MASTER THESIS

Submitted within the UNIGIS MSc. programme
at the Department of Geoinformatics - Z_GIS
University of Salzburg, Austria
Under the provisions of UNIGIS joint study programme with
Kathmandu Forestry College, Kathmandu, Nepal

Geospatial Modelling of Urban Sprawl in Kathmandu Valley, Nepal.

By

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GIS_104470

A thesis submitted in partial fulfilment of the requirements of
the degree of
Master of Science (Geographical Information Science & Systems) – MSc (GISc)

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Kathmandu, Nov 2018

Science Pledge

By my signature below, I certify that my project report is entirely the result of my own work. I have cited all sources of information and data I have used in my project report and indicated their origin.

Kathmandu Nov 2018	Signature

Acknowledgements

I would like to express my deepest and sincere gratitude towards my supervisor Dr. Shahnawaz for his guidance, suggestion and encouragement throughout the thesis. Without his support and guidance this thesis couldn’t have been completed.

Furthermore, I would like to acknowledge with much appreciation towards Dr. Him Lal Shrestha, whose inspiration and suggestion helped me to complete the thesis. I am very grateful for wonderful support of my seniors Er. Sanjeevan Shrestha, Er. Abhash Joshi, Er. Krishna Prasad Pokharel, Er Sharad Chandra Mainali and Er. Pravesh Yogal, whose feedbacks and advices guided me complete the thesis. I would like to acknowledge the effort given by UNIGIS Kathmandu team.

I am thankful for my Father: Mr. Ramesh Kumar Koirala, Mother: Mrs. Kabita Koirala, wife: Dr. Srija Chapagain and Sister: Ms. Seema Koirala for providing me moral support and encouragement during entire study period.

Finally I am grateful for all my friends whose inspiration and suggestion was very helpful for completing the thesis.

Sumeer Koirala

November, 2018.

Abstract:

In global context, Kathmandu Valley typically symbolizes rapid and haphazard urbanization trends. Immigration tendency in cities and towns for quality life and employment opportunities has caused rapid and haphazard urbanization. Kathmandu valley has experienced rapid urbanization during last two decades. Haphazard development of built-up areas without proper planning has caused furious growth of urban sprawl in Kathmandu valley. Major aim of this thesis is to understand the prevalent urban sprawl type, pattern of urban sprawl, spatial development trend of urban sprawl and model its future prospects in Kathmandu valley. Change in spatial concentration of different landscape is basis for measuring urban sprawl. This research started with Land Use Land Cover (LULC) change analysis from 2001 to 2018. During this period, LULC changed drastically; major chunks of fertile cultivation land and bare areas were converted in to built-up lands. Immigration from different part of country is reason for intensive population growth in the valley. Urban growth was expanding horizontally from the zero point along and outside the ring roads and major roads as well. Urban sprawl showed multi directional nature in Kathmandu valley.

Major objectives of this study has been summarized as a) Identity the change of urban sprawl in Kathmandu valley during the period of 2001 to 2018; b) Evaluate concentration of urban sprawl; c) Identify the form of urban sprawl and finally d) Model future growth of urban sprawling in the year 2031. This thesis integrates Remote Sensing (RS) and Geographic Information System (GIS) technology for derivation of LULC classification, analyzing LULC changes. Whereas, statistical analysis approach were used for measurement of urban sprawl. Cellular Automata (CA) Markov model was used for modeling future urbanization and urban sprawl.

Satellite image analysis was used for determining different LULC classes in Kathmandu valley. During the period of 2001 to 2018 urbanization increased by two folds.

Concentration of built-up area increased from 53.9 km^2 to 170.7 km^2. Spatial distribution of built-up area illustrates dominance of dispersed growth than compact settlement development. Dominant urban sprawl pattern in Kathmandu valley is outward “extension” beyond the ring road areas; outward “extension” was dominating mostly in 5 to 10 km buffer during decade of 2001 to 2011. Whereas, during the period of 2011 to 2018 outward “extension” was majorly dispersed in 10 to 15 km buffer from the zero point. Spatial concentration of “infill” type of urban sprawl was observed in the distance of 5 km to 10 km from zero point during the period of 2001 to 2011, whereas it expanded from 10 km to 15 km in period of 2011 to 2018. Considerable amount of suburbs areas and urban fringes were converted to dense settlement area during the study period. This study can contribute for understanding urban sprawl pattern, intensity and development trend in Kathmandu valley. Further, this research can be important assets for planner and policy makers to formulate appropriate plans and policy for sustainable city development.

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List of abbreviations:

CA	Cellular Automata
CA	Class Area
CBS	Central Bureau of Statistics
DEM	Digital Elevation Model
DOS	Department of Survey
EEA	European Environment Agency
ESRI	Environmental System Research Institute
FRAC_AM	Fractal Index Dimension Area Weighted Mean
GIS	Geographic Information System
KM	Kilometer
KML	Keyhole Markup Language
LPI	Largest Path Index
LULC	Land use land cover
NP	Number of Patch
RGF	Raster Group File
RS	Remote Sensing
SRTM	Shuttle Radar Topography Mission
URL	Uniform Resource Locator
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System

Chapter-1: Introduction

1.1. Background

Nepal is land locked country. Country is divided into three ecological zones: mountains, mid hills, and Terai regions. Geographically Nepal is extending from 26˚ 22' N to 30˚ 27' N latitude and 80˚ 04' E to 88˚ 12' E. Although, Nepal is considered as one of the rapidly urbanized country, but it is also in the list of least developed country (Bakrania, 2015). According to UN DESA (2014) level of urbanization in Nepal was 18.2 percent with urbanization rate 3 percentages and total urban population 51, 30,000. Within the period of 2014 to 2050, Nepal will be amongst the top ten rapidly urbanized countries with the annual rate of urbanization of 1.9 percentages. Furthermore, Nepal is expected to have projected urbanization level above 30 percent in 2050 (UN DESA, 2014).

Kathmandu valley is composed of three districts Kathmandu, Bhaktapur and Lalitpur. Amongst the urbanized cities in Nepal, major share of population concentration is in Kathmandu valley. It has been most rapidly growing urban agglomeration in south-asia (Muzzini & Apericio, 2013; MoUD, 2015). Kathmandu valley shares 24 percentages of total urban population of the country and Kathmandu Metropolitan City (KMC) alone accounts 9.7 percentage of total urban population (MoUD, 2015). Although urbanization and population growth in Kathmandu valley has been increasing abruptly, but lack of proper planning and haphazard infrastructure development is adding constraints and setbacks for sustainable development in Kathmandu valley. There is high demand for fostering sustainable development, regeneration of haphazard urbanization, development of strategic and planned urban clusters for sustainability of the population growth, urbanization, economic status and population dynamics (Muzzini & Apericio, 2013).

Kathmandu valley demonstrates haphazard urbanization, sprawling characteristics. Rapid urbanization and urban sprawling have generated several economic, social, environmental, and many other problems (Ishtiaque *et al*., 2017). Major issues caused with urban sprawl can be summarized as but cannot be limited to air pollution, water pollution, smog, water table level decline, traffic congestion and change of agricultural and open space into other land use (Thapa & Murayama, 2009).

Not only population growth has contributed rapid urban growth in the valley, but migration shares major volume of population in the valley (Thapa *et al*., 2008). Conflict in the last decade resulted 42 percent of total population of valley contributing with migration. Beside conflict, development of facilities like health services, transportation system, telecommunication and other infrastructure accounts for major influx of population in the valley (ICIMOD, 2007). Kathmandu valley has witnessed ruthless growth in population and urban areas, and is most urbanized city of Nepal. In 1952 to 1954, 47.4 percentage of total Kathmandu valley population was in urban region, while this rate rise up to 60.5 percentages in the year 2001 (Sharma, 2003).

Urbanization comes up with the cost of growth of population in urban areas, with the impact on environment. Urbanization concept comes together with specialization, economic development and industrialization. Urbanization can also be referred to territorial response to economic growth in the country (Sharma, 2003).

Urban Sprawl can be defined as rapid extension of urban areas, development of built-up fringes in suburbs and rural areas (Galster *et al*., 2001). Urban sprawl refers to transfer of urban population, from zero point areas or towns to low density rural fringe or rural areas. Urban sprawl can also be stated with low density in residential and industrial development in rural areas. With rapid change in urbanization, government faces many challenges in sustainable development, challenges in formulation, and structuring urban planning and decision.

LULC change analysis is the best way to identify urban sprawl process and can be effective tool to determine urbanization in the future prospect. GIS and RS is effective tool for monitoring and modeling LULC change. RS technique provides cost effective method and acts as primary data for urban sprawl analysis. GIS and RS techniques extract built-up area, urban area and other LULC classes from satellite image (Jat *et al*., 2008). Multi spectral and multi temporal satellite image can be used to determine LULC pattern and process (Oluseyi, 2006). Application of GIS, RS technique and statistical approach are used for urban sprawl assessment. In order to study characteristics of urban sprawl, pattern of urban sprawl is necessary to detect, in order to measure level of urban sprawl, appropriate statistical technique alongside with GIS technique is necessary (Jat *et al*., 2008).

Despite such chaotic urbanization change, urban sprawl growth and population growth, there have been very few urban sprawl change studies in Kathmandu valley. There has been some study in urbanization change. Haack and Rafter (2006) studied the LULC change between 1978 and 2000 and concluded the urban area has been growth up to four fold in this study duration. There has been another study by Thapa and Murayama (2011) studied LULC from 1967 to 2000 and concluded urbanization started rapidly after 1980s. Ishtiaque *et al*. (2017) studied urbanization in Kathmandu valley and concluded the urbanization in Kathmandu valley has expanded along the major roads making concentric pattern.

Urbanization in Kathmandu valley results in conversion of 31% of agricultural land to urban land. This developed urban sprawl has caused major consequences in traffic congestion and impact on open spaces. There are series of challenges in physical environment and structure of Kathmandu valley. Major Chunks of population of Kathmandu valley are facing series of consequences in drinking water, pollution due to road extension, accessibility to health services and quality of life has been declining day by day.

1.1.1. Need Assessment

Substantial increase in urban population causes governments, policy makers and civil society face major challenges in sustainable development of the city (Ibrahim *et al*., 2015). Haphazard increase in urban sprawl causes unlimited challenges in preserving agricultural areas, forest area, open spaces and cultural heritages as well. Study on Urban Sprawl type and dynamics by Hao *et al*. (2012) determines method of combining present and past urban sprawl type and its pattern to better understand its future expansion. Stan (2013) proposed five morphological pattern of urban sprawl as clusters, tentacles, patches, zippers and fringes. Author further identifies urban sprawl pattern is very decisive in determining the effect of sprawl and modeling its extent in the future. Kityuttachai *et al*. (2013) has pointed to the need for local planner to foresee the extent, direction and future prospect of urban sprawl in order to plan for resources to support people and sustainable environment. Although Ishtiaque *et al*. (2017) studied qualitative prospect of urban expansion but the quantitative prospect, pattern of urban sprawl and its future modeling has not been done.

This project was aimed to understand urban sprawl pattern and models its future prospects, which can be milestone for sustainable development of the Kathmandu valley. In order to identify cure, factors responsible for urban sprawl needs to be understood. Application of remote sensing, statistical analysis and modeling technique presents clear perception on understanding causes and consequences of urban sprawl.

Research approach for “Modeling Urban Sprawl of Kathmandu Valley with the application of GIS and Remote Sensing” begin with literature review. Theories on urban sprawl, cause, effects, methods for urban sprawl measurement, application of RS and GIS for urban sprawl analysis and related high quality literature were the foundation of this research. Necessary data multi-temporal satellite image of various time series, topographic data, land use land cover data, and necessary software were collected in parallel with literature review.

1.1.2. Research Approach:

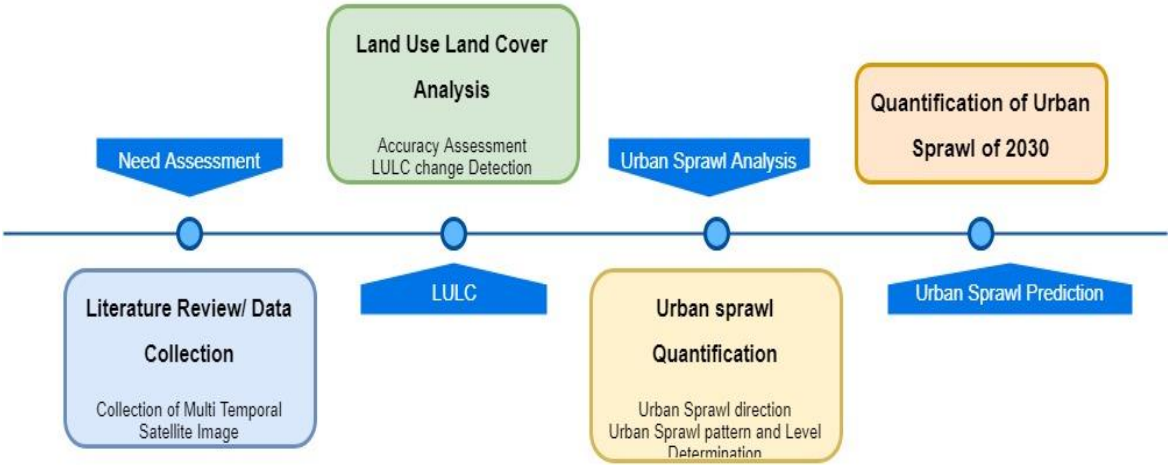


Figure 1: Research Approach for Urban Sprawl modelling of Kathmandu Valley.

LULC maps have been generated from multi temporal satellite image and accuracy of those maps was accessed. After achieving accuracy within tolerance level, land use land cover change analysis maps were generated. Similarly, transition tables were generated, showing transformation of land use land cover from one class to another class. Modeling of urban sprawl was done based on suitability analysis of: proximity to road network, slope suitability and existing LULC. Measurement of urban sprawl pattern, direction and its level was determined based on statistical analysis of landscape metrics and Shannon’s entropy. CA Markov model was used for modeling of LULC map in 2018, thus obtained map was validated with LULC map of 2018. Finally urban sprawl of Kathmandu valley was determined for the year 2031 and report was prepared using the same validated model. Figure 1 pictorially depicts the overall research approach conducted. Details procedure is shown in Figure 6.

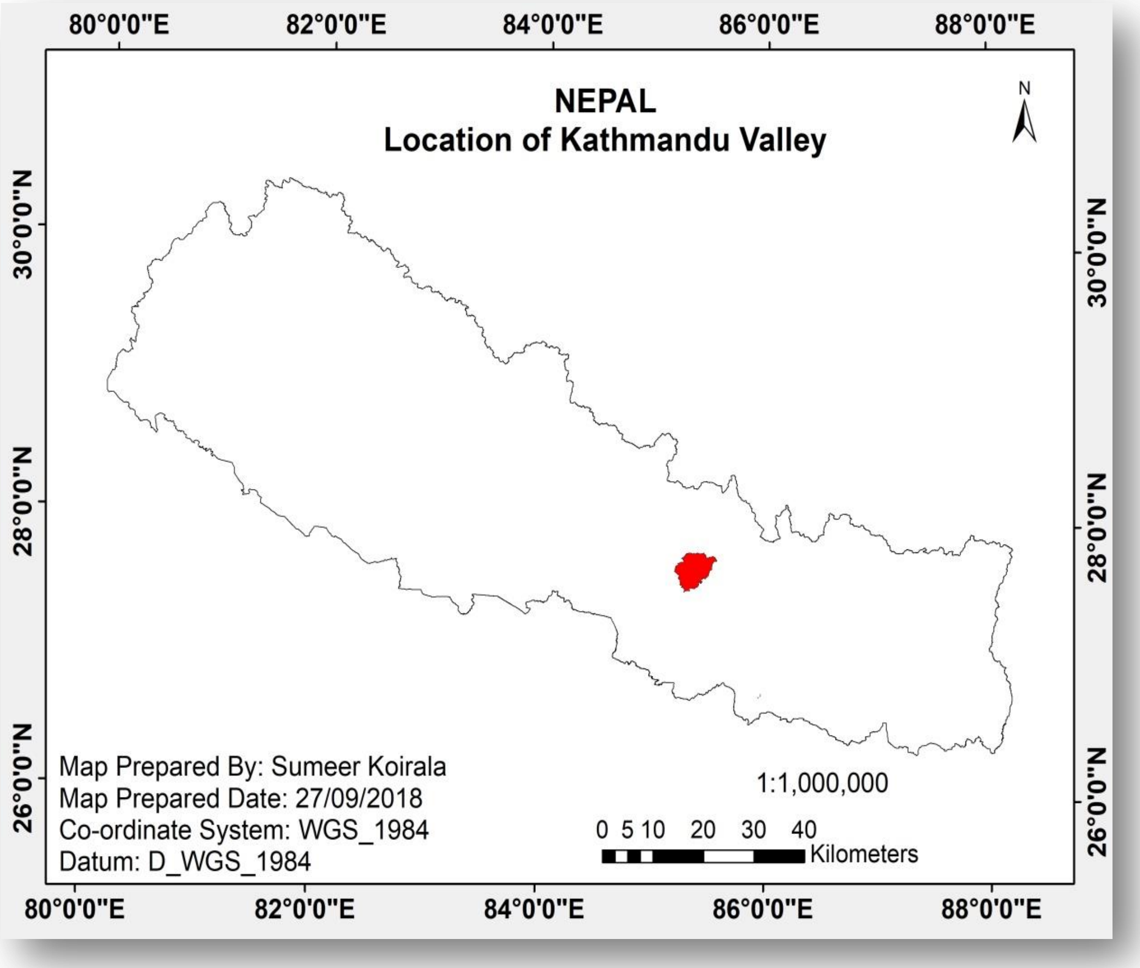
1.2. Objective

The main objective of the project is to model urban sprawl growth in Kathmandu valley in 2031. The Specific objectives of this thesis are:-

- Analyze Land use land cover change in Kathmandu Valley between 2001 and 2018 using Landsat 5 (TM) and Landsat 8 (OLI) (Section 3.2 and Section 3.3).
- Measure urban sprawl distribution and extent in Kathmandu Valley between 2001 and 2018 using entropy and land scape metrics (Section 3.4).
- Analyze “types” of urban sprawl present in Kathmandu Valley using urban landscape analysis tool (Section 3.5).
- Model extent, types and level of urban sprawl in Kathmandu Valley for the year 2031 (Section .3.6.).

1.3. Location and General Description of Study Area

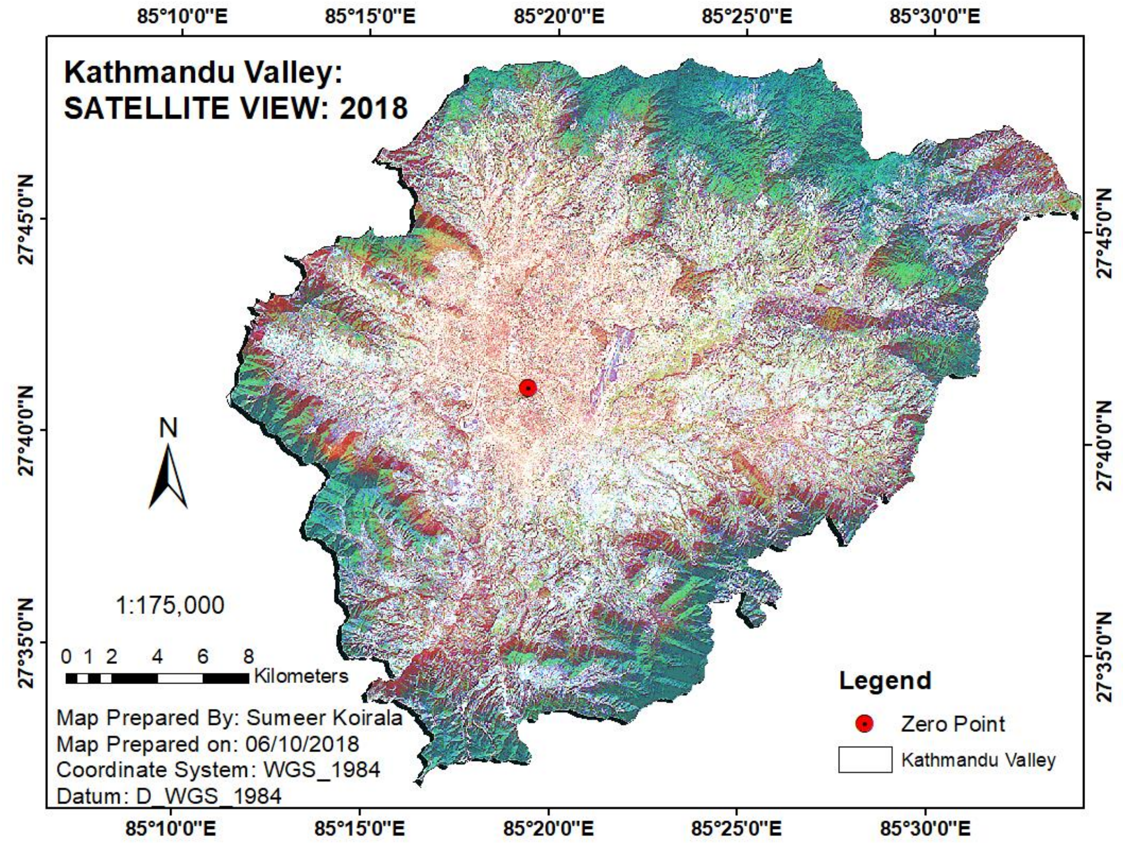
Kathmandu is capital city of Nepal. Kathmandu Valley is situated in State 3, and in central region of Nepal. Kathmandu Valley is located between $27^{\circ}36'$ and $27^{\circ}48'$ N, between $85^{\circ}12'$ and $85^{\circ}31'$ E. Kathmandu valley constitute all the municipalities and metropolitan of three districts: “Kathmandu, Bhaktapur and Lalitpur”. Kathmandu Valley is most developed and densely populated city in the Nepal with population of 25 million (CBS, 2011) and comprises area approximately 695 km^2. Kathmandu valley constitutes flatbed valley floor with average elevation of 1300 m, surrounded by mountain ranging elevation from 1900 to 2800 meter. Kathmandu valley is bowl shaped valley, having more than 50 percentages of total area lies within 5° slope.



Map 1: Location of Kathmandu Valley

Precipitation of Kathmandu valley is mostly caused by monsoon. More than 80 percentage of annual rainfall is received during monsoon months (June to August). Average annual rainfall in the valley is 1407 mm. Temperature of Kathmandu valley ranges from average winter temperature of 10˚ Celsius to average summer temperature 30˚ Celsius. The geographic location of the Kathmandu Valley is shown in Map 1.

Landsat Image of Kathmandu valley in the year 2018 is shown in Map 2. Zero point is shown in Map 2, spatially located at Maitighar Mandala. Maitighar mandala is zero point or origin for major transportation network inside valley and highways as well.



Map 2: Kathmandu Valley: Satellite View, 2018

1.4. Literature Review

Literature review in this thesis report is gateway for understanding the concept of urban sprawl, causes, drivers, consequences, methods of measuring, and modeling future growth. Literature review was useful in gathering significant study reports from different scholars. Comprehensive knowledge of the literature of the field is essential to every research papers. Thus literature review in this context was very crucial in preparation of overall thesis report.

1.4.1. Urban Sprawl:

In the present context there has been several definition of urban sprawl (US), still agreement on common definition has not been determined. Urban sprawl was first used by Earle Draper in 1937 as unaesthetic and uneconomic settlement form. According to Oxford Dictionary, urban sprawl is been defined as “the disorganized and unattractive expansion of an urban or industrial area into the adjoining countryside” this statement is significant as disoriented and haphazard urbanization and industrialization resulted in series of problems in developing countries. There have been several researches regarding urban sprawl. Brueckner (2000) highlights the forces behind urban expansion as growing population, rising incomes and falling commuting costs. Although these factors are reason behind urban growth, but failing to account for benefit in opens space, excessive commuting failure in accounting social congestion cost, and failure to sustain planned development results in uncontrolled urban sprawl. Squires (2002) recognizes population are rapidly expanding in suburban areas and urban areas, he further analyzed rapid growth in population leads in concentrated poverty elevation, racial segregation and fueling in discriminatory practices of urban sprawl. Brueckner (2000) agrees with the definition and further established parameters for determining urban sprawl by study of excessive spatial growth of cities, i.e. in order to accommodate growing population cities must grow, but contrary cities grows unacceptability and unreasonably (Christiansen *et al*., 2011). In developing countries, Ardeshiri and Ardeshiri (2011) synthesized the concept of urban sprawl in context of built-up area density, he emphasized the importance of land price and un controlled housing leads in lack of government control in land market and building construction, thus resulting in uncontrolled urban sprawl, this study was crucially illustrated by Habibi and Asadi (2011) by pointing out urban sprawl as unusual and excessive growth if cities putting pressure on boundaries and city in context of sustainable development. Peiser (2001) defined urban sprawl as everything that was happening badly about urban growth today as congestion, blight, monotony, endless development and ecological destruction. For future planning and developments city planner needs to understand the pattern of urban sprawl (Sudhira *et al*., 2004). Urban Sprawl can be characterized as low density dwelling outside city borders, low density development and loss of open area (Eryilmaz *et al*., 2008). European Environment Agency (EEA) described sprawl as the phenomena of low density expansion of large urban areas under market condition and dedicated in surrounding agricultural area. This definition is significant in context of patchy, scattered and discontinuous urban expansion following leap frog pattern and leaving agricultural enclaves. Sprawl can be defined as low density development of residential area, commercial areas, business areas that are segregated, with lack of thriving activity center and limited choice of travel route (Jiang *et al*., 2007), author described four important factors which can be used to measure sprawl as residential density, neighborhood mix homes, occupation and services, strength of service centers and accessibility network.

Nechyba and Walsh (2004) stated different forms of urban sprawl, from low density residential development or “edge cities”, or the form of planned communities or “downtown” or individual houses that pop up in formal rural areas. Burchell *et al*. (1998) conceptualized in order to define characteristics of urban sprawl, spatial pattern, root causes and main consequences of sprawl needs to be determined. He further lists the spatial pattern of sprawl as “low density, unlimited outward expansion, land uses spatially segregated, “leapfrog” development, and widespread commercial strip development.

Many authors defined urban sprawl in several ways, but Franz *et al*. (2006) summarized the several definition of urban sprawl based on various concept, Siedentrp (2005) defined urban sprawl in five different ways, in the form of density attributes, de-concentration process, structure and form of attributes, socially relevant effect, and normative planning and other prospective. Firstly Urban sprawl was defined in terms of density attributes considering low density settlement form, decrease in density and breakdown of cities or core areas in the form of sprawl (Glaeser & Kahn, 2003; Fulton *et al*., 2001). Secondly urban sprawl was defined in the form of de-concentration process, which exhibits the urban function defined with combination of spatial expansion of urban areas into rural areas (Glaeser *et al*., 2003; Pumain, 2003).

Thirdly US was characterized in the form of attributes of settlement system considering urban form building process disrupting mono-centric structure to discontinuous and dispersed settlement (Galster *et al*., 2000). Fourthly, urban sprawl was defined in terms of social effect on land use changes: traffic congestion, loss of water sources and soil fertility, transformation of agriculture area to non-agriculture purpose etc. (Ewing, 1997; Downs, 1999).

And finally US have been defined in terms of normative planning and order perceptions: Which can be summarized as unplanned development of urban areas which opposes the goal of sustainable development (Gassner, 1978). Although US was defined by different author on the basis of variety of features, but authors seems to agree on multidimensional phenomenon of sprawl. Sprawl can be better simplified as condition of land use which can be stated by general approach of aesthetics, efficiency, equity, and environmental aspect (Galster, 2001) as shown in Figure 2.

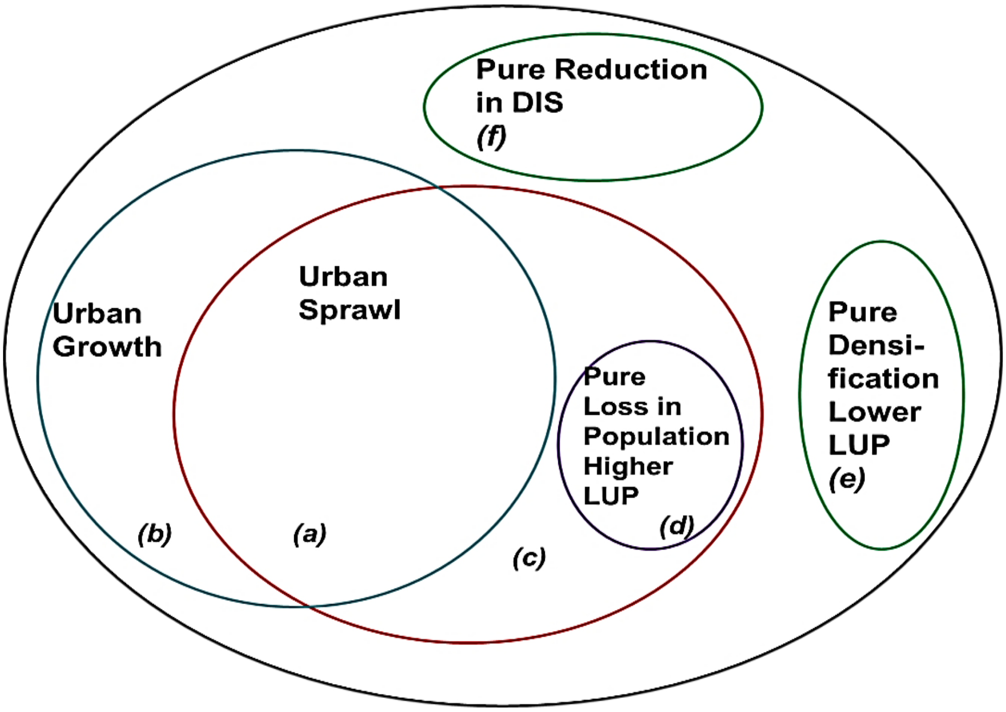


Figure 2: Urban Sprawl and relationship with different components (Galster, 2001).

1.4.2. Cause of Urban Sprawl:

Urban Sprawl growth is dependent on variety of factors. Causes of sprawl are "Population growth, Independence of decision, Economic growth, Industrialization, Speculation, Expectations of land appreciation, Land hunger attitude, Legal disputes, Physical geography, Development and property tax, Living and property cost, Lack of affordable housing, Demand of more living space, Public regulation, Transportation, Road width, Single-family home, Nucleus family, Credit and capital market, Government developmental policies, Lack of proper planning policies, Failure to enforce planning policies, Country-living desire, Housing investment, Large lot size" (Bhatta ,2010).

