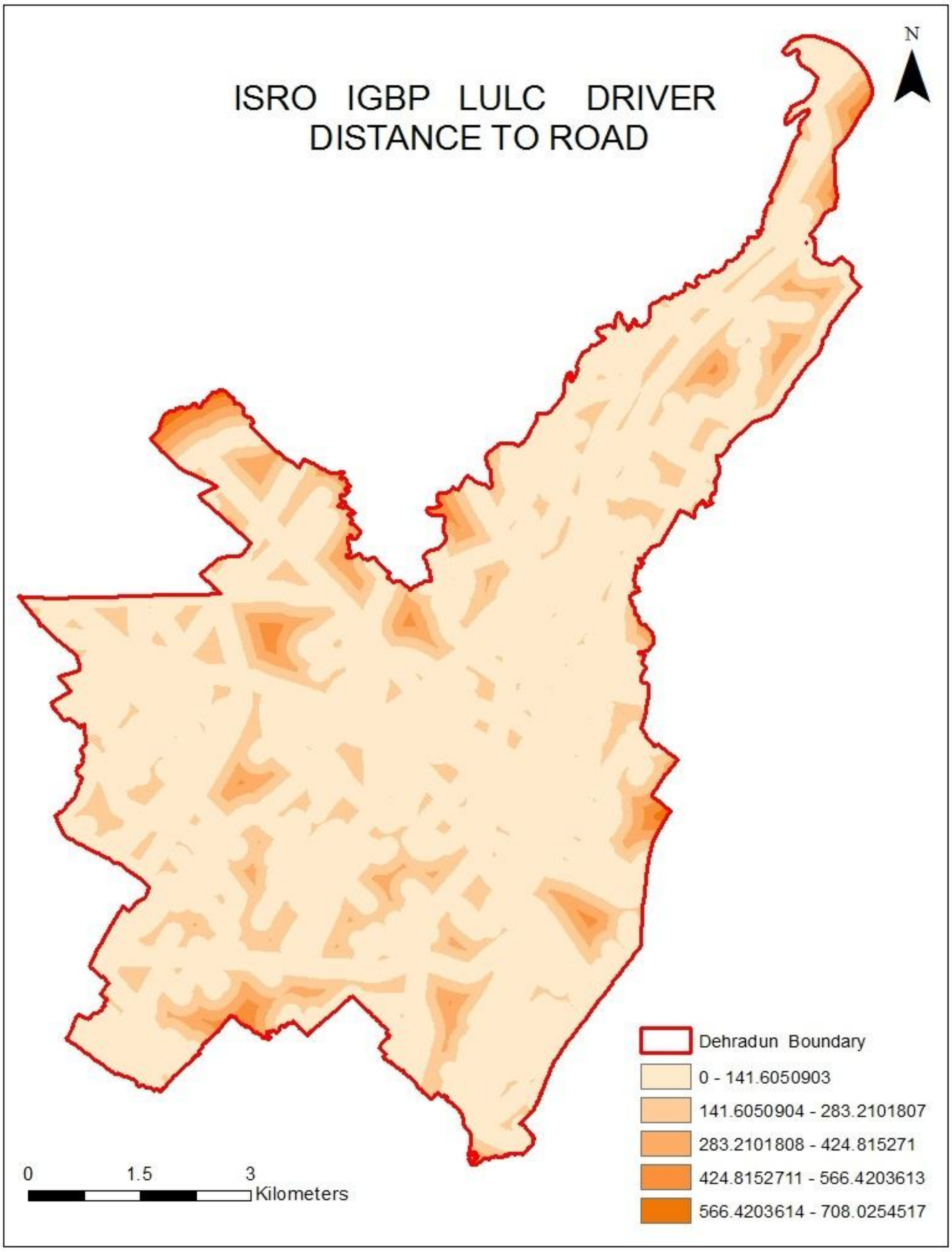


Figure 5.7 (c): Distance to roads

5. Distance to schools

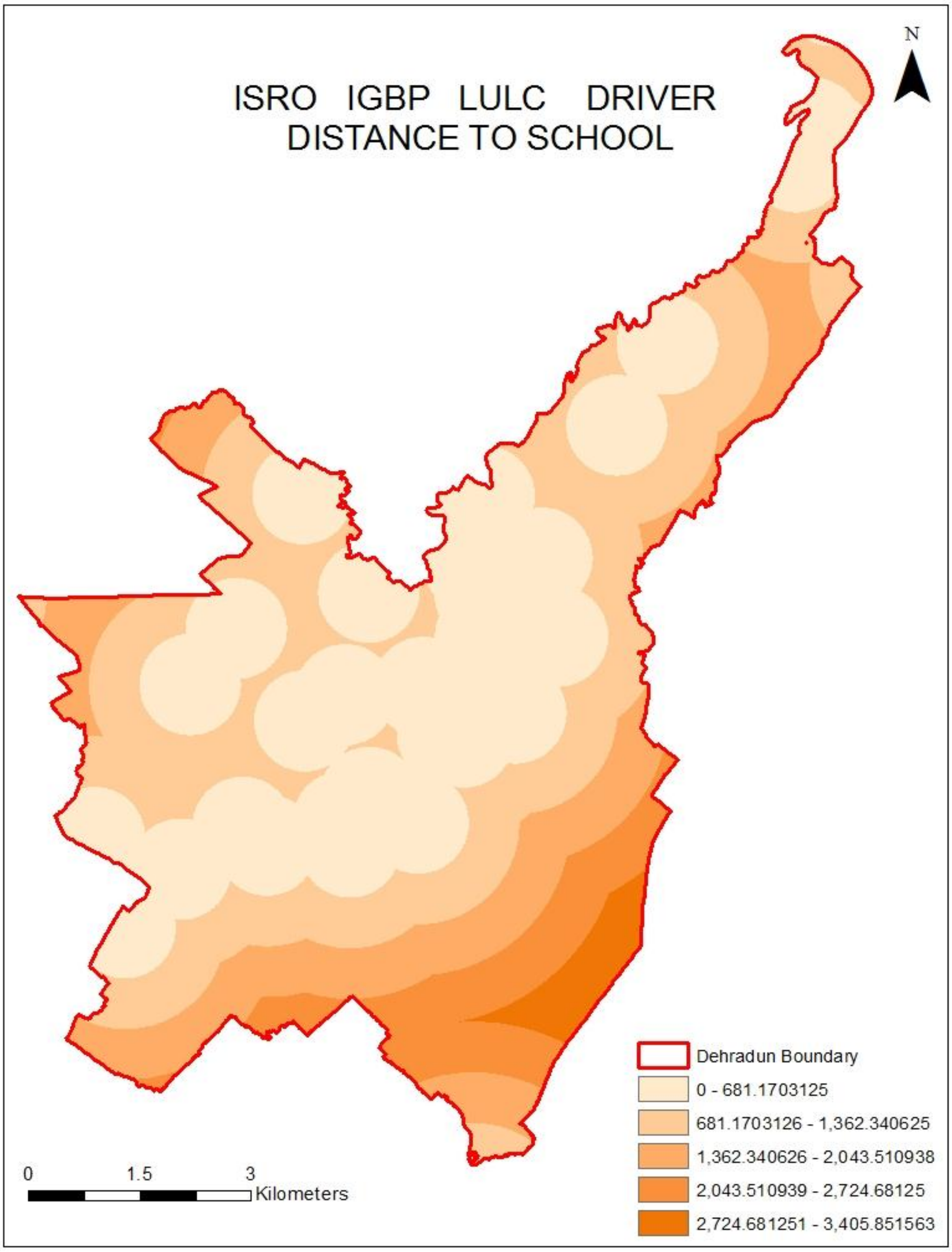


Figure 5.7 (d): Distance to schools

6. Distance to hospitals

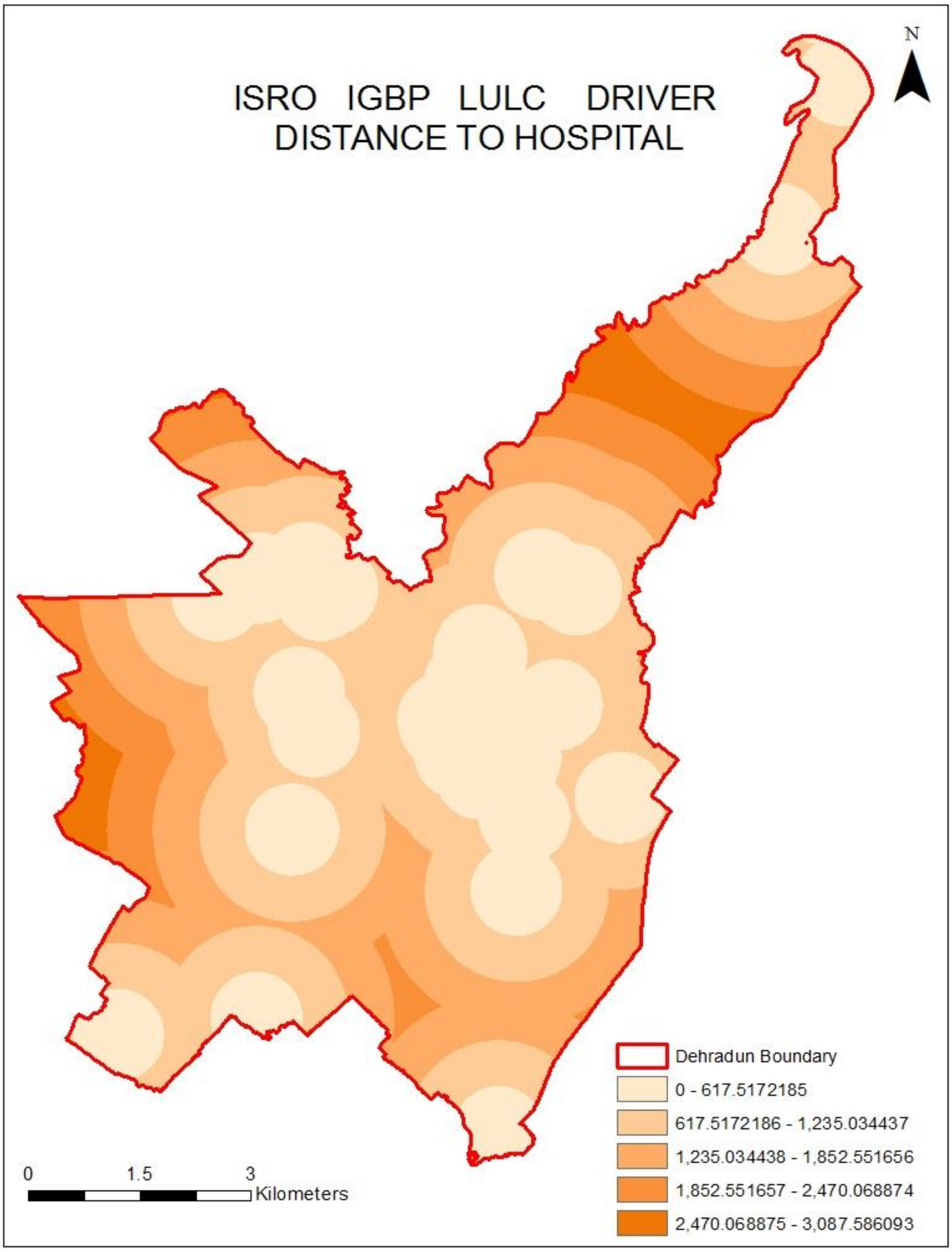


Figure 5.7 (e): Distance to hospitals

7. Elevation

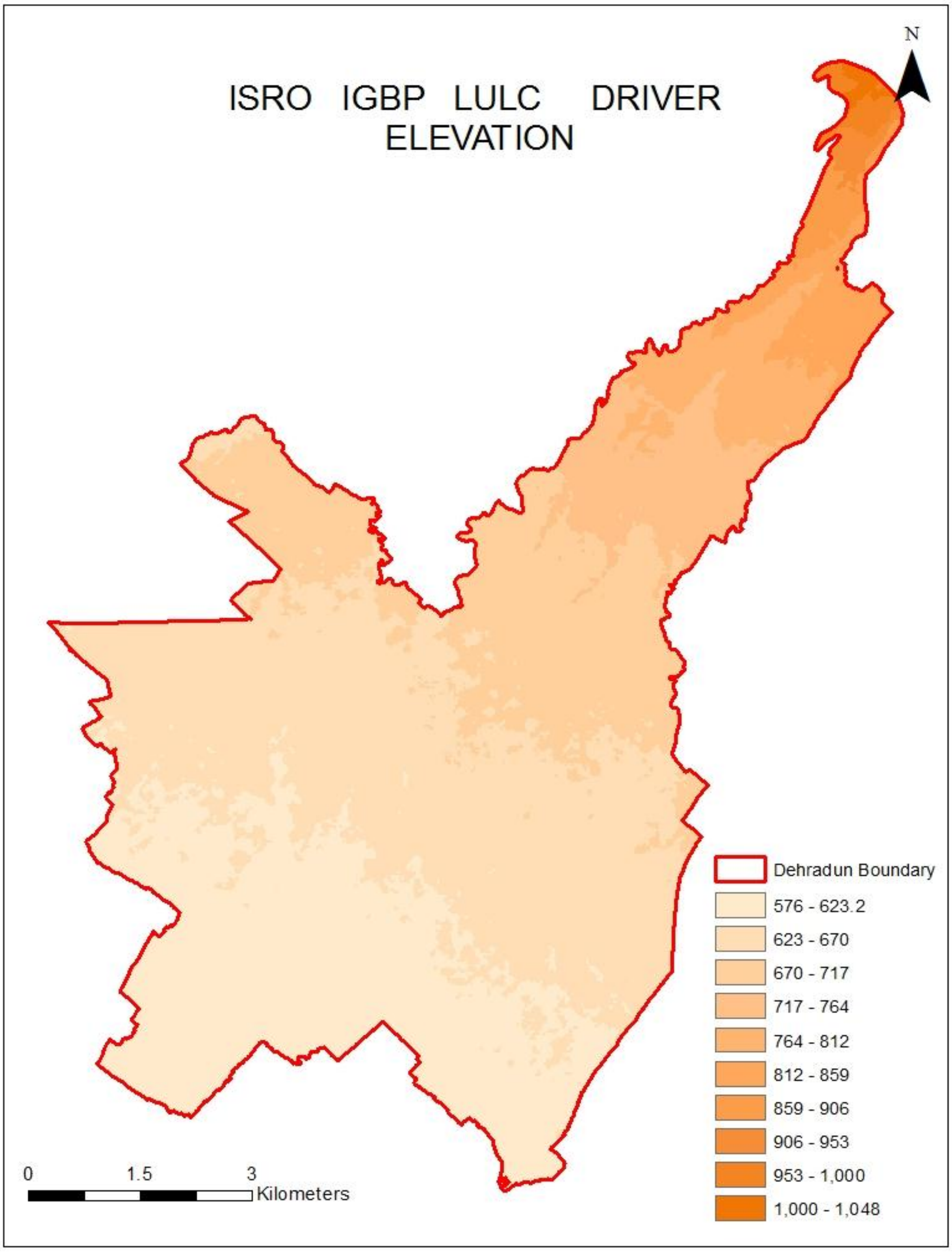


Figure 5.7 (f): Elevation

8. Socio economic drivers
    1. Population density

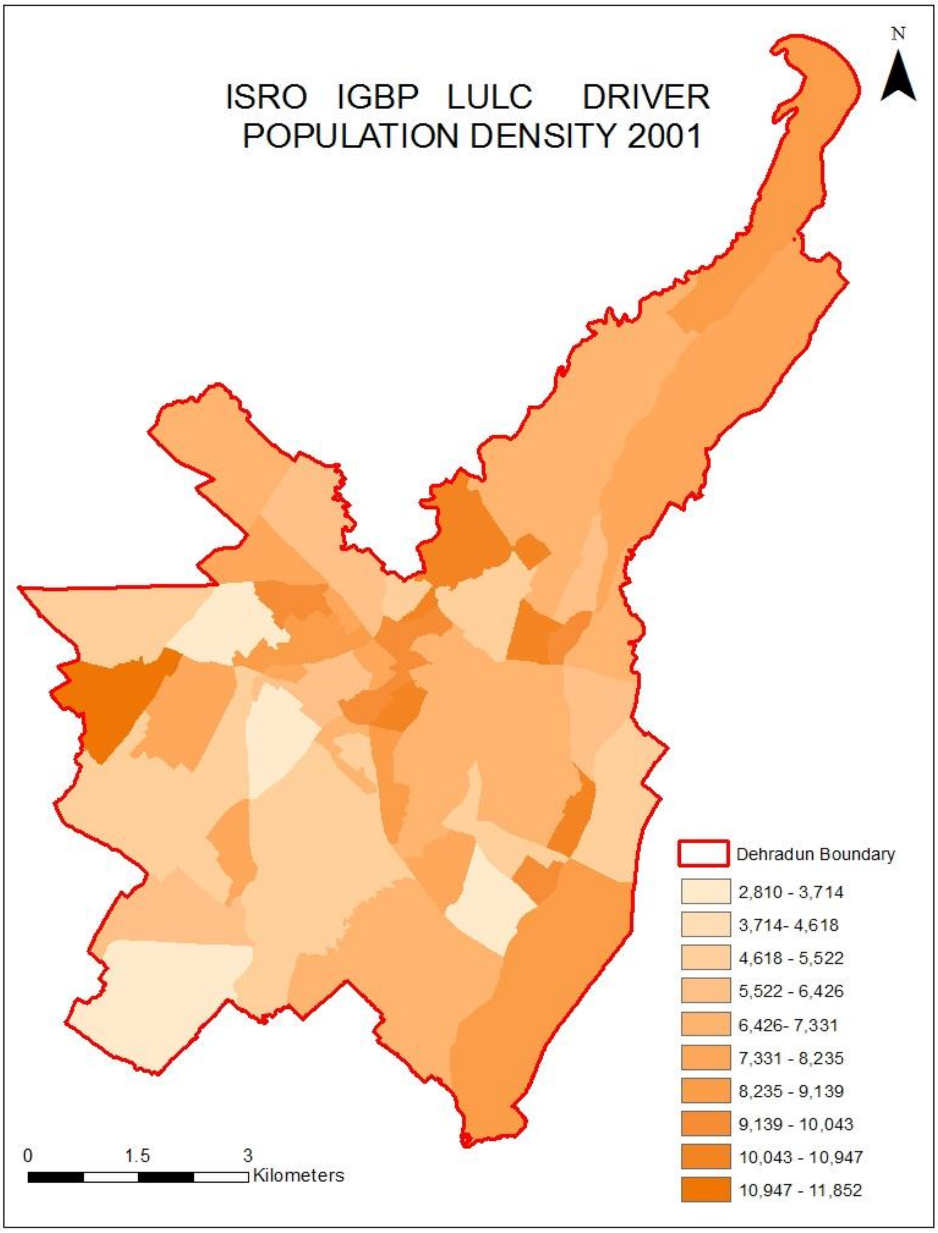


Figure 5.7 (g): Population density 2001

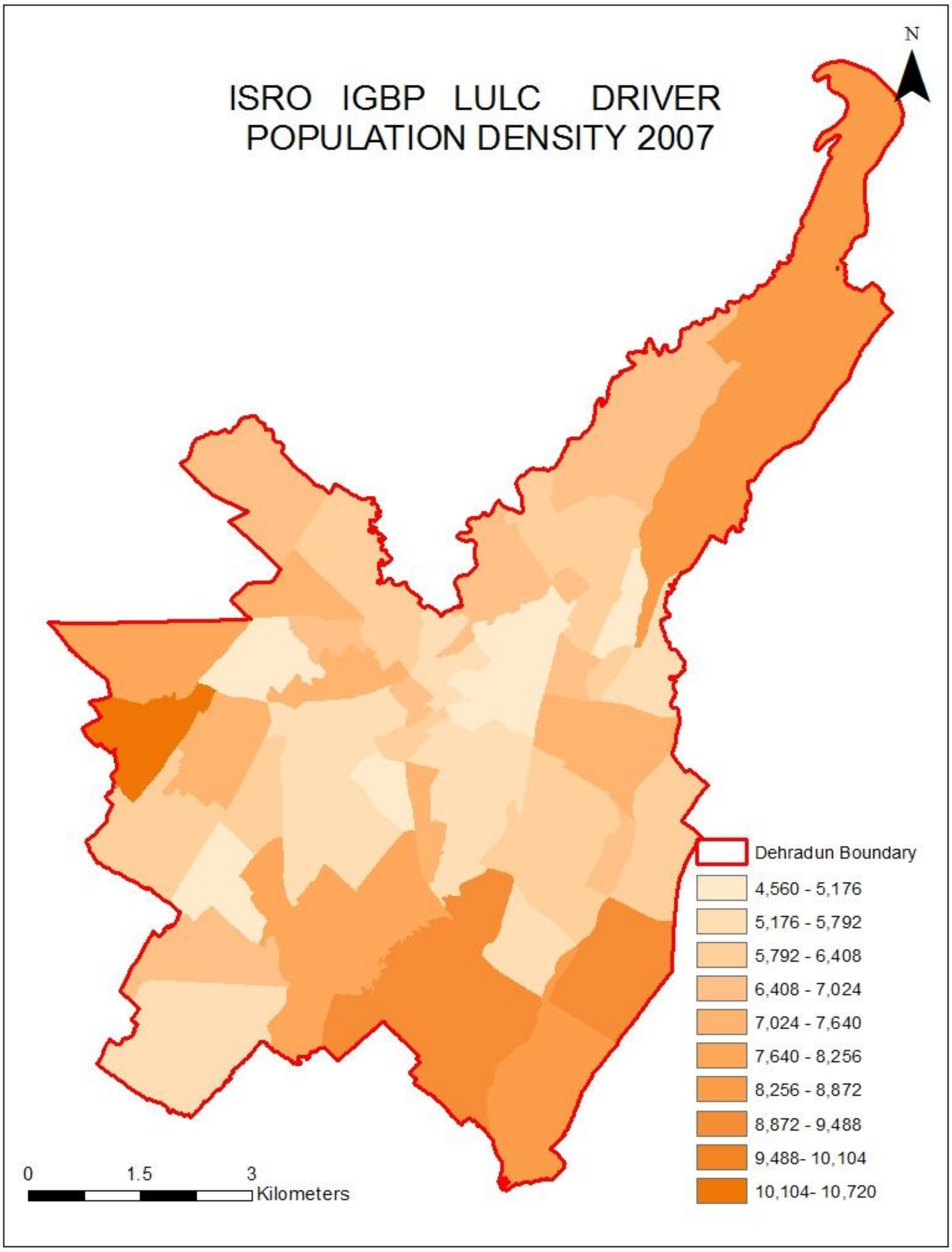


Figure 5.7 (h): Population density 2007

2. Literacy rate

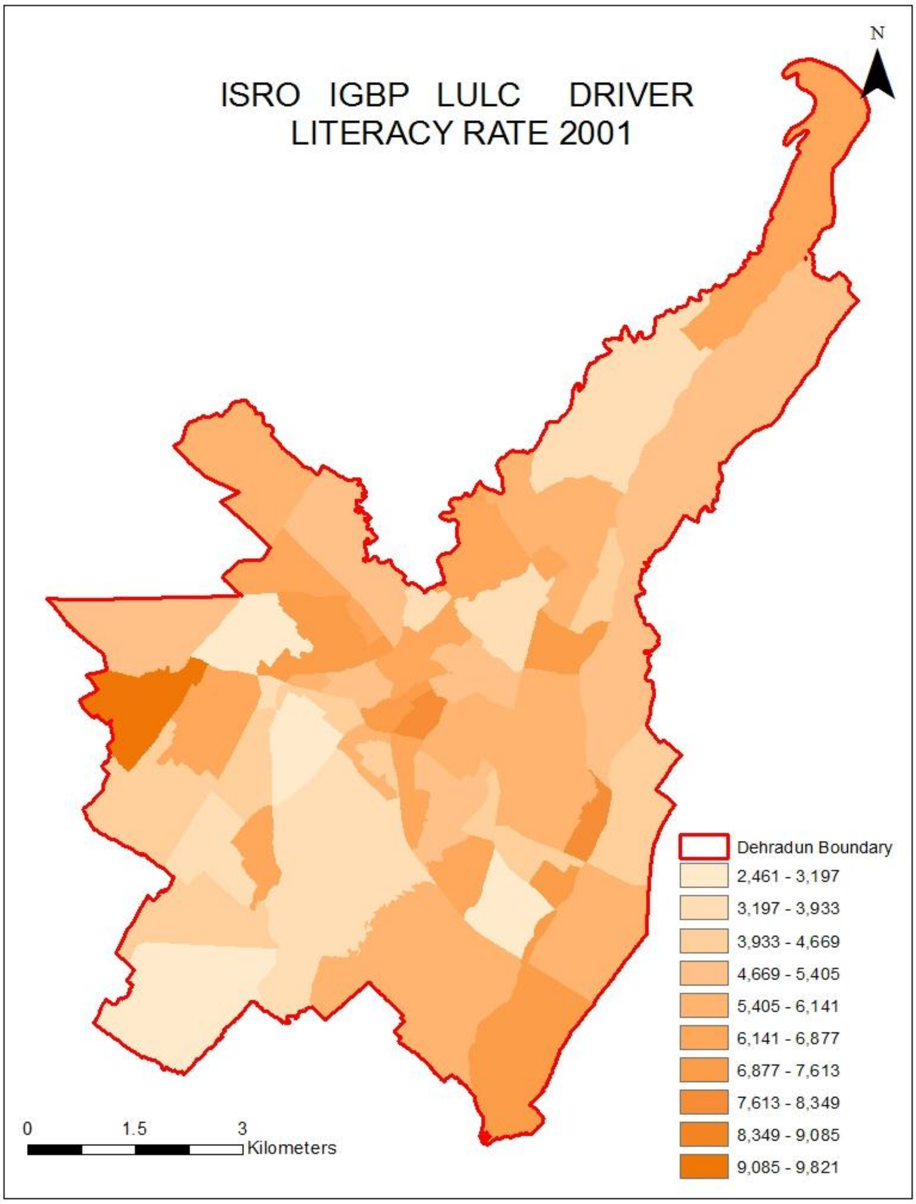


Figure 5.7 (i): Literacy rate 2001

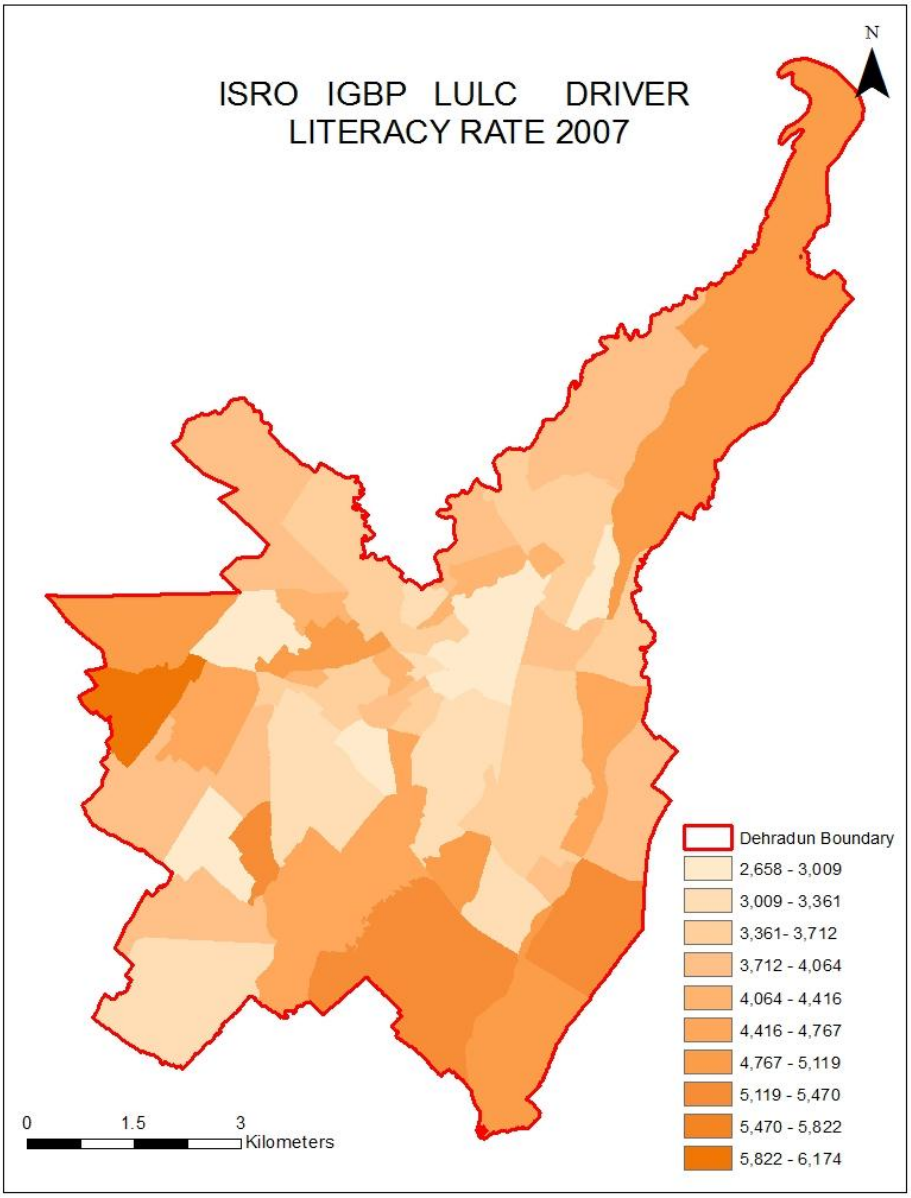


Figure 5.7 (j): Literacy rate 2007

3. Household

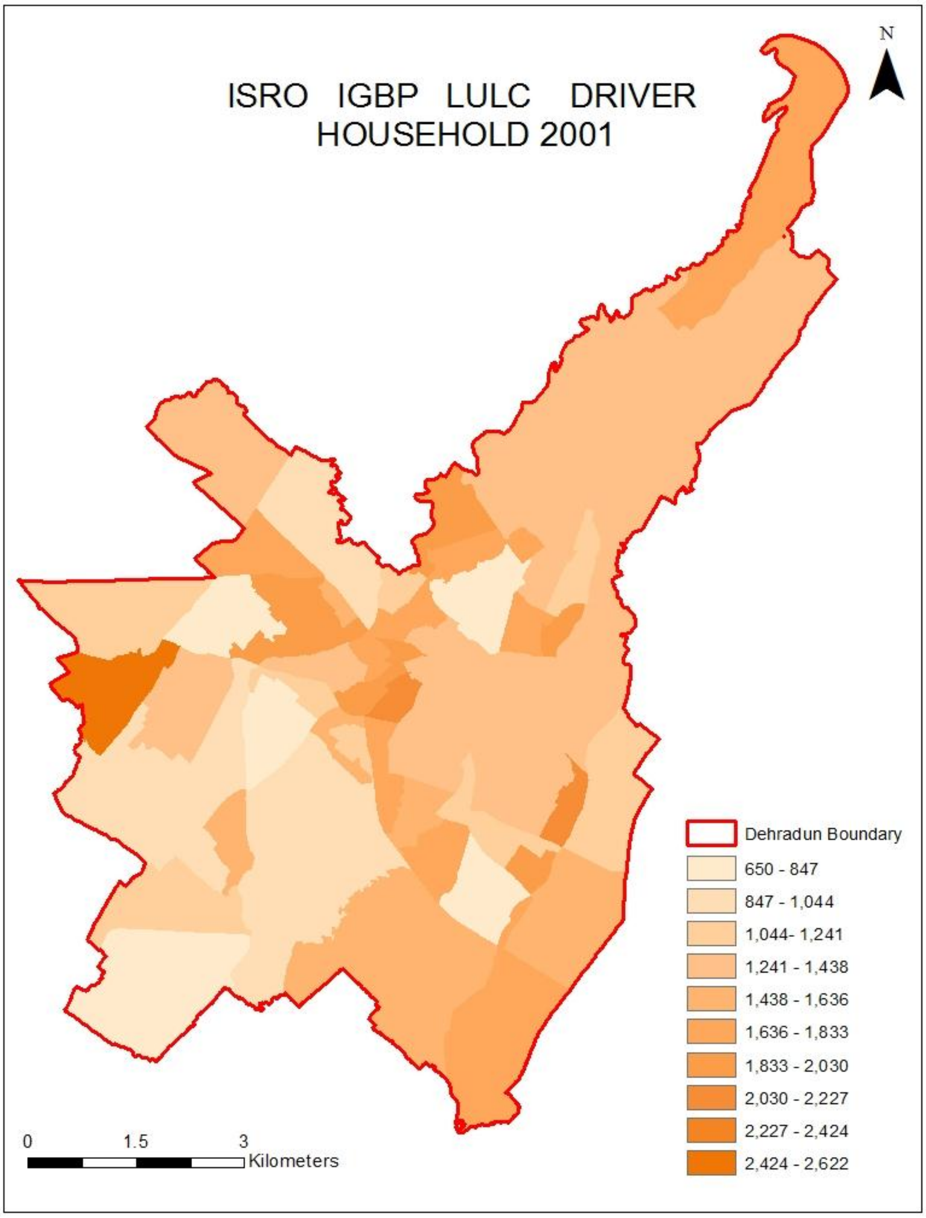


Figure 5.7 (k): Household 2001

