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# **ASSESSMENT OF URBAN SPRAWL AND ITS IMPACTS IN BHARATPUR METROPOLITAN CITY**

By

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the degree of  
Master of Science (Geographical Information Science & Systems) – MSc (GISc)

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**Kathmandu, November 20, 2021**

## Science Pledge

By signing my thesis report below, I at least acknowledge that my own work results entirely. I mentioned and indicated their origin all the sources of data and information I used in my thesis report.

**Kathmandu, November 20, 2021**

A handwritten signature in black ink, appearing to read 'Kathmandu' with a date '20/11' written below it.

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## ABSTRACT

Rapid changes in socio-economic condition in Bharatpur Metropolitan City (BMC) caused the rapid urban growth and which led to a several environmental damages such as: land fragmentation, unplanned settlements, uncontrolled land use conversion, increasing environment pollution and anthropogenic disasters. In recent years migration rate increases rapidly. This type of projections presented that gradual shift of human population from rural area to urban areas. Rapid urbanization plays a crucial role for arable land fragmentation and irregular land use changes. Which are major issues for urban planners and land developers. Due to irregular urban growth, urban managers and developer cannot predict the process of city growth and its modeling in future with precise methods for management. Major objectives of this study are: (i) To identify the sprawl pattern, major driving forces of urban growth, sprawl types (ii) To identify most significant urban expansion zone, urban expansion rate. (iii) To develop the future urban growth model of BMC. Analysis of spatiotemporal distribution pattern of land use from (1990 – 2020) shows that most of the arable agricultural land and forest area changes to urban and settlements during this study period. This study has been executed through Cellular Automata (CA) model for validation and development of future model and GIS based multi criteria decision making (MCDM) for land suitability analysis. Analytic hierarchy process (AHP) is a combination of qualitative and quantitative method used to calculate the weights of multi criterion by using pairwise matrices. By this method the biophysical and socioeconomic factors underlying the expansion has identified. Medium resolution satellite imageries of 1990, 2000, 2010, 2020 has used for analysis of land use and land use pattern 2020 used for model calibration. This study predicts the LULC in BMC for 2030 and 2040. Finally, suitability maps have been prepared for several classes: highly suitable, moderate suitable, less suitable and restricted area and its percentage of area.

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## ABBREVIATION

AHP	Analytical Hierarchy Process
AOI	Area of Interest
BMC	Bharatpur Metropolitan City
CA	Cellular Automata
CR	Consistency Ratio
DEM	Digital Elevation Model
ERDAS	Earth Resource Development Assessment System
GCS	Geographic Coordinate System
GIS	Geographic Information System
GPS	Global Positioning System
LANDSAT	Land Satellite
LCM	Land Change Modeler
LULC	Land Use Land Cover
MCDM	Multiple-Criteria Decision-Making
MSS	Multi Spectral Satellite
MUTM	Modified Universal Transverse Mercator
NASA	National Aeronautics and Space Administration
NRIW	Normalized Relative Importance Weight
OLI	Operational Land Imager
QGIS	Quantum GIS
RS	Remote Sensing
SRTM	Shuttle Radar Topography Mission
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
ULAT	Urban Landscape Analysis Tool
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System

# Chapter 1: INTRODUCTION

## 1.1 Background

Nepal is a landlocked country of South Asia and has diverse geography. Nepal is situated in the Himalayas, Indo-Gangetic plain, Tibet of China to the north and south, east and west to India. Nepal's hilly and mountain regions comprise about 86% of its total area (Paudel et al., 2013). Most of the people are dependent on traditional farming. In recent years urbanization in Nepal goes rapidly. Nepal is one of the ten least urbanized countries in the world. However, it is also one of the top ten fastest urbanizing countries (Bakrania, 2015). Recent years Nepal faces the problems of climate changes like as: precipitation patterns and rates and timing of glacial melt, which could impact agriculture, biodiversity, and hydropower energy production (Metternicht et al., 2014).

Urban sprawl is defined as "continuous expansion of big cities' marginal area, moreover, it always has strips of lands in the process of transformation from country to the city" (Gottman, 1961). Most of the population lives on urban areas so, a proportion that is expected to increase to 68% by 2050 (UNDESA, 2018). This projection shows that a kind of rapid urbanization, where the gradual shift of human population from remote/rural areas to urban areas. Combined with the overall growth of the world's population could add another 2.5 billion people to urban areas by 2050, with close to 90% of this increase taking place in Asia and Africa, according to a new United Nations data set launched today ((UNDESA, 2018).