Batty *et al*., (2003) identified decentralization and centrifugal forces as reason for urban sprawl. US forces city to develop new activities far from existing city, but these cities are connected through better transportation. Author's defined centrifugal forces are based on population growth, infrastructure development, workforce, need of more space related to "economies of agglomeration". Stan (2013) characterized the driving forces behind US phenomena and summarized as: economic growth, increased standard of living, real estate speculation, increased vehicular mobility, haphazard urban and regional development without any control. Batty *et al*., (1999) suggested with implication of mathematical model, drivers of urban sprawl in the context of changing priorities for consumption of available free space and its effect in growth can be investigated. US driving factor is not concentrated in single factor, variety of factors proliferates the urban expansion (Christiansen *et al*., 2011).

Various author link urban sprawl with car based living (Glaeser & Kahn, 2004), or even the extension of public transportation in highway (Lawrence, 2005). But authors agree on multi-dimensional driving force for urban sprawl extension (Brueckner, 2000; Anas *et al*., 1998). Five driving factors of sprawl are classified by (Hersperger & Bürgi, 2009; Christiansen *et al*., 2011; Habibi & Asadi, 2011) as demographic, socio-economic, political, technological and geophysical. Christiansen *et al*. (2011) defined the drivers of urban sprawl as follow:

Demographic drivers: With the increase in population size and structure there will be increasing need of new built-up area. With increase in population, larger area will be required to accommodate people. Population is often concentrated in cities; also there will be ongoing higher consumption of agricultural areas outside point of reference. Author further stated the degradation of core city also contribute population to shift towards more desirable areas.

Socio-economic driver: Socio economic prospect of inhabitants is one of the major driver for urban sprawl (Christiansen *et al*., 2011). With upgrade to anticipated lifestyle, and increase in consumption of resources, increased income, people tends to buy sophisticated household in the urban periphery than core city apartment. With increase in Gross Domestic Product (GDP) and per capita income, urban sprawl has increased in individual countries (Bresson *et al*., 2004; Barbero-Sierra *et al*., 2013). With the growth in GDP, possession of facilities and vehicles will be increased. It further increases sophistication, accessibility and timely mobilization (Torrens, 2006). Glaeser and Kahn (2004) considered automobile dependency of people as the major diver of urban sprawl. To regulate the movement of vehicles in flexible way, there is need of proper transportation system. With the development of sophisticated road transportation network major chunks of population settles down in sub-orbs or far from core city (Verburg *et al*., 2004; Müller *et al*., 2010). With improvement in infrastructure (road) facilities in suburbs areas, new investors are attracted to expand their business in those areas. Shift in economic activities from core to suburbs increases built-up environment in the suburbs area. Development activities like construction of large offices, business empires and other market places are localized in suburbs area (Christiansen *et al*., 2011). On the other hand it is more expensive to construct residential purpose house or apartment in core area than in suburbs or fringes areas.

Political Driver: Christiansen *et al*. (2011) consider political factors as one of the crucial driver for urban sprawl development. Political decision related to planning system, subsidies, taxation system, legislative norms can limit or prevent urban sprawl. Politics plays major role in establishing legislative norms that can helps in promoting sustainable development and on the other hand control urban sprawl. There are several examples of politics and urban sprawl: Nuissl and Rink (2005) stated that German government subsidies growth of urban sprawl by promoting tax relief for investment in new houses by 50%. Whereas Wiewel *et al*. (1999) figured out although the cost for development of infrastructures like houses, apartment, schools, parks, public transportation system, will be shared within the residing community, but due to weak policy all the services will be benefited by wealthy minority. Subsidy facility on buying and acquiring new automobiles can also plays major role in promotion of urban sprawl (Su & DeSalvo, 2008). On the other hand with the practice of stipulation can check the creation of new built-up area rather promotes the densification of existing built-up area (Bertaud & Brueckner, 2005). Cheshire and Sheppard (2002) estimated built-up area can be increased by 26% if there are fewer restrictions related to green belt.

Technological drivers: Christiansen *et al*. (2011) consider technological driver as one of the major cause of urban sprawl, with advent to 20th century, there was tremendous development in technologies. Basically during the industrialization era, residential area and industrial area were close to each other, due to lack of proper vehicular mobility. Factory workers were forced to work near factories. With advancement of transportation network and automobile accessibility, restriction to live within the proximity of factory was diminished (Knowles, 2006). Also, Living expenses in the core area amplified with development in infrastructure in core area increased. Thus high living expenses in core area was one of the drivers for more dispersed settlement along the fringe. (Anas *et al*., 1998).On the other hand with advancement in communication technology and automation in different task, people can work from home, thus people reside in up skirt (Hardill &

Green, 2003). Thus need of commuting can be reduced in remarkable amount, with advancement in technology, resulting in dwelling pattern in more dispersed location, like wisely increases urban sprawl as well.

Geophysical drivers: Geophysical characteristics of landscape also play vital role in urban sprawl development. Characteristics of terrain (sloppy terrain), irreclaimable areas such as glaciers, lakes where construction of built-up areas are not possible can hinder development of urban sprawl (Christiansen *et al*., 2011). Author further discussed urbanization process is basically concentrated in area with feasible topography. On the other hand industrialization and exploration of resources is also significant urban sprawl driver. Agricultural lands nearby to the residential area are more vulnerable to development of urban fringes due to low land value and higher pressure for transformation (Mann, 2009). ESPON (2010) discussed the driver of sprawl in the context of horizontal and vertical drivers into five contexts as shown in Figure 3.

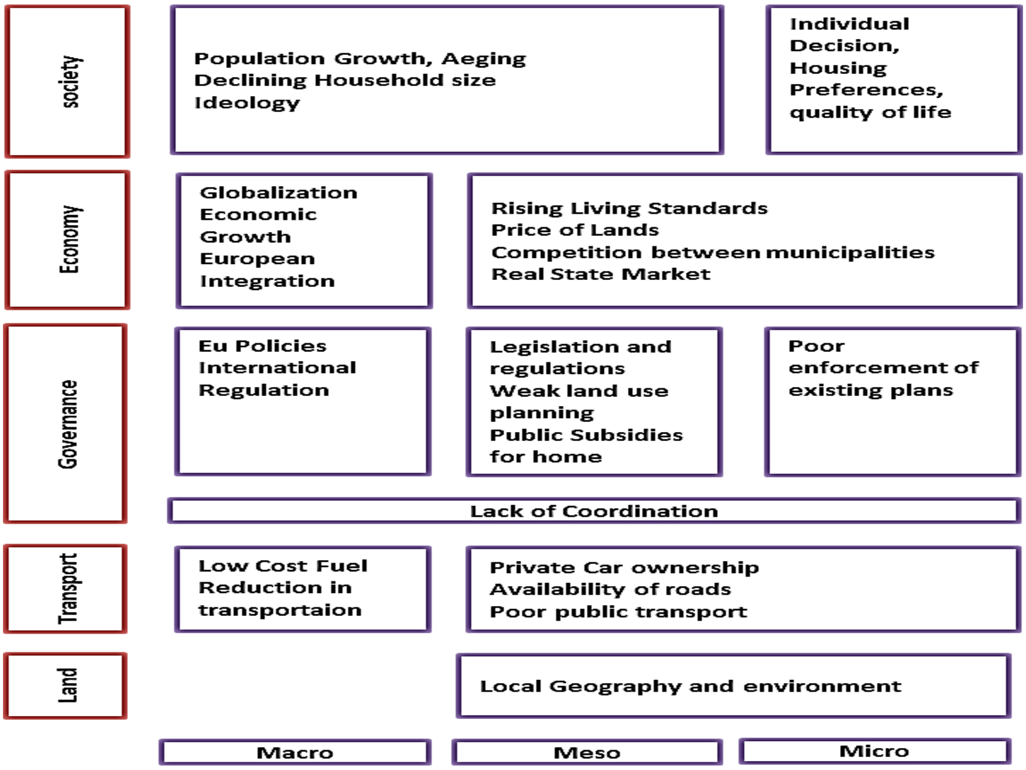


Figure 3: Driver of Urban Sprawl (ESPON, 2010)

1.4.3. Types of Urban Sprawl:

It is necessary to identify type of sprawl to determine characteristics of urban sprawl. Urban sprawl type varies amongst countries and their context (Christiansen *et al*., 2011). Batty et. al (2003) has described the type of sprawl shown in Figure 4. Author illustrated urban sprawl type as compact development, scattered development, linear strip development, poly-nucleated development and finally “leapfrog” development. Scattered development and “leapfrog” development is the form of urban sprawl which is result of car ownership. Scattered development is directly related to good accessibility to cars and road. Due to availability to car population can settle in any location, with subsequent travel time and travel distance. Urban Sprawl of these forms may have fewer incentives to intense housing in settlement center, thus resulting in more dispersed land development. Linear urban sprawl strip is developed along the rail transportation route. In linear strip development population area basically concentrated maximum at the major railway stations. Nechyba and Walsh (2004) also distinguished different form of urban sprawl. US take the form of “edge cities” involving low-density residential density, containing population clusters and related economic activities at urban fringe. It can also takes the form of planned communities with their own “downtown” or even aligned along lake or town. US may also take form of Urban sprawl in this form of individual houses constructed in rural area. Gets rises to business and commercial activities.

Based on the structure as shown in Figure 4, Galster *et al*. (2001) classified US into following types: Compact contiguous development: US of this type are slowly concentrated around existing urban area, without patches and having higher. Strip or linear development: US of this type are developed along river or roads; expansion of this type is continuous but scattered in nature.

Poly-nucleated nodal development: US of this type, aggregates smaller towns, but nature of sprawl are discontinuous, segregated from nearby urban city and low population and infrastructure density than urban cities. Thus new larger aggregated town is created separated from each other (Batty *et al*., 2003).

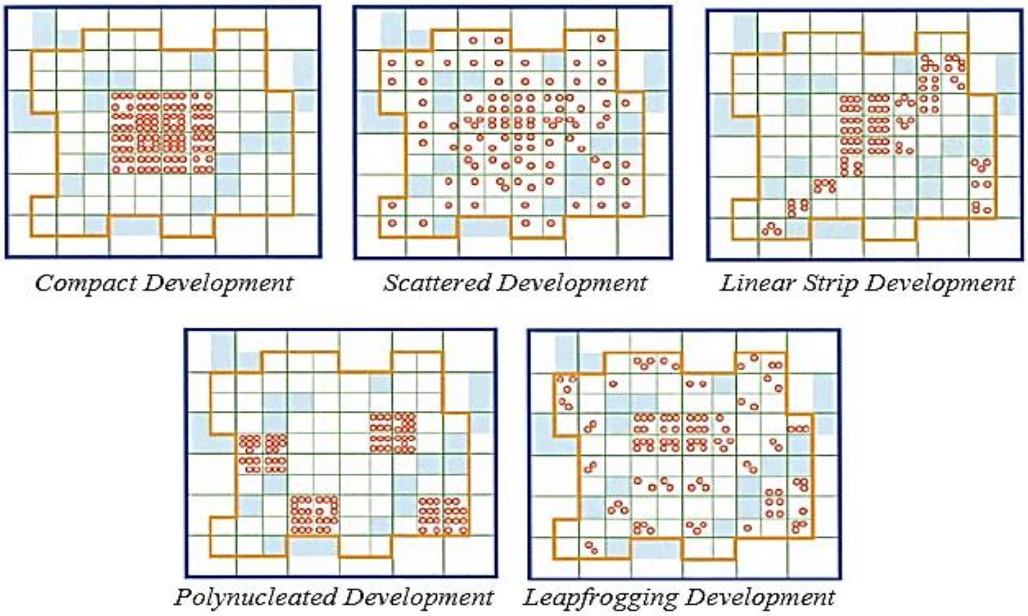


Figure 4: Type of urban sprawl development (Batty et.al, 2003)

The scattered sprawl development: US of this type consists haphazard and uncoordinated development away from core city. Residential cluster comprise open areas between newly created built-up areas. “Leapfrog” development: US of this type develop with leap frog pattern over existing boundaries (Batty *et al*., 2003; Besussi *et al*., 2010). Zhao *et al*. (2014) characterized urban sprawl into three types as “infilling”, “edge-expansion” and “outlying type” as shown in Figure 5.

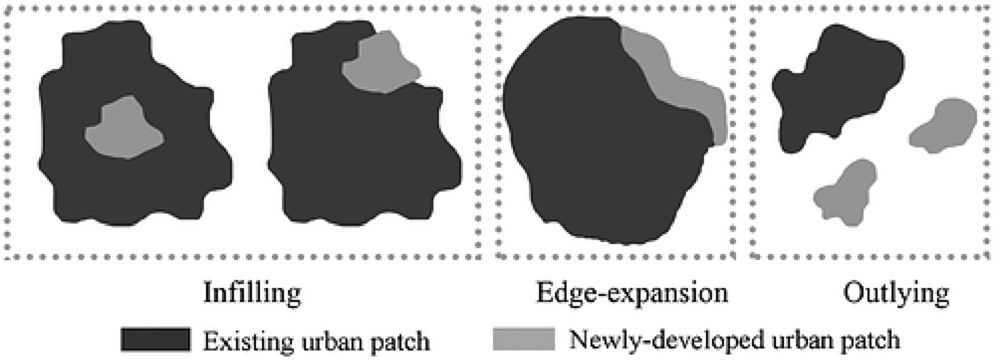


Figure 5: Types of sprawl (Zhao *et al*., 2014)

1.4.4. Consequences of Urban Sprawl:

Urban sprawl is generally considered as adverse effect as compared to densely developed city, lacking diversity and economic activities and social infrastructure (Batty *et al*., 2003). Authors further discussed urban sprawl as haphazard operation of land market, and outcome of uncompetitive process of urbanization. The problem with urban sprawl causes failure in land market strategy accounting for long term economic misbalance in the society.

Urban sprawl effect cannot be isolated within single entity, but their effects are accumulated in multiple entities. Mostly consequences of urban sprawl are related to land fragmentation (EEA & FOEN, 2011). Effect due to urban sprawl can be realized in gradual perception. Although single house construction can be visible easily and may be considered in significant in overall effect in urban sprawl, but the long term effect on larger period of time cannot be easily determined (Christiansen *et al*., 2011). Authors further stated, alternations due to single landscape are generally underestimated and marginalized, thus cumulative impacts of urban sprawl are neglected. Authors generalized this effect as ‘pitfall of marginalization’. Urban Sprawl was characterized as negative impact in terms of crowding, accessibility, degradation of agricultural areas, and poor social infrastructure. Urban sprawl effect was summarized by Batty *et al*. (2003) as destruction of country side, ruining economic activities in rural areas, transforming agricultural area into built-up areas. Urban sprawl will also effect on sustainable development, loss of greenery and open spaces, fragmentation of land, destruction of flora and fauna, degradation of ecosystem, ground water recharge etc. Likewise, soil fertility, water permeability, biodiversity loss will be damaged in irreversible way. Soil sealing with impervious material like building, blacktopped road, concrete accounts devastating change in water flow pattern and water induces hazard (Batty *et al*., 2003; EEA, 2006; Jat *et al*., 2008).

Another, consequences of urban sprawl can be characterized in terms of efficiency of infrastructure, utilities and related services. Urban Sprawl directly effects on livelihood of people, property values, commutation, and several other aspects of urban environment (Lynch, 1981), he further suggested urban sprawl in cities can be evaluated in the basis of five dimensions “viability, sense, fit, access and control.” With urban sprawl consumption of resource per capita will increase (Batty *et al*., 2003; EEA, 2006).Structure of society is the third consequences of urban sprawl. Urban sprawl causes exclusion of population, limiting better accommodation and quality life to wealthy individual or family (Batty *et al*., 2003; EEA, 2006). Thus urban sprawl distorts the social wellbeing of the citizen and creation of inequity in the community.

Urban sprawl has negative impact in landscape through process of “transformation, degradation and fragmentation” (Christiansen *et al*., 2011). Agricultural area is mostly transformed into concrete built-up area resulting in loss of agricultural productivity and biodiversity. On the other hand energy consumption for commuting in low density sprawl area is greater in comparison to core areas (Kenworthy *et al*., 1999). There will be need of production of larger amount of energy for maintaining energy balance in up skirts also results in unsustainable land use practices in sprawl area. There will also be increased competition of land (Haber, 2007. Vulnerability and risk of flood will increase with extension of impervious surface and blockage of river channels or stream channel during urbanization process (Feyen & Dankers, 2009).

Although urban sprawl is considered as negative impact in society, still there are some of benefits of sprawl. Batty *et al*. (2003) specified with increase in urban sprawl, there will be increase in residential, commercial area and industrial area creating more job opportunity and freedom of job selection to individual. Secondly, with increase in spatial extent of urbanization, there will be spread of metropolitan area, thus public service can be provided to rural population as well (Carruthers & Ulfarsson, 2003). Urbanization also decreases cost of buying houses or apartment, thus relieving pressure of accommodation of people in cities. People are encouraged to live further away from cities, where living expenses, commuting cost will be comparatively low than living in cities. With development of urban sprawl in “leapfrog” pattern, developers are attracted to develop markets, apartments and housing in relative lower cost than that of cities (Holcombe, 1999).

1.4.5. Measurement of Urban Sprawl:

Urban sprawl can be measured by variety of way, depending upon the parameters, data used and application. One of the methods for measuring urban sprawl is empirical analysis. Empirical analysis with the relationship with development pattern and relationship of variables with public service cost (Carruthers & Ulfarsson, 2003). Authors provided following stages for measuring urban sprawl.

1. Urban sprawl is measured by providing framework of measuring physical and political characteristics.
2. Data and parameter for urban sprawl development is described after specifying empirical model.
3. Finally, urban sprawl estimation is delivered based on different form of expenditure as “: total direct, capital facilities, roadways, other transportation, sewerage, trash collection, housing and community development, police protection, fire protection, parks, education, and libraries” (Carruthers & Ulfarsson, 2003).

Measures for urban sprawl can be measured in dynamic concept, with the application of land use change, land use pattern, and configuration of landscape metrics (Sudhira *et al.*, 2004). Implication of land use change analysis provides dynamic change composition of the land. Land cover change pattern delivers the information of coverage, type and direction of urban sprawl. Whereas landscape metrics give relationship between land cover class and landscape. Urban sprawl modeling can be measured by correlating land cover matrices and sprawl pattern. Landscape metrics provide statistical perceptions for configuration of urban sprawl. Landscape metrics provides the relationship between land fragmentation and spatial concentration of land cover distribution.

Christiansen *et al*. (2011) stated the following methods for measurement of urban sprawl: "Use of many variables in parallel:" Galster *et al*. (2001) used eight parameters for urban sprawl using parameters as (density, continuity, concentration, clustering, centrality, nuclearity, mixed uses and proximity) for determining urban sprawl in USA. Solon (2009) used seven land scape metrics "(spatial share, mean patch size, patch size coefficient of variance, mean shape index, mean nearest neighbor distance, mean proximity index and interspersion and juxtaposition index)" to study urban sprawl in Warsaw metropolitan city. Tsai (2005) used different variables related to spatial analysis "population, metropolitan density, degree of equal distribution, degree of clustering" for measuring statistical dispersion and spatial relatedness. Although use of multivariable approach based on spatial variables for determination urban sprawl, but these methods doesn't shows the relationship amongst each other. Thus, inter relatedness between different variables cannot be revealed in this method (Christiansen *et al*., 2011).

Second method for determination of urban sprawl is integration of many variables (Christiansen *et al*., 2011). In this method, different indices are grouped together to form fewer variables and applying statistical approach urban sprawl is measured. Frenkel and Ashkenazi (2008) categorized 13 variables in the form of configuration and composition. They separately measured settlement unit and values of indices integrated weighting scheme sprawl index. Siedentop and Fina (2010) used nine indices in combined form to describe land characteristics, urbanization pattern and urban density. Later these indices were processed through statistical analysis to determine urban sprawl in Germany. Although the method of integration of different variables is more complicated and they constitute information from different indices, but on the other hand the statistical model used makes the relationship of different indicator less transparent, also the relationship amongst the indices is difficult to establish. Christiansen *et al*. (2011) stated for determining prime component depends upon landscape indices used for statistical analysis. Factors used for statistical analysis differs between different input indices, making it impossible to directly compare the integrative measures of these indices.

Third measure for urban sprawl measurement is based on one or few variables. Yue *et al*. (2013) used population measures for determining urban sprawl. Authors used high and low population growth area and their relationship with total population of area to determine urban sprawl in Hangzhou, China. Arribas-Bel *et al*. (2011) integrated indices of connectivity, decentralization, density, scattering, and open space availability into self-organizing map algorithm and urban sprawl was determined. On the other hand Ewing *et al*. (2003) used residential area density, parcel size, mixed land use, degree of centering and accessibility to road network and Rutgers-Cornell sprawl indicators to measure sprawl in USA metropolitan cities. On the contrary to these approach Jat *et al*. (2008) used remote sensing based approach using patchiness and map density for determination of urban sprawl. Even though this approach is simpler than other two approaches but this approach is concentrated on only single aspect of urban sprawl, retaining risk of missing major characteristics of settlement resulting in incomplete urban sprawl picture.

Sudhira *et al*. (2004) proposed dynamic method of measuring urban sprawl, this method used configuration of land use change, pattern identification and landscape metrics. Land Use change analysis is used as parameter in this method, as change analysis gives dynamic property of land composition. Pattern identification is key measures for determination of type and direction of urban sprawl, and landscape metrics provides details about landscape configuration and land cover classes as well. Determining urban sprawl, landscape metrics and sprawl pattern should not be segregated; these two components have correlation relationship with each other. Pattern of urban growth is primary input, and the landscape metrics gives statistical perception of urban sprawl configuration. Landscape metrics further describes land configuration, i.e. fragmentation or concentration of land use classes.

According to Sudhira *et al*. (2004) change detection is primary input for land use change analysis. Different time stamp land use data are used to identify change. Application of remote sensing and GIS multi-temporal datasets are used for land change detection. Change detection studies land use land cover alteration, biodiversity change, environmental impact assessment, risk and vulnerability assessment (Singh, 1989). Change detection provides clear perspective of gradual to rapid change in land use land cover. There are several change detection method using image differentiation, image regression, image rationing, and vegetation index differencing. These methods were categorized using two change detection method of pre-classification and post classification methods (Mubea *et al*., 2010). Authors further proposed post classification method compares the independent classified image, and the overall accuracy of the change map is dependent upon accuracy and precision of the classified land use map, quality of satellite image, error assessment.

Second phase of urban sprawl modeling is visual interpretation of occurrence of urban area location. Pattern identification is vital for determining shape, future sprawl direction and predicting consequences of urban sprawl. Landscape metrics are used to describe pattern and configuration of urban sprawl. This phase is necessary to classify sprawl in period of time, to understand the type of urban growth, expansion of urban sprawl in future etc. Sudhira *et al.* (2003) stated urban sprawl pattern with the application of GIS and Remote Sensing. The Method helps in identifying linear and radial pattern of urban growth and its rate of expansion. Authors imposed use of land cover, land use, spatial and temporal urbanization growth pattern recognition. Remote sensing data was classified for generation of land use, built-up, transportation, water bodies, agricultural and bare land. Third phase for measuring urban sprawl is determining landscape metrics. Land scape matrices can be used to identity effects, property, and basis of urban sprawl, type, demarcation and exploration of urban sprawl. Land scape metrics identify and quantify landscape and their spatial relationship (Walz, 2011). Area of urban sprawl can be described with landscape metrics. Landscape structure describe landscape pattern. Landscape metrics measures quantitative aspect of structure and urban pattern, which can be used to describe urban sprawl. Landscape pattern are classified on the basis of "size, shape, arrangement and distribution of individual landscape elements. The reason for using metrics in spatial analysis may be to record the structure of a landscape quantitatively on the basis of area, shape, edge lines, diversity and topology descriptive mathematical ratios" (Walz, 2011). Land scape metrics can be subdivided into three levels of measurement. Patch level, Class level, and landscape level.

1. Patch Level: Patch are dynamic in nature and occurs in both spatial and temporal scales that form in organism centered perspective (Wiens, 1976; Wiens & Milne, 1989). Patch has internal structure with reflection of patchiness at finer scales, mosaic pattern which is based on patchiness at border scales (Kotliar & Wiens 1990). Landscape is not composed of single mosaic pattern but composed in hierarchy of patch mosaic across range of scales. Based on organism-centered prospective, patch can be defined on the basis of hierarchy in scales ranging from grain, individual extent, population and range of species (Kotliar & Wiens, 1990). Patch level, differentiate individual patches as area, provides detailed information about spatial metric information for individual patches. These patch metrics serves as primary input data for computation of landscape metrics. Variety of patch configuration metrics can be differentiated in the form of whole class, landscape and depending on emphasis requirement (McGarigal *et al*., 2012). For computation of patch level each patch can be represented as core area each patch, mean patch of Class Area, total Class Area. Configuration and sample representative metrics are described as (McGarigal *et al*., 2012):

- Patch area and edge- This is simplest measure to configure patch size, which represents a fundamental attributes based on spatial characteristics of patch. Most landscape metrics directly incorporate patch size information. Patch size distribution can be summarized in the form of mean, median, max, variance, etc. Patch size can be computed in the form of area of patch and spatial characteristics. Patch size can be characterized in spatial extent in the form of patch radius of gyration. Radius of gyration measures average distance an organism can move within patch boundary from random point of start. When using the sum for the class using weighted area mean, the matrices so obtained is correlation length matrices and measures traverse length from particular patch from random point of start and in random direction (Keitt *et al*, 1997). Thus edge length can be summarized as patch parameter and landscape levels as total edge length including focal class.

- Patch Shape Complexity: Patch Shape complexity can be defined as geometry of patch, that tend to form simple or complex structure, irregular or convoluted structure. Although shape index is very complicated to measure, but the most efficient measure of shape complexity is based upon the “perimeter to area ratio, fractal dimension or Euclidean shape. Higher the value of mean denotes greater shape complexity or farther departure from Euclidean geometry (McGarigal *et al*., 2012).

- Class Area: Class Area refers to the interior patch area, after edge buffer is eliminated from the patch. The edge buffer is area of the core or interior patch that is unaffected by edge (McGarigal *et al*., 2012). Authors defined edge effect distance in context of phenomena under consideration, that can be either be fixed or changeable for each edge. Class Area is integrated form of patch size, shape, and edge effect. Similar patches with small patch size but greater complexity have less Class Area. Matrices like mean patch size and variability patch size are associated with Class Area.Contrast: Contrast can be defined as the differences amongst patch type. Contrast can be computed with the use of contrast weight density, where different edge type area assigned with definite contrast weight. Contrast can be also defined as attribute properties associated with the edge (McGarigal *et al*., 2012).

- Aggregation: Aggregation can be defined as degree of attachment of patch types. Aggregation is associated with landscape texture. Aggregation is diversified phenomena which can be closely related to dispersion, interspersion, subdivision and isolation. Aggregation metrics is related with spatial properties of patch in the form of dispersion and interspersion. Where dispersion refers how much dispersed or spread out patch type is without reference to other patch type? Whereas interspersion refers to spatial intermixing of different explicit patch type. Most of the matrices of aggregation type are cell adjacency matrix, where different frequency of patch type appears alongside (McGarigal *et al.*, 2012).

- Subdivision: Subdivision refers to degree in which landscape was segregated into separate patch or fragments irrespective of shape, size, spatial arrangement and location of patch. Subdivision is derived from suite of metrics from cumulative distribution of patch size and gives better measure of subdivision (Jaeger, 2000). These metrics can be used to measure fragmentation degree from focal patch.

- Isolation: Isolation can be defined as property of patch to remain in isolation form other associated patch or similar ecological class. Isolation is related to subdivision.

2. Class Level: Class level metrics uses data of the similar land use type. Class indices measures amount of patch and spatial configuration associated with each type of patch separately, thus providing the measures of extent and fragmentation of each patch type (McGarigal *et al.*, 2012). Class metrics can be computed for every class of landscape and of every patch type. Class level uses two basic types of metrics. First indices denoting class size and spatial configuration, while second type sets distribution of first order, second order statistical summaries of patch metrics for each class in focus. These metrics are used for summarizing mean, median, standard deviation, variation, range, coefficient of variation in the patch attribute properties across all patches in focal class (McGarigal *et al.*, 2012).

- Class distribution statistics: Class metrics measures the established relationship between patch belonging to same type or class. One of the best way of configuring class metrics is to summarize the aggregation of patch matrices for particular patch metrics type. Class is representation of aggregated patch belonging to same class, thus class can be characterized with summarized class metrics belonging to same class. Fragstats compute both first and second order statistics for patch distribution summary in the form of mean, area weighted mean, median, range, standard deviation and coefficient of variation (McGarigal *et al*., 2012).

3. Landscape level: Third method for measuring urban sprawl is measurement of landscape level. Landscape level measures entire landscape in the form of landscape mosaic, spatial characteristics and distribution of landscape patches (Szabó *et al*., 2008). Landscape metrics are associated with entire patch mosaic. Landscape metrics consists of two metrics at landscape level first is landscape composition and spatial configuration and second is statistical distribution of first and second order statistical summaries of entire landscape patch metrics (McGarigal *et al*., 2012).

- Landscape distribution statistics: Landscape metrics is measure of aggregate properties of patch mosaic. Best way for analyzing patch distribution is to summarize all the patches metrics present over landscape. Both first and second order statistics can be used to characterize properties of all landscape patches. Fragstats computes mean, area weighted mean, median, range, standard deviation, and coefficient of variance. All these statistics are computed at landscape level (McGarigal *et al*., 2012).

1.4.6. Land use land cover:

Land cover of any area is directly related to factors like terrain, lithology, soil type, rainfall pattern, socio-cultural practices, and relative location. Thus land use planning is function of multiple elements as mentioned above. Thus abstraction of feature and arranging in appropriate class is another vital aspect of land use planning. Sokal (1974) stated that "the ordering or arrangement of objects into groups or sets on the basis of their relationships”. Classification is systematic approach of distinguishing classes and adding in appropriate clusters and assigning relationship between associated classes. Gregorio and Jansen (2005) stated that classification requires definition of classes boundary must be clear, precise quantitative and based on objective criteria. One concept that has much merit is that land use refers to, "man's activities on land which are directly related to the land" (Clawson & Stewart, 1965). Land cover, on the other hand, describes, "Vegetation and artificial constructions covering the land surface" (Burley, 1961). Concepts concerning land cover and land use activity are closely related and in many cases have been used interchangeably. The purposes for which lands are being used commonly have associated types of cover, whether they are forest, agricultural, residential, or industrial. Remote sensing image-forming devices do not record activity directly. The remote sensor acquires a response which is based on many characteristics of the land surface, including natural or artificial cover.