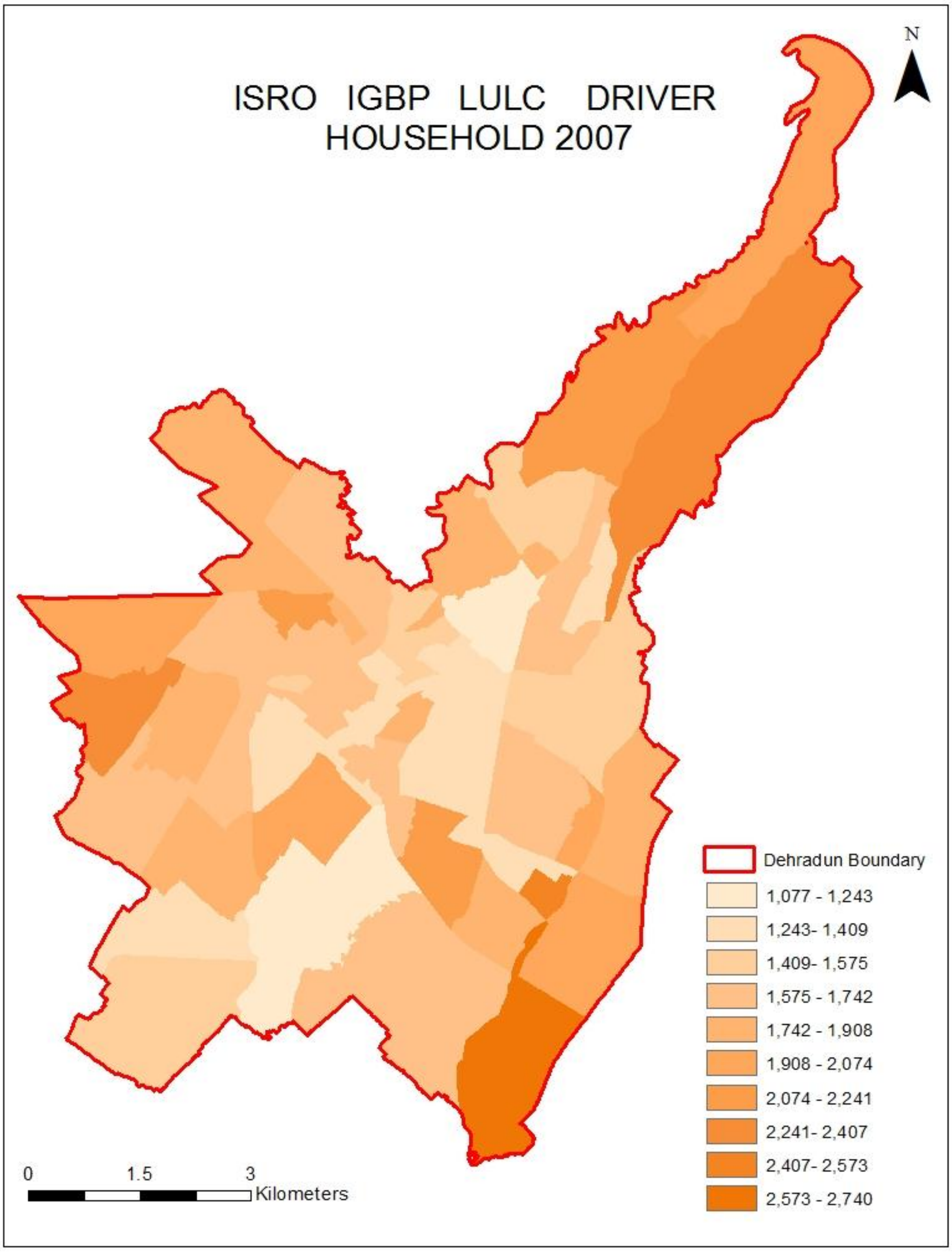


Figure 5.7 (l): Household 2007

4. Circle Rate

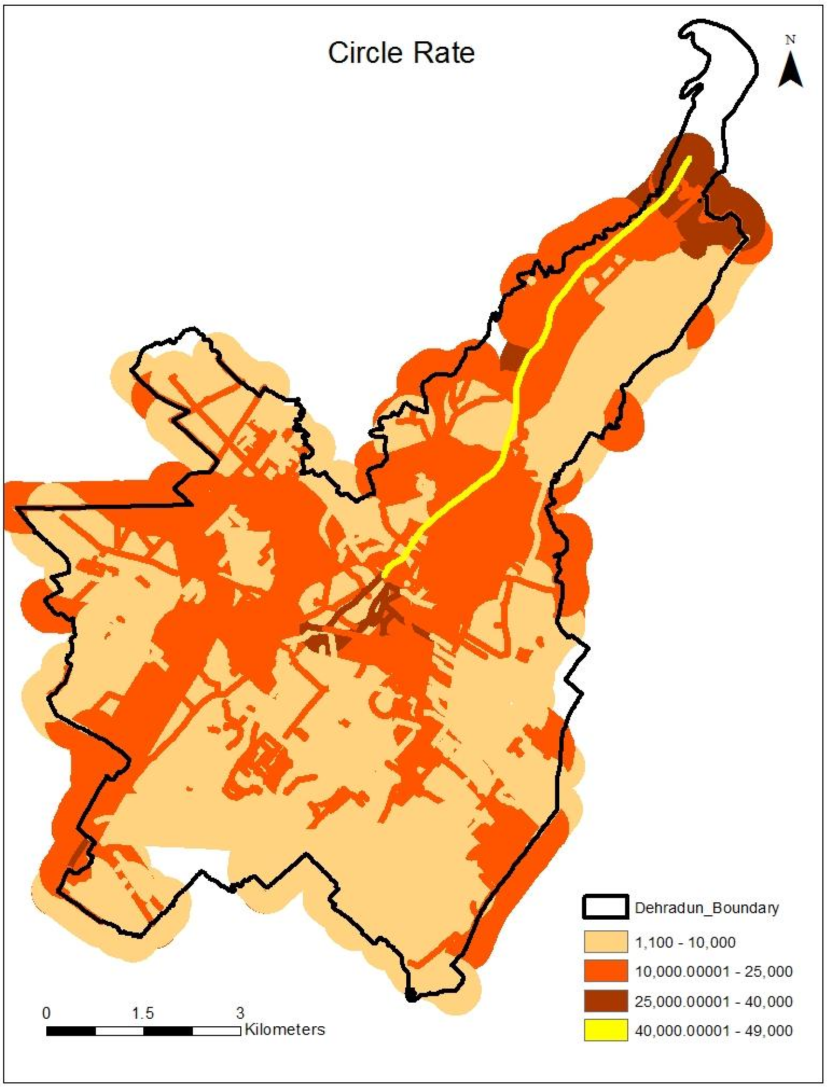
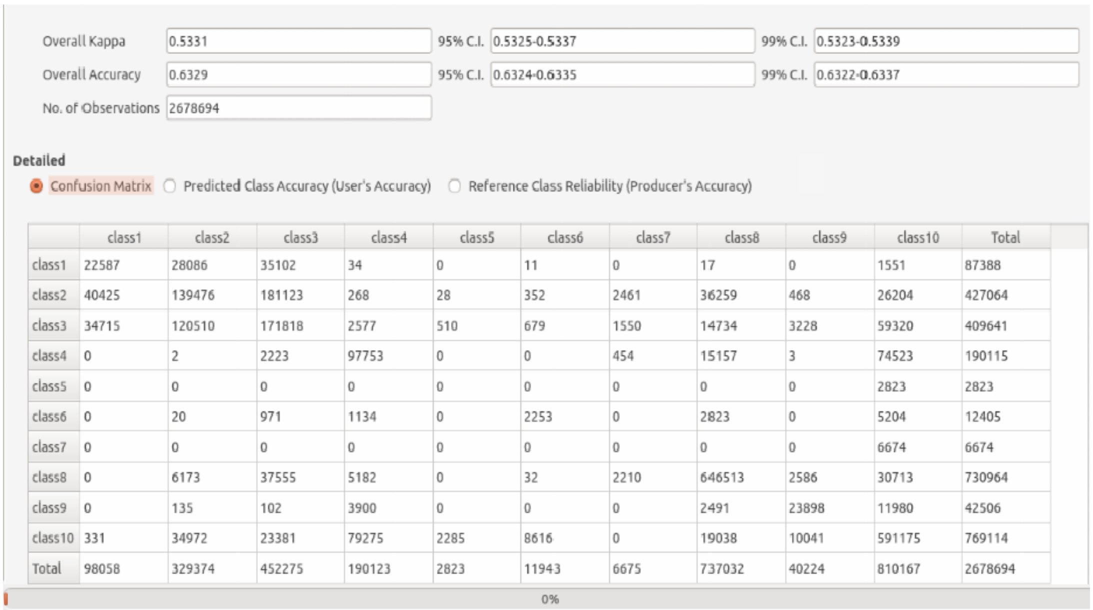


Figure 5.7 (m): Circle Rate

5.3.3 Simulation and Accuracy assessment

In ISRO IGBP LULC model, LULC 2001, LULC 2007 as shown in Fig 5.1 and Fig 5.2, are used to simulated with different LULC drivers like distance to built-up 2001, distance to built-up 2007, population density 2001, population density 2007, distance to hospitals, distance to schools, distance to roads, household 2001, household 2007, literacy rate 2001 and literacy rate 2007 as shown in section 5.3.1 for the prediction of LULC 2013. It was observed that accuracy of this model is less than that of CA-Markov model. The kappa coefficient for this model was 53.31 % with overall accuracy of 63.29% is shown in Figure 5.8.