In 2014, the level of urbanization was 18.2 %, with an urban population of 5,130,000, and a rate of urbanization of 3%. High urban growth is occurring in the Kathmandu Valley, the Pokhara Valley, the Inner Terai valleys, and in market and border towns located on highway junctures between the east-west highway and the five main north-south corridors. Urban growth centres are also emerging close to the border with India (Muzzini & Aparicio, 2013). Antalyn &

Weerasinghe, (2020) states urban sprawl is unplanned and uneven pattern of growth, driven by a multitude of processes and leading to inefficient resource utilization. To determine LULC change during a study period maximum likelihood supervised classification was applied for Landsat-8 OLI/TIRS and Landsat-5 TM satellite imageries socioeconomic data.

Chitwan is one of 77 districts of Nepal, and takes up the southwestern corner of Bagmati Province. Bharatpur, largest city of Nepal after Kathmandu, is its administrative centre (CBS, 2011). Chitwan district covers 2,238.39 km<sup>2</sup> (864.25 sq mi), and in 2011 had a population of 579,984 (279,087 male and 300,897 female) people (CBS, 2011).

Bharatpur is one of the major commercial and service centers of south-central Nepal. Also, it is a prominent destination for higher education, health care and transportation in the region(BMC, 2018). It lies in the Terai region of Nepal. It is in the drainage basin of the Gandaki River and is roughly triangular, taking that river as its meandering northwestern border, and a modest watershed border, with India, as the basis of its southern limit. So, in this research RS and GIS techniques is used for LULC change during the period of (1990 – 2020). Multi spectral satellite imageries are used to detect the urban sprawl in Bharatpur metropolitan city.

Main objectives of this study are to analyze the spatial and temporal dynamics of LULC from 1990 to 2020 and urban expansion rate in BMC. This study is embedded in various thematic areas. Basically, those areas are: RS/GIS analysis of urban growth and land suitability, Impacts of urban growth in agricultural land and interaction between municipal water supply, sewage disposal and environment. Research areas is presented in Figure 1.