1.4.7. Remote Sensing techniques:

Remote Sensing is advanced technique of collection of data from space borne technique or airborne technique without having any physical contact in the earth surface (Campbell *et al*., 2011). RS provides flexibility of multispectral, multi temporal, multi resolution data, which are valuable assets for urban analysis, urban modeling and urban sprawl modeling as well. Due to its nature of timely, cost effectiveness, high temporal frequency, this technique was widely used for urban modeling, land use land cover change detection and variety of other urban study related field (Araya & Cabral, 2010). Urban growth/urban sprawl growth can be monitored properly with the application of GIS and RS.

LULC mapping can be best achieved with the application of classification technique in RS, classification can be defined as process of applying pixel based continuous data to land cover classes (Araya & Cabral, 2010). Quality of image interpretation is dependent upon the remote sensing data quality, algorithm used, and classification technique. There are two types of classification techniques, object based and pixel based classification technique. Overall quality of the output is related upon the quality of data and classification technique, thus it is very important to use suitable classification technique (Araya & Cabral, 2010). Object based classification approach uses segmentation technique in image data, and assigns multiple levels. Objects are created and class are assigned with application of training sets, fuzzy classification and nearest neighbor algorithm, whereas in pixel based approach, there are two standard classification technique, unsupervised and supervised classification technique, supervised classification takes training data and appropriate classification algorithm (Whiteside *et al*., 2011). It is obligatory to access accuracy of classified data for quality assurance.

1.4.8. Urban Growth Analysis with application of GIS and Remote Sensing:

Land use land cover (LULC) change provides basic platform for study in natural resource management, environment prospect, urban planning and policy formulation (Fichera *et al*., 2011). Land use land cover change analysis is very information need for local, regional and state level planner. Authors further stated application of GIS and RS integrated with spatial data processing technique has value added for cost efficient, competitive, accurate and timely LULC monitoring. Michalak (1993) stated the application of GIS provides conceptual framework for land use land cover change analysis, GIS platform provides most comprehensive conceptual approach for spatial data analysis, essential for planning and policy making. Application of spatial analysis is not sufficient for urban growth analysis; there is need of temporal datasets as well.RS technology with the advent of different platform and different sensors provides historical and recent satellite image which is valuable assets for urban growth analysis (Masek *et al*., 2000). Fichera *et al*. (2011) used integrated technique of GIS and RS for land cover classification and land cover change analysis for determining urban sprawl growth phenomena. Author highlighted the process of integration of GIS and RS created LULC maps, used it for change detection and identify urban sprawl pattern in rural and urban fringe. Commonly used indices with application of GIS and statistical analysis for determination of urban sprawl can be summarized as growth rate of population or built-up area growth rate, density of population or built-up area, determination of spatial configuration consisting of proximity, fragmentation and accessibility (Jiang *et al*., 2007). Analyzing time series of archive and recent satellite image data can generate LULC change and also predict future urban growth. RS technique can be used for measuring variety of morphological structure of cities development, urban sprawl extent, density and shape (Webster, 1995). Implication of conversion matrix is frequently used for generation of land use conversion or change detection. Conversion matrix subsequently shows the encroachment on different land use types for formulation of built-up areas (Yeh & Li, 2001).

1.4.9. Application of Entropy in Urban Sprawl Modeling:

Entropy concept was first formulated by German physicist Rudolph Clausius, in second law of thermodynamics (Clausius, 1867).Entropy is originated from Greek word гротгη, which implies change occurring in object during work is produced from heat. Statistical characteristics to entropy were first given by Claude Shannon as a scientific domain (Cabral *et al*., 2013). Shannon defined entropy as a property of particle, where bits are used as symbol and entropy is defined as logarithm of possible outcome of arrangement of bits, with relative proportion of message. It is denoted with equation:

$H= -\sum P(x_i)\log p(x_i)$

Where H is entropy and $p(x_i)$ is the probability of the variable x to assume values of $x_i... x_k$.

Entropy with integration of GIS and RS can be used for modeling urban sprawl (Yeh & Li, 2001). Shannon's entropy (h) is used to calculate dispersion or concentration of spatial variable (xi) among zones (Thomas, 1981).

Use of Entropy after integration of GIS and RS technique has been most effective tool for measuring urban sprawl (Sun *et al.*, 2007). Implication of Shannon's Entropy with application of GIS and RS can calculate degree of spatial concentration or dispersion of urban sprawl (Yeh & Li, 2001). Urban system is associated with urban sprawl. For proper functioning of urban system, firstly they must deliver necessary cultural assets and commodities for better life of inhabitants, and secondly system should be flexible to resist internal and external abrupt changes (Cabral *et al.*, 2013). In order to achieve first system, there is necessity of low entropy in services, built-up area, commute, and utilities services. If the entropy is below H_{min} value, then urbanization is uniform and vulnerable to abrupt change; whereas, if entropy is above H_{max}, then urban system will not be able to cope up with necessary resources for proper functioning of daily livelihood (Cabral *et al.*, 2013).

1.4.10. Cellular Automata (CA)- Markov Model for Urban Sprawl Modeling:

Cellular Automata (CA) - Markov model depicts urbanization, as a lattice of pixels or cells. Each cell representing a unit cell for finite state sets (Kityuttachai *et al.*, 2013). CA Markov model predicts the future urbanization or urban sprawl pattern, taking time series raster data as input, and using transition rules describing the cell behavior (Piyathamrongchai, 2006). CA Markov model uses the principle of Markovian chain analysis of n states uses, state vector, which is column vector, whose ith element represents the possibility of system being at ith state at that point of time with the sum of state vector being 1. x_{ij} being the probability of LULC change from one state j to another state i, then resultant matrix $T=[x_{ij}]$ is transition matrix of Markov chain analysis (Herold *et al.*,2005). CA Markov model is based on evaluating time series LULC data, for predicting spatial distribution of urban sprawl in the future.

In most primitive level, CA can be defined as array of raster or cells. During the changing process, LULC's cell state changes interactively and synchronology in a repetitive pattern using transition rules. CA is based on five principles: a) Lattice: array of cells, b) Cell State: Cell state from given finite states, c) Contiguous Neighborhood: Cell adjacent to particular LULC cells, d) Transition Rule: Transition rule defines rules of a current cell sate in next period of time, based on current cell state and its neighborhood. ,e) temporal space: Time space for CA evolution (Maithani, 2010).

$\{S_{t+1}\}=f(\{S_t\}*\{Ih_t\}*\{V\})$

Where, $\{S_{t+1}\}$ is the state of the cell in the CA at time (t+1), $\{S_t\}$ is the state of the cell in the CA at time (t), $\{Ih_t\}$ refers to the neighborhood, {V} is the suitability of a cell for urban growth f () denotes the transition rules, t is the time steps in temporal space and h is the neighborhood size

1.5. Concluding remarks

Objective oriented methodology for this thesis was determined using these literature reviews, need assessment, location of study area and research approach. Urban Sprawl extent and its form can be effectively modeled using RIS and Remote Sensing. There are several models that can be used to determine urban sprawl, amongst these different models "CA Markov" model is one of the best model for urban sprawl, as it take reference of suitability factors for urban sprawl modeling. As this model uses degree of resemblance between driving factor and urban sprawl development, thus this model was used for analyzing urban sprawl for 2031.

Chapter-2: Methodology

Urban Sprawl modeling of Kathmandu Valley study was based on spatial and temporal remote sensing data. This study focused on analyzing present and past land use land cover pattern in Kathmandu valley, with application of Landsat image and demographic data. Multi- temporal Landsat images of 2001, 2011 and 2018 were used to create LULC map of Kathmandu valley using ERDAS Imagine 2015 and ArcGIS 10.5. Urban Sprawl was measured using FRAGSTAT 4.2 software and finally Urban Sprawl for 2031 was modeled using IDRISI Selva Version 17.0. Urban sprawl type and its extent were determined using Urban Landscape Analysis Tool. Details process is presented in following sections.

2.1. Workflow

Overall methodology for Modeling Urban Sprawl of Kathmandu Valley with the application of GIS and Remote Sensing composed of following procedures portrayed in Figure 6:

- Landsat Image of Kathmandu Valley of 2001, 2011 and 2018 was downloaded from USGS website in GeoTIFF format, and census data of 2001 and 2011 was downloaded from CBS. Furthermore, LULC, roads and administrative boundary in shape file format was collected from department of survey Nepal.
- Downloaded Landsat images were extracted using “extract by mask” tool in ArcGIS 10.5 using boundary of Kathmandu valley. Followed by, image Classification and generation of LULC of the year 2001, 2011 and 2018.
- Accuracy assessment of classified images of the year 2011 and 2018 was done by linking ERDAS Imagine with Google Earth Pro Version 7.3. Accuracy assessment of classified LULC map of 2001 was done by using LULC map of Kathmandu valley prepared by survey department of Nepal.
- LULC change analysis of 2001-2011, 2011-2018 and 2001-2018 was done.

- Delineation of 5 km multi ring buffer from zero point “Maitighar Mandala” (it is the reference origin for highways and major roads in Kathmandu valley).
- Extent of Urban Sprawl was measured in each ring of multi ring buffer by analyzing landscape metrics (Number of patch, Class area, Largest Patch Index and Fractal Index) in FRAGSTATS version 4.2.
- Level of Urban Sprawl was determined in each ring of multi ring buffer was done using Shannon’s Entropy. Shannon entropy measured the pattern of urban growth, by measuring degree of spatial concentration and dispersion of built-up area.
- Types of urban sprawl in Kathmandu valley for each year were determined using “Urban Landscape Analysis Tool”. Types of Urban sprawl (“infill”, “extension” and “leapfrog”) was calculated in each buffer ring of multi ring buffer.
- Markovian change model was generated using LULC of 2001 and 2011.
- Transition model between 2001 and 2011 was generated from Markovian change model, using change/no change matrix obtained in change detection analysis.
- Suitability analysis was done using distance from roads, distance from built-up areas, and distance from forest and slope suitability for development of built-up areas.
- CA Markov model in IDRISI Selva 17.0 was used to model LULC of 2018, using transition area matrix of 2001 and 2011, suitability classes (raster group file), considering 2011 LULC as base map.
- Validation of model was done using classified LULC of 2018 and model generated 2018 LULC map using Kappa variation.
- CA Markov model in IDRISI Selva 17.0 was used to model LULC of 2031, using transition area matrix of 2011 and 2018, suitability classes (raster group file), and considering 2018 LULC as base map.
- Level of urban sprawl for 2031 was modeled using Shannon’s entropy model in Fragstats 4.2.

- Types of urban sprawl in Kathmandu valley for 2031 were determined using “Urban Landscape Analysis Tool”. Types of urban sprawl (“infill”, “extension” and “leapfrog”) were calculated in each ring of multi ring buffer.
- Finally direction of urban sprawl from 2001 to 2031 was analyzed.

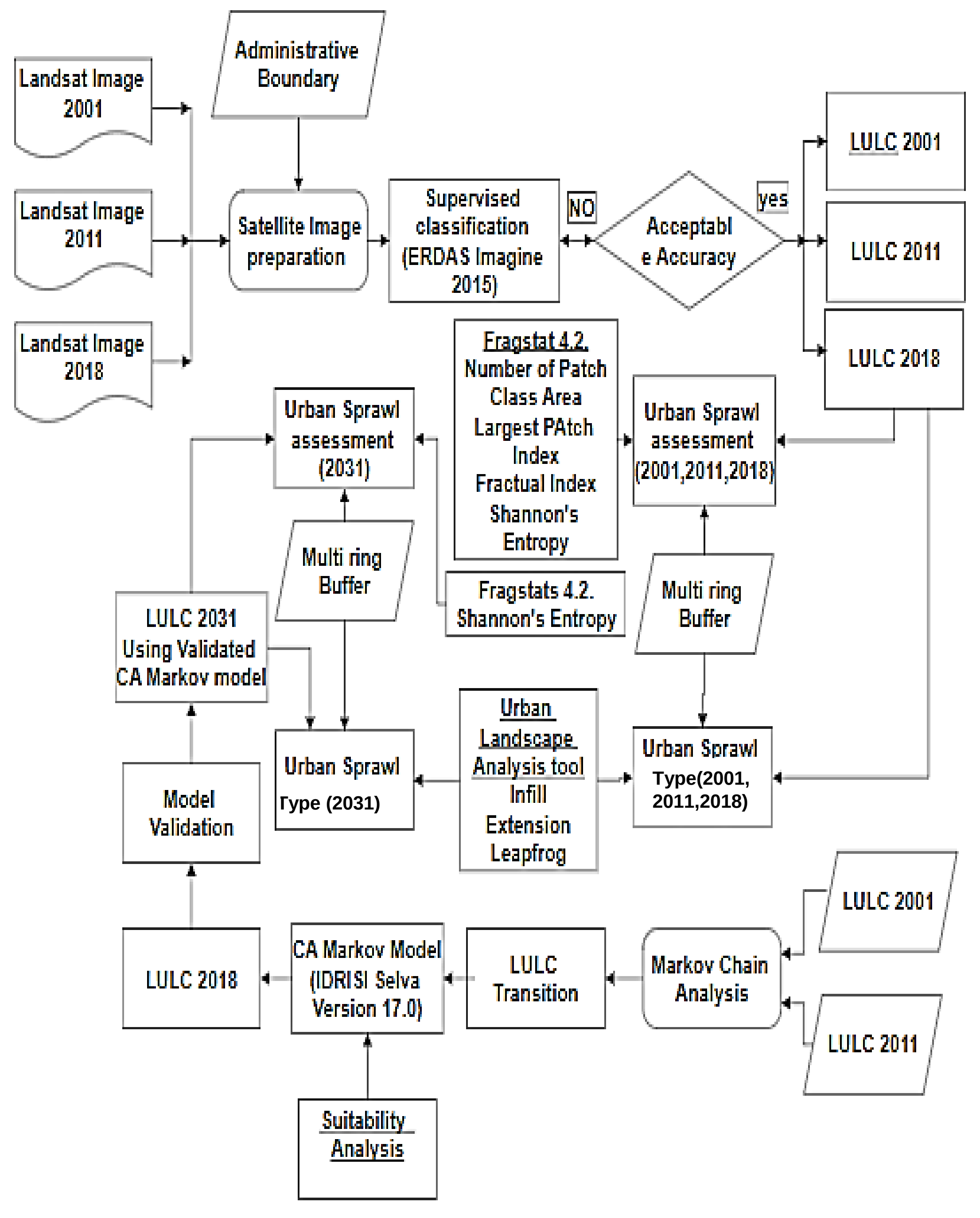


Figure 6: Workflow of urban sprawl analysis.

2.2. Data Used

Urban sprawl analysis of Kathmandu valley was evaluated using Landsat Image, administrative boundary, landuse land cover map of Kathmandu valley.

2.2.1. Landsat Image:

Landsat 5 TM with row/path 41/ 141 for 2001 and 2011 and Landsat 8 ("OLI_TIRS") with row/path 41/ 141, having ground resolution of 30 meter covering temporal scenes of 2001, 2011 and 2018 details shown in Table 1 and Table 2. Images were freely downloaded from United States Geological Survey website (USGS, 2018) in GeoTIFF format and WGS84 datum. Downloaded data were enhanced and extracted by mask of the study area.

Table 1: Landsat 5 TM Image band and resolution

Landsat 5 (TM)			
Acquisition Date: 02/02/2001 and 29/01/2011			
Row/Path: row/path 41/ 141			
No.	Band	Wavelength (µm)	Resolution (m)
1	Blue-Green	0.45 – 0.52	30
2	Green	0.52 – 0.60	30
3	Red	0.63 – 0.69	30
4	NIR	0.76 – 0.90	30
5	Mid-IR	1.55 – 1.75	30
6	TIR	10.40 – 12.50	120
7	Mid-IR	2.08-2.35	30

Source: USGS, Earth Explorer (Landsat)

Table 2: Landsat 8 OLI Image band and resolution

Landsat 8 (OLI)			
Acquisition Date: 03/01/2018			
Row/Path: row/path 41/ 141			
No.	Band	Wavelength (µm)	Resolution (m)
1	Coastal	0.433 – 0.453	30
2	Blue	0.450 – 0.515	30
3	Green	0.525 – 0.600	30
4	Red	0.630 – 0.680	30
5	NIR	0.845 – 0.885	30

6	SWIR1	1.56 – 1.66	30
7	SWIR2	2.10 – 2.30	30
8	Pan	0.500 – 0.680	15

Source: USGS, Earth Explorer (Landsat)

2.2.2. Elevation Data:

Slope is one of the major parameter for built-up suitability analysis; slope grading is classified based on their significance in development of built-up areas. Slope layer was prepared with Digital Elevation Model (DEM) downloaded from USGS Earth Explorer with spatial resolution of 30 meters. Slope condition has direct impact on structural stability and strength. Detail Description of the SRTM DEM is mentioned in Table 3. Kathmandu valley is covered with scene “n26_e087_1arc_v3”. Elevation of the district ranges from 1300 m to 2800 m.

Table 3. SRTM DEM details

DEM Details	
Projection	Geographic
Horizontal Datum	WGS84
Vertical Datum	EGM96 (Earth Gravitational Model 1996)
Vertical Units	Meters
Spatial Resolution	1 arc-second for global coverage (~30 meters)
Raster Size	1 degree tiles
C-band Wavelength	5.6 cm
Scene	n26_e087_1arc_v3

Source: USGS, Earth Explorer (SRTM)

2.2.3. Land Use Land Cover Data of 2001

Land use land cover data was collected from former National Land Use Project in shapefile format. LULC Data was in the form of polygon feature. LULC vector data was converted to raster format with spatial resolution of 30 meters and referenced in Universal Transverse Mercator (UTM) 45 N coordinate system. LULC data consisted fields like Agriculture, coniferous, grazing, hardwood, sand and boulder, urban, shrub etc. These data was reclassified to four class (Cultivation, Forest, Built-up and Bare) as of classified

LULC map of 2001. LULC data had Projected Coordinate System: MUTM_84, Projection: Transverse_Mercator, with False_Easting: 500000.00, False_Northing: 0.00, Central_Meridian: 84.00, Scale_Factor: 0.9999, Latitude_Of_Origin: 0.00, Linear Unit: Meter, Geographic Coordinate System: GCS_Nepal_Nagarkot, Datum: D_Nepal_Nagarkot, Prime Meridian: Greenwich, Angular Unit: Degree.

2.2.4. Administrative Boundary:

Administrative boundary for Kathmandu Valley was downloaded from geographic information infrastructure division's geoportal (GIID, 2018). Administrative boundary of Kathmandu, Bhaktapur and Lalitpur district were in polygon feature. Administrative boundary data had Projected Coordinate System: MUTM_84, Projection: Transverse_Mercator, with False_Easting: 500000.00, False_Northing: 0.00, Central_Meridian: 84.00, Scale_Factor: 0.9999, Latitude_Of_Origin: 0.00, Linear Unit: Meter, Geographic Coordinate System: GCS_Nepal_Nagarkot, Datum: D_Nepal_Nagarkot, Prime Meridian: Greenwich, Angular Unit: Degree. Administrative boundaries were referenced in UTM 45 N coordinate system and this boundary was used for study area delineation.

2.2.5. Road Network:

Road network for Kathmandu valley was collected from survey department of Nepal. Road layer consist highways, primary roads, secondary roads, tertiary roads and local roads of Kathmandu, Bhaktapur and Lalitpur district. Road network data had Projected Coordinate System: MUTM_84, Projection: Transverse_Mercator, with False_Easting: 500000.00, False_Northing: 0.00, Central_Meridian: 84.00, Scale_Factor: 0.9999, Latitude_Of_Origin: 0.00, Linear Unit: Meter, Geographic Coordinate System: GCS_Nepal_Nagarkot, Datum: D_Nepal_Nagarkot, Prime Meridian: Greenwich, Angular Unit: Degree Road network were referenced in UTM 45 N coordinate system and was used for suitability analysis for built-up area.

2.2.6. Population data:

Population data was taken into reference from census conducted by government of Nepal. Also the population projection of 2031 was taken in consideration for urban sprawl result comparison with current state. Central bureau of statistics population modeling data of 2014 was used. Data was available in tabular form. Data consisting total population, male and female population was available in tabular form.

2.3. Software Used

Modeling Urban Sprawl of Kathmandu valley with the application of GIS and Remote Sensing, ERDAS Imagine 2015 software was used for image processing, ArcGIS 10.5 was used for spatial analysis and map preparation, like wise Fragstat Version 4.2. was used for urban sprawl measurement in Kathmandu valley. IDRISI Selva Version 17.0 software was used for Urban Sprawl modeling and modeling for 2031. Finally, Word and MS Excel Software were used for report preparation.

2.4. Concluding remarks

Using the methodology stated above using Landsat image, road network data, administrative boundaries urban sprawl modeling was performed stated in chapter 3. Furthermore, landscape metrics, urban landscape analysis tool and CA-Markov model was used for modeling of urban sprawl in Kathmandu valley for the year 2031.

Chapter-3: Process and Result

This chapter discusses the process and result of LULC classification using Landsat images, LULC change, urban sprawl extent using landscape analysis in FRAGSTATS 4.2, types of urban sprawl using urban landscape analysis tool and future prospects of urban sprawl in Kathmandu Valley using CA Markov model in details.

3.1. Land Use Land Cover Classification

Satellite Image classification technique was implied for LULC map generation. Image Classification was used to create LULC maps in temporal dimension (Dadras *et al*., 2014). LULC patterns for three different years (2001, 2011 and 2018) were generated. Landsat 5 TM with row/path 41/ 141 for 2001 and 2011 and Landsat 8 ("OLI_TIRS") with row/path 41/ 141, having ground resolution of 30 meter was used for land use land cover map.

Landsat images were visually enhanced to improve the image visual quality using haze correction and histogram equalization in ERDAS Imagine 2015. Supervised Classification technique was used for classifying the Landsat Image. Reference training sites for each LULC classes were taken to generate training signatures. Landsat image was displayed in image viewer in false color composite. Signature editor tool was used from classification menu in ERDAS Imagine 2015 to create signature polygons. Features resembling similar characteristic of LULC types, Area of Interest (AOI) were drawn in image viewer. Signature was created from these AOI representing different LULC type. Several training areas for each LULC types with different characteristics were drawn before merging them into single signature class. Supervised classification was performed, checking seperatibility of each signature classes. Maximum likelihood technique was used for supervised classification. In the process of classification landscape type and cover were detected. LULC were classified; categories of LULC were 1) Built-up, 2) Bare, 3) Cultivation and 4) Forest. Table 4 lists four different LULC and definition of each category.

Table 4. Land use land cover classified classes

S.N.	Classes	Definitions
1	Built-up	Areas consisting buildings, roads.
2	Bare	Area consisting bare Land and no vegetation area.
3	Forest	Area consisting forest area, Shrub and bushes
4	Cultivation	Area consisting cultivation area

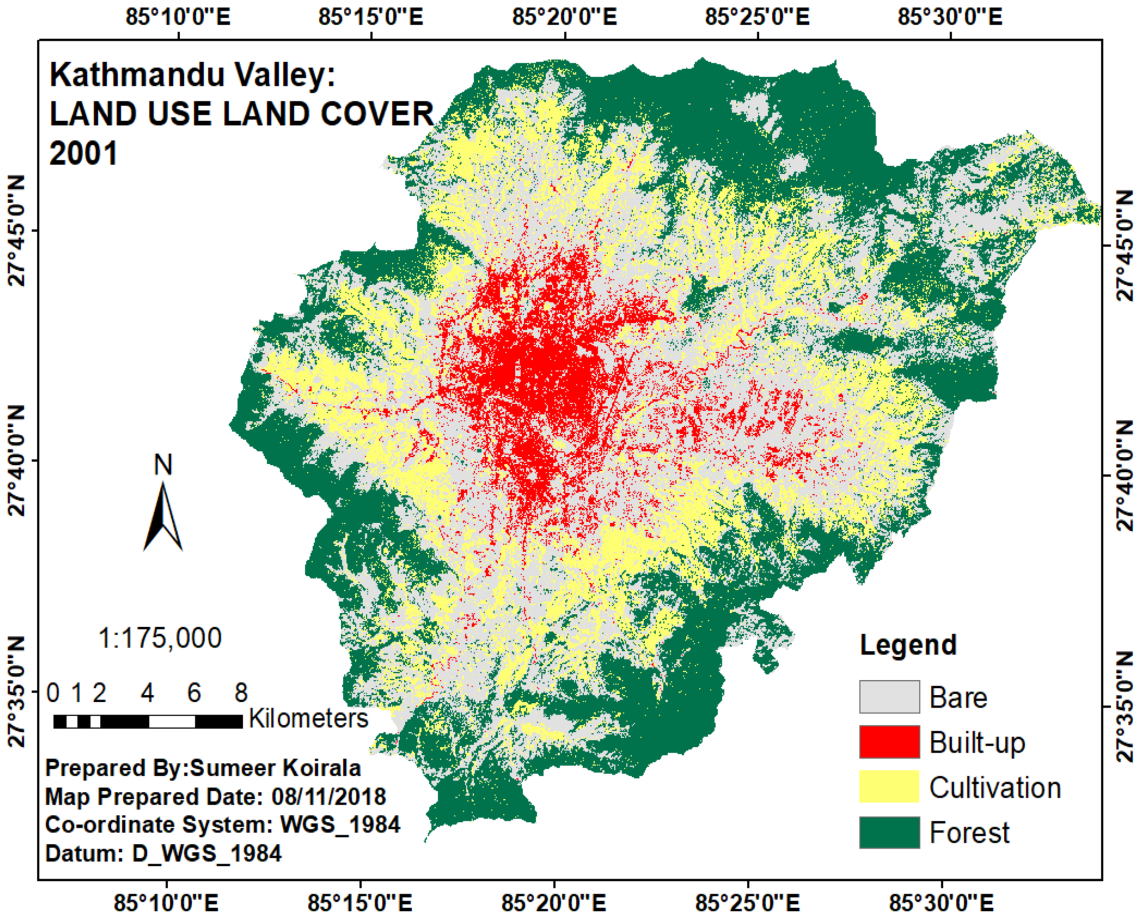
3.2. Kathmandu Valley: Land Use Land Cover; 2001, 2011 and 2018

Supervised classification technique was used for preparing LULC map of Kathmandu Valley during 2001, 2011 and 2018. Overall land use land cover distribution, accuracy accessed is presented in this section.

3.2.1. Kathmandu Valley: LULC, 2001

Map 3 depicts the spatial distribution of LULC of 2001. Bare land is most dominant LULC class in 2001. Out of 697.35 km^2 land, bare land occupies 277.59 km^2 of total land, which was 40 percentage of total LULC of Kathmandu Valley.

Likewise Forest area was second dominating LULC class in 2001. Forest area covers 231.42 km^2 of total land, which covers 33 percentage of total LULC. Cultivation land was third dominating LULC class in 2001. Cultivation land covers 134.41 km^2 of total land, which was 19 percentage of total LULC. Finally built-up area is least dominating class. In 2001, built-up area was very low in comparison to other LULC. Out of total area it occupies only 53.94 km^2 of total area, which was 8 percentage of total LULC of Kathmandu Valley. In 2001, built-up area was significantly less; mostly bare areas were prominent in KV. Figure 7 depicts the LULC composition in Kathmandu valley.



Map 3: Kathmandu Valley:Land Use Land Cover - 2001

Overall classification accuracy of LULC map for 2001 is 92%. The kappa coefficient for LULC map of 2001 was 0.8933. Producer accuracy of the LULC map of 2001 for different LULC classes ranges from 86% to 100%. Bare area exhibit 88% of producer accuracy, Built-up area exhibit 95.83% of producer accuracy, Forest area 100% and cultivation area had the lowest producer accuracy 86.21%. Likewise user accuracy of LULC map of 2001 ranges from 88% to 100%. Bare area exhibit 88% of user accuracy, Built-up area has 92%, Forest area has 88.0% and finally cultivation area has 100% of user accuracy. Forest area has highest classification accuracy as forest area was located in top of the hilly terrain surrounding the valley, with distinct signature in comparison to other LULC classes.

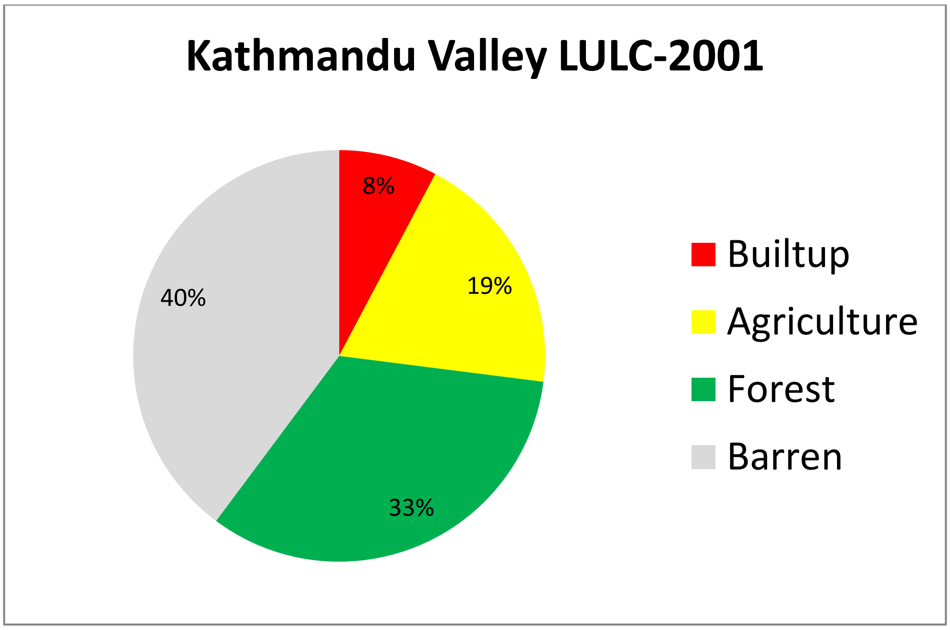
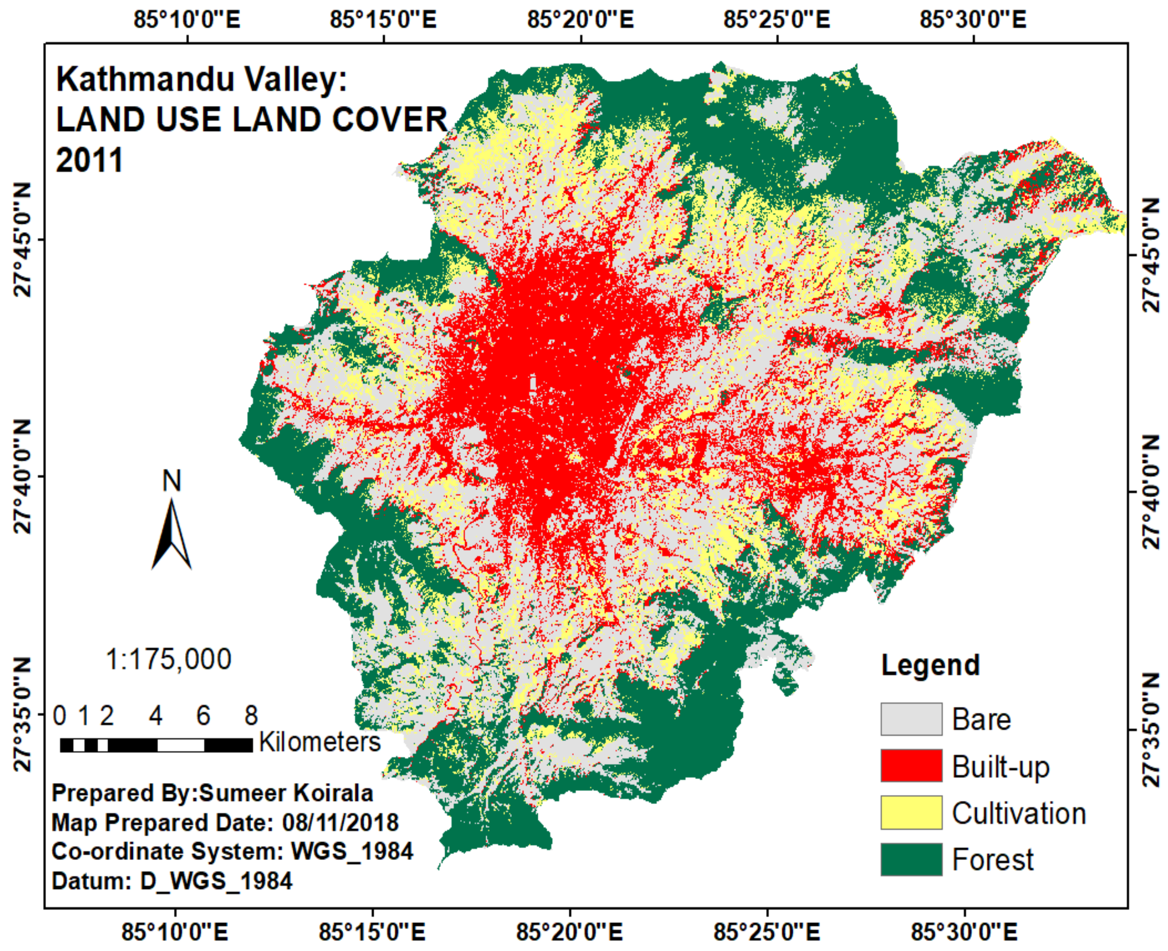


Figure 7. Kathmandu Valley: LULC - 2001.