	class1	class2	class3	class4	class5	class6	class7	class8	class9	class10	Total
class1	22587	28086	35102	34	0	11	0	17	0	1551	87388
class2	40425	139476	181123	268	28	352	2461	36259	468	26204	427064
class3	34715	120510	171818	2577	510	679	1550	14734	3228	59320	409641
class4	0	2	2223	97753	0	0	454	15157	3	74523	190115
class5	0	0	0	0	0	0	0	0	0	2823	2823
class6	0	20	971	1134	0	2253	0	2823	0	5204	12405
class7	0	0	0	0	0	0	0	0	0	6674	6674
class8	0	6173	37555	5182	0	32	2210	646513	2586	30713	730964
class9	0	135	102	3900	0	0	0	2491	23898	11980	42506
class10	331	34972	23381	79275	2285	8616	0	19038	10041	591175	769114
Total	98058	329374	452275	190123	2823	11943	6675	737032	40224	810167	2678694

Figure 5.8: Screen shot of ISRO LULC IGBP model showing different parameter of accuracy assessment.

Where Class 1- High Density Residential, Class 2-Medium Density Residential, class 3-Low Density Residential, Class 4-Institution, Class 5-Public Semi Public, Class 6-Recreational, Class 7-Transportation, Class 8-Urban Agriculture, Class 9-Urban Forest, Class 10-Vacant Land

According, to Figure 5.8, total number of cells in high density residential was 87388 out of which 22587 cells were classified correctly, 35102 were classified as medium density residential and 35102 were classified as low density residential. In case of medium residential, 427064 cells out of which 40425 cells were present in high density residential, 181123 cells were in low density residential. This model can be optimized to further improvement its accuracy. This result successfully discusses objectives mentioned in section (1.6.2). The predicted LULC 2013 generated by ISRO IGBP LULC model is shown in Figure 5.9.