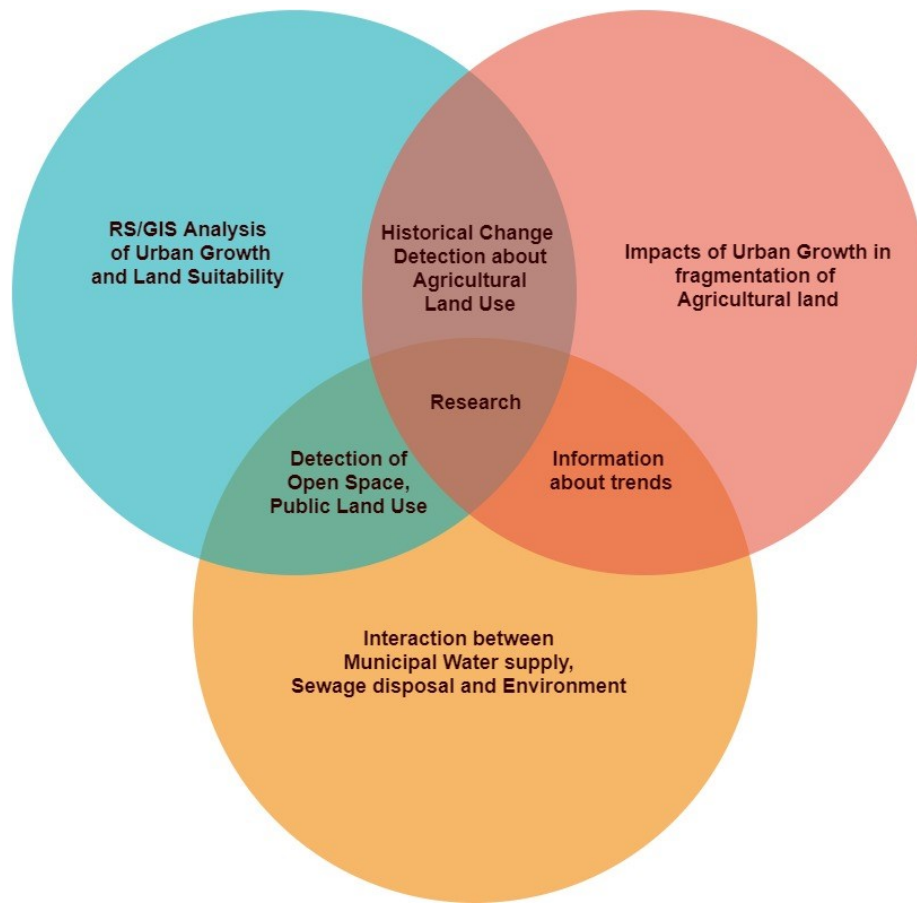


Figure 1: Research areas

## 1.2 Rationale

Human population and settlements have been increased in the world due to rapid shift of human population from rural area, especially like developed country like Nepal. In Nepal rapid urban growth subjected to massive losses of arable land and helps to increased environment pollution. Due to lack of sustainable development practice, proper vision, practice and management most of the cities in Nepal faced haphazard urbanization. Most of the people has been migrated in city for better facilities and luxurious life, such facilities are: transportation, health, education and employment etc. Due to lack of research about public space, environment protection and land use policy creates the massive reduction of public land and green forest. It tends to have significant influences on public life and activities (Chitrakar et al.,

2016). Nepal is mountainous country, most of the area of the country occupied by mountain and hilly region. In these regions peoples are depend on traditional agriculture. In recent years, due to lack of proper irrigation facilities and modern technology in agriculture most of the agricultural land were converted to dense forest and barren land. According to ILO during fiscal year 2020, more than 50 lakhs labour permits were issued by MOLESS Nepal to work abroad. In 2018/19, 272,216 migrant workers renewed their labour approval. Most of the foreign employer want to purchase the one plot of land in urban area for residents in future for children and family. During two decades remittances. The net migration rate of Nepal was at level of 1.49 migrants per thousand population in 2020, down from -15.11 migrants per thousand population in 2015, this amount is change of 109.84% (KNOEMA, 2019). Migration rate of Nepal was decreased in 2015 due to devastating Nepal earthquake. Migration rater of Nepal has presented in following Figure 2.

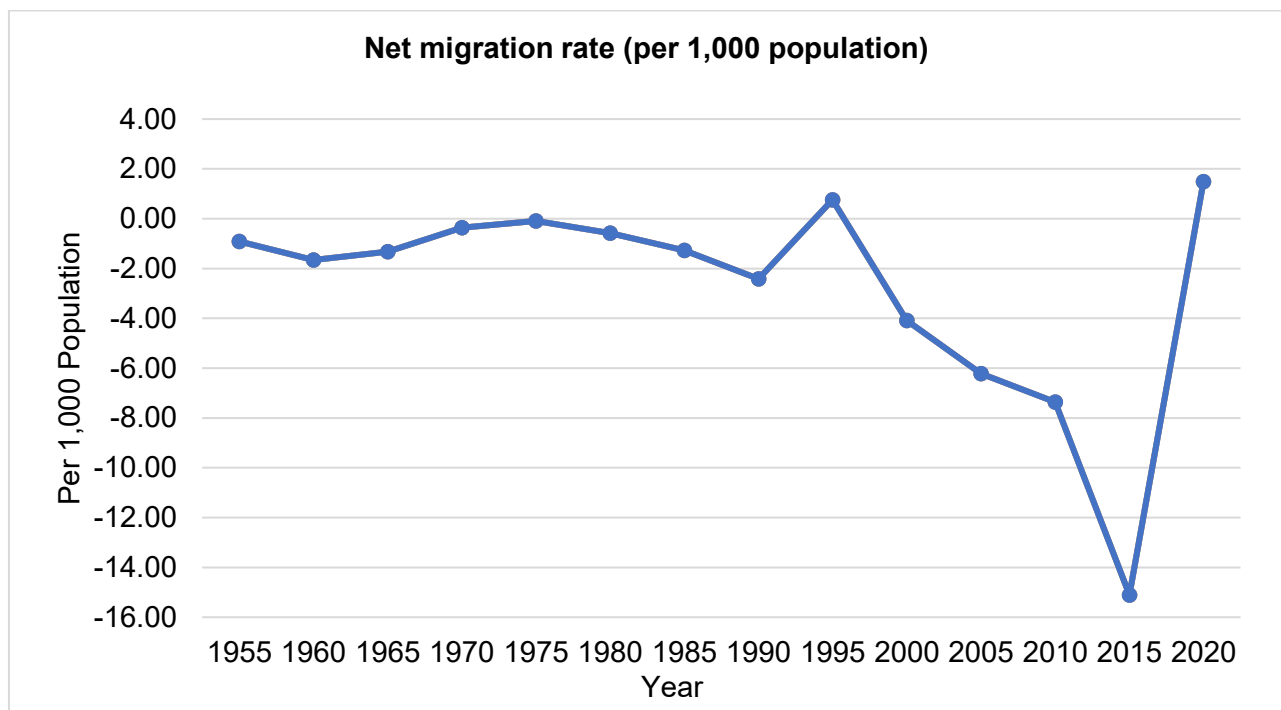


Figure 2: Nepal net migration rate (1955 – 2020)

Curiosity of understanding the natural phenomena and socioeconomic status of world is a natural trait of human being. With the advent of computers, GIS/RS tools, cellular automata, AHP tools which increased the visualization and analysis capabilities of GIS has increased study in urban sprawl and its impacts on fragmented arable land.