3.2.2. Kathmandu Valley: LULC, 2011

Map 4 depicts the spatial distribution of LULC of 2011. Bare land was most dominant LULC class in 2011. Out of 697.35 km^2 land, bare land occupies 228.08 km^2 of total land, which was 33 percentage of total LULC of Kathmandu valley. Built-up land covers 139.69 km^2 of total land, which was 20 percentage of total LULC. Finally cultivation area was least dominating class. In 2011, cultivation area was very low in comparison to other LULC. Out of total area it occupies only 98.16 km^2 of total area, which was 14 percentage of total LULC of Kathmandu Valley. Figure 8 depicts the LULC distribution of Kathmandu valley.

Overall scenario of LULC of Kathmandu Valley in 2011, depicts there was haphazard development of built-up area on the expense of bare area and agricultural area. During 2001 built-up area contributes 8 percentage of total LULC distribution in Kathmandu valley, while in 2011, built-up area increased to 20 percentage. There was increase in buildings and road networks inside the valley. With development of new residential areas there was considerable increase in roads networks and vice versa.



Map 4: Kathmandu Valley: Land Use Land Cover - 2011

Overall classification accuracy of LULC map for 2011 is 91%. The kappa coefficient for LULC map of 2011 is 0.88. Producer accuracy of the LULC map of 2011 for different LULC classes ranges from 85.71% to 100%. Bare area exhibit 85.71% of producer accuracy, Built-up area exhibit 100% of producer accuracy, Forest area 92% and cultivation area had the lowest producer accuracy 88.46%. Likewise user accuracy of LULC map of 2011 ranges from 84% to 96%. Bare area exhibit 96% of user accuracy, Built-up area had 84%, Forest area had 92.0% and finally cultivation area had 92% of user accuracy. Forest area has highest classification accuracy as forest area was located in top of the hilly terrain surrounding the valley, with distinct signature in comparison to other LULC classes.

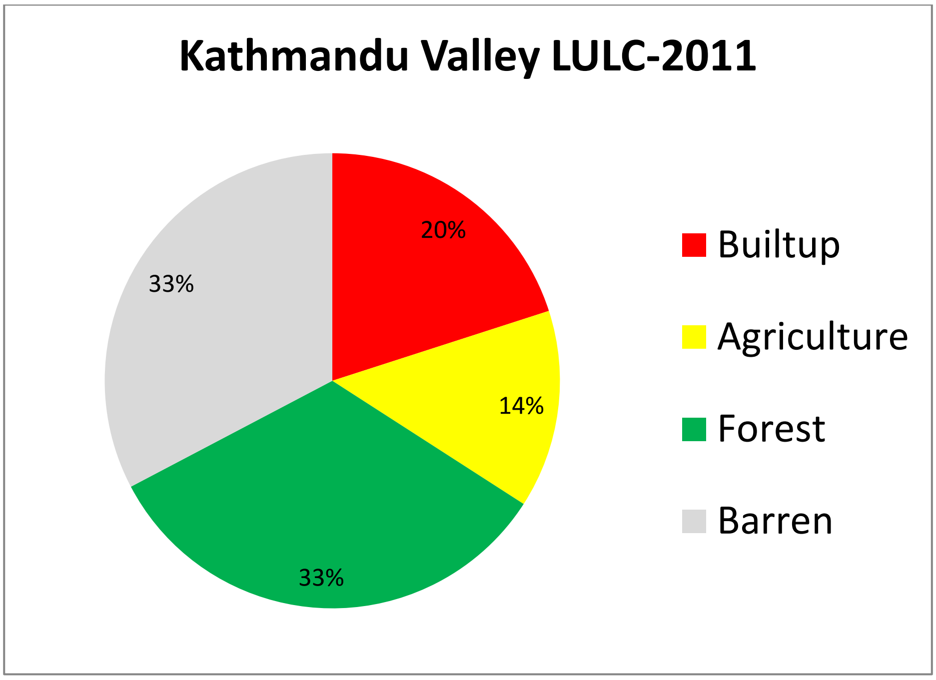
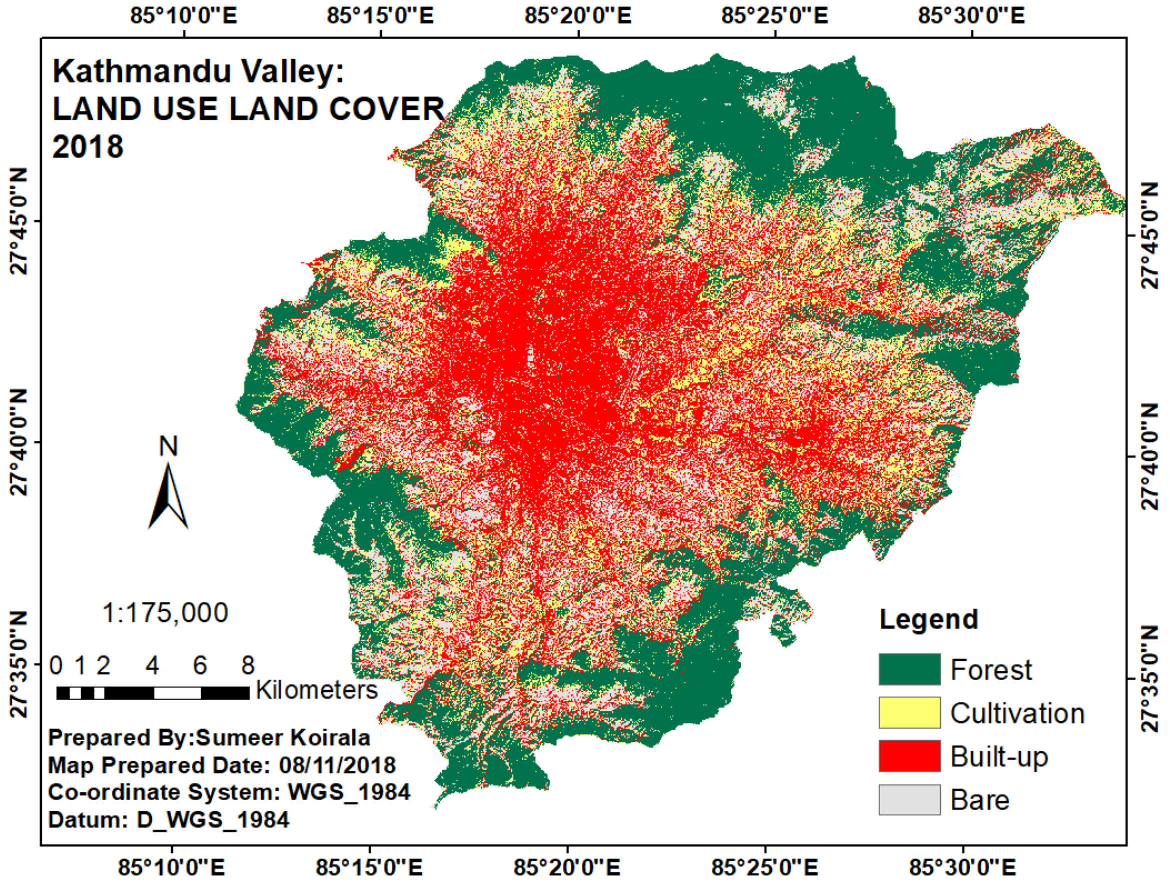


Figure 8. Kathmandu Valley: LULC - 2011.

3.2.3. Kathmandu Valley: LULC, 2018

Map 5 depicts the spatial distribution of LULC of 2018. Forest land is most dominant LULC class in 2018. Out of 697.35 km^2 land, forest land occupies 231.46 km^2 of total land, which was 33 percentage of total LULC of Kathmandu valley. Likewise bare area was second dominating LULC class in 2018. Bare area covers 191.35 km^2 of total land, which covers 27 percentage of total LULC. Built-up land was third dominating LULC class in 2018. Built-up land covered 170.71 km^2 of total land, which was 25 percentage of total LULC. Finally cultivation area was least dominating class. In 2018, cultivation area was very low in comparison to other LULC. Out of total area it occupied only 103.84 km^2 of total area, which was 15 percentage of total LULC of Kathmandu Valley. Figure 9 depicts the LULC distribution of Kathmandu valley. LULC of Kathmandu valley in 2018 is shown in Map 5. There has been increase in built-up area from 2001 to 2018 in dramatic manner. Mostly, bare areas contributed for development of new built-up areas. Forest area remained unchanged in larger extent during the study period.



Map 5: Kathmandu Valley:Land Use Land Cover - 2018

Overall classification accuracy of LULC map for 2018 is 88%. The kappa coefficient for LULC map of 2018 is 0.84. Producer accuracy of the LULC map of 2018 for different LULC classes ranged from 82.14% to 91.67%. Bare area exhibited 85.71% of producer accuracy, Built-up area exhibited 90.91% of producer accuracy, Forest area 91.67% and cultivation area had producer accuracy 88.46%. Likewise user accuracy of LULC map of 2011 ranged from 80% to 92%. Bare area exhibited 92% of user accuracy, Built-up area had 80%, Forest area had 88.0% and finally cultivation area had 92% of user accuracy. Forest area had highest classification accuracy as forest area is located in top of the hilly terrain surrounding the valley, with distinct signature in comparison to other LULC classes.

Overall scenario of LULC of Kathmandu Valley in 2018, depicts there was gradual increase of built-up area as compared to decade of 2001 to 2018. During 2011 built-up area contributed 20 percentage of total LULC distribution in Kathmandu valley, while in 2018, built-up area increased to 25 percentage. Road widening and improvement in roads caused gradual increase in built-up area.

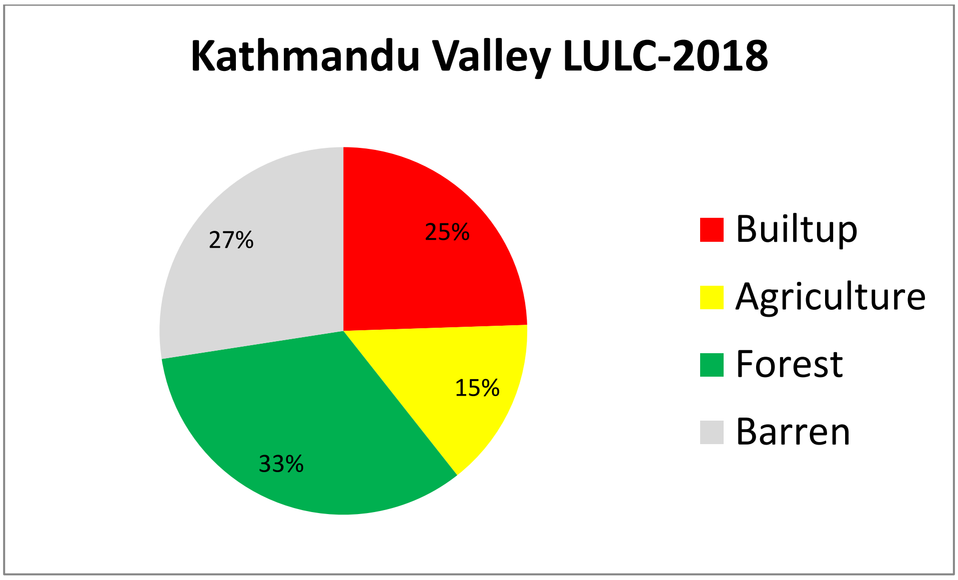
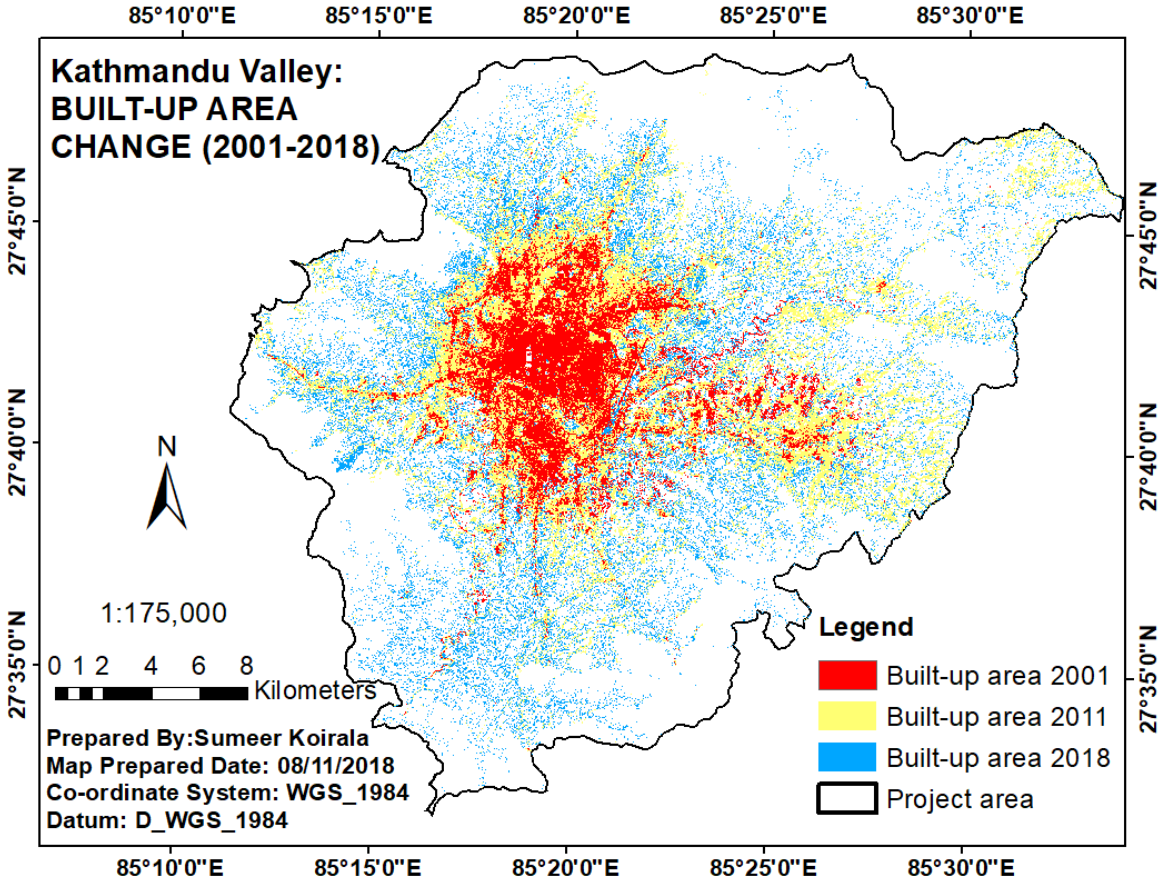


Figure 9. Kathmandu Valley:Land Use Land Cover - 2018

3.3. Land Use Land Cover change

Land use land cover of Kathmandu valley was spatially depicted in maps 3, 4 and 5. In Map (3 and 4) significant increase in built-up area can be detected; this expansion of built-up area was detected during the period of 2001 to 2011. In 2001, total built-up area in Kathmandu valley was 53.94 km^2. During the period of 2001 to 2011, the built-up area increased up to 139.69 km^2, and during the period of 2011 to 2018 built-up area stretched up to 170.71 km^2.

With the increase in built-up area, there was degradation in agricultural area. Agricultural area compensates the changed for built-up area. In 2001, total agricultural area was 134.41 km^2. During the period of 2001 to 2011, there was extreme depredation of agricultural area. Agricultural area has decreased from 134.41 km^2 to 98.16 km^2. During the period of 2011 to 2018, agricultural area remains in similar amount whereas bare areas were transformed to built-up areas.



Map 6 : Kathmandu Valley: Built-up area change (2001-2018)

The area of bare land in 2001 was 277.59 km^2, during the period of 2001 to 2011 there was change in bare land to 228.08 km^2, and during the period of 2011 to 2018, bare land decreased from 228.08 to 191.34 km^2. One of the most fascinating LULC patterns of Kathmandu valley was Forest area, forest area did not seems to be disturbed during the entire period. Forest area contributed almost 33 percentage of the total LULC of the Kathmandu valley.

Map 6 demonstrates rapid urban expansion in Kathmandu valley during the study period. Urban expansion in Kathmandu Valley, increased by three times, from 2001 to 2018. In the period of 2001 to 2011 Kathmandu valley experienced major urban expansion. Urbanization in Kathmandu valley experienced 12 percent change. In 2001, the overall population of Kathmandu valley was 11 million (CBS, 2012). In 2011, population of Kathmandu valley increased to 18 million and estimated population of Kathmandu valley in 2018 was 25 million (CBS, 2014).

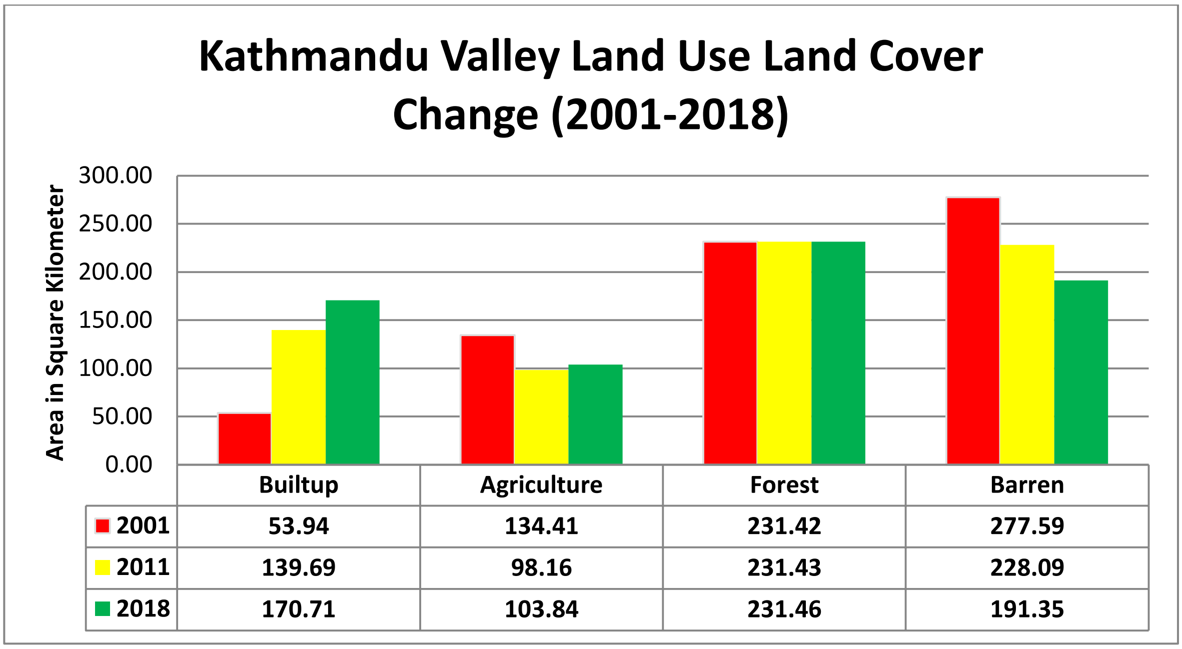
Urban expansion in Kathmandu valley was a result of population increase, population growth is indispensable factor for urbanization or urban growth (Herold *et al*., 2003). Population growth in Kathmandu valley is resultant of several factors. Immigration is the major cause of rapid population growth. Kathmandu Valley consists of three districts Kathmandu, Bhaktapur and Lalitpur district. Kathmandu being the country capital, it serves as major hub for industrialization, commercialization, educational, infrastructure, and technological development. Due to lack of proper city planning and strict policy in controlling haphazard urbanization, Kathmandu valley has suffered massive uncontrolled urbanization. During the mass insurgence in Nepal during the era of 2001-2011 there was highest population density 4,416 person per km^2 (CBS, 2012). During the period Kathmandu valley, exhibit the fastest decadal population growth rate of 61.23 percentages (CBS, 2012). Massive population migrated from rural areas to urban areas, mostly in district headquarters. During the insurgency period, most of the people from village and suburbs migrated to Kathmandu valley seeking security.

In the present scenario, Kathmandu valley has population of 2.5 million populations, with growth rate of 4 percentages per year. With this growth trend, Kathmandu valley has been identified as one of the fastest growing metropolitan city is whole south east area. Within Kathmandu valley cluster of non-agricultural land transforming into urban center and development of new town along major roads, with increase in population by 5-7 percentage each year is causing urban sprawl in alarming rate.

Figure 10 represents LULC change in Kathmandu valley during the period of 2001 to 2018. There is significant increase of built-up area in the period of 2001 to 2011. There was increase of built-up area by 158 percentages during this period. During the period of 2011 to 2018, there is urban expansion in Kathmandu valley not as alarming as it was during the period of 2001 to 2011.

Rapid expansion of urban or built-up area outside from the zero point Class Area boundary of urban area extended from fringes to peripheral rural regions outside the Class Area. Kathmandu valley is composed of three districts, and headquarters of each district is densely populated areas. During the period of 2001, urban extent was limited almost within the Class Areas of these cities. There were slightly developed built-up areas within some proximity of the connection routes of these cities, along the highway region, area within proximity to ring road region and areas along major roads connecting some small towns within the valley. During the period of 2001 to 2011, confined built-up areas within cities cores and along major roads and highway extended outwards in all direction. During the period of 2001 to 2018, urban expansion occurred in two ways, first way of urban expansion existed in filling the preciously open spaces between urban cores during the period of 2001 to 2011, large volume of agricultural areas and bare or fallow areas lying within the urban expansion were in filled during the period of 2011 to 2018. Secondly, urban expansion during this period were not only concentrated within urban fringes, but it was radially distributed in all direction, rural areas were rapidly urbanized during the period. 40 km^2 of newly formed urban or built-up areas was added to existing area. Likewise, areas within proximity to major roads, ring road and highway was heavily densified and also extended radially from the transportation route.

Newly developed built-up area went outward almost in every direction, there was rapid development of road network. Thus, peripheral suburbs areas were connected to central areas. With improvement of road width and transportation facilities, area around these roads has undergone rapid LULC change. With development of new built-up areas in fringes and peripheral rural areas, there was rapid construction of new roads, and improvement of roads as well, thus creating positive impact for densification of built-up areas in suburbs and small towns.



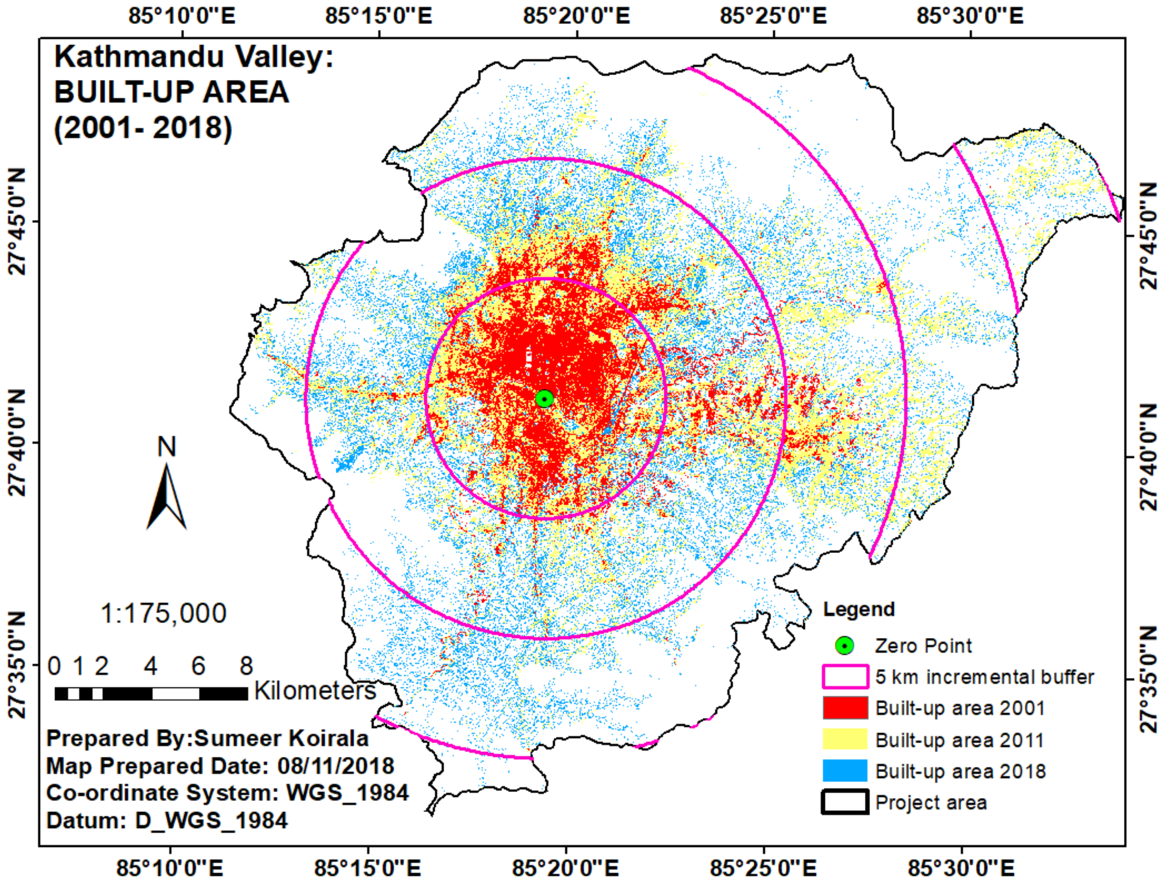
	Builtup	Agriculture	Forest	Barren
🟥 2001	53.94	134.41	231.42	277.59
🟨 2011	139.69	98.16	231.43	228.09
🟩 2018	170.71	103.84	231.46	191.35

Figure 10. Kathmandu Valley: Land Use Land Cover Change (2001- 2018)

Figure 10 represents land use land cover change in graphical form, we can observe, there was rapid growth of built-up areas, while there was rapid decrease in fallow or bare land and agricultural areas. Northern hill of Kathmandu valley is surrounded by Shivapuri Nagarjun National park, and abundant amount of community forest and government forest covering the hills surrounding the valley, is main reason having not much change in forest areas.

3.4. Kathmandu Valley: Extent of Urban Sprawl (2001-2018)

During the urban expansion or growth process, change in phase (expansion or shrinkage) of different landscape metrics under influence of human activities can be summarized as urban sprawl change (Niemela *et al.*, 2011). Landscape metrics used for analysis of heterogeneity of land use land cover pattern or landscape diversity in ecological investigation (Katayama *et al*., 2014).



Map 7: Kathmandu Valley: Built-up area (2001-2018) within incremental 5 km buffer from the zero point.

Calculation of landscape metrics for determination of urban sprawl extent was computed using built-up areas of the years 2001, 2011 and 2018 as shown in Map 7. Calculation of landscape metrics helped in explaining land scape configuration in relation to urban sprawl computation. Implication of built-up area patch indices and density indices can be used for evaluation of landscape pattern distribution for a particular landuse land cover in regional or global scale (Bagan & Yamagata, 2012; Jat *et al*., 2008; Ji *et al*., 2006). Fragstats Version 4.2 developed by McGarigal and Marks (1995) was used for landscape metrics analysis. For urban sprawl analysis landscape metrics were implied shown in Table 5 with description. Four landscape metrics were used for quantification of urban sprawl of Kathmandu valley from 2001 to 2018. These landscape metrics used three levels a) Class Area level and b) landscape level for quantification and determining pattern of land use land cover change in project area.

Table 5. Landscape metrics for used for urban sprawl extent determinaiton

S.N.	Landscape Metrics	Description	Range
1	Class Area Metrics (CA)	Aggregation of class area in the landscape	CA > 0, without limit
2	Number of Patches (NP)	Number of patches of landscape classes	NP ≥ 1, without limit
3	Largest patch Index (LPI)	Percentage of the landscape included by the largest patch	$0 < LPI \leq 100$
4	Fractal Index Distribution (FRAC_AM)	To measure area weighted mean patch fractal dimension	$1 \leq FRAC\_AM \leq 2$

Source: McGarigal, K. (2015).

Class Area Metrics (CA) measures the landscape composition i.e. how much the land scape metrics composed the particular land use land cover patch. CA metrics was applied for the analysis as this metrics acts as important byproduct of vegetation fragmentation and habitat loss McGarigal, K. (2015). For the study of urban sprawl extent CA metrics was used to determine increase in urban class (Padmanaban *et al*., 2017).