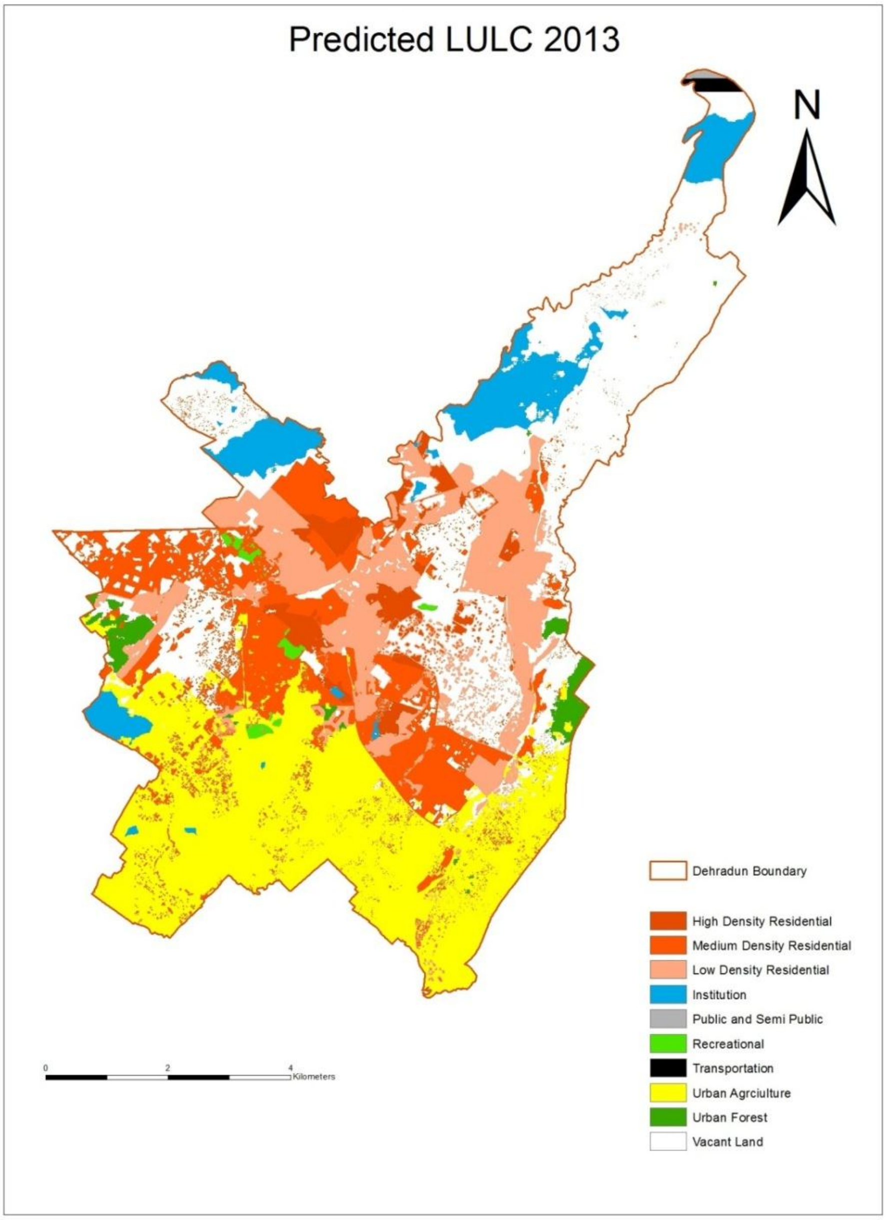


Figure 5.9: Predicted LULC 2013 Using ISRO IGBP LULC Model

5.4 Agent based model

5.4.1Implementation of proximity rules

Two different scenarios are modelled based on different proximity rules (explained in section 4.5) that are implemented to examine the urban settlement growth in Dehradun city in the year 2013. Scenario 1 is implemented using rule 4 and rule 5, where the household agent will decide to build house on the basis of socio economic status e.g. circle rate, total number of households built in year 2013 (Census Data) and distance from road. Scenario 2 is the complete implementation of all the rules.

Scenario-1 - Implementing rule 4 and 5

Proximity rule 4, describe the location of the area and socio economic status e.g. cost of the land, population density of the area, literacy rate and distance from the commercial area, and rule 5 says the agent searches for a location which is easily accessible to road.

In scenario 1, during simulation three household agents – low income, medium income and high income households – are created based on circle rate of land and distance from road in which they are residing and commercial area is identified for future investments.

1. Low income residential

   Small portion of the codes is mention below that indicates the flow of conditions that are implemented in this simulation:

```
if Land_cost < 10000:
        if distance_road < 500:
                print Low income residential area
```

   Encircle area in red describe in the Figure 5.8 (a) show the low income residential area where the cost of the land is less than 10000 rupees and distance to nearest road is less than 500 meter. It was observed that low incomes residential areas are present in the outskirts of the city.

2. Medium income residential

In case of medium income residential living in the area where the circle rate is between 10000 rupees to 25000 rupees and nearest distance from the road should be less than 500 meter which is encircle in red in Figure 5.8 (b). Small portion of the code is given below:

```
if Land_cost > 10000 and Land_cost < 25000  :

        if distance_road < 500:

                print Medium income residential area
```

3. High income residential

   High income residential are settled in the center of the city where the land cost is more than 25000 rupees and less than 40000 rupees with a minimum distance of 500 meter away from the road which is encircle in red in red in Figure 5.8 (c). Small portion of the code is given below:

```
if Land_cost > 25000 and Land_cost < 40000  :

        if distance_road < 500:

                print high income residential area
```

4. Commercial area

   It is observed that commercial areas are built where the land cost is more than 40000 rupees and less than 500 meter from the road indicated by encircling in red in Figure 5.8 (d).Small portion of the code is mention below:

```
if Land_cost > 40000  :

        if distance_road < 500:

                print commercial area
```

Vacancy rate was calculated based on total available vacant land of a certain minimum size or above (depending upon the income group the agent belongs to) available to build a house in the area. It was observed that if the agent belongs to low income group and can’t afford to build a house in an area of high circle rate, then the agent should move to the area where he can afford the land price. It was observed that medium income household can build a house in medium income areas as well as in low income areas. Similarly high income group agent can build a house in high income and medium income areas only if there is proper road connectivity and the area is near to school, hospital and workplace.

After simulation of the model, it was observed that the total number of households built was 19096. The simulated households for the year 2013 are shown on three different maps, one for each income level. Figure 5.10(a) to 5.10(d) show these simulation results.