It is compulsory to monitor and control the uneven urban growth in major cities, local levels and newly expanding cities. Also, the impacts of rapid urban growth regards to environmental issues should be reflect one of the significant subject for urban planners, policy makers and environmentalist of those regions (Wakode, 2016). This study presents the current scenarios of various social, demographic and economic aspects; water supply, sanitation and health aspects; household details and housing pattern as well as urban environmental infrastructure, access to community facilities, awareness to public health and other information. Socio-economic data, DEM, aspect, soil, geology and others various information collected along with urban base map and GIS and ERDAS IMAGINE would provide invaluable insight in the current and historical pattern of Land use Land cover, land suitability, socio-economic disparities and environment issues due to uneven urban growth of this city.

After all, future urban growth model has generated and also relation between urban growth and its impacts on fragmented arable land as well as environment be established. This relationship will be useful for qualitative and quantitative analysis of various projects groundwater analysis, scientific land use planning etc. So, researchers, analyst and developers will use those analysis to control the uneven urban growth.

### **1.3 Significance of the Study**

This study is intended to provide baseline information for further study and research to find out impacts on environment and agricultural land due to urban growth. It helps to gives awareness

to the policy makers, politician and planners about possible disasters due to urban growth. This study was expected to be helpful to planners, engineers engineering students, different organizations for the paper presentations and research material. This study was expected to be beneficial to investigator to gain depth knowledge about urban growth modelling.

#### **1.4 Research Objectives**

The study is being carried out to is to develop a method of using RS/GIS for urban sprawl assessment by applying multi temporal and multi resolution remote sensing data and socioeconomic data. The intentions of the research are to determine urban growth on agricultural land and scientific management for the sustainable development of BMC. General objectives of this study can be listed as follows.

- i. To analyze the urban growth and its trends in the last 30 years and identify spatial and temporal dynamics of LULC trend of Bharatpur and effect of urban sprawl.
- ii. To identify most significant urban expansion zone, urban expansion rate and to study impacts of uneven urban growth on municipal water supply, sewage disposal and environment.
- iii. To develop a model for forecasting the urban sprawl in various time frame.

#### **1.5 Limitation of the Study**

Different versions of Multispectral satellite data were available for years (1990-2020), Some LANDSAT imageries are affected by cloud, fog. LANDSAT imageries with 30 m spatial resolution imageries are medium quality imageries and land use classification is more tedious. For rigorous urban sprawl assessment higher resolution imagery and more than 40 years imageries are essential.

## **1.6 Outline of the Study**

This study contains four chapters.

Chapter 1: Introduction highlights the background and objectives of the study. Literature Review covers previous research carried out in the field of drought assessment as well as role of remote sensing and GIS technology in the arena of monitoring, prediction, and assessment of droughts so far. Study area gives a brief overview of the study area.

Chapter 2: Materials and Method explains the data used and the selected methodology adopted for the research. Here acquisition of satellite images and its processing and analyzing has been discussed briefly.

Chapter 3: Results and Discussion gives a critical observation for urban sprawl and its impacts. It gives a brief discussion based on the results achieved and the analysis carried out.

Chapter 4: Conclusion and Recommendations draws conclusion of this study and gives recommendations for further research.

## 1.7 Literature Review

### 1.7.1 Urban Sprawl

Several numbers of research works have been done in regard to the assessment of urban sprawl. Some literatures have been studied and reviewed and which is explain below.

Urban sprawl is defined as unplanned and uneven pattern of growth, driven by multitude of processes and leading to inefficient resource utilization (Bhatta, 2010). Urban sprawl expansion is becoming a serious problem of many urban areas due to not much a picture of sprawl in priority, urban areas lack the infra structure and basic facilities like treated water supply, electricity, sanitation services (Allah Yar, 2017).

Nepal is a country that has experienced population explosion and accelerated urbanization in the last six decades. Chitrakar et al., (2016) states: two factors that have played a major role in the valley's current urban growth are the development of physical infrastructure and the increases of migration and population.