Number of Patches (NP) measures the homogeneity of the landscape, whereas patch can be better understood as landscape with its independent structure irrespective to its surroundings (Bhatta *et al*., 2010). NP was used to evaluate evenness in landscape distribution and diversity (Harrison, 1999). Having higher NP value indicates dispersed distribution of patches whereas lower value of NP indicates compact distribution of patches. In this case Built-up area was considered.

Largest patch index (LPI) quantifies the total landscape area in project area which is comprised by largest patch. LPI can simply be understood as measure of dominance of patch in overall landscape. Having LPI value close to zero indicates corresponding patch size increasingly small, whereas larger patch size indicates entire land scape is dominated by particular patch type (McGarigal, K., 2015).

Area Weighted Mean Fractal Dimension Index (FRAC_AM) is specialized landscape metrics for landscape pattern analysis. Calculation of FRAC_AM of landscape metrics was done in Fragstats 4.2. FRAC_AM value ranges from 1 to 2. FRAC_AM determines overall shape and edge of landscapes. Aggregated shapes better establishes connection amongst various patches (McGarigal, K., 2015).

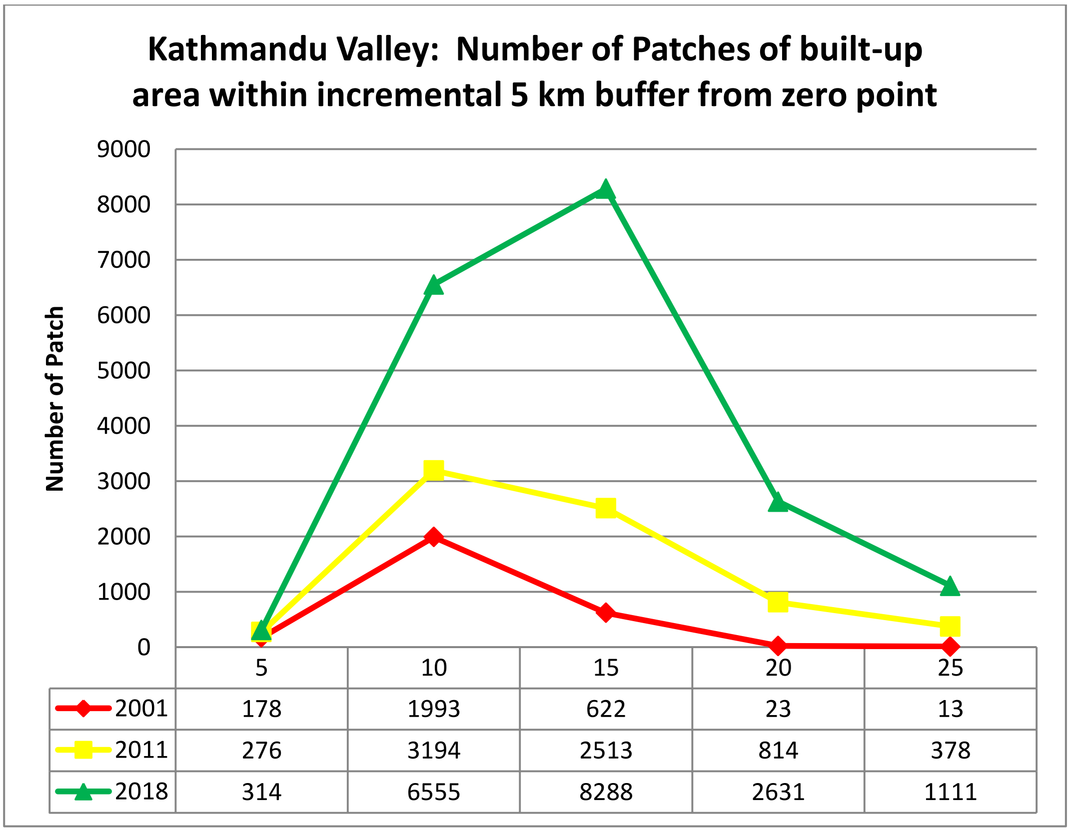
Landscape metrics was computed for the period from 2001 to 2018. Whole period was divided into 2001 to 2011, 10 years period and 2011 to 2018 7 year period. Kathmandu valley was divided into buffer of 5 km, due to having a round like shape of Kathmandu valley round buffer was selected, and landscape metrics for each buffer region was computed and urban sprawl for each buffer ring was computed.

3.4.1. Number of Patches:

Five landscape metrics were used to determine urban sprawl extent in Kathmandu valley. Development of Built-up area in Kathmandu valley from 2001 to 2018 along 5 km incremental buffer is depicted in map 11, built-up data from these periods were used for Number of patches(NP) analysis, and result is portrayed in Figure 11. Within the first 5 km from zero point of (Maitighar mandala), NP in this region was calculated and shown in Figure 11. Number of patch in different proximity for three different years was represented.

NP in first proximity of 5 km during 2001 was 178; this was due to highly scattered settlement in Kathmandu valley. During 2001, segregated settlement area with open spaces between those areas existed, resulting in higher amount of dispersed distribution of built-up patches, resulting in heterogonous distribution of built-up area within 5 km. NP increased from 178 to 276 in 2011. Open spaces and agricultural area between the built-up areas was populated with new built-up area. Urban area became more densified, with development of new buildings, road network and other infrastructures. NP increased from 276 in 2011 to 314 in 2018. Due to urban redevelopments occurring during this period, new built-up areas was developed during the period, resulting in dispersed distribution of newly developed built-up area. Increase in patches indicates urban sprawl in this region within the period.

Within the proximity of 5 km to 10 km, this region suffered rapid increase in built-up area patches. In 2001, numbers of patches were 1993, in the year 2011 NP extended up to 3194. 60 percentage of increase in NP of built-up values within this period. Built-up area are converted from bare area and agricultural area. Increase in “NP” values in this region suggests transformation of other LULC classes to built-up classes and diffusion of existing built-up area into smaller fragment of property. Basically, urban fringes area lying in this region of Kathmandu valley.



	5	10	15	20	25
2001	178	1993	622	23	13
2011	276	3194	2513	814	378
2018	314	6555	8288	2631	1111

Figure 11. Kathmandu Valley: Number of patches for built-up area within 5 Km incremental buffer from zero point.

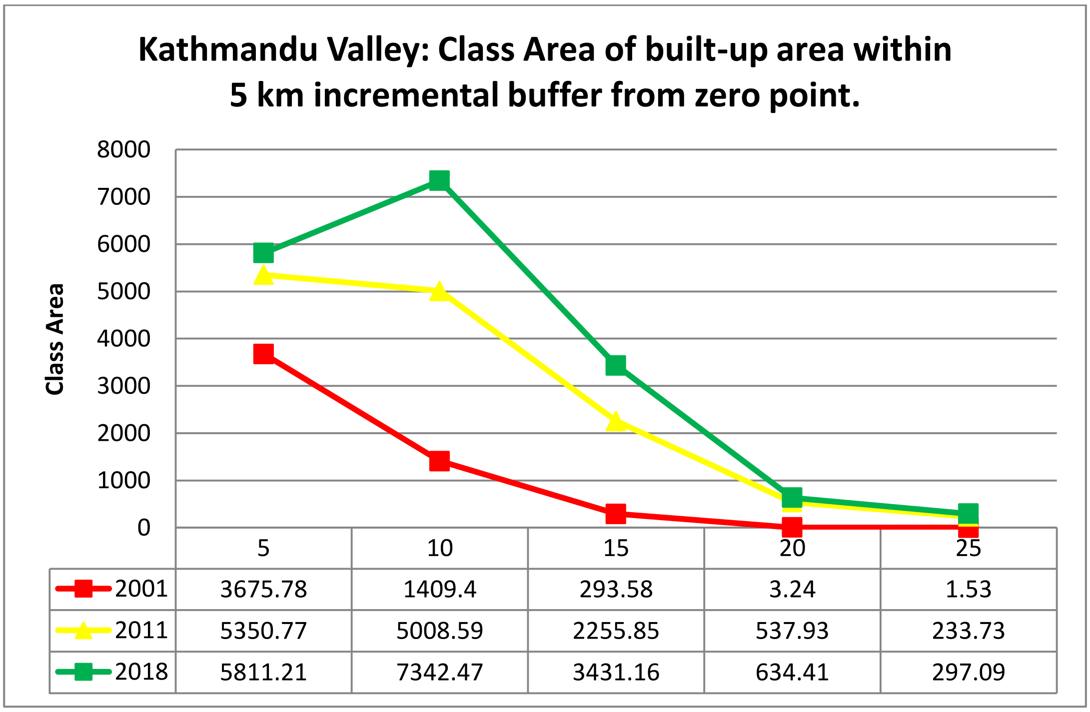
Within the proximity of 10 km to 15 km, this region suffered rapid increase in built-up area patches. In 2001, numbers of patches were 622, in the year 2011 NP extended up to 2513. During the period of 2011 to 2018, NP of built-up areas increased to 8288, which is increased by two fold increase in NP of built-up values within this period. Rapid degradation of agricultural area resulted in this region. Basically, urban fringes and rural area are lying in this area. Thus we can understand, there is rapid urban sprawl development occurred in this third proximity region.

Within the proximity of 15-20 km and 20-25 km, during the period of 2001 to 2018, there was rapid increase in NP of built-up area. Rural fringes and suburbs regions are highly fragmented. Bare land and agricultural land are converted to built-up areas in alarming rate in this region. Mostly some suburbs and rural areas are laying within these areas, having NP value 23 in 2001, 814 in 2011 and 2631 in 2018 for 15-20 km buffer region. Like wisely, within the proximity of 20-25 Km almost all of the areas are rural areas, having just 13 NP for built-up area in 2001, in 2011 NP was 378 and in 2018 NP increases to 1111.

NP observation in three different years with five kilometers buffer ring from zero point, it was observed there was rapid and abrupt increase in built-up area patches. Built-up areas were substantially increased in suburbs, fringes and rural areas. Increase in NP value is result in rapid urban sprawl development in Kathmandu valley expanding in all direction from the zero point. Rapid transformation of LULC and rapid fragmentation of large patch into smaller fragments land are reason behind increase in NP.

3.4.2. Class Area Metrics:

Development of Built-up area in Kathmandu valley from 2001 to 2018 along 5 km incremental buffer is depicted in map 11, built-up data from these periods were used for Class area(CA) analysis. CA in first proximity of 5 km during 2001 was 3675.78 this is due to highly scattered settlement in Kathmandu valley. During 2001, segregated settlement area with open spaces between those areas existed, resulting in higher amount of dispersed distribution of built-up patches, resulting in heterogonous distribution of built-up area within 5 km. CA increased from 3675.78 to 5350.77 in 2011. During the period of 2011 to 2018 there was no significant increase in CA, due to lack of open space or new area for construction of built-up area, also hiking of land price after 2011, resulted in slightly increased from 5350.77 in 2011 to 5811.77 in 2018. During the period of 2001 to 2011, there was change of 45 percentage of CA for built-up area, while during the period of 2011 to 2018, although there was increase in CA for built-up area, but it was limited to 9 percentages. Figure 12 graphically represents the status of CA in three years and within proximity of 5 km area.



	5	10	15	20	25
🟥 2001	3675.78	1409.4	293.58	3.24	1.53
▲ 2011	5350.77	5008.59	2255.85	537.93	233.73
🟩 2018	5811.21	7342.47	3431.16	634.41	297.09

Figure 12. Kathmandu Valley: Class Area for built-up area within 5 Km incremental buffer from zero point.

Within the proximity of 5 km to 10 km, this region suffered rapid increase in built-up area patches. In 2001, CA was 1403.9, in the year 2011, CA extended up to 5008. There was increase in urban sprawl by more than two fold in this proximity. In 2018, CA within this proximity increased by 46 percentages with CA value for built-up area 7342. Built-up area were converted from bare area and agricultural area. Increase in CA values in this region suggests transformation of agricultural and bare land classes to built-up classes. Basically, urban fringes area lying in this region of Kathmandu valley.

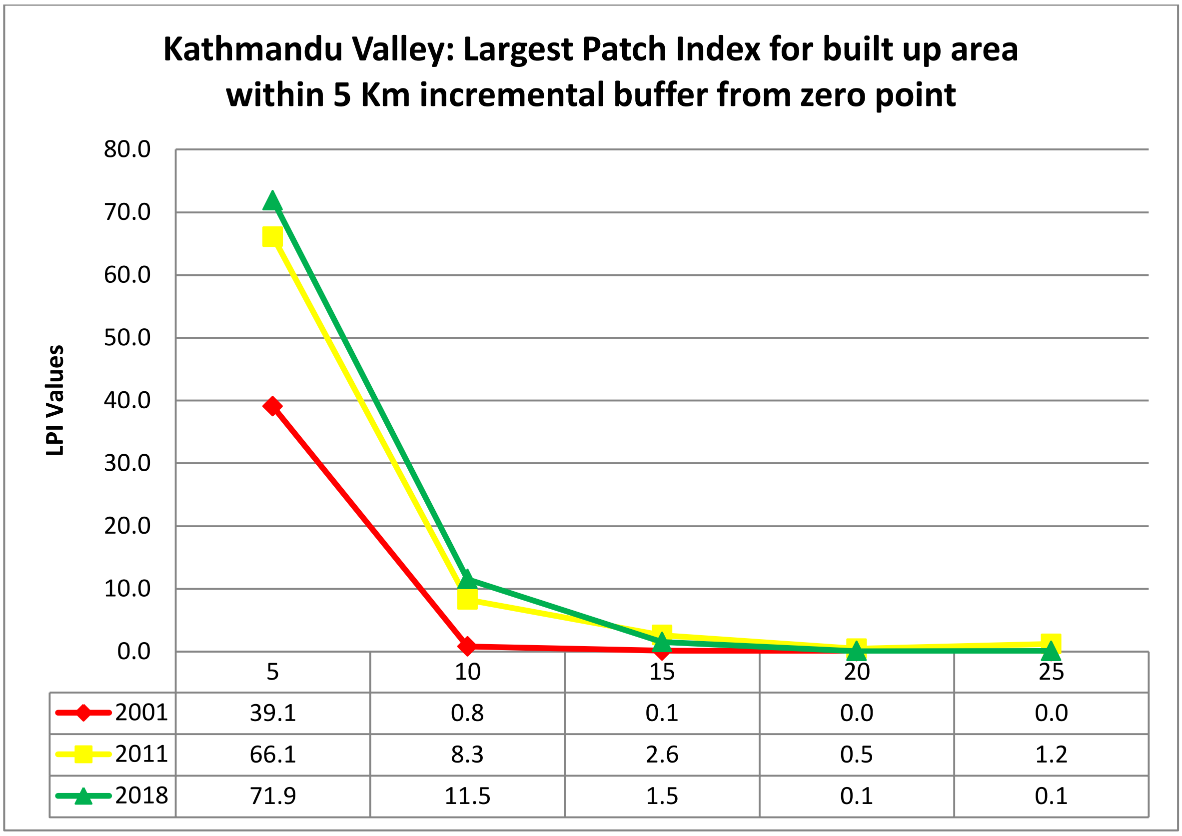
Within the proximity of 10 km to 15 km, this region suffered increase in built-up area patches. In 2001, CA value was 293; in the year 2011 CA value was 2255. During the period of 2011 to 2018, CA of built-up areas increased to 3431, which was increased by 52 percentage of increase in CA of built-up values within this period. Rapid degradation of agricultural area resulted in this region. Basically, urban fringes and rural area are lying in this area. Thus we can understand, there was rapid urban sprawl development occurred in this third proximity region.

Within the proximity of 15-20 km and 20-25 km, during the period of 2001 to 2018, there was very rapid increase in CA of built-up area. Mostly suburbs and rural areas are lying within these areas, having CA value 23 in 2001, 573 in 2011 and 634 in 2018 for 15-20 km buffer region. Like wisely, within the proximity of 20-25 Km almost all of the areas were rural areas, having just 1.5 CA for built-up area in 2001, in 2011 CA was 233 and in 2018 CA increases to 297.

From the Figure 12, CA value has increased mostly in proximity of 10-20 km from zero point. Thus, within this extent there was more depth of edge influence.

3.4.3. Largest Patch Index:

Development of Built-up area in Kathmandu valley from 2001 to 2018 along 5 km incremental buffer is depicted in map 11; built-up data from these periods were used for Largest Patch Index (LPI) analysis. LPI measures the percentages of landscape included by built-up patch. Figure 13 represent LPI values in five different proximities and in three different time period. Within first proximity of 5 km during 2001 LPI was 39 percentages; this was due to compact built-up landscape within this proximity of Kathmandu valley. During decade of 2001 to 2011, LPI increased from 39 to 66 percentages.



	5	10	15	20	25
2001	39.1	0.8	0.1	0.0	0.0
2011	66.1	8.3	2.6	0.5	1.2
2018	71.9	11.5	1.5	0.1	0.1

Figure 13. Kathmandu Valley: Largest Patch Index for built-up area within 5 Km incremental buffer from zero point

Open spaces and agricultural area between the built-up areas were converted to compact built-up area. LPI increased from 66 in 2011 to 72 percentage in 2018. Due to fragmentation in previous built-up area and compact development, rate of LPI in the period of 2011 to 2018 increased gradually. During the decade of 2001 to 2011 the LPI increased by 69 percentage, whereas during the period of 2011 to 2018 LPI increased by 8 percentage. These values strongly suggests development of urban sprawl in 2001 to 2011 and during the period of 2011 to 2018 there gradual continuation of urban sprawl.

In second proximity of 5-10 km during 2001 LPI was 0.7 percentages; this was due to sparse built-up landscape within this proximity of Kathmandu valley. During decade of 2001 to 2011, LPI increased very rapidly from 0.7 to 8 percentages. Open spaces and agricultural area between the built-up areas was converted to compact built-up area. LPI increased from 8 in 2011 to 12 percentage in 2018. Due to fragmentation in previous built-up area and compact development, rate of LPI in the period of 2011 to 2018 increased more rapidly within this proximity. During the decade of 2001 to 2011 the LPI increased by 9 fold, while during the period of 2011 to 2018 LPI increased by 40 percentage. These values strongly suggests rapid development of urban sprawl in 2001 to 2011 and during the period of 2011 to 2018 there gradual continuation of urban sprawl.

In second proximity of 10-15 km during 2001 LPI was 0.1 percentages; this was due to very sparse built-up landscape within this proximity of Kathmandu valley. Mostly forest area and bare area lies within this proximity with LPI. During decade of 2001 to 2011, LPI increased very rapidly from 0.1 to 2.6 percentages. LPI decreased from 2.6 in 2011 to 1.5 percentages in 2018. Most of the areas are forest area and agricultural land thus there was decrease in LPI. Rate of LPI in the period of 2011 to 2018 decreased within this proximity. During the decade of 2001 to 2011 the LPI increased by 9 fold, while during the period of 2011 to 2018 LPI decreased by 40 percentage.

Within the proximity of 15-20 km and 20-25 km, during the period of 2001 to 2018, there was very rapid increase in LPI of built-up area. Mostly suburbs and rural areas were lying within these areas, having LPI value 0.01 in 2001, 0.5 in 2011 and 0.1 in 2018 for 15-20 km buffer region. Like wisely, within the proximity of 20-25 Km almost all of the areas are rural areas, having just 0.1 LPI for built-up area in 2001, in 2011 LPI was 1.2 and in 2018 LPI increases to 0.1.

3.4.4. Fractal Index Distribution:

Development of Built-up area in Kathmandu valley from 2001 to 2018 along 5 km incremental buffer is depicted in map 11; built-up data from these periods were used for Fractal Index (FRAC_AM) analysis. Within first proximity of 5 km during 2001 FRAC_AM was 1.12. During decade of 2001 to 2011, FRAC_AM increased from 1.12 to 1.33. FRAC_AM increased from 1.33 in 2011 to 1.42 in 2018. Rate of FRAC_AM changes during the period of 2011 to 2018 increased by 7 percentages. During the decade of 2001 to 2011 the FRAC_AM increased by 18 percentages. These values strongly suggests during the decade of 2001 to 2011, landscape had larger rate of growth in built-up area, also suggests major dispersed urban sprawl during the period of 2001 to 2011 than during the period of 2011 to 2018 for proximity of 5 km.

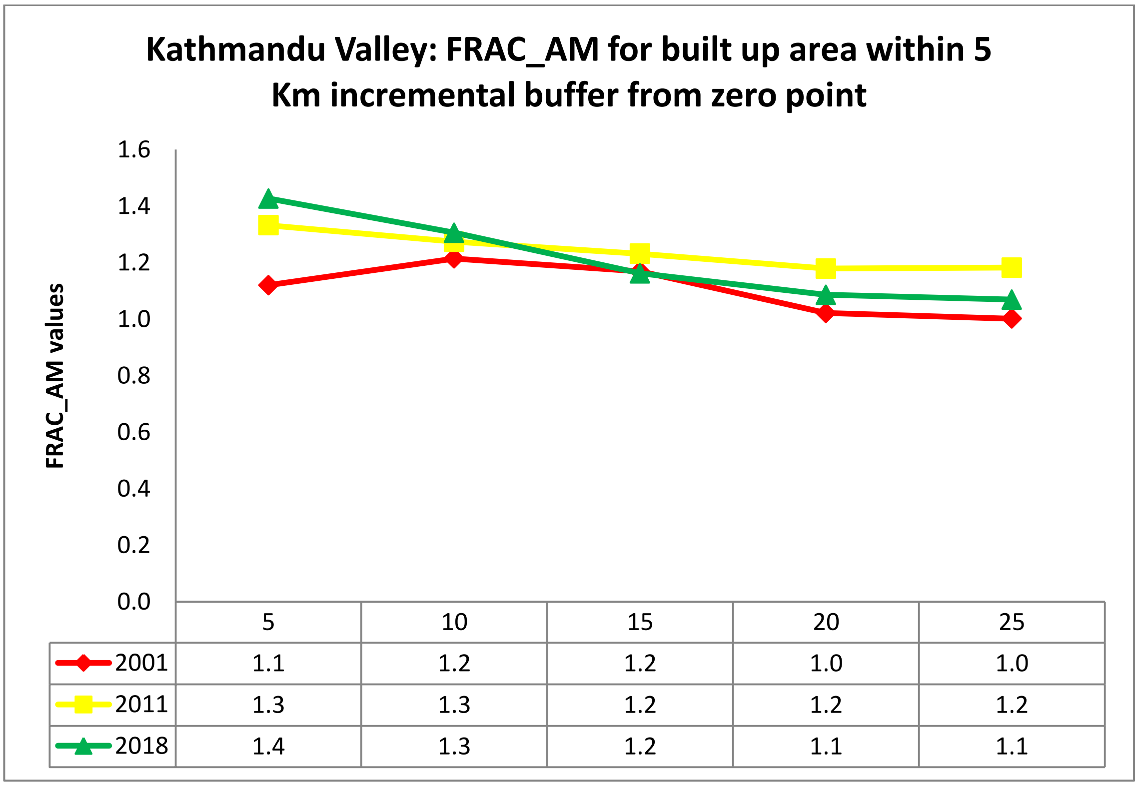


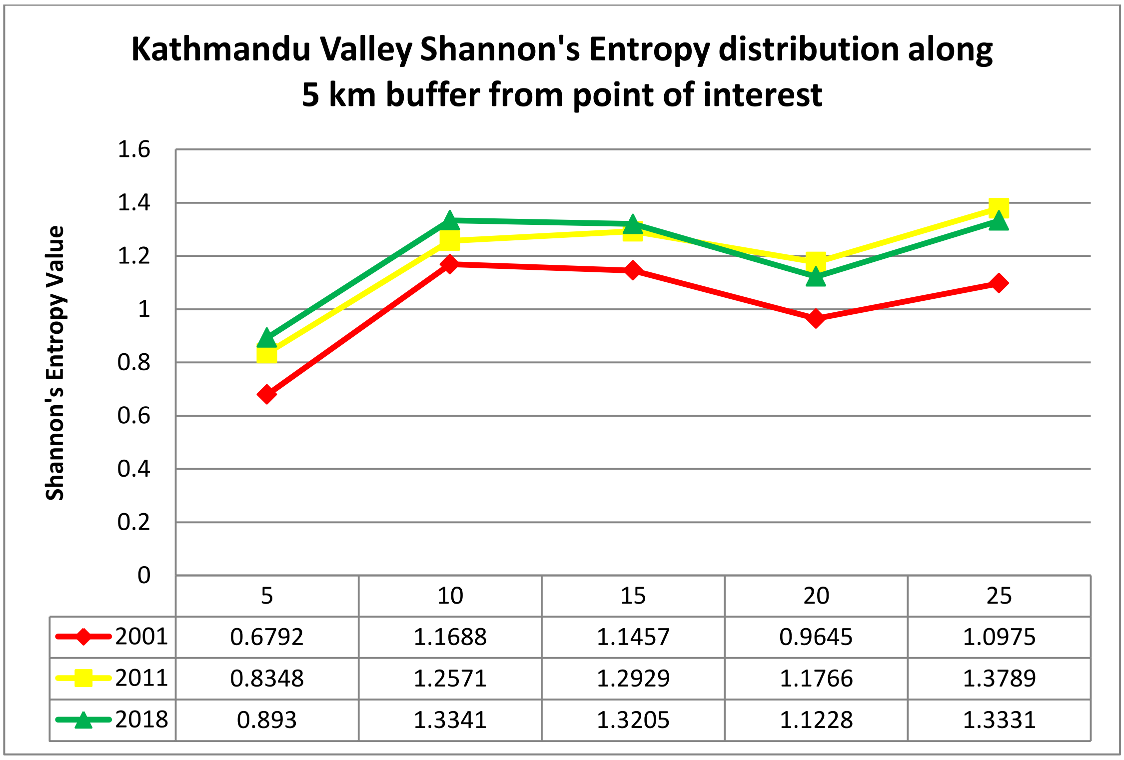
Figure 14. Kathmandu Valley: FRAC_AM for built-up area within 5 Km incremental buffer from zero point

Within first proximity of 10 km to 15 km during 2001 FRAC_AM was 1.16 percentages. During decade of 2001 to 2011, FRAC_AM increased from 1.16 to 1.23. FRAC_AM decreased from 1.23 in 2011 to 1.16 in 2018. Rate of FRAC_AM changes during the period of 2011 to 2018, decreased by 5.6 percentages. During the decade of 2001 to 2011 the LPI increased by 5.3 percentages. These values suggest there were more compact built-up area distribution in this proximity during period of 2011 to 2018. More dispersed built-up area development occurred during the period of 2001 to 2011.

Within the proximity of 15-20 km and 20-25 km, during the period of 2001 to 2011, there was very rapid increase in FRAC_AM of built-up area. Mostly suburbs and rural areas were lying within these areas, having FRAC_AM value 1.02 in 2001, 1.18 in 2011 and 1.1 in 2018 for 15-20 km buffer region. Like wisely, within the proximity of 20-25 Km almost all of the areas were rural areas, having just 1 FRAC_AM for built-up area in 2001, in 2011 FRAC_AM was 1.18 and in 2018 FRAC_AM increases to 1.06. Figure 14 represents graphical distribution of FRAC_AM values during the years 2001, 2011 and 2018 for 5 km.

3.5. Level of Urban Sprawl

Development of Built-up area in Kathmandu valley from 2001 to 2018 along 5 km incremental buffer is depicted in map 11; built-up data from these periods were used for Shannon’s entropy analysis. Shannon’s Entropy was used to calculate the level of urban sprawl of Kathmandu valley from 2001 to 2018. Determining change detection of urban sprawl relationship of landscape pattern and process needs to be considered as well, Urban Sprawl can be measured with application of entropy (Yeh & Xia, 2001). Shannon’s entropy is technique of information communication, which measures uncertainty of random variable. Entropy is one of the frequently used measures in developing countries for determining urban sprawl decades (Bhatta *et al*., 2010; Sudhira *et al*., 2004). Shannon’s entropy measures the degree of spatial compactness or dispersed nature of geographic variable (Jat *et al*., 2008; Yeh & Xia, 2001). Shannon’s entropy was used in this research to determining degree of concentration or dispersion of built-up area, and also used for determining compactness or dispersed urban growth.



	5	10	15	20	25
2001	0.6792	1.1688	1.1457	0.9645	1.0975
2011	0.8348	1.2571	1.2929	1.1766	1.3789
2018	0.893	1.3341	1.3205	1.1228	1.3331

Figure 15. Kathmandu Valley: Shannon’s Entropy for built-up area within 5 Km incremental buffer from zero point.

Shannon’s entropy analysis was used for determination of degree of urban sprawl in Kathmandu valley (Bhatta, 2009; Jat *et al*., 2008). Shannon’s entropy for urban sprawl analysis in this analysis is understood considering n number of characteristics of urban sprawl, for determining sprawl, n*lg(n) value Overall Kathmandu valley was divided by buffer ring with radius of 5 km. Having four LULC classes for analysis, upper range of entropy value for this analysis is 1.81 and the lower value is 0.

Value close to 0 represents compact growth of built-up areas, whereas value close to upper limit refers, more dispersed built-up area, or higher degree of urban sprawl. n this study, in 2001 Shannon’s entropy value in 5 km proximity was 0.68, while in 2011 entropy value was 0.83 and that of 2018 was 0.89. Entropy value increased by 23 percentage during the decade of 2001 to 2011, while entropy value increased by 7 percentage during the period of 2011 to 2018. The entropy values states that during the decade of 2001 to 2011 - built-up area were dispersed by 26 percentages, than that of 2011 to 2018. Degree of urban sprawl was much higher during this period than that of 2018.

Within the proximity of 5 to 10 kilometer in the year 2001 Shannon's entropy value was 1.17, while in 2011 entropy value was 1.25 and that of 2018 was 1.33. These values of entropy states during the decade of 2001 to 2011, built-up area were less dispersed than that of 2011 to 2018. Degree of urban sprawl was much higher during this period than that of 2018. Within this proximity urban sprawl increased over time period. Built-up areas are continuously developed from agricultural area and bare land.

Within the proximity of 10 to 15 kilometer in the year 2001 Shannon's entropy value was 1.15, while in 2011 entropy value was 1.29 and that of 2018 was 1.32. These values of entropy states that, during the decade of 2001 to 2011, built-up area was more compact than that of 2011 to 2018. More agricultural and built-up area contributed to built-up area, and growth of impervious area for conversion of built-up area causing higher degree of urban sprawl within the proximity.