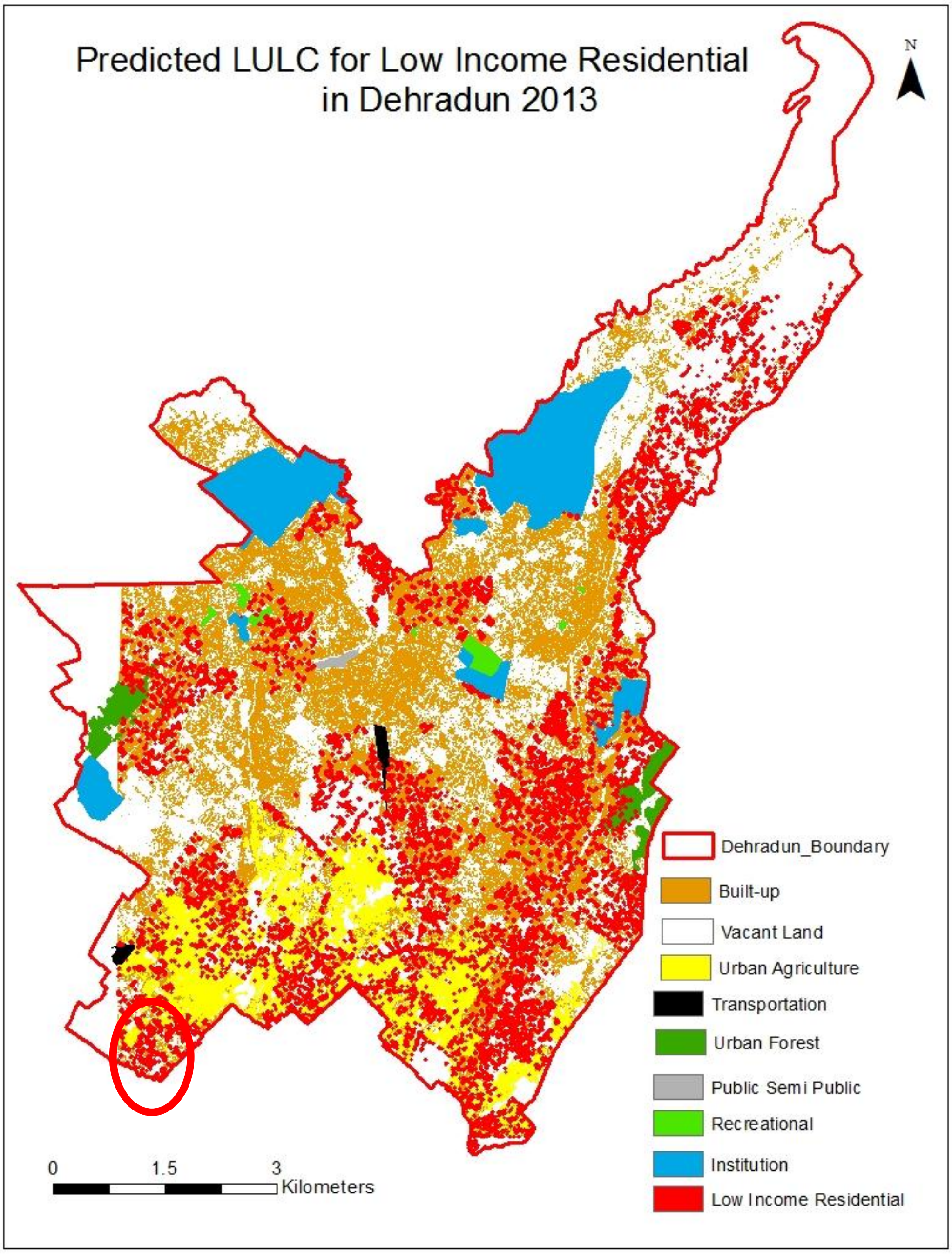


Figure 5.10(a): Predicted LULC for low income area in 2013 using simulation

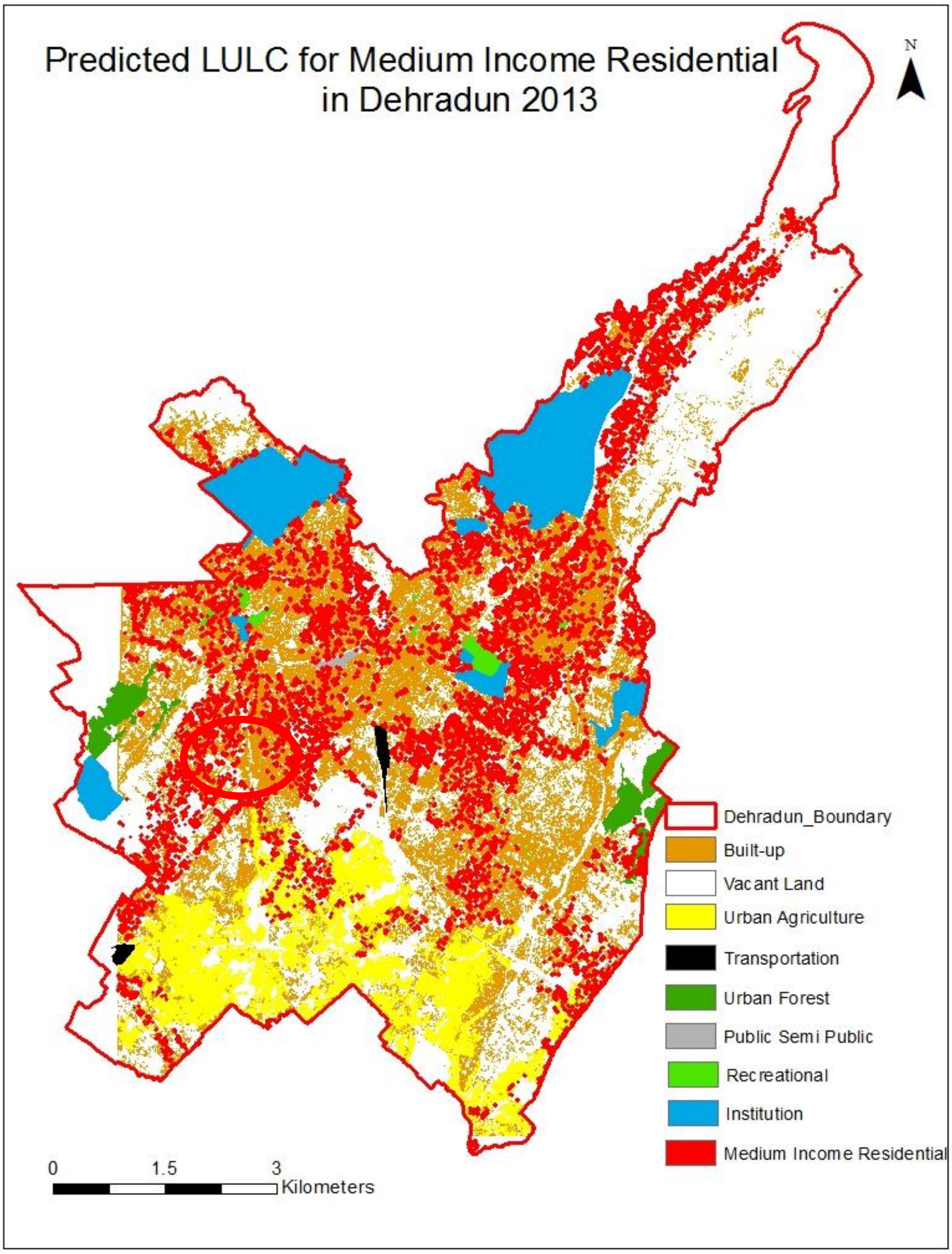


Figure 5.10(b): Predicted LULC for medium income area in 2013 using simulation

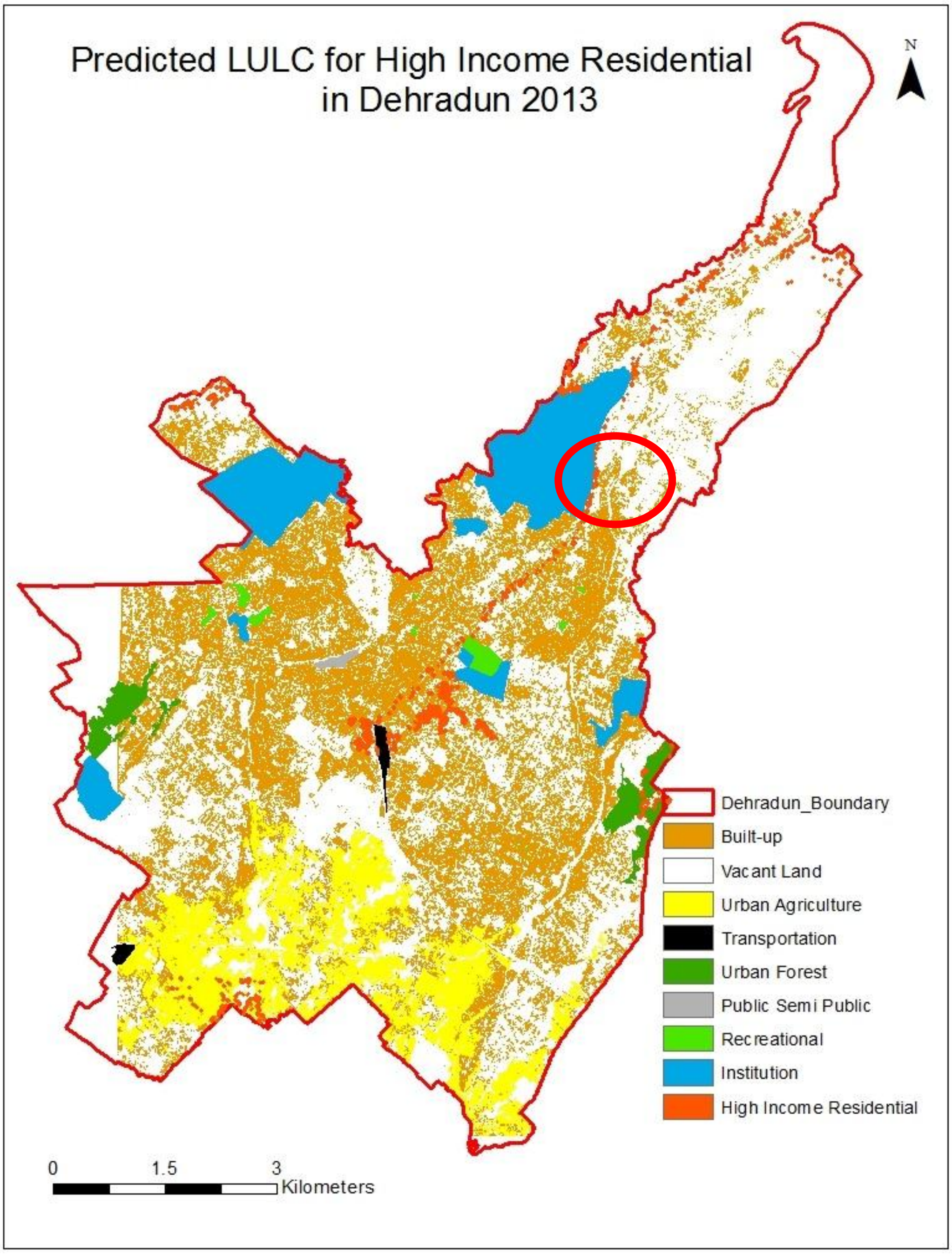


Figure 5.10(c): Predicted LULC for high income area in 2013 using simulation

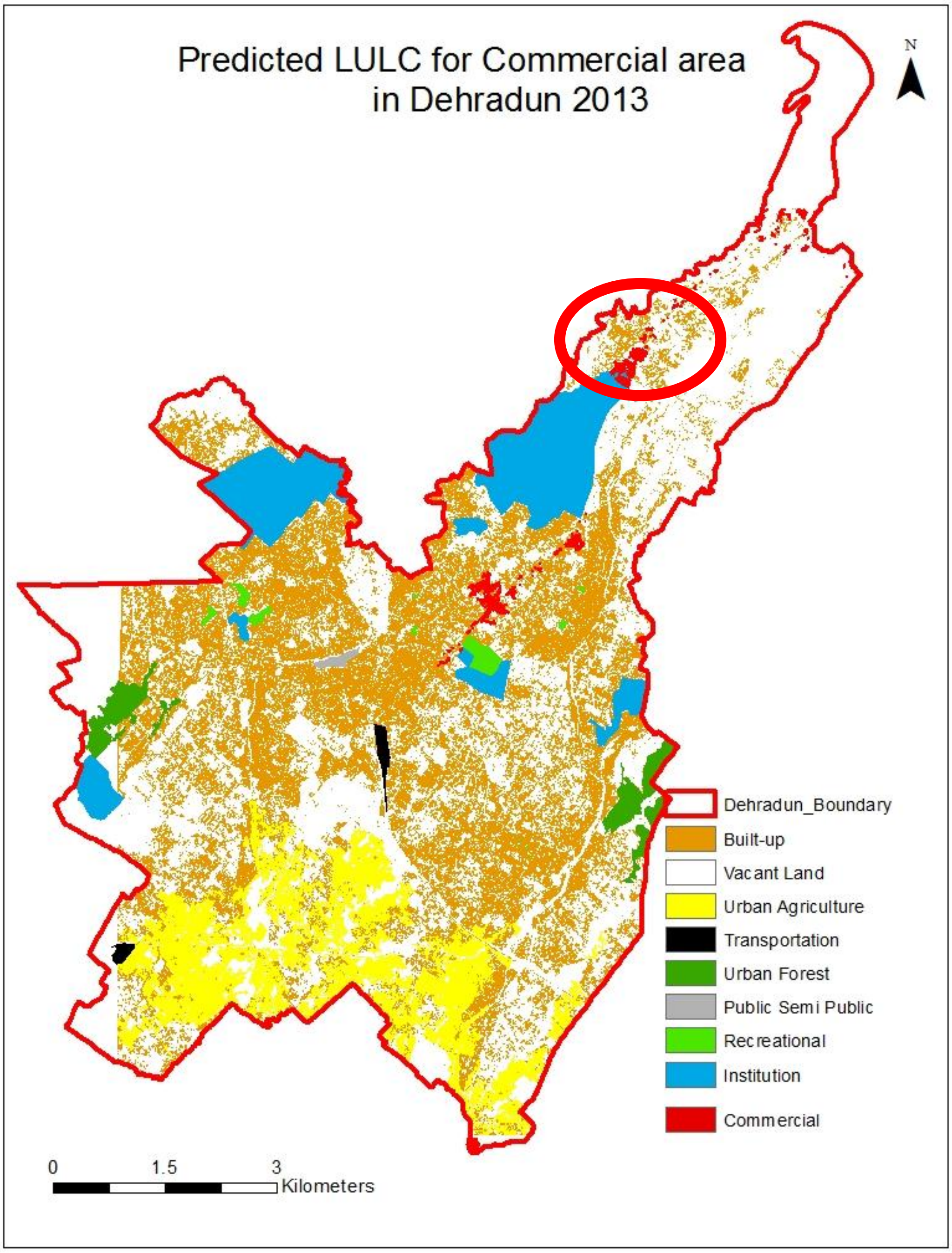


Figure 5.10(d): Predicted LULC for commercial area in 2013 using simulation

Scenario -2: All Rules

In this scenario, simulation is done by applying all the proximity rules discussed in section 4.5. New software module is developed to model the rules. Python and java programming language is used to develop the software module to generate the simulation based on rules defined for the agent to interact with the input parameters for the prediction of LULC 2013.

Rule 4 is implemented successfully to check whether the cost of land defined in circle rate is affordable by the agent. Based on this rule, search is done for the suitable area to build a new household. The agent checks the cost of the land using circle rate as one of the inputs in the model, if the land cost is less than 40000 rupees then the land is allocated to different income groups based on the area occupied by them, otherwise the and will be allocated as *commercial area*. In the second iteration, the agent will recheck for the land cost, if land cost is less than 10000 rupees. Rule 1 is implemented to check the size of the land. If the size is between 100 sq. meter and 120 sq. meter then the land is allocated to low income residential; if it is between 120 sq. meter and 300 sq. meter then land is allocated to medium income residential; if it is more than 300 sq. meter but less than 400 sq. meter then it is allocated to high income residential. Further, if the size of the land is more than 400 sq. meter and if the land to road distance is less than 50 meter then only the land is allocated as *commercial* otherwise the land remains unused. If land allocated is between 100 sq. meter and 120 sq. meter then rule 2, which is distance to schools and hospitals, is considered. Distance to schools should be less than 2 miles and distance to hospitals should be less than 4 miles. Before deciding to build a house agent should check for proper road connectivity. Rule 5 is implemented to check that the land available to the agent is not far from the road. It should be less than 500 meter from the road. Rule 3 i.e. neighbourhood qualities are then checked. Distance to commercial area should be less than 3 miles. Similarly, for land cost varying from 10000 rupees to 25000 rupees and from 25000 rupees to 40000, all the above mentioned rules are checked. If the land cost is more than 40000 rupees, the size of the land is varying from 50 sq. meter to 1000 sq. meter and distance to road is less than 500 meter, then the land is allocated to commercial area.