Urban sprawl assessment has been applied for different field of applied science. For example: Rimal et al., (2017) performed the research on Monitoring Urban Growth and the Nepal Earthquake 2015 for Sustainability of Kathmandu Valley, Nepal, Shao et al., (2020) did study on urban sprawl and its impact on sustainable urban development: a combination of remote sensing and social media data.

Almeida, (2005) used both the GIS and the neighborhood statistic calculations to describe the spatial distribution of urban sprawl in the Richmond, Virginia area. Also, he found three varieties of density development and set threshold values for these densities. Gervasoni et al., (2017) used three main dimensions of sprawl: dispersion, land use mix, and accessibility. Each parameter leading to the computation of a dedicated numerical index. Falah et al., (2020) practiced Cellular automata (CA) for computational method for urban growth modelling.

Litman, (2015) concludes that for better urban sprawl assessment impact analysis should consider various land use factors including development density, mix, centrality, transport network connectivity and design, the quality of transport options (walking, cycling, public transit, automobile, etc.). Suwal, (2009) suggested that the country needs a strong and responsible governance structure to accomplish the future goals for development.

### **1.7.2 Causes of urban sprawl**

Basically, urban sprawl causes due to socioeconomic and cultural forces. These factors have significant role in rapid urban growth. Land value is one of the chief driver of sprawl patterns. Urban growth tends to occur where property values are lower on the periphery of densely populated area (Pendall, 1999).

Three underlying forces that interrelated with land values to increases the spatial urban sprawl (Carruthers & Ulfarsson, 2002). These forces are (i) Population growth in periphery of central urban areas (ii) Rising income of people (iii) Third, decreasing commuting costs due to historical investment in transport infrastructure (Brueckner, 2000). Major driving forces of urban sprawl is presented in below in Figure 3.

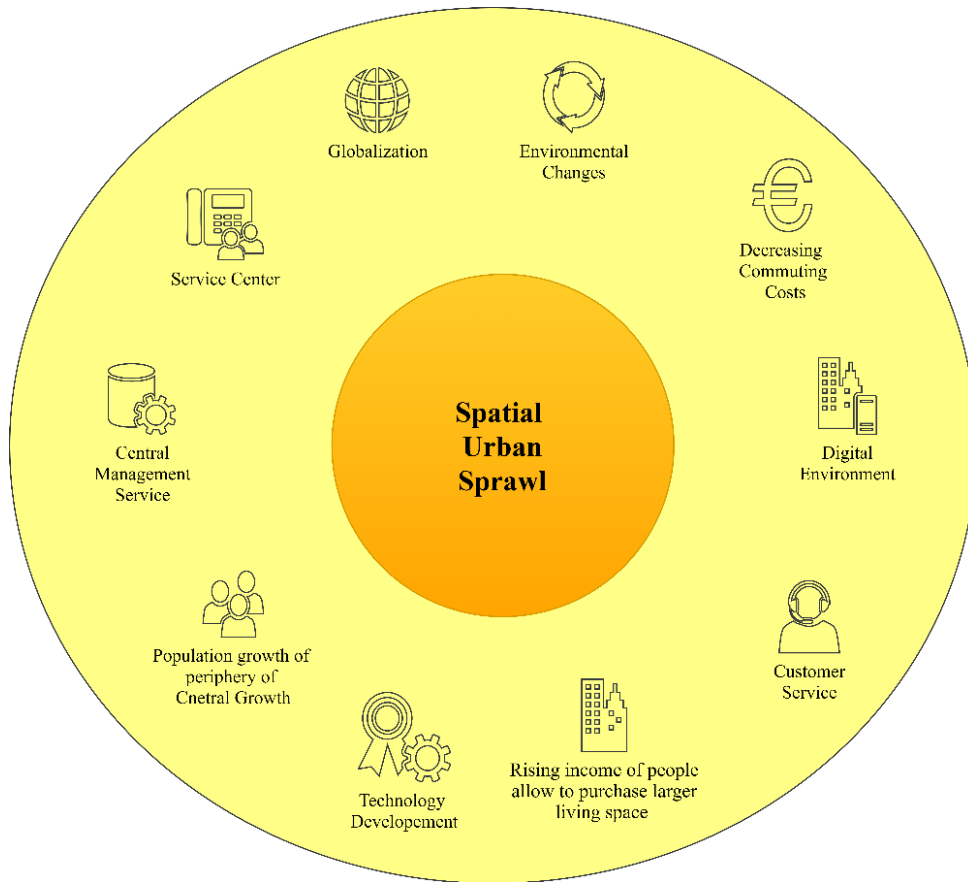


Figure 3: Major driving forces of urban sprawl (Carruthers & Ulfarsson, 2002)

Nepal has a profound effect on land management in the case of labor migration. Two examples are provided in the hills of Nepal, where the growing emigration trend continues unabated and the consequences of this trend. The aim of this study is to understand the impacts on land management and how this affects households from the resulting labor shortage (Jaquet et al., 2019; Noszczyk, 2019; Ishtiaque et al., 2017). The change in land use is a result of a combination of human and environmental drivers. Studying the interplay of these drivers helps shed light on actual changes and concessions (Verburg et al., 2015).