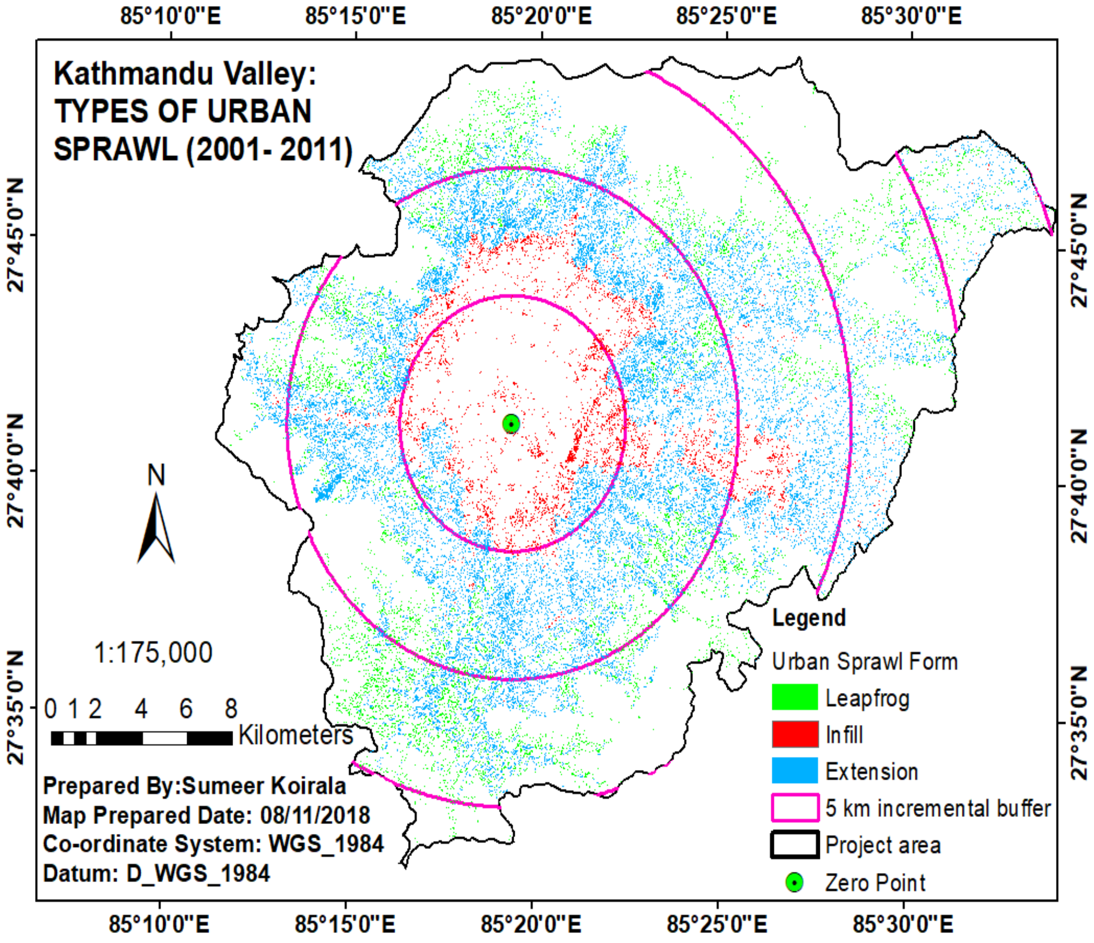
Within the proximity of 15 to 20 kilometer in the year 2001 Shannon's entropy value was 0.96, while in 2011 entropy value was 1.17 and that of 2018 was 1.12. For the proximity of 20-25 km area, entropy value for 2001 was 1.09, for 2011 values increased to 1.38 and in 2018 entropy value decreased to 1.33. These values of entropy clearly suggest urban sprawl increased due to conversion of other LULC to built-up area, and dispersed settlement development. During the period of 2011 to 2018, settlement area or built-up area were developed in more compact way than that of 2011. Figure 15 graphically represents Shannon's entropy value within the proximity of 5, 10, 15, 20 and 25 km.

With the hike of land price in Class Area, development of transportation network, and increased vehicular mobility in the suburbs area, urban fringe and rural area, dispersed built-up area keeps on developing in these areas. Built-up area grows in more dispersed and segmented way. During the period of 2001 to 2018, there was rapid increase of urban sprawl in Kathmandu valley, than that of 2011 to 2018. Built-up area seems to be developed around existing built-up area than in new places. Agricultural and bare lands nearby existing built-up area are rapidly converted to built-up area. Urban sprawl was increased in all direction from zero point.

3.6. Types of Urban Sprawl

Likewise, urban sprawl can be differentiated in three type based on extent of sprawl. Three form of urban sprawl are “leapfrog”, “infill” and expansion (Angel *et al*., 2007, Batty *et al*., 2003; Besussi *et al*., 2010). Urban sprawl type can be identified with the application of Urban Landscape Analysis Tool (ULAT), developed by Jason (2009). Calculation was based on classification of developed area with varying density and also identification of under developed land within proximity of developed area, which were intended to be degraded due to development trend. This tool analyzes land use land cover data in different temporal extent. For each time, maps regarding built-up area density class and second map were degeneration map of underdeveloped land lying within proximity of developed area (Jason, 2009). ULAT uses landuse land cover maps, area of interest as input data. LULC maps have to be reclassified into four categories, i.e. 0 for no data, 1 for other areas, 2 for water and 3 for built-up or urban data. Finally ULAT generate urbanized map and urban footprint map will be generated. For each map, new development classification maps will be generated (Jason, 2009). ULAT differentiated area into three different classes as: first is “infill” growth area: this area refers to new development in open area lying within existing urbanized area i.e. “newly developed pixels that are in the urbanized open land of the previous time period”. Second is expansion: this area refers to non-”infill” new development built-up area which is overlapped with existing urban footprint i.e. “newly developed pixels that are in the fringe open land of the previous time period”, and third is “leapfrog” development which is development of new built-up area which is non-overlapping with existing urban area i.e. “newly developed pixels that are outside of the rural open land of the previous time period” (Angel *et al*., 2007). Types of urban sprawl are shown in Map 7, Map 8 and Map 9. These maps represent three different form of urban sprawl i.e. “infill”, “extension” and “leap frog”.

3.6.1. Kathmandu Valley: Types of Urban Sprawl (2001-2011):



Map 8: Kathmandu Valley: Types of Urban Sprawl (2001-2011)

Map 8 represents types of urban sprawl during the decade of 2001 to 2011 was depicted. “Infill” areas developed between existing built-up areas. In this period, out of total urbanization 9.37 km^2 of total urban expansion was due to “infill”. Mostly area in the proximity of 5 km from the zero point is mostly urbanized with this type of urban sprawl. Red color patches represents “infill” type of urban growth.

66.5 km^2 of newly developed area were due to “extension” growth type. “Extension” area surrounds existing urban area or urban city. Mostly urban fringes and suburbs were urbanized with “extension” built-up type. Area within the proximity of 5 to 10 and 10 to 15 were urbanized with “extension” urbanization type. Blue patches represent “extension” type of urban growth. 53.41 km^2 of total urbanization in this period was due to leap frog expansion. Area beyond 10 km proximity was urbanized with this type of urbanization. Suburbs, rural fringes and rural areas had undergone urbanization with “leapfrog”. Green patches represent “leapfrog” expansion type.

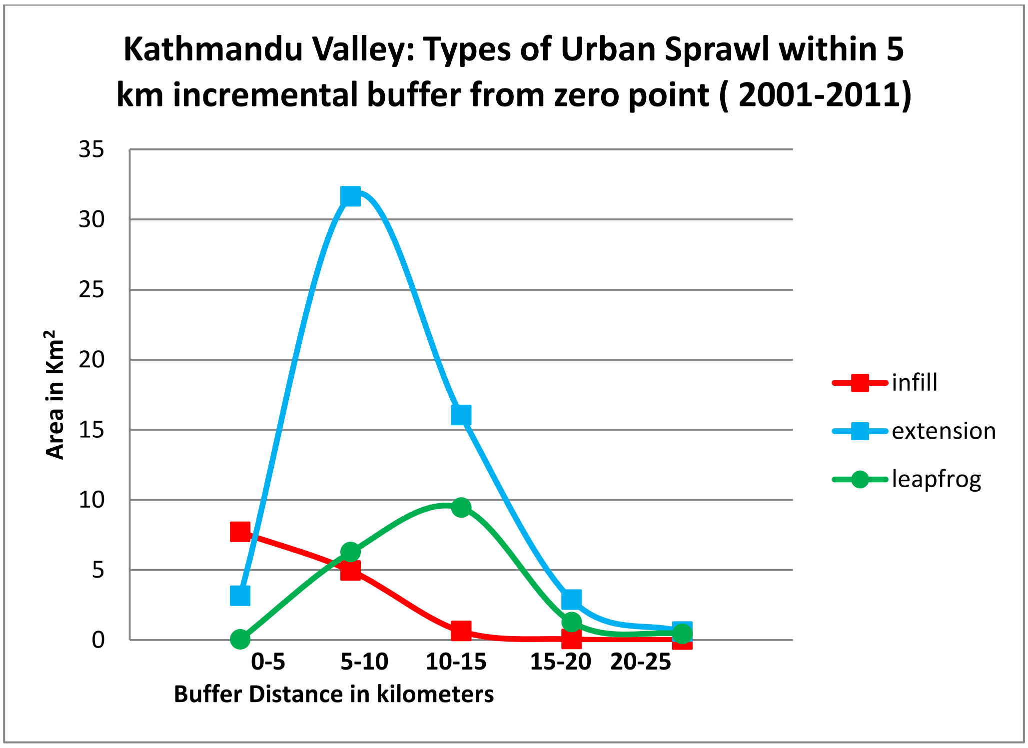


Figure 16. Kathmandu Valley: Types of Urban Sprawl within 5 km incremental buffer from zero point (2001-2011)

Within the buffer of 10 km to 15 km, “extension” is most dominating form of urban sprawl. Out of total built-up area expansion 16.03 km^2 is caused due to “extension” type, 9.43 km^2

built-up expansion is due to “leapfrog” form of urban development, and 0.62 km^2 due to result of “infill” form of urban development. Like wisely, within the buffer of 15 to 20 km and 20 to 25 km, “extension” type of urban development is dominating, followed by “leapfrog” and “infill”.

Figure 16 represents types of urban sprawl during the period of 2001 to 2011 in multi ring buffer of 5 km from zero point. Amongst new form of urban sprawl development, “extension” type is dominant growth type. 52 percentage of total urbanization is “extension” type. Although “extension” type is dominant but it is mostly occurring mostly in 5 km to 10 km radius. “Extension” type is supported by “Shannon’s entropy” value within this region which keeps on increasing value.

Substantial outward expansion in suburbs and urban fringes are due to “extension” form of urban sprawl. Whereas, “leapfrog” expansion is reason behind dispersed urban sprawl in rural area around Kathmandu valley. Figure 17 represents types of urban sprawl during the period of 2001 to 2011.

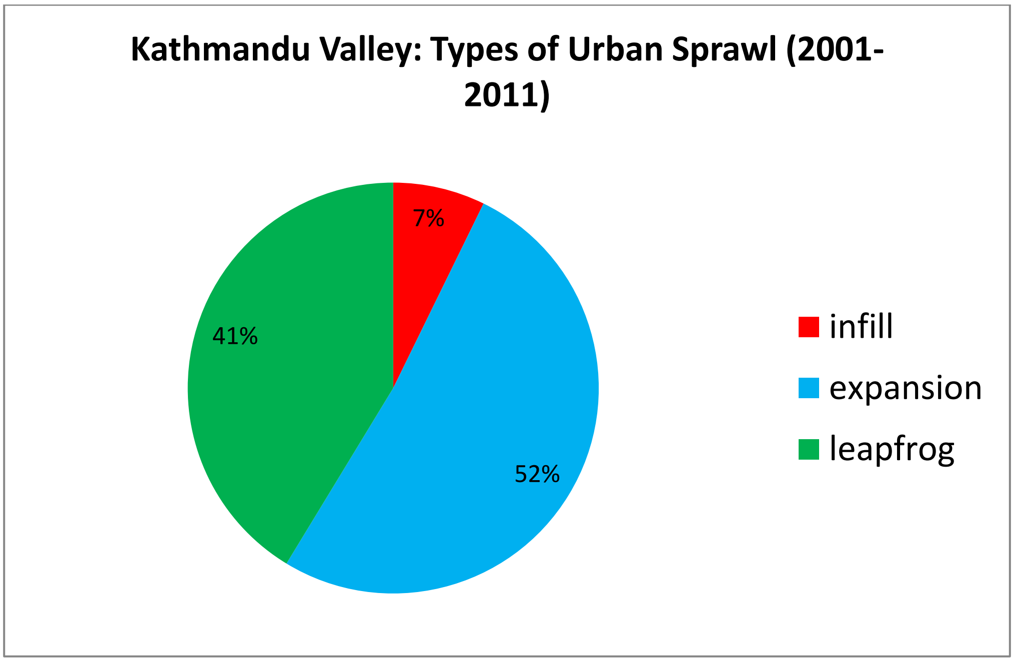
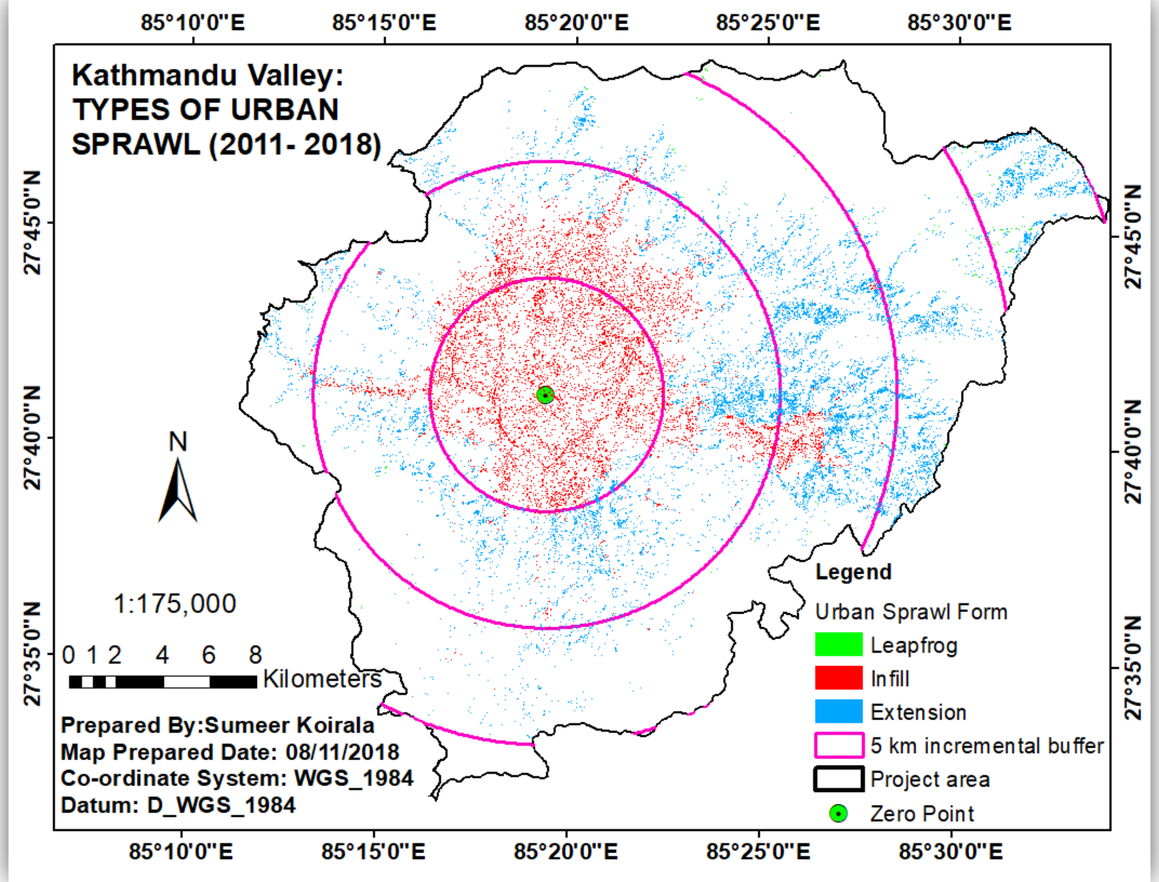


Figure 17. Kathmandu Valley: Types of Urban Sprawl (2001-2011)

3.6.2. Kathmandu Valley: Types of Urban Sprawl (2011-2018):



Map 9: Kathmandu Valley: Types of Urban Sprawl (2011-2018)

Map 9, depicts “types of urban sprawl” from 2011 to 2018. In this period, out of total urbanization 14.28 km^2 of total urban expansion were due to “infill”. Mostly area in the proximity of 5 km from the zero point was mostly urbanized with this type of urban sprawl. (Koteshwor, Suryabinayak) highway extent, also progressed with rapid “infill” expansion. Red color patches represents “infill” type of urban growth.

20.9 km^2 of newly developed area were due to “extension” growth type. “Extension” area surrounds existing urban area or urban city. Mostly urban fringes and suburbs were urbanized with “extension” built-up type. Area within the proximity of 5 to 10 and 10 to 15 were urbanized with “extension” urbanization type. Blue patches represent “extension” type of urban growth. 0.34 km^2 of total urbanization in this period is due to “leapfrog” expansion. Area beyond 15 km proximity was urbanized with this type of urbanization. Suburbs, rural fringes and rural areas had undergone urbanization with “leapfrog”. Green patches represent “leapfrog” expansion type.

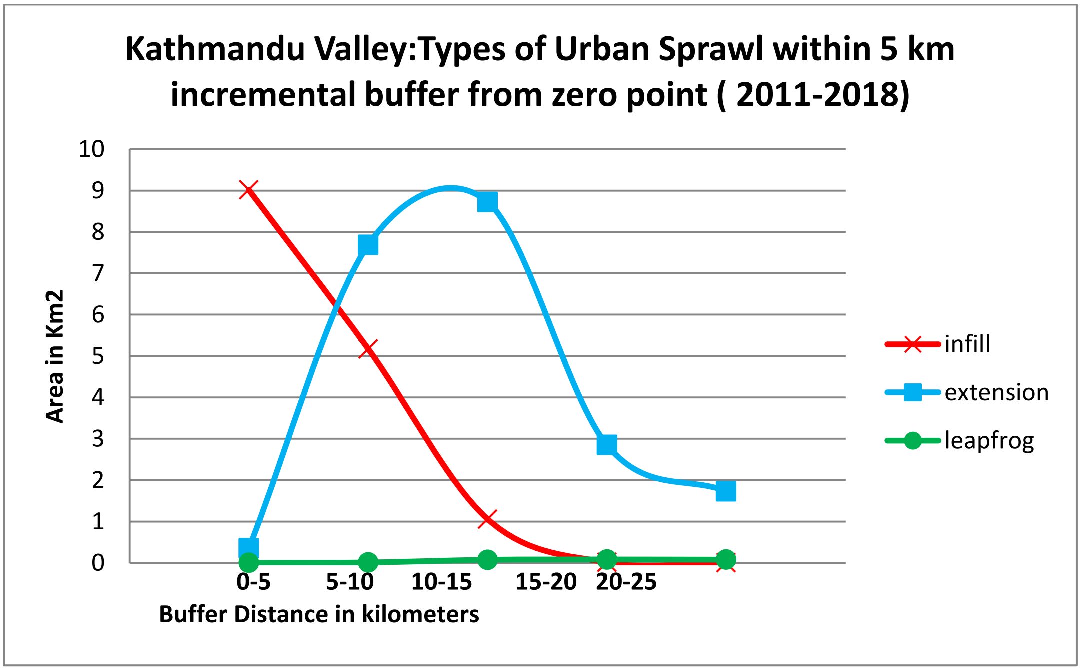


Figure 18. Kathmandu Valley: Types of Urban Sprawl within 5 km incremental buffer from zero point (2011-2018).

Figure 18 represents urban sprawl types for different buffer from zero point. Within the buffer of 5 km from the zero point urban sprawl was due to “infill”, which was most dominating type of urban development. Out of total built-up area expansion 9.01 km^2 was caused due to “infill” type, 0.35 km^2 built-up expansion was due to “extension” type of urban development, no “leap frog” type of urban development.

Within the buffer of 5 km to 10 km “extension” was most dominating type of urban sprawl. Out of total built-up area expansion 7.69 km^2 caused due to “extension” type, 5.17 km^2 built-up expansion was due to “infill” type of urban development and no “leap frog” type of urban development. Within the buffer of 10 km to 15 km, again “extension” was most dominating type of urban sprawl. Out of total built-up area expansion 8.73 km^2 was caused due to “extension” type, 1.05 km^2 built-up expansion was due to “infill” type of urban development, and very trace amount of “leapfrog” form of urban development. Likewise, within the buffer of 15 to 20 km and 20 to 25 km, “extension” type of urban development was dominating, followed by “leapfrog” and “infill”.

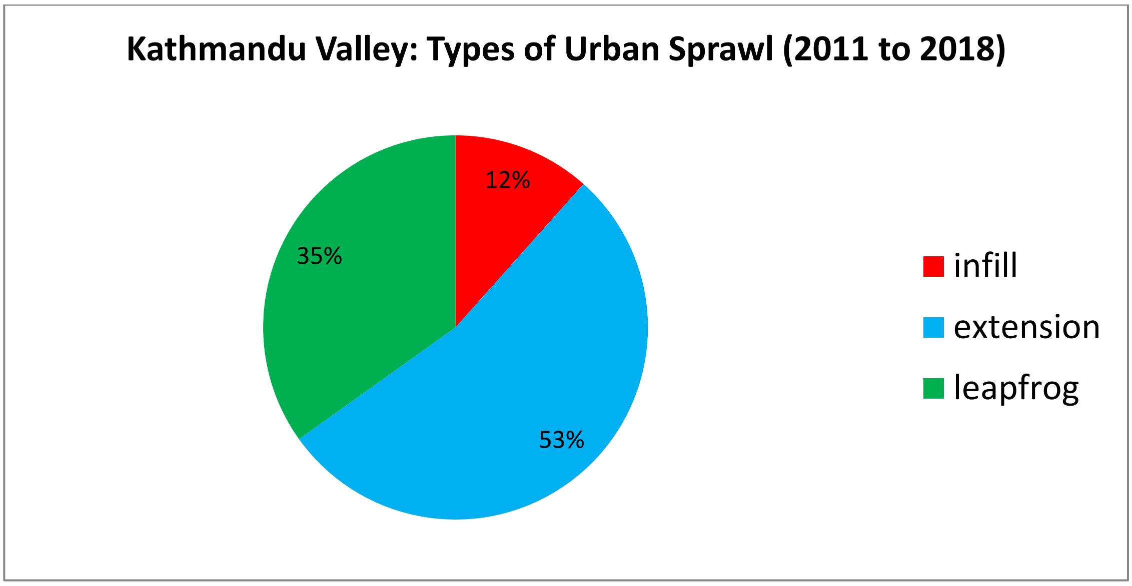


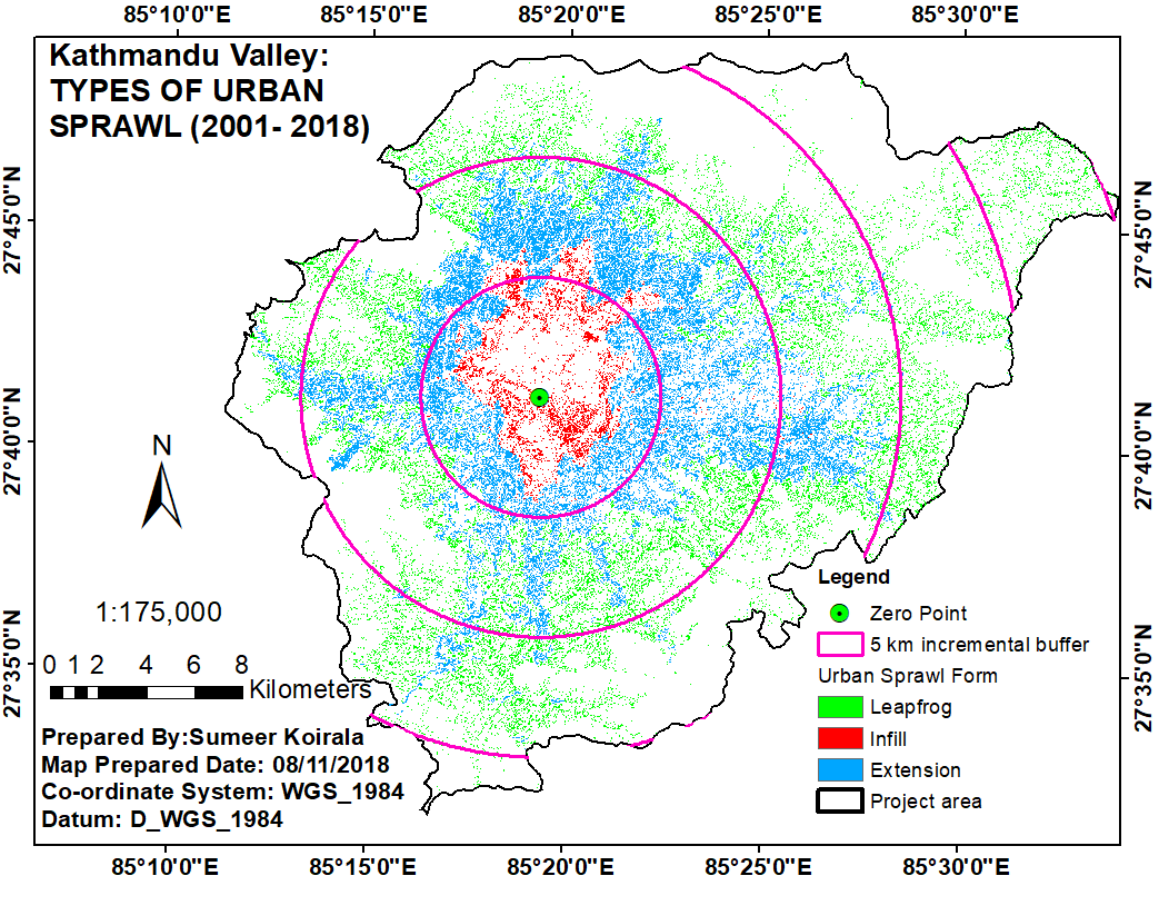
Figure 19. Kathmandu Valley: Types of Urban Sprawl (2011 - 2018).

Figure 19 represents urban sprawl types during the period of 2011 to 2018. “Extension” type was dominant growth type. 49 percentage of total urbanization was expansion type. Although “extension” type was dominant but it mostly occurring mostly in 5 km to 10 km and 10 to 15 km proximity and along koteshwor to suryabinayak highway extent.

Urban sprawl growth in core areas, during the study period was as a result of “infill” type of urban development, and it was mostly concentrated in outer extent of zero point. Substantial outward expansion in suburbs and urban fringes were due to “extension” type of urban sprawl. Whereas, “leapfrog” expansion was reason behind dispersed urban sprawl in rural area around Kathmandu valley.

With progression in time from 2011 to 2018, new roads were developed, roads were widened, and thus “infill” occurred in the section of newly developed roads. Urban areas were more likely to be expanded further in this direction in future as well. Landscape lying closer to the road network was benefitted with better connectivity, resulting in transformation of other landscape to built-up area with further enhancement of road, more built-up area were likely to be developed along the road Tannier *et al*. (2012). Area undergone expansion in 2011, were transformed into more dense settlement in 2018 with “infill” development type, and new expansion growth occurred in area surrounding these newly developed area. This study clearly identifies that; urbanization pattern in Kathmandu valley shifted from “leapfrog” to expansion and expansion to “infill”. Urbanization was expanding intensively outwards of existing city of urban core and suburbs areas.

3.6.3. Kathmandu Valley: Types of Urban Sprawl (2001-2018):



Map 10: Kathmandu Valley: Types of Urban Sprawl (2001-2018)

In comparison to other areas, central core of Kathmandu, Bhaktapur and Lalitpur district expanded more due to “infill” type of growth. With progress of time, outer extent of zero point of these three places undergone intense extension types of urban sprawl. Map 10, depicts different types of urban sprawl prevalent in Kathmandu Valley from 2001 to 2018.

The reason behind for extension urban growth was due to intense hike in land price, better transportation system, commercialization in suburbs areas, and due to increase in remittance from foreign country, rural population migrated towards fringes of Kathmandu valley in seek of better education, logistic facilities and other opportunities. These urban areas were developed on the expense of agricultural and bare area.

Agricultural area was majorly transformed into built-up area; mainly “leapfrog” expansion had greater impact on cultivation area and bare or fallow land. Map 9 depicts urbanization change from 2001 to 2018. Mostly “extension” and “leapfrog” were dominating urban sprawl during the study period. Core areas of Kathmandu valley, experienced densification as a result of “infill” form of urban development. Whereas, urban fringes and suburbs undergone urban development due to “extension” and “leapfrog” form of urban development.

Figure 20 represents urban sprawl types for different buffer from zero point. Within the buffer of 5 km from the zero point urban sprawl due to “extension” was most dominating type of urban development during the study period of 2001 to 2018. Out of total built-up area expansion 14.96 km^2 was caused due to “extension” type, 9.17 km^2 built-up expansion was due to “infill” type of urban development, 0.26 km^2 was due to “leap frog” type of urban development. Within the buffer of 5 km to 10 km “extension” most dominating forms of urban sprawl. Out of total built-up area expansion 41.93 km^2 was caused due to “extension” type, 17.62 km^2 built-up expansion was due to “leapfrog” type of urban development and 0.03 km^2 due to “infill” type of urban development. Within the buffer of 10 km to 15 km, again “leapfrog” was most dominating type of urban sprawl. Out of total built-up area expansion 19.02 km^2 was caused due to "leapfrog" type, 9.52 km^2 built-up expansion was due to "extension" type of urban development, and very trace amount of "infill" type of urban development. Likewise, within the buffer of 15 to 20 km and 20 to 25 km, "leapfrog" type of urban development was dominating, followed by "extension" and "infill".