Small portion of the codes is mention below that indicates the flow of conditions that are implemented in the simulation:

```
if  land_cost < 40000:
        if land_cost < 10000:
              if landallocated < 100 and  landallocated > 120:
```

```
        if distance_schools <  2 and distance_hosiptals < 4 :
          if distance_ road < 5000:
              land is allocated to low income residential
    if landallocated < 120 and  landallocated > 300:
        if distance_schools <  2 and distance_hosiptals < 4 :
          if distance_ road < 5000:
                  land is allocated to medium income residential
          if landallocated < 300 and  landallocated > 400:
                if distance_schools <  2 and distance_hosiptals < 4 :
                  if distance_ road < 5000:
                     Land is allocated to high income residential
         if landallocated < 400 and  landallocated > 1000:
                 if distance_ road < 50:
                 land is allocated to commercial area

if land_cost > 10000 and land_cost > 25000:
          if landallocated < 120 and  landallocated > 300:
            if distance_schools <  2 and distance_hosiptals < 4 :
                 if distance_ road < 5000:
                   Land is allocated to medium income residential
          if landallocated < 300 and  landallocated > 400:
              if distance_schools <  2 and distance_hosiptals < 4 :
               if distance_ road < 5000:
                   Land is allocated to high income residential
          if landallocated < 400 and  landallocated > 1000:
                 if distance_ road < 50:
                   Land is allocated to commercial
```

```
        if land_cost > 25000 and land_cost < 40000:
                if landallocated < 300 and  landallocated > 400:
                        if distance_schools <  2 and distance_hosiptals < 4 :
                           if distance_ road < 5000:
                            Land is allocated to high income residential



        if landallocated < 400 and  landallocated > 1000:
                if distance_ road < 50:
                 Land is allocated to commercial
if  land_cost < 40000:
        if landallocated < 50 and  landallocated > 1000:
          if distance_ road < 50:
                Land is allocated to commercial
```

Figure 5.11 show the predicted LULC of 2013, when the entire rule set is implemented. In the predicted LULC 2013, the low income group is shown in very light orange, medium income in light orange and high income in dark orange. The commercial areas are shown in beige.

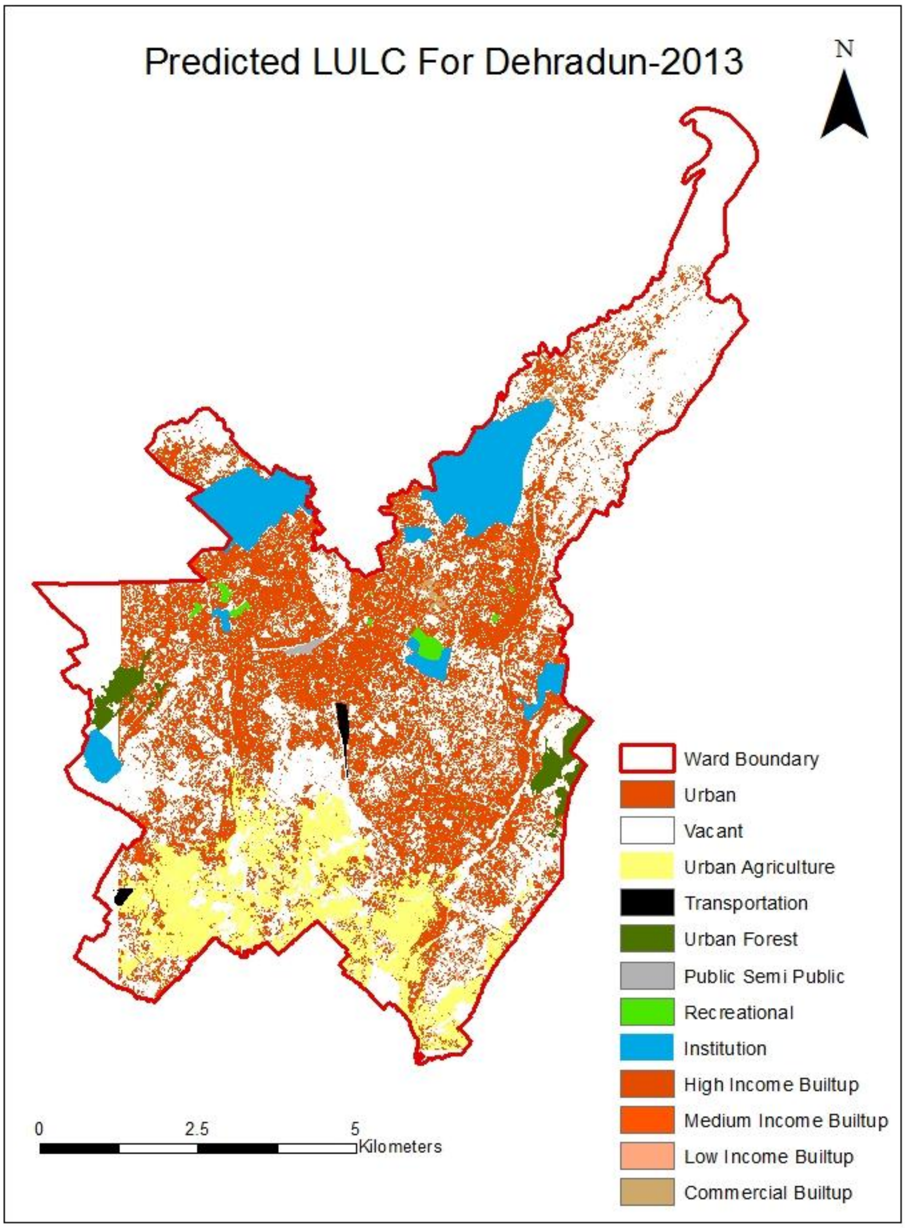


Figure 5.11: Predicted LULC for 2013 using simulation

5.4.2 Accuracy assessment of Agent based modeling and simulation

According to Table 5.5, it is observed that moran index value obtained in low income household is negative that indicates that low income households are randomly distributed in the city whereas medium income households are highly clustered than high income households. Threshold distance is less in low income household as compared to high income and medium income households as shown in figure 5.10. Table 5.6 shows the number of houses in different years. 19,525 houses were predicted by the simulation model.

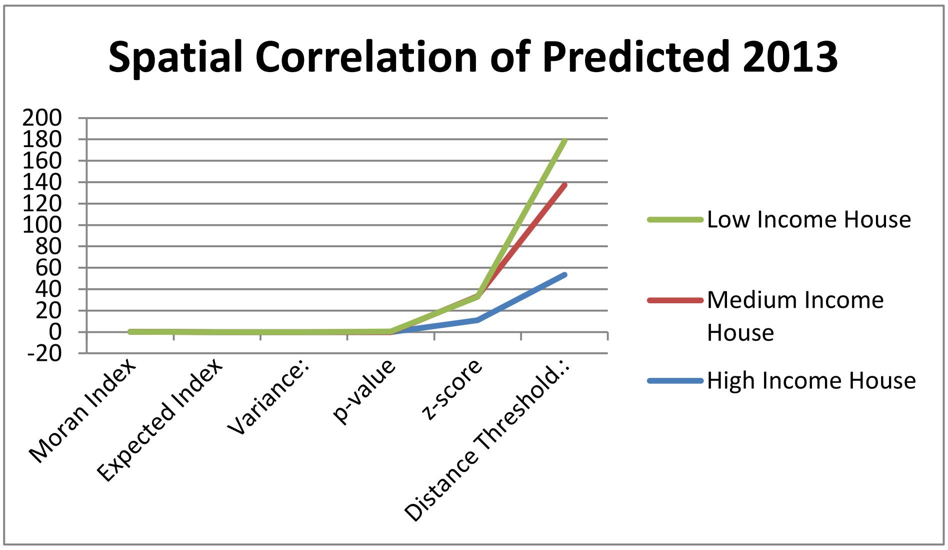


Figure 5.12 Spatial correlation between income groups in predicted LULC 2013

Table 5.5 Spatial correlation for each income class

Correlation	High Income House	Medium Income House	Low Income House
Moran Index	0.120805	0.225545	-0.041636
Expected Index	-0.000482	-0.000565	-0.000565
Variance:	0.000123	0.000101	0.000101
p-value	0	0	0.537
z-score	10.920655	22.496938	-0.617356
Distance	53.38877077	83.80392975	41.46612936

Table 5.6 shows the number of houses in different years. 19,525 houses were predicted by the simulation model.

Table 5.6: Number of predicted households

Year	Total number household predicted
2001	10115
2007	16565
2013	21565
Predicted 2013	19525

Accuracy assessment has been done by comparing the predicted LULC with the actual LULC of 2013. These results are shown in Table 5.7. The relative error in the area occupied by households was found to be 10.62% and the total built-up accuracy to be 87.732%. The kappa coefficient of the predicted LULC 2013 and actual LULC 2013 was found to be 0.84724. This result successfully discusses objectives mentioned in section (1.6.2).

Table 5.7: Accuracy assessment

<table>
<tr><th colspan="4">Accuracy Assessment</th></tr>
<tr><td rowspan="2">Area accuracy</td><td>Actual area</td><td>1071677m^2</td><td rowspan="2">Relative error = 10.62%</td></tr>
<tr><td>Predicted area</td><td>1185459m^2</td></tr>
<tr><td rowspan="2">Spatial accuracy</td><td>Kappa coefficient</td><td>0.84724</td><td>84.724%</td></tr>
<tr><td>Change detection (accuracy of built-up area)</td><td>0.87732</td><td>87.732%</td></tr>
</table>

Chapter 6

Conclusions and Recommendations

This chapter presents the conclusions and answers to the research questions addressed during the project. It also presents some recommendations and future scope for the discussed modeling approach.

6.1 Conclusions

This research has successfully predicted the future settlement growth pattern in the city using socio economic factors. Three phases are discussed in the methodology to explain the simulation process. First phase is the data preparation phase where visual interpretation and object based feature extraction techniques are used. Using these techniques LULC of 2001, 2007 and 2013 are prepared. Physical and socio economic drivers are also prepared. LULC consisting of three different urban classes – residential, open space and industrial - are generated. Each of these classes are further classified according to second level of classification in urban land use: Residential - low density residential, high density residential and medium density residential; open space - urban forest, urban agriculture, recreational, vacant land; Industrial - government institution, public and semi-public, and transportation. Physical and socio economic drivers are distance to roads, distance to built-up, distance to schools, distance to hospitals, elevation, population density, literacy rate, circle rate and household density. After successfully completing the first phase, second phase is implemented. Second phase involves two modeling approaches for the identification of spatial and non-spatial drivers used for the simulation and to find out the suitable areas for future development. CA-Markov model and ISRO IGBP LULC model are introduced in second phase of the methodology. CA- Markov model is used to find out the suitable areas for future development whereas ISRO IGBP LULC model is used to study the effect of socio economic factors on urban land use classes. Both the models works on the principal of cellular automata where CA Markov model works only on spatial data and ISRO IGBP LULC model works on spatial as well as with non- spatial data like socio economic data. 89.06 % accuracy is obtained by CA- Markov model for predicted LULC of 2013. The kappa coefficient for ISRO LULC model is 53.31 % with overall accuracy of 63.29%. This model can be optimized to further improvement its accuracy. Outcomes of these models are used in third phase of the methodology.