In rural and sub-urban area land are less expensive. In Nepal most of the people are working on abroad, they earned greater amount of money with comparison to people in Nepal. Due these reasons, most of the peoples can purchased the house and land in urban area. Historical

increment of real estate business in urban areas helps to increase land fragmentation. Many peoples purchased the plot of land having small area for residential purpose in outskirts of metropolitan city and municipality. Every development increased the infrastructure and providing better framework for residential development.

After new development take place, the demands of residents are increased, such demands are: improvements in transport infrastructure, health and education facility. So, land developers and real estate developers utilize these facilities to develop the residential area outside the city center (Gillham et al., 2002). Technology and service center has been identified as another major indicator of urbanization and urban sprawl. Use of computer has Impact on individuality that implies reducing of human relationship and production of better quality of goods/services at low costs, efforts and time. So, developers, contractors used computer technology in development activities in urban area. Also, age has been considered as chief factor to determining the spatial pattern of urban sprawl. Specifically, younger families promote sprawl and patterns by seeking out affordable housing options at the urban fringe (Zhang, 2001). That why urban sprawl cannot be define by a single parameter (Kasanko et al., 2006).

Galster et al., (2001) describes urban sprawl; that is pattern of land use land cover defines sprawl as a pattern of urbanized area which exhibits eight different dimensions they are: density, continuity, concentration, clustering, centrality, nuclearity, mixed uses and proximity. These eight attributes also combine two dimensions of the compacity/sprawl characterisation: physical and functional. The physical compactness refers to the spatial configuration of land use development within the city, the functional compactness to the density and the mix of daily activity for the purpose of this work this eight-dimensions will be considered whenever the information is available. Finally, it should not be overlooked that even though sprawl may be

an unsustainable form of growth, people strongly prefer to live on larger lots in suburban communities. Summarization of major drivers are presented below in Figure 4.

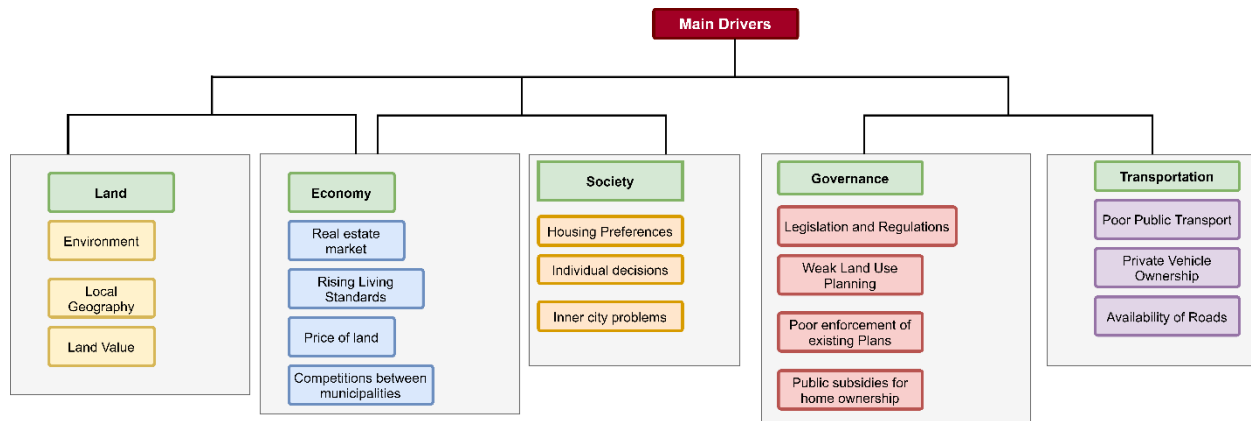


Figure 4: Main drivers of current urban sprawl in Nepal (Nikolov, 2013)