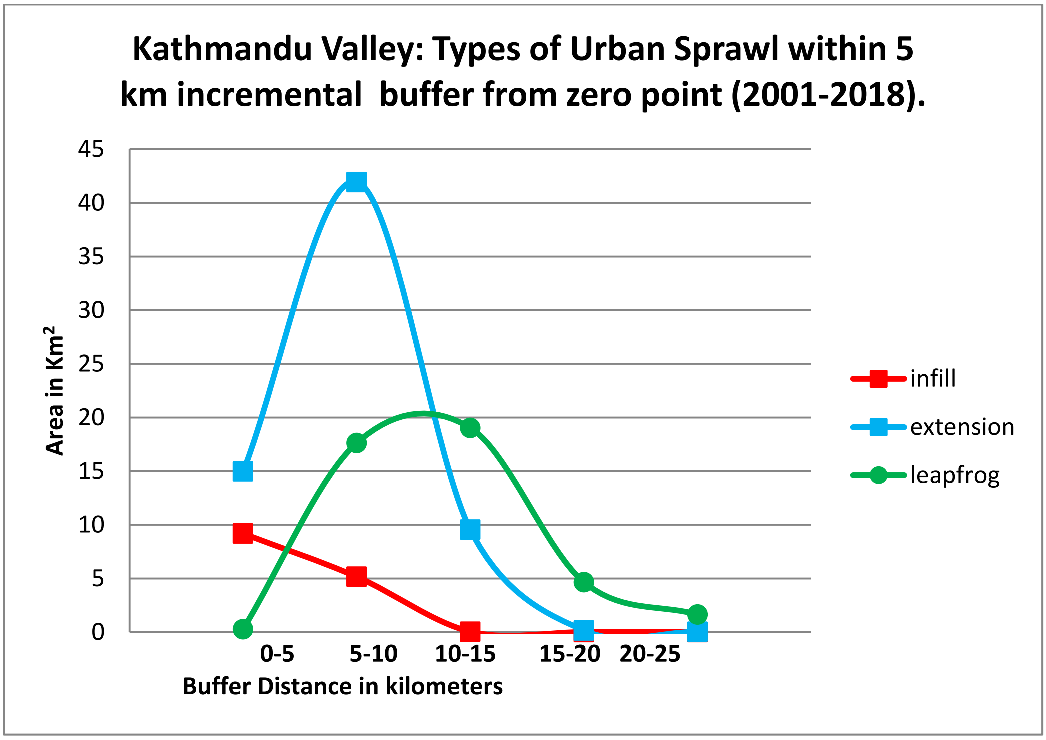


Figure 20. Kathmandu Valley: Types of Urban Sprawl within 5 km incremental buffer from zero point (2001-2018).

Figure 21 represents urban sprawl types during the period of 2001 to 2018. Amongst new types of urban sprawl development, "extension" type was dominant growth type. 53 percentage of total urbanization was expansion type. Although "extension" type was dominant but it was mostly occurring mostly in 5 km to 10 km and 10 to 15 km proximity and along koteshwor to suryabinayak highway extent.

Whereas, "leapfrog" form of urban development accounts 35 percentage of total urban development, and this form of urban development and 12 percentage of total urban development was due to infill development within the ring road area and along "Suryabinayak-Koteshwor" section of Arniko highway.

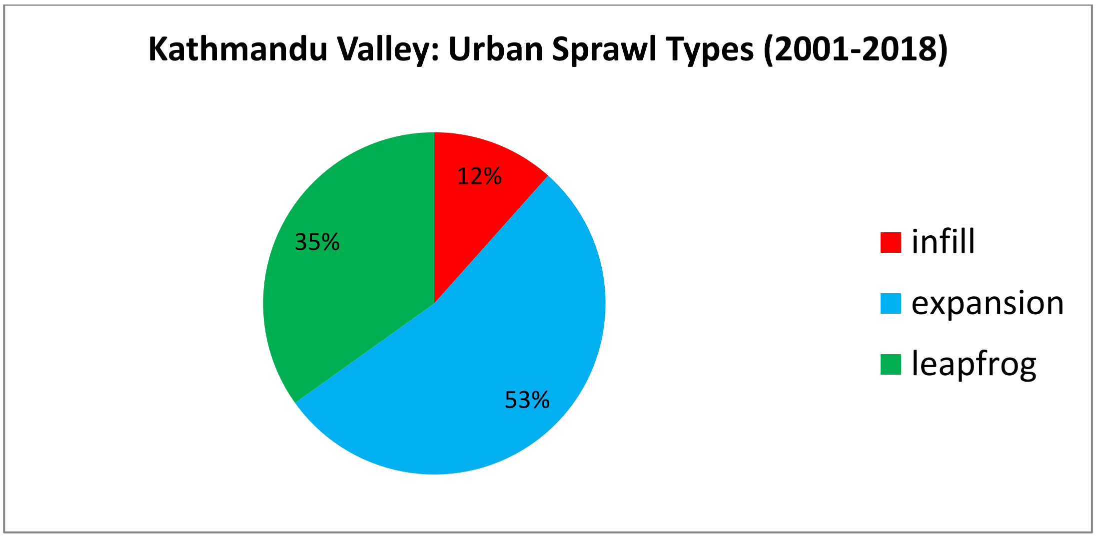


Figure 21. Kathmandu Valley: Types of Urban Sprawl (2001-2018)

3.7. Urban sprawl extent modeling for 2031

Modeling of future urban sprawl extent was performed with the application of IDRISI Selva Version 17.0 software. Land Change modeler was used for modeling future prospects of urban sprawl in Kathmandu valley. For the purpose of modeling of extent of Kathmandu valley following steps was followed: a) urban sprawl quantification from 2001 to 2011; b) transition modeling from 2001 and 2011; c) urban sprawl modeling for 2018 and d) validation of 2018 model comparing with classified LULC data of 2018.

LULC change analysis was conducted using LULC maps of 2001 and 2011. Land cover change between 2001 and 2011 were obtained and transition table was created. Change map was generated from 2001 to 2018 using change analysis of 2001 and 2011. Change probability grid for 2001 to 2018 was generated. With application of CA - Markov model using Markov Chain analysis (Padmanaban *et al*., 2017) change map and change probability grid was generated for the period 2001 to 2018.

Urban Extent for Kathmandu valley was modeled for year 2018 with the application of CA - Markov model in IDRISI software. Urban Extent modeled map of 2018, was compared with LULC map of Kathmandu valley. Accuracy assessment of modeled LULC map was done by generation of kappa variation with classified LULC map (Langley *et al*., 2001). Calibrated LULC and Validated CA - Markov were used to simulate urban extent of 2031 using urban extent of 2018 as base or reference map and transition matrix.

CA-Markov model implication divides total area into grid or lattice of cells, this model represents built-up area with lattice or raster grid, representing finite set of state (Kityuttachai *et al*., 2013). CA-Markov model consist discrete steps, which allows modeling of future pattern as a function of time progression, which was determined by transition rule specifying the cell properties over time (Piyathamrongchai, 2006). The pixel value for each grid or lattice in both modeled and classified image represents LULC type. Cell size of 30 m was selected for LULC classification. This study assigned 30 m^2 objects as smallest unit for LULC. Implication of suitability indices for development of built-up areas was determined based on four parameters. Distance from existing built-up, major road; slope and distance from forest. Although, distance from agricultural areas and bare areas were considered, but due to built-up area are exclusively developed in those areas, suitability analysis on these areas were not included for modeling future prospect of urban sprawl.

3.7.1. Parameter Selection:

Suitability analysis for built-up area development was based upon distance from forest, distance from roads, distance from existing built-up and slopes. Based on local expert knowledge, literature review and condition of the study area relative importance of each parameter over another parameter were determined and used for determination of urban sprawl in future.

3.7.2. Suitability Analysis for built-up area development:

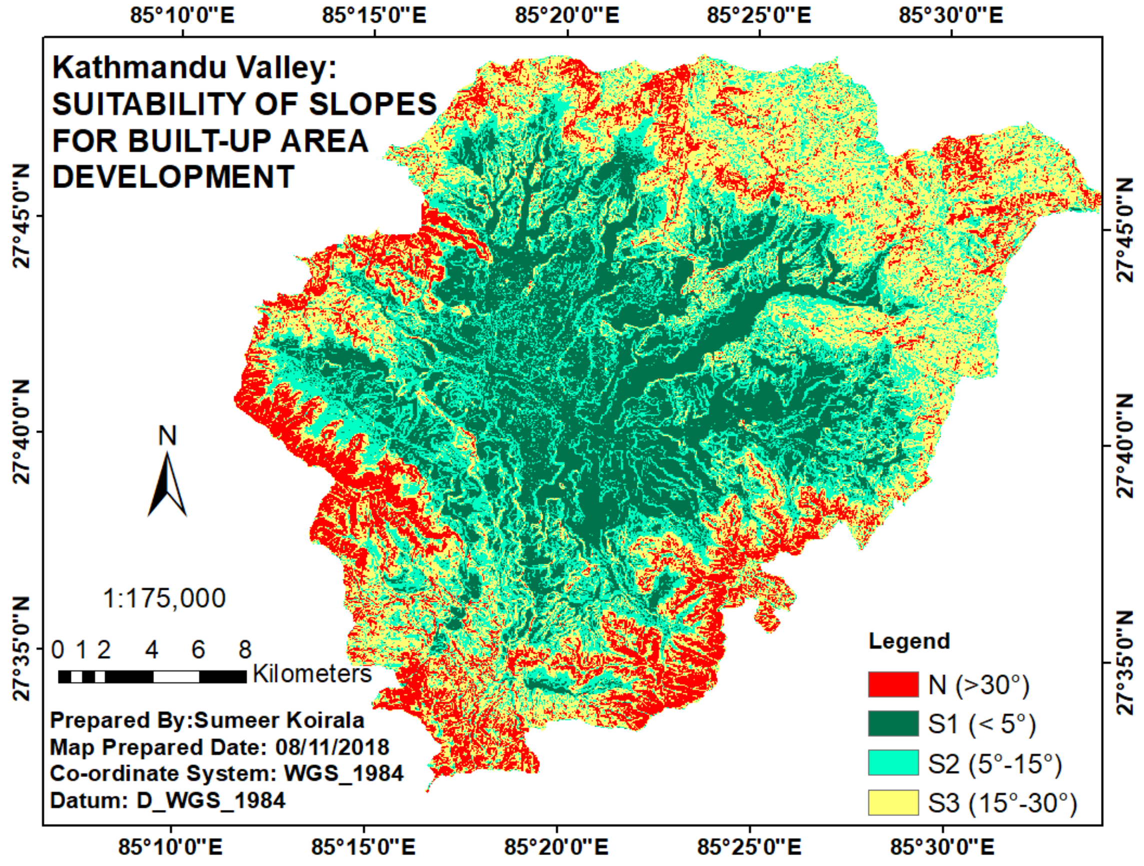
Suitability analysis transformed geographic data inputs of 4 parameters (distance from forest, distance from roads, distance from built-up and slope) into suitability classification. All these data were converted to raster datasets. Raster data were reclassified into same UTM 45N coordinate system with raster resolution of 30 meters. These reclassified raster datasets with 30cm resolution was used for final product. Raster data were reclassified in the range of 1-4, where 4 is most suitable and 1 is least suitable as shown in Table 6. Raster data were reclassified into suitability indices with the application of IDRISI Selva 17.0 software.

Table 6: Suitability criteria of different parameters

S.N	Suitability Class	Slope in degree	Distance from roads in meters	Distance from built-up class in meters	Distance from forest class in meters
1	Highly Suitable (S1)	0-5	<50	<50	>150
2	Moderately Suitable (S2)	5-15	50-100	50-100	100-150
3	Least Suitable (S3)	15-30	100-150	100-150	50-100
4	Not Suitable (N)	>30	>150	>150	<50

3.7.2.1. Suitability of slopes for built-up area development:

Slope was considered as one of the major aspect for built-up area development. Steeper slopes causes severe hurdle for stability and strength of construction. With increase in slope there will be hike in construction cost and floor limit (Santosh *et al*., 2018). Built-up area planning in high altitude area cost lots of amount in facilitating basic infrastructures like water, electricity, roads (Al-shalabi. et. al., 2006). Thus steeper slopes should be avoided during suitability classification. Study area slope ranges from 0 to 64.85 degrees and classified into four classifications. Area with lower degree of slope was highly suitable for built-up areas while areas with higher degree of slopes were not suitable as shown in Map 11.

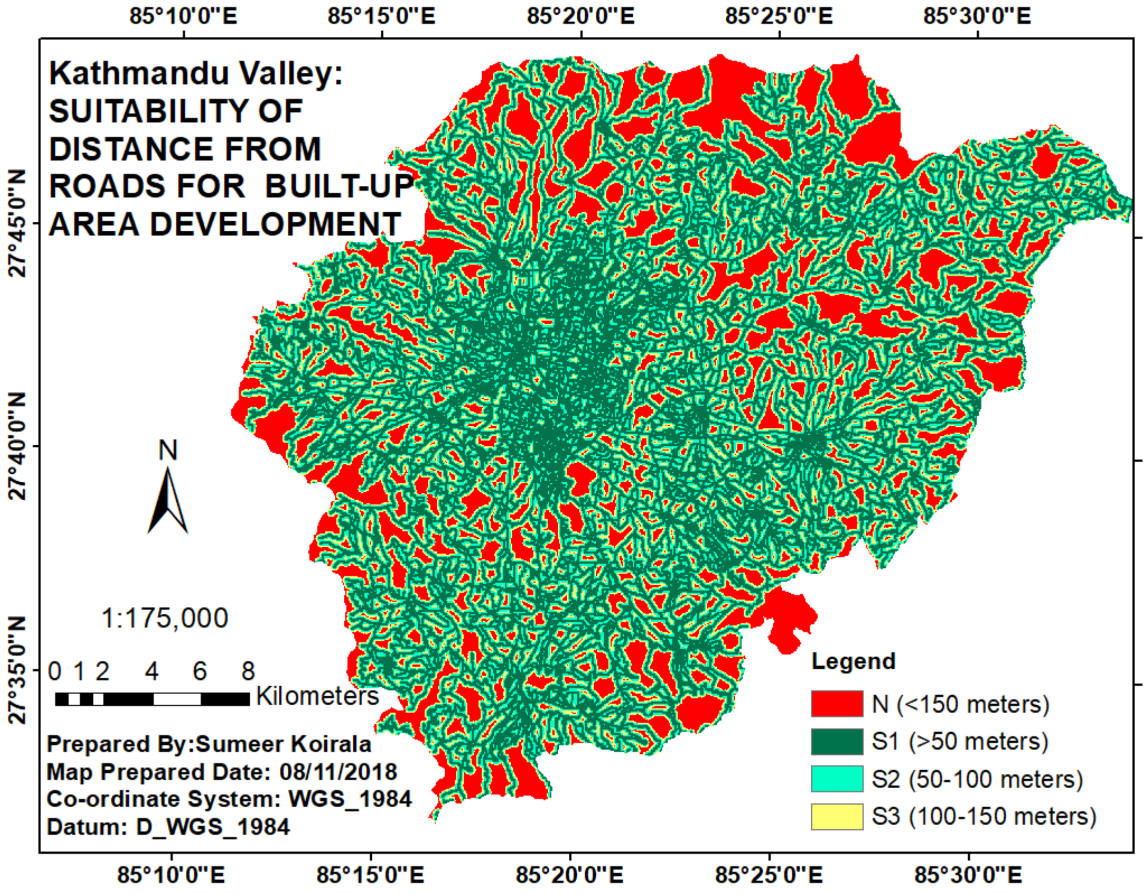


Map 11: Kathmandu Valley: Suitability of Slopes for built-up area development.

SRTM DEM was downloaded from USGS Earth Explorer Website “n27_e085_1arc_v3” scene was downloaded. Dem value of Kathmandu valley ranged from 1300 meters to 2800 meters. Slopes of Kathmandu valley were created using Raster to Slope, tool in ArcGIS 10.5 environment. Suitability requirement for slope analysis was generated using Raster Reclass tool in ArcGIS 10.5 Environment. Slope angle was calculated in degree system. Area having slope degree value up to 5˚ was classified as highly suitable or S1 class, for S1 class value 4 was assigned. Slope angle between 5 ˚ to 15 ˚ was classified as moderately suitable class or S2 Class, for S2 class value 3 was assigned. Slope angle ranging between 15˚ - 30 ˚ was classified as low suitable class or S3 Class, for S3 class value 2 was assigned. Finally slope angle above 30° was classified as not suitable class, not suitable class was assigned as N class and value 1 was assigned for not suitable class as shown in Table 6. Thematic map of slope classification was prepared in ArcGIS 10.5 software using Reclassify tool. Reclassified slope raster consisted spatial resolution of 30 meters, referenced in UTM 45 N coordinate system. Map 11 depicts slope angles in the project area as well as suitability rating assigned for slope in study area.

3.7.2.1. Suitability of distance from road for built-up area development:

Proximity to roads was considered as one of the vital factor for built-up area development. Road network is one of the parameters for development of built-up areas from cost of infrastructure development point of view.



Map 12: Kathmandu Valley: Suitability of distance from road for built-up area development.

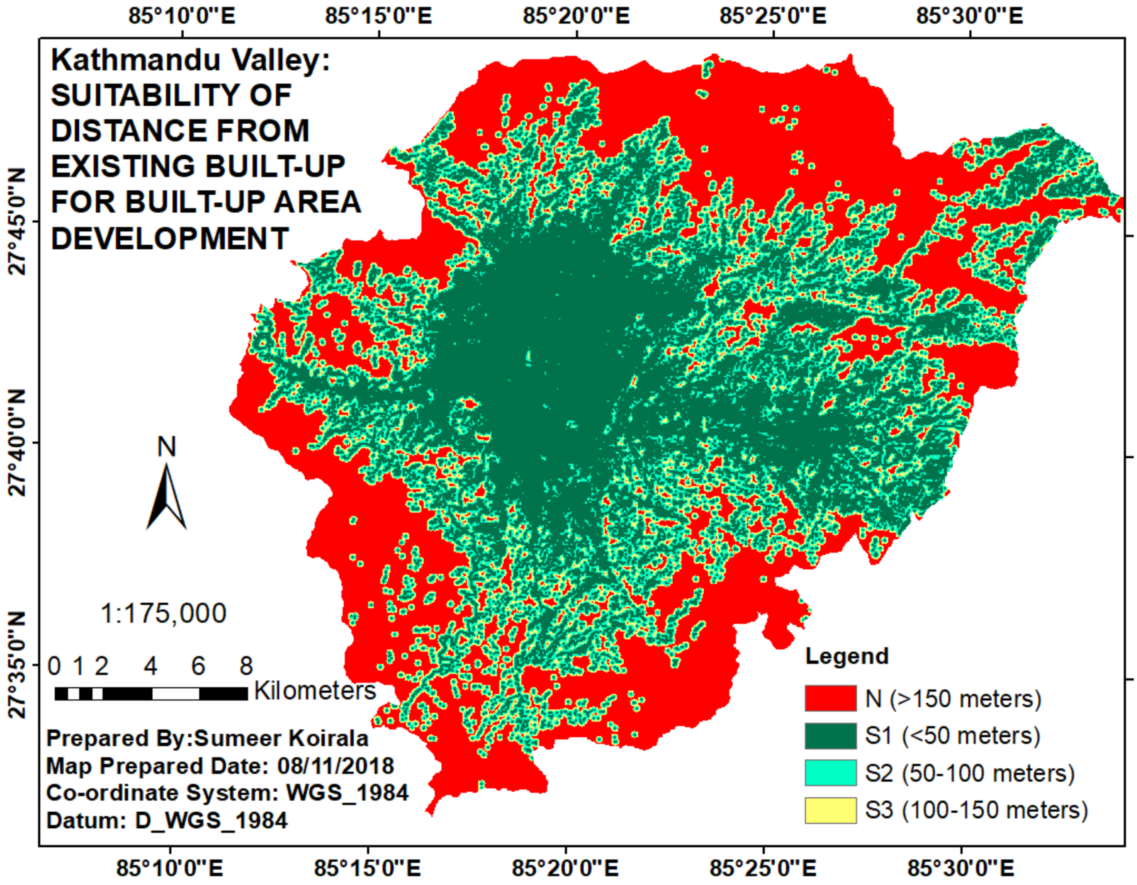
Development of built-up area nearby road networks is highly beneficial as it significantly decrease moving cost (Al-shalabi. et. al., 2006). Area nearby existing roads provides better transportation and mobility, whereas areas further away from major roads are always hideous for mobility and transportation of raw materials for built-up area development (Santosh *et al*., 2018). Major roads were taken for consideration for built-up area suitability analysis. Areas nearby roads are highly suitable for built-up areas while areas very much away are not suitable as shown in Map 12.

Road vector data was collected from survey department, containing various road classes. Euclidean Distance tool in ArcGIS 10.5 Environment was used for calculation of distance from road center line. Suitability requirement for distance from road analysis was generated using Raster Reclass tool in ArcGIS 10.5 Environment.

Area lying within distance of 50 meters from the roads was classified as highly suitable or S1 class, for S1 class value 4 was assigned. Distance between 50 meters to 100 meters was classified as moderately suitable class or S2 Class, for S2 class value 3 was assigned. Distance from 100m to 150m was classified as low suitable class or S3 Class, for S3 class value 2 was assigned. Finally distance above 150 meters was classified as not suitable class, not suitable class was assigned as N class and value 1 was assigned for not suitable class as shown in Table 6. Thematic map of distance to road classification was prepared in ArcGIS 10.5 software using Reclassify tool. Reclassified distance to main roads raster consisted spatial resolution of 30 meters, referenced in UTM 45 N coordinate system. Map 12 depicts distance to roads in the project area as well as suitability rating in the study area.

3.7.2.2. Suitability of distance from existing built-up areas for new built-up development:

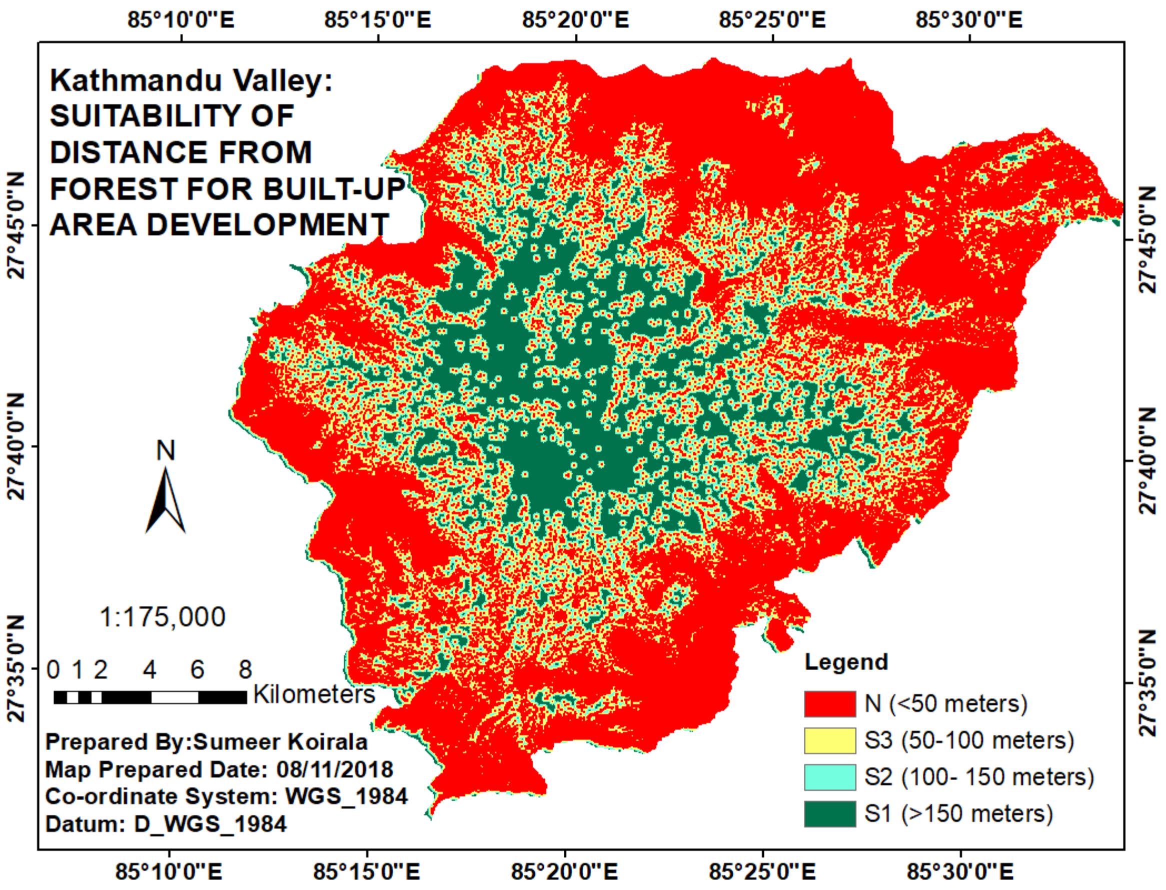
Development of built-up areas is always favorable within the proximity of existing settlement areas. Area nearby existing built-up areas provides better service facility, access to market, education, employment and better transportation facilities, whereas areas further away from existing settlements although land value will be lower than within proximity of existing settlement, but it is extremely difficult to develop basic infrastructure.



Map 13: Kathmandu Valley: Suitability of distance from existing built-up areas for new built-up area development.

Built-up areas were extracted from 2011 for modeling 2018 LULC map and from 2018 for modeling 2031 LULC map. Euclidean Distance tool in ArcGIS 10.5 environment was used for calculation of distance from existing settlement area. Suitability requirement for distance from built-up area analysis was generated using Raster Reclass tool in ArcGIS 10.5 Environment. Distance within 50 meters from existing built-up area up was classified as highly suitable or S1 class, for S1 class value 4 was assigned. Distance between 50 meters to 100 meters was classified as moderately suitable class or S2 Class, for S2 class value 3 was assigned. Distance from 100m to 150m was classified as low suitable class or S3 Class, for S3 class value 2 was assigned. Finally distance above 150 meters was classified as not suitable class, not suitable class was assigned as N class and value 1 was assigned for not suitable class as shown in Table 6. Thematic map of distance to existing built-up were prepared in ArcGIS 10.5 software using Reclassify tool. Reclassified distance to existing settlements raster consisted spatial resolution of 30 meters, referenced in UTM 45 N coordinate system. Map 13 depicts distance to existing settlements in the project area as well as suitability rating in the study area.

3.7.2.3. Suitability of distance from forest areas for new built-up development:



Map 14: Kathmandu Valley: Suitability of distance from forest areas for new built-up area development.

Environmental constrains for development of new built-up area must be considered for sustainable development. Development of built-up areas should be away from forest area and its buffer extent. Area nearby forest should be avoided for development of settlements, whereas areas further away from forest should be chosen for development of infrastructure. Forest areas, were extracted from LULC 2018. Euclidean Distance tool in

ArcGIS 10.5 Environment was used for calculation of distance from forest area. Suitability requirement for distance from forest area analysis was generated using Raster Reclass tool in ArcGIS 10.5 Environment.

Area having distance from forest area above 150 meters was classified as highly suitable or S1 class, for S1 class value 4 was assigned. Distance between 150 meters to 100 meters was classified as moderately suitable class or S2 Class, for S2 class value 3 was assigned. Distance within 50 - 100 was classified as low suitable class or S3 Class, for S3 class value 2 was assigned.

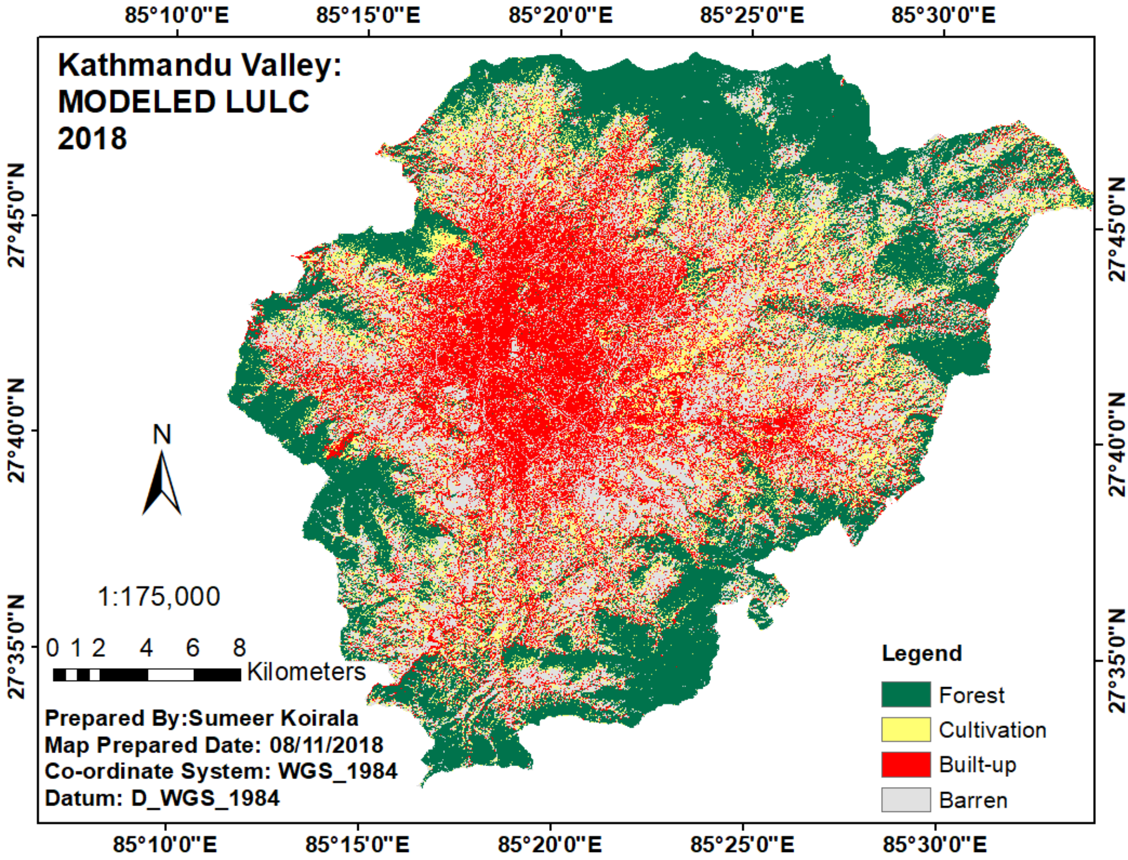
Finally distance less than 50 meters was classified as not suitable class, not suitable class was assigned as N class and value 1 was assigned for not suitable class as shown in Table 6. Map of distance to forest was prepared in ArcGIS 10.5 software using Reclassify tool. Reclassified distance to forest raster consisted spatial resolution of 30 meters, referenced in UTM 45 N coordinate system. Map 14 depicts distance to existing forest in the project area as well as suitability rating.

3.7.3. Land use land cover modeling of 2018:

LULC of 2018 was modeled, based on LULC classified image of 2001 and 2011. Further transition table (transition area) from year 2001 to 2011 was computed using Markov model. Using this suitability classes using distance to road, distance to existing built-up, slope and distance to forest, LULC of 2018 was modeled using CA Markov model.

In Markovian process LULC in the state of time 2018, was modeled with state of 2011. Houet and Hubert (2006) implied application of state of time (t_1) can be used to model state in time (t_2). Markov model used to obtain transition probability area matrix. Transition probability matrix computes the possibility or likelihood for a pixel contributing a class, changes to other class or stays in the same class within the specified time period (Behera *et al*., 2014). Transition matrix was recorded into text file which was later used for CA

Markov analysis. Transition area matrix obtained during the period of 2001 and 2011 was used for modeling of LULC of 2018. The LULC of 2001 was used as t_1 period and LULC of 2011 was used as t_2 in Markov model for transition area matrix, to obtain transition area matrix between 2001 and 2011. Map 15 depicts the modeled LULC of Kathmandu valley of the year 2018.