Third phase is the phase where agent based modeling and simulation is used for the prediction of future settlements based on socio-economic factors. Agent based modeling has shown dynamic approach in identifying settlement pattern based on socio-economic, demographic and commercial factors that are affecting the housing market in relation to circle rate. Proximity rules are designed to influence the households' decision to build a house in the area of their choice. The entire set of rules has some limitations because of the agent's heterogenetic nature to interact with the environment and also because of the influence of the land market representation. Parameters studied during preparation of the proximity rules, are taken as inputs for the agent to take decision like whether to stay in his known area or search for an area where the neighbourhood factors influence his decision to relocate; resource constraints defines the buying capability of the agent; competitive bidding indicates the agent's capacity to own a land of his own choice. Socio economic status changes with the demand of land so as to accommodate the increased population. Change in diversity is monitored using moran index to study the urban settlement pattern over time. Simulated results are obtained through agent based modeling have area accuracy of 10.62% (relative error) and kappa statistics of 84.724%.

6.2 Recommendations and future scope

Calibration of the simulation model can be done to the find the most suitable parameter that shows the reality of the modern city. More generic algorithm can be designed to improve the performance of the model. It is recommended that calibration and validation of model should be done based on more accurate data at household level. Urban regeneration policies are reconsidered to identify the urban settlement pattern. Uncertainty within the survey data and predicted data is an obstacle in simulation, causing inconsistency in the observed pattern. To avoid this, ground data must be used for modeling.

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Appendix

Table A.1: Population ward wise

Ward Name	Ward Number	Population 2001	Population 2007	Population 2013
Raipur	1	8746	8594	8725
Sahastradhara	2	7586	8600	13753
Jakhan	3	7267	6495	12262
Hathi Barkala	4	7243	5935	6375
Aryanagar	5	7193	6245	7020
Dobhalwala	6	10114	7022	7284
Vijay Colony	7	10242	6992	7423
Krishan Nagar	8	6147	6378	8456
DL Road	9	5869	5120	5875
Rispana	10	9719	6296	5406
Karanpur	11	10046	6508	5869
Bakralwala	12	4886	5040	6745
Chhukhuwala	13	9319	5532	4833
Indira Colony	14	5364	5380	7710
Clock Tower	15	7010	4732	4330
Race Course(North)	16	6644	5208	5464
M.K.P	17	6763	5346	5277
Kalika Mandir Marg	18	9645	5260	4278

Tilak Road	19	7937	6900	7405
Khurbura	20	6305	5323	5309
Shivaji Marg	21	7489	5594	5444
Indresh Nagar	22	5885	5424	7038
Dhamawala	23	10518	5588	3917
Jhanda Mohhala	24	9493	6355	5509
Dalanwala(North)	25	7134	7078	9232
Dalanwala(East)	26	10130	6803	5726
Basant ViharDalanwala(South)	27	6909	6084	6820
Adhoiwala(North)	28	6754	5558	6280
Adhoiwala(South)	29	6098	7633	12273
Bhagat Singh Colony	30	5066	6200	8832
Rajeev Nagar	31	8413	9425	15633
Defence Colony	32	8769	8854	10684
Nehru Colony	33	9868	6329	5618
Dharmpur	34	5480	6006	7792
Deepnagar	35	7231	8910	13865
Ajabpur	36	3421	5513	11352
Mata Mandir Road	37	7931	8978	12205
Race Course(South)	38	6960	5645	6560
Rest Camp	39	8291	7474	8884
Reetha Mandi	40	4972	4828	5852

Lakhibagh	41	6684	4845	4209
Kargi	42	5466	7685	15929
Patelnagar(East)	43	4803	5343	8297
Bharmpuri	44	7899	8006	10048
Niranjanpur	45	5294	4560	5682
Majra	46	6025	6706	9830
Turner Road	47	3408	5580	11263
Indirapuram	48	5394	6078	8538
Dornapuri	49	4666	5742	8669
Kanwali	50	7525	7230	7867
Indira nagar	51	11852	10720	11703
Vasant Vihar	52	5522	8122	14097
Mohit Nagar	53	3699	4841	8489
Patelnagar(West)	54	2810	5189	10945
Gandhi Gram	55	3503	5177	9575
Yamuna Colony	56	8039	6077	5502
Govind Garh	57	8697	7534	7879
Shri Dev Suman Nagar	58	9964	6842	6671
Ballupur	59	7815	7104	7583
Kaulagarh	60	6752	6964	8832

Table A.2: Litearcy ward wise

Ward Name	Ward Number	Literacy 2001	literacy 2007	literacy 2013
Raipur	1	6609	4816	3510
Sahastradhara	2	5378	5110	4856
Jakhan	3	3441	3905	4433
Hathi Barkala	4	5526	3497	2213
Aryanagar	5	5555	3556	2277
Dobhalwala	6	6771	4122	2509
Vijay Colony	7	6586	3970	2393
Krishan Nagar	8	4811	3679	2813
DL Road	9	4463	2854	1825
Rispana	10	7333	3999	2181
Karanpur	11	7217	3720	1917
Bakralwala	12	3766	2924	2271
Chhukhuwala	13	6332	3484	1917
Indira Colony	14	3755	3193	2715
Clock Tower	15	5172	2960	1694
Race Course(North)	16	4964	3120	1961
M.K.P	17	5416	3259	1962

Kalika Mandir Marg	18	6468	3083	1470
Tilak Road	19	6430	4172	2708
Khurbura	20	5339	3422	2193
Shivaji Marg	21	5748	4354	3299
Indresh Nagar	22	4180	3410	2782
Dhamawala	23	7971	3414	1462
Jhanda Mohhala	24	7333	3861	2033
Dalanwala(North)	25	5427	3626	2423
Dalanwala(East)	26	8082	4690	2722
Basant ViharDalanwala(South)	27	5428	3592	2377
Adhoiwala(North)	28	4919	3501	2493
Adhoiwala(South)	29	4748	4652	4559
Bhagat Singh Colony	30	4352	3893	3483
Rajeev Nagar	31	5682	5285	4915
Defence Colony	32	7337	5087	3528
Nehru Colony	33	7131	3809	2034
Dharmpur	34	4630	3514	2668
Deepnagar	35	5726	5214	4748
Ajabpur	36	2678	3221	3875
Mata Mandir Road	37	6605	5035	3839
Race Course(South)	38	4858	3246	2169
Rest Camp	39	6288	4492	3210

Reetha Mandi	40	3984	2954	2190
Lakhibagh	41	5578	2973	1585
Kargi	42	3708	4549	5583
Patelnagar(East)	43	3441	3242	3055
Bharmpuri	44	6380	5320	4437
Niranjanpur	45	3660	3008	2473
Majra	46	4575	3914	3349
Turner Road	47	2765	3328	4006
Indirapuram	48	4328	3946	3598
Dornapuri	49	3804	3447	3124
Kanwali	50	6646	4526	3082
Indira nagar	51	9821	6174	3882
Vasant Vihar	52	4680	4935	5204
Mohit Nagar	53	2761	2658	2559
Patelnagar(West)	54	2461	3072	3836
Gandhi Gram	55	2800	3240	3750
Yamuna Colony	56	6712	3540	1867
Govind Garh	57	7204	5003	3475
Shri Dev Suman Nagar	58	7019	4112	2408
Ballupur	59	6656	4049	2464
Kaulagarh	60	5491	3810	2644

Table A.3: Household ward wise

Ward Name	Ward Number	Household 2001	Household 2007	Household 2013
Raipur	1	1641	2057	2579
Sahastradhara	2	1374	2327	3943
Jakhan	3	1345	2111	3314
Hathi Barkala	4	1302	1530	1798
Aryanagar	5	1414	1626	1870
Dobhalwala	6	1796	1877	1962
Vijay Colony	7	1925	1890	1856
Krishan Nagar	8	1030	1616	2535
DL Road	9	1127	1335	1583
Rispana	10	1901	1652	1436
Karanpur	11	1819	1665	1525
Bakralwala	12	769	1191	1845
Chhukhuwala	13	1720	1489	1290
Indira Colony	14	1112	1464	1927
Clock Tower	15	1353	1284	1218
Race Course(North)	16	1280	1360	1446

M.K.P	17	1323	1351	1379
Kalika Mandir Marg	18	1907	1437	1082
Tilak Road	19	1669	1362	1112
Khurbura	20	1298	1644	2084
Shivaji Marg	21	1407	1526	1656
Indresh Nagar	22	1124	1609	2303
Dhamawala	23	2043	1849	1674
Jhanda Mohhala	24	1850	1362	1003
Dalanwala(North)	25	1399	1442	1487
Dalanwala(East)	26	2157	1995	1846
Basant ViharDalanwala(South)	27	1381	1612	1882
Adhoiwala(North)	28	1301	1568	1890
Adhoiwala(South)	29	1292	1518	1785
Bhagat Singh Colony	30	1049	1905	3460
Rajeev Nagar	31	1602	2019	2546
Defence Colony	32	1806	2740	4157
Nehru Colony	33	1884	2506	3334
Dharmpur	34	1136	1366	1644
Deepnagar	35	1499	1739	2018
Ajabpur	36	731	1840	4633
Mata Mandir Road	37	1742	2214	2814
Race Course(South)	38	1447	2178	3280

Rest Camp	39	1744	1661	1583
Reetha Mandi	40	1060	1694	2707
Lakhibagh	41	1441	1386	1333
Kargi	42	964	1077	1203
Patelnagar(East)	43	921	2050	4564
Bharmpuri	44	1569	1758	1970
Niranjanpur	45	930	1879	3799
Majra	46	1201	1363	1546
Turner Road	47	693	1439	2990
Indirapuram	48	945	1676	2975
Dornapuri	49	981	1642	2748
Kanwali	50	1420	1816	2322
Indira nagar	51	2622	2310	2036
Vasant Vihar	52	1046	2018	3894
Mohit Nagar	53	671	1732	4472
Patelnagar(West)	54	650	1271	2487
Gandhi Gram	55	694	1398	2819
Yamuna Colony	56	1550	1871	2259
Govind Garh	57	1903	1685	1492
Shri Dev Suman Nagar	58	2018	2129	2248
Ballupur	59	1700	1790	1886
Kaulagarh	60	1334	1760	2324

CODE:

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  for cougar as household in self.households:

    #print "Cougar", cougar.name, "is", cougar.age, "years old"

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  self.addRaster("tracking", raster)
  raster = ESRIRaster("F:/abm/", "inco")
  self.addRaster("inco", raster)
  raster = ESRIRaster("F:/abm/", "circle_rate")
  self.addRaster("circle_rate", raster)
  raster = ESRIRaster("F:/abm/", "roaddehra")
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title="Sequence Graph" xAxisTitle="Time"
 yAxisTitle="yAxis" xAxisStart="100.0" yAxisStart="10.0">


<RePastEvolver:file_property doWrite="false" fileName="" />
<RePastEvolver:seqAction name="food" imports="" retVal="double" paramNames=""
color="" pointType="-1">
<![CDATA[
# get the number of agents
count = self.highresi.size()


sum = 0.0
```

```
for house as household in self.households:
  # sum is the running tabulation of the food gathered by each cougar
  sum = sum + house.foodCount

# return tha average food for all agents
return sum/count
]]>
</RePastEvolver:seqAction>
<RePastEvolver:schedule_item action="update" tick="1.0" type="1" last="false"
target="Sequence Graph: _sequenceGraph" id="11"/>

</RePastEvolver:EvolverBean>
```