### 1.7.3 Consequences of urban Sprawl

The impact of urban sprawl can be felt throughout time. Although single-family home construction is plainly apparent and may be deemed significant in overall urban sprawl, the long-term impact over a longer period of time is difficult to predict (Christiansen & Loftsgarden, 2011). The commonly held belief that this type of growth pattern provides relatively affordable housing possibilities and a supposedly greater quality of life must be evaluated against these negative repercussions of sprawl. Alterations caused by a single landscape are often underestimated and downplayed, according to the authors, and therefore the cumulative repercussions of urban development are overlooked (Thapa & Murayama, 2012). This impact was dubbed the 'pitfall of marginalization' by the authors. Urban sprawl has been described as having a negative impact in terms of crowding, accessibility, agricultural land degradation, and bad social infrastructure (Li et al., 2018). Another way to describe the effects of urban sprawl is in terms of infrastructure, utilities, and related services efficiency. Urban sprawl has a direct impact on people's livelihoods, property values, commuting, and a variety of other facets of the

urban environment (Lynch, 1984). With the expansion of impervious surfaces and the blocking of river channels or stream channels as part of the urbanization process, flood vulnerability and risk will rise (Feyen & Dankers, 2009).

While the research points to a variety of social and economic repercussions of urban sprawl, this article focuses on environmental issues. Air pollution from automobile dependence, water pollution caused in part by increased impervious surfaces, loss or disruption of environmentally sensitive areas such as critical natural habitats (e.g., wetlands, wildlife corridors), reductions in open space, increased flood risks, and overall reductions in quality of life are just a few of the negative consequences (Kenworthy & Laube, 1999; Hirschhorn, 2001; Kahn, 2000). Due to the increasingly sophisticated road network plans for the future, in the 2000s the building areas continued to expand on the major roads which link the outskirts to five municipalities and there is no sign it will cease any time soon. Most of the newly built areas replace farmland that was once considered the most productive and fertile in the country (Ishtiaque et al., 2017).

The reliance on automobiles, in particular, has contributed to deterioration of air and water quality as well as the rapid depletion of fossil resources (Nechyba & Walsh, 2004). While new urban models have provided insight into urban dynamics, in South Asian countries there are still limited deeper understanding of physical and socioeconomic patterns and urbanization processes. Emerging geospatial technology bridges the spatial data gap recently but there are still very few empirical case studies (Thapa & Murayama, 2011). In general, population density, the gross domestic product per head, passenger volume and the amount of goods loaded and unloaded per head were the most relevant variables affecting landscape fragmentation (EEA & FOEN, 2011).

A number of environmental effects are associated with landscape fragmentation caused by transport infrastructure and built-up areas. It significantly contributes to the decline and loss of wildlife populations and to the growing threat to species, by dissecting and isolating populations

and affects water regime and landscape recreation (EEA & FOEN, 2011). The number of automobiles in the United States has far exceeded population expansion, and car owners are driving longer distances than ever before (Dunphy et al., 1997; Daniels, 2001). Land is being consumed at a faster rate as populations shift from urban areas to suburban fringes (Porter, 2000; Kahn, 2000; Dwyer & Childs, 2004).

#### 1.7.4 Types of Urban Sprawl

To determine the characteristics of urban sprawl, one must first identify the type of sprawl that is occurring (Christiansen & Loftsgarden, 2011). Depending on the country and its context, urban sprawl can take many forms. Following figure depicts the type of sprawl described by (Batty et al., 2003). According to their findings, in addition to the relationship between newly grown urban patches and pre-growth patches, there are three distinct types of urban growth (Xu et al., 2007). These are infilling, edge expansion, and spontaneous growth according to their findings. The relative importance of different growth types can help explain how the landscape pattern changes over time (Francis & Chadwick, 2013; Li et al., 2013) The Landscape Expansion Index value determines whether a growth patch is referred to as infilling, edge expansion, or spontaneous growth. There are three types of urban growth: infilling, edge expansion, and spontaneous growth, according to Xu et al., (2007) each type of growth has a different level of dominance in the population. Figure 5 represents the hypothetical sequence of the spatial evolution of an urban area.