Map 15: Kathmandu Valley: Modeled Land use land cover 2018.

The purpose of validation of modeled 2018 LULC with classified LULC was to monitor the deviation of output model data with the actual data. CA Markov model output for 2018 was validated with reference LULC classified map. The validation model when compared with classified image the component of agreement and disagreement determined from original and CA-Markov modeled LULC shows agreement of 0.73. Overall accuracy of the model was based on the average value of agreement and disagreement of tendency of correct result and kappa index (Kityuttachai *et al*., 2013). The kappa index value during validation was 0.82. Figure 22 represents modeled LULC distribution for the year 2018. Validated result matched with actual LULC in both location and cell state level.

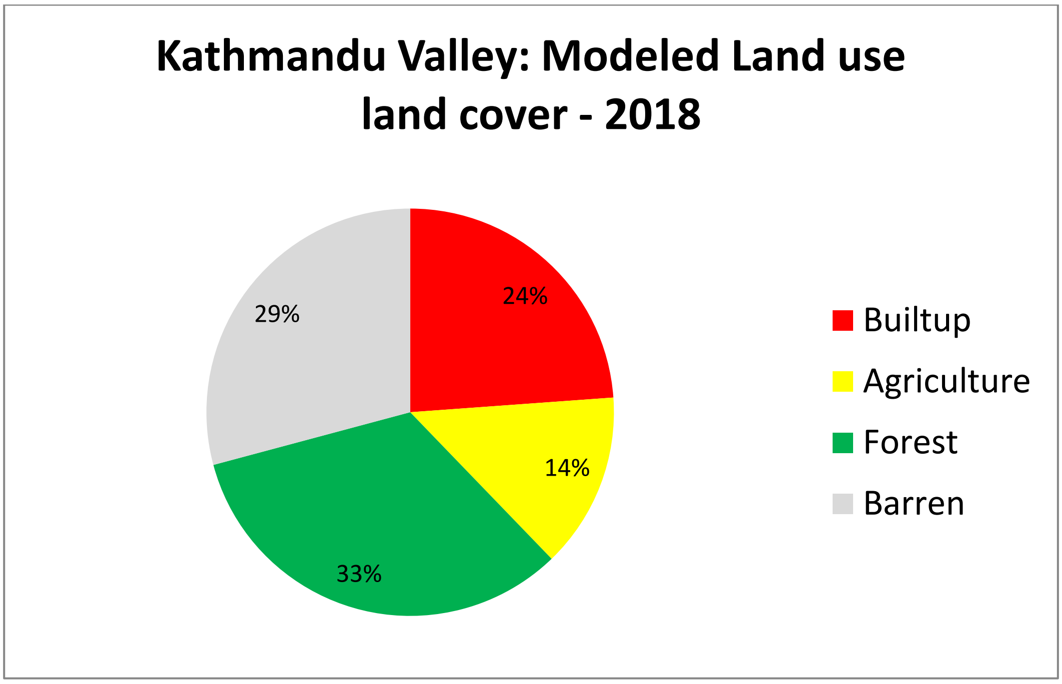
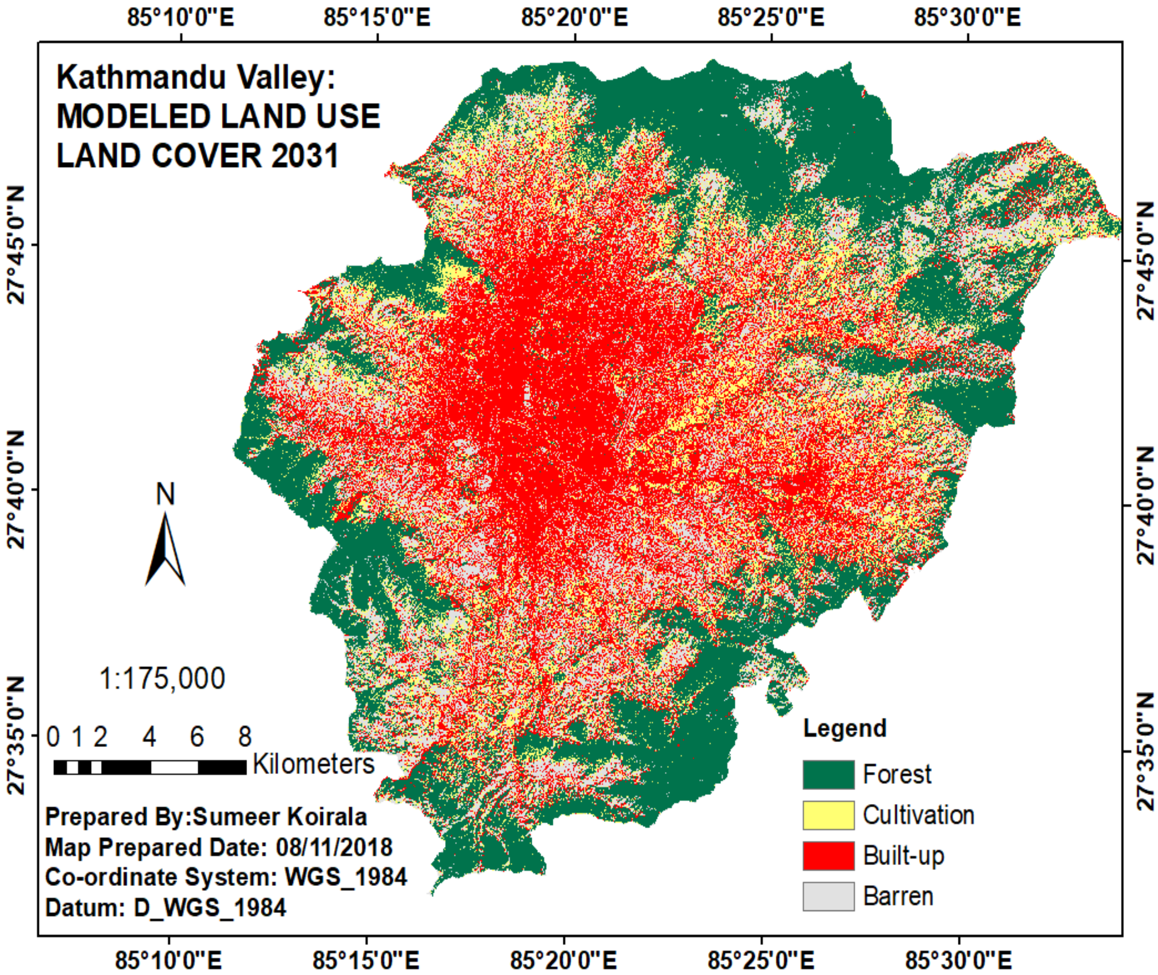


Figure 22. Kathmandu Valley: Modeled Land use land cover - 2018.

3.7.4. Land use land cover modeling of 2031:

LULC map of Kathmandu valley is spatially depicted in map 15. It was observed that built-up area expansion was driving force behind decline in bare land and agricultural land. With the rapid increase in population, rapid increase in residential development and commercial area development was modeled during the period of 2018 to 2031.

Large amount of change of bare land and agricultural land within proximity to road network and existing built-up areas is predicted to be converted into built-up area. Significant increase in built-up area can be detected during the period of 2018 to 2031. During 2018 built-up area composite the 25 percentage of total LULC of Kathmandu valley, in 2031 built-up area will constitute 32 percentage of total LULC in Kathmandu valley. This massive increase in built-up area is expected to be contributed from bare land and agricultural area as well. Bare land will contribute 28 percentages in 2018, while in 2031 its value will decrease to 20 percentages. There will be 8 percentage decrease in bare land. Figure 23 represents distribution of LULC in 2031.



Map 16: Kathmandu Valley: Modeled Land Use Land Cover - 2031.

Map 16 demonstrates the significant increase in built-up area. In 2001, total built-up area in Kathmandu valley was 53.94 km^2. During the period of 2001 to 2031, the built-up area increased up to 225 km^2. Built-up area during the period of 2001 and 2031 is expected to increase by more than three folds. There will be substantial decrease in bare land. Bare land is expected to decrease by 100 percentages, whereas agricultural land is expected to be converted to built-up area by fifty percentages. Forest around the valley is either conservation area or community forest, thus forest area is not expected to be converted to other form of LULC.

During the period of 2018 to 2031 there is estimated increase in built-up area by almost 35 percentages. There is expected rise of population of 38.3 million (CBS, 2014). During this period forty percentage of bare land contribute to built-up area to fulfill residential needs for growing population.

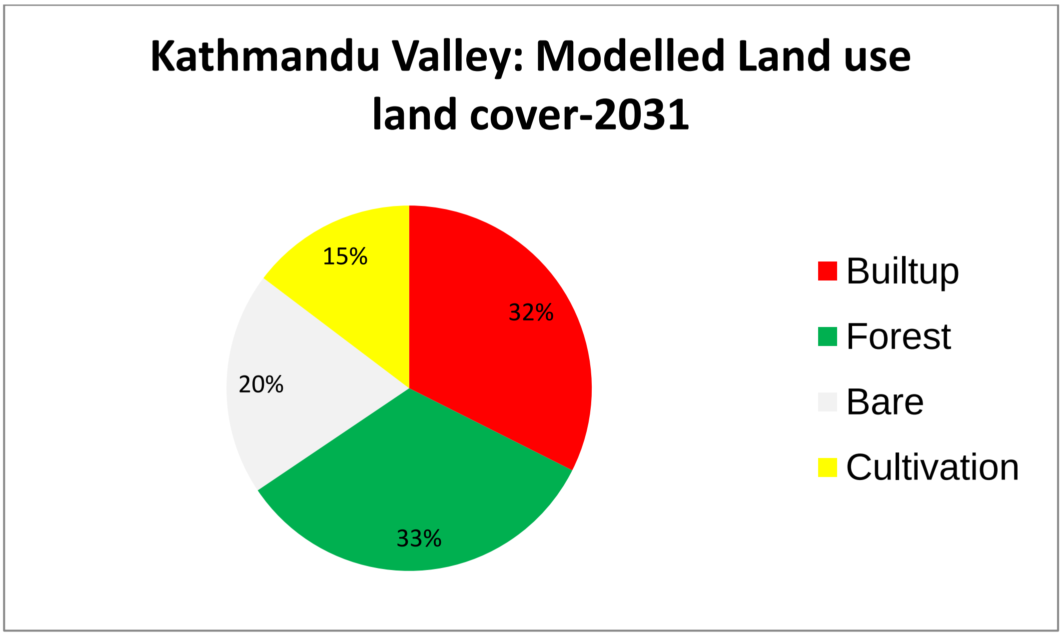


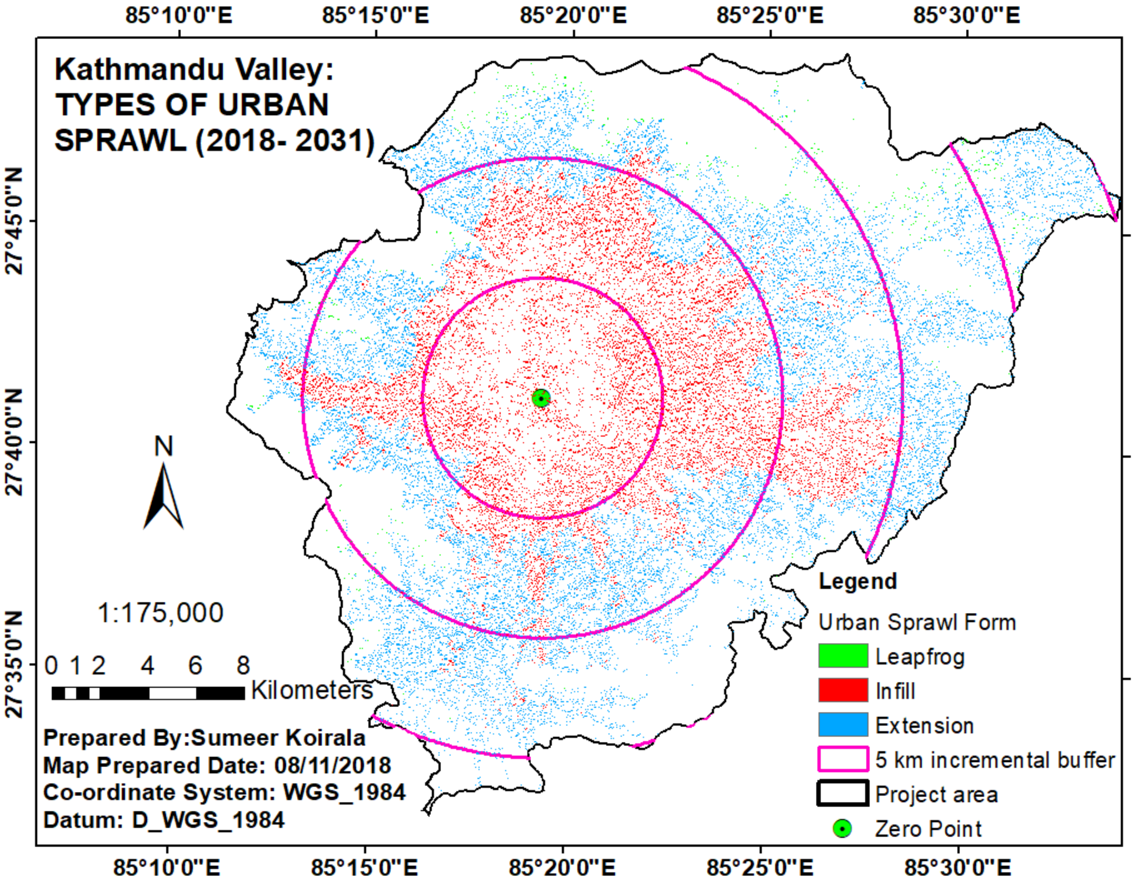
Figure 23: Kathmandu Valley: Modeled Land use land cover - 2031

3.8. Urban Sprawl extent of 2031

In this study, in Shannon's entropy examination in modeled LULC of 2031, entropy value in 5 km proximity was 0.68, whereas entropy value within the proximity of 5 to 10 km radius was 1.30, within the proximity of 10 to 15 km radius was 1.29, for 15 to 20 km radius entropy value was 1.07 and finally for 20 to 25 km radius entropy value was computed to be 1.29. These values clearly indicate urbanization will be much denser in the radius up to 10 km from the zero point with increase in radius from the core. It was concluded degree of Urban sprawl development was much higher during this period than that of 2018.

3.9. Types of Urban Sprawl, 2031

In the map 17, types of urban sprawl during the period of 2018 to 2031 are depicted. Map represents three different types of urban sprawl.



Map 17: Kathmandu Valley: Types of Urban Sprawl (2018-2031).

In this period, out of total urbanization 22.21 km^2 of total urban expansion will be due to "infill". Mostly area in the proximity of 5 km to 10 km from the point of interest will be mostly urbanized with this type of urban sprawl. Red color patches represents "infill" type of urban growth. 28.57 km^2 of total newly developed area will be due to "extension" growth type. “Extension” area surrounds existing urban area or urban city. Mostly urban fringes and suburbs are urbanized with “extension” built-up type. Area within the proximity of 5 to 10 and 10 to 15 are urbanized with “extension” urbanization type. Blue patches represent “extension” type of urban growth. 1.56 km^2 of total urbanization in the period of 2018 to 2031 is due to “leapfrog” expansion. Area beyond 10 km proximity is urbanized with this type of urbanization. Suburbs, rural fringes and rural areas underwent urbanization with “leapfrog”. Green patches represent “leapfrog” expansion type.

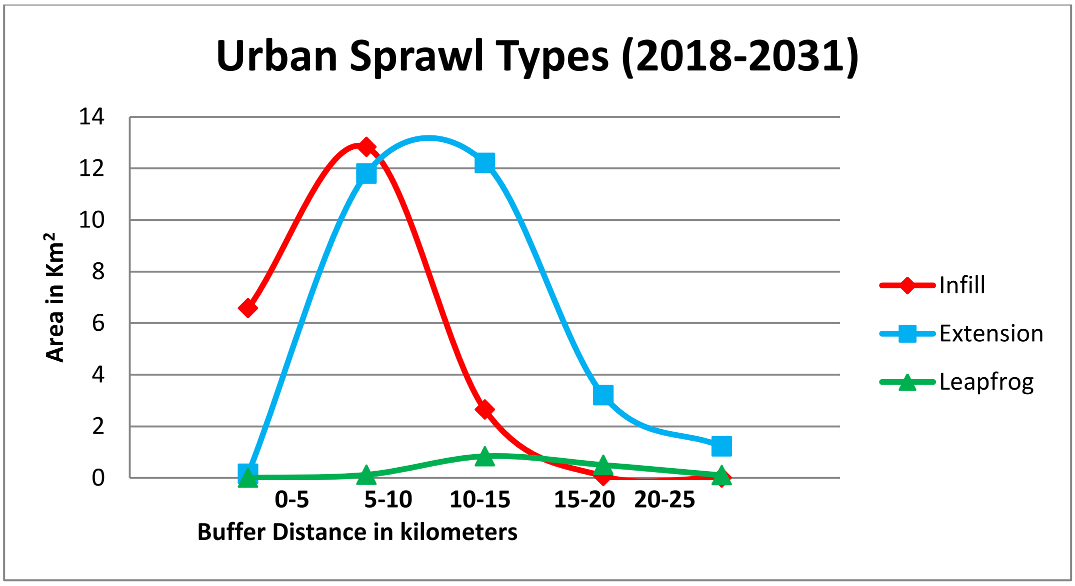


Figure 24: Kathmandu Valley: Types of Modeled Urban Sprawl within 5 km incremental buffer from Zero point (2018-2031).

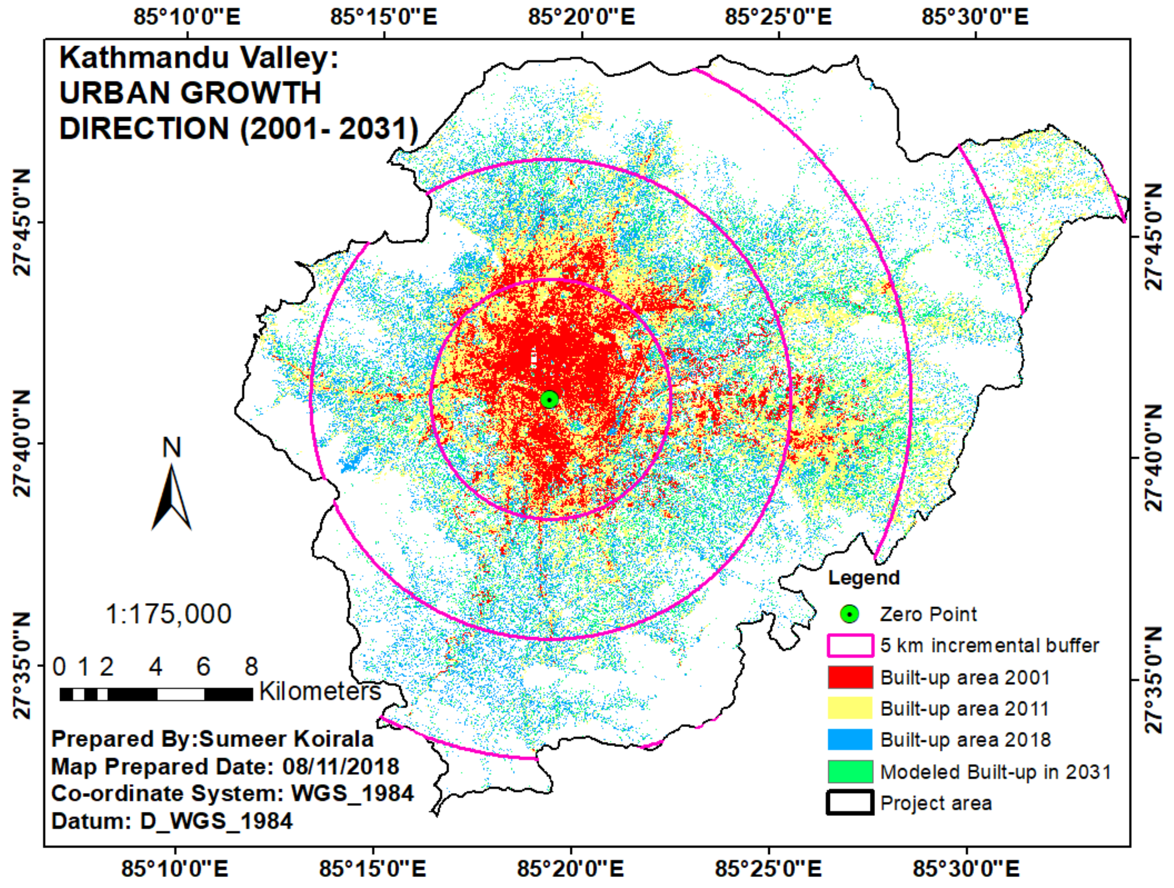
Figure 24 represents types of urban sprawl for different buffer from zero point. Within the buffer of 5 km from the zero point urban sprawl due to “infill” was the most dominating from of urban development.

Out of total built-up area expansion 6.57 km^2 was caused due to “infill” type, 0.15 km^2 built-up expansion was due to “extension” form of urban development, and no “leapfrog” development. Within the buffer of 5 km to 10 km again “infill” was the most dominating form of urban sprawl. Out of total built-up area expansion 12.82 km^2 was caused due to “infill” type, 11.79 km^2 built-up expansion was due to “extension” form of urban development, and 0.12 km^2 due to result of “leapfrog” form of urban development. Within the buffer of 10 km to 15 km, “extension” was most dominating form of urban sprawl. Out of total built-up area expansion 12.21 km^2 was caused due to “extension” type, 2.64 km^2 built-up expansion was due to “infill” form of urban development, and 0.84 km^2 was due to result of “leapfrog” form of urban development. Likewise, within the buffer of 15 to 20 km and 20 to 25 km, “extension” form of urban development was most dominating, followed by “leapfrog” and “infill”.

Built-up area will be transformed by degradation of cultivation area and bare area. From the study we can observe there was massive transfer of bare and cultivation land to settlement area around the existing built-up areas. Another decisive factor for rapid urbanization will be development of road network in urban fringes, suburbs and rural areas. In this study proximity from major roads and existing built-up areas were major driving force behind development of settlement areas. It was observed within the proximity of 500 meters from existing major roads and settlement areas, development of new settlement area were most suitable, thus bare and cultivation LULC of these area were rapidly converted in built-up LULC. Beyond this proximity, there was reduction in development of dense built-up areas. New built-up areas were developed in prominent way during the decade of 2001 to 2011. Mostly “extension” form of urbanization was developed during this decade. There was massive fragmentation in bare and cultivation land for development of built-up area. Area between 1 to 10 degree slopes was rapidly converted into built-up area. Area from 15 to 30 degree slope was gradually converted to built-up land.

3.10. Direction of Urban sprawl

From result of CA Markov analysis and LULC classification it was observed that growth of built-up area is radially outward from zero point. During the period of 2001 to 2011, growth seemed to be concentrated within existing built-up areas. There was vast expansion of new built-up area. Mostly north west, north east side and north side were mostly converted to built-up area. While in the period of 2011 to 2018, there were developments of new built-up areas in south east and south west area as well. But remarkable development was in north east and North West side. East part of Kathmandu valley also experienced growth of urban areas. From the Map 18 shows overall development of built-up is concentrated in all direction from the zero point.



Map 18: Kathmandu Valley: Direction of urban growth (2001 - 2031).

Urbanization in Kathmandu valley seems to have occurred in horizontal dimension. Factor behind development of built-up areas in urban fringes, suburbs and rural areas are low slope, low land price and construction of new roads across the valley. Development of roads in almost all the part of valley was most influential factor for multi directional LULC transformation in the valley. Areas inside the ring roads were transferred to built-up areas mostly during the decade of 2001 to 2011. With massive hike in land price inside ring road, urbanization in Kathmandu valley shifted radially outwards. Meanwhile, areas outside of ring road were connected to ring roads and were less expensive as compared to core areas, thus these area were also undergone urbanization. However, urban area also expanded extremely outside of major road as well because of better transportation facility in nearby fringes.

According to 2011 census population of Kathmandu valley was 2.5 million, during the year 2018 population was expected to reach up to 2.9 million, with this increase in population, there is necessity of development of new built-up areas, commercial areas, service center and other infrastructure facilities. These newly developed built-up areas outside of core areas served attractive facilities for business opportunity and possess high commercial values. Whereas, residential areas within the nearest proximity of core cities, major roads changed from residential facilities to commercial or business facilities. Therefore, direction of urban sprawl is not localized within major roads and zero point, but it rapidly grows in all direction.

Land value played major role in urban sprawl development. Area near to zero point and major roads has highest land price. Thus cultivation and bare land in these areas were haphazardly converted to built-up areas. Also, rapid population growths in the valley, residential area were shifted towards outer reach of ring roads, due to low land values. Mostly Kathmandu valley lies in flat terrain with very gradual change in slope. Most of the sloppy terrain in Kathmandu valley is covered with forest, thus land chunk of flat land is available for development of built-up areas, resulting in multi-directional development of urban sprawl.

Chapter-4: Discussion and Conclusion

Urban sprawl analysis revealed built-up area rapidly increased in Kathmandu valley. Spatial distribution of built-up area demonstrated fast grown, disoriented, low efficiency and scattered spatial distribution characteristics, which clearly suggests typical urban sprawl tendency. Built-up areas increased by more than two folds during the period of 2001 to 2018. Built-up areas contributed 53.9 km^2 in 2001, whereas built-up area contributed 170.7 km^2 in 2018. Uncontrolled urbanization resulted rapid degradation of cultivation and bare land. Cultivation area and bare area degraded from 412 km^2 to 295.19 km^2 during this period. Vegetation area and bare lands decreased by 116.81 km^2. Newly developed built-up area expanded in multi direction from the core cities. North-eastern and north-western side underwent major change in built-up area in comparison to other area. Outward expansion of built-up area from inner city was observed during the study period. Several satellite towns were developed with passage of time. Most of the suburbs and urban fringes underwent massive urbanization. South-eastern and south-western side underwent more dispersed urbanization than northern side. CA Markov model showed development of urban or built-up area can reach up to 225 km^2 inside Kathmandu valley.

During 2001 Shannon’s entropy value for Kathmandu valley was 1.23 and this value increased to 1.41 during the 2011. During 2018, entropy value was 1.46. These values suggest built-up area were much dispersed in 2011 than in 2001 and most dispersed or scattered in 2018. Intensity of urban sprawl was determined with relation to entropy value. Entropy value suggested more urban sprawl occurred in period of 2001 to 2011 than during 2011 to 2018. The urban sprawl result obtained by entropy analysis was supported by spatial pattern and distribution of built-up areas.

Urban sprawl analysis in different radius from core cities, showed within radius of 5 km from zero point gradually increased; this is due to densification of built-up area within existing open spaces between settlement areas. There was homogenized distribution of settlement area within this proximity. Within the proximity of 5 to 10 km there was higher development of urban sprawl. Mostly suburbs and urban fringes were abruptly converted to residential clusters within this proximity. Built-up areas continuously developed around existing settlement areas, as a result small patches of built-up area merged into larger patches and in homogenized direction. Outside the buffer of 10 km new settlement areas were developed, which were more haphazard and dispersed.

“Infill” phenomena occurred mostly within the proximity of 5 km. In 2001 urban core boundary was concentrated within this proximity. In 2011, urban core boundary extended from 5 km to 10 km from point of interest. In 2001 sub urban areas were from 5 to 10 km, where as in 2018 suburban boundary expanded up to 15 km. Most intensive development of built-up area was observed up to 10 km radius. Mostly “infill” and “extension” form of urban sprawl were observed within this proximity. Most of the built-up or settlement area occurred along main roads, inside ring roads and adjacent to existing settlement cluster. Built-up area continuously developed in major road periphery and expanded outwards within the reach of major roads. Within 10 to 15 km radius vegetation and bare land were considerably transformed to urban areas. There was major fragmentation of cultivation and bare land. Mostly leap frog form of development was observed from 10 km radius and onwards. Mainly population growth, better public transportation, land values and economic activities were major drivers for urban sprawl development in Kathmandu valley. It is vital to keep balance in population growth and urbanization for development of quality life. Better planning, law enforcement and vertical direction urban growth is felt very necessary to restrict haphazard urban sprawl development in Kathmandu valley.

Chapter-5: Limitations and Recommendation

Limitations

Study was conducted based on medium resolution Landsat image, due to 30 meters spatial resolution image classification was greatly affected. In some case multiple land use land cover class were prevalent in single pixels. Water bodies could not be mapped due to coarser resolution of satellite image. Not all the features could be aggregated in the LULC maps. Vectors data of road network was prepared in 2007 and were not updated later. Temporal resolution of road data affected future modeling of urban.

This research concentrated on urban expansion in two dimensional spaces. This study analyzed expansion of built-up areas in inwards and outwards direction. It is essential to understand the vertical expansion of built-up area for properly determining urban sprawl and its associated problems and risk. But, lack of building data and mono satellite image, three dimensional change analyses was not possible during this research.

This research was based on geographic prospective of land use land cover change. Aspects of population growth and population change were incorporated to relate the growth of built-up area. But this will not be sufficient enough to give the socio economic prospective of urban sprawl. Urban sprawl was analyzed based on methodological approach derived from literature review and expert consultation. Urban Sprawl analysis without social, economic, environmental, development trends, land value and standard of living of population cannot give actual result for decision makers and planners.

Future prospective and Recommendations

On the basis of this research following future prospects and recommendation can be made:

- From the research, urbanization of Kathmandu valley from 2001 to 2031 is expected to rise by more than three folds, causing severe impact on socio economic and environmental aspects. It is high time for planner and policy makers to develop urbanization not only in horizontal dimension but in vertical dimension as well. Furthermore, implementation of building bylaws and land use plans is highly recommended.
- Urban sprawl development should be integrated with environmental factors, socio-economic prospective, land values for development of proper plans and bi laws for city planning and development.
- Kathmandu valley is facing major traffic congestion, drinking water, sewerage disposal problem and many other environmental and socio economic problems, which cannot be solved without taking consideration of problems associated with urban sprawl.
- In future research, researchers could incorporate factors such as land value, education, quality of life, and economic activities to better understand causes and consequences of urban sprawl.
- Further environmental impact like, water pollution, air pollution, ecological imbalance, temperature rise and urban heat island effect can be studied in response to growth of urban sprawl in Kathmandu valley.

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