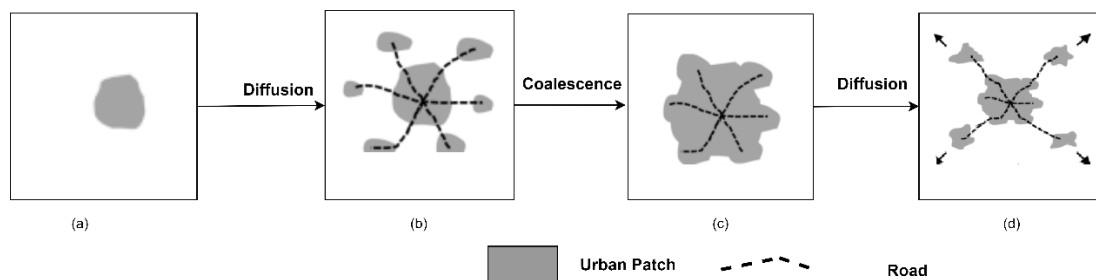


Figure 5: Hypothetical sequence of the spatial evolution of an urban area (Xu et al., 2007)

Characterization of agricultural to urban landscape transition patterns and processes in Hanoi used a hypothetical model of spatial evolution (Dietzel et al., 2005). The urban land area grows as a result of diffusion and coalescence in the spatial evolution model (Fig 5). When new developments are built on the outskirts of an urban core, the once-compact landscape (Figure 5a) becomes increasingly fragmented (Figure 5b). They start to aggregate as they grow and eventually cover the entire landscape has grown in population and urbanization (Fig 5c), and the next diffusion–coalescence cycle begins as the city takes things to the next level (Fig 5d). We analyzed the spatiotemporal patterns of urban patches using spatial metrics and the type of urban growth to calculate and monitor these changes. Three urban growth types is presented in Figure 6.

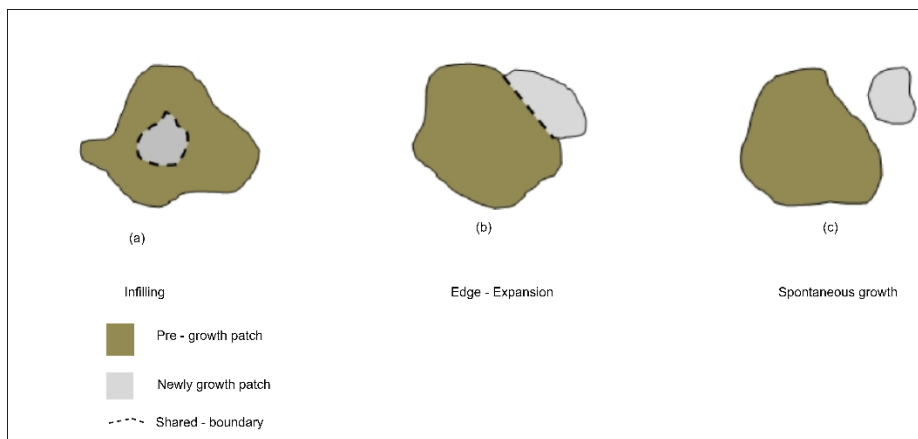


Figure 6: Three urban growth types (Dietzel et al., 2005)

- (a) Infilling types of growth that occurs within urbanized open space and increases built-up area contiguity by filling in that space;
- (b) edge expansion that refers to non-infill development that intersects the urban footprint and extends outward from previous developments; and
- (c) spontaneous growth that neither intersects the urban footprint nor is adjacent to previously developed areas and has the greatest impact on open lands fragmentation.

### **1.7.5 Measurement of Urban Sprawl**

The urban sprawl metrics and indices used come from a variety of fields of study, including urban planning, ecology, and fractal geometry (Frenkel & Ashkenazi, 2008). The extent of urban sprawl can be determined in a number of ways, depending on the parameters, data, and application used. Empirical analysis is one way to gauge urban sprawl. An empirical study of the link between development patterns and the relationship between different variables and the cost of public service (Carruthers & Ulfarsson, 2003). Urban sprawl is a multifaceted issue that is difficult to define, quantify, and evaluate accurately. As a result, switching from a "sprawl" to a "compact" form is more likely to be a direction on a continuum than a specific and measurable one (Frenkel & Ashkenazi, 2008).

Galster et al., (2001) identify eight measurable dimensions: density, continuity, concentration, compactness, centrality, nuclearity, diversity, and proximity. Lopez & Hynes, (2003) find some limitations in the dimensions' applicability, particularly in comparing the spread of metropolitan areas. Simple measures of sprawl in the literature include population density, dwelling unit density, or a gauge of how many jobs have decentralized.

However, as Bourne, (2001) points out that even more important indicators of urban form change are demographics that identify cohorts of people undergoing urbanization or suburbanization. As long as there is no agreed-upon definition of sprawl, a wide range of methods will be used to approach various concepts of sprawl, the efficacy of which will be contested. Urban sprawl is measured by following stages in Figure 7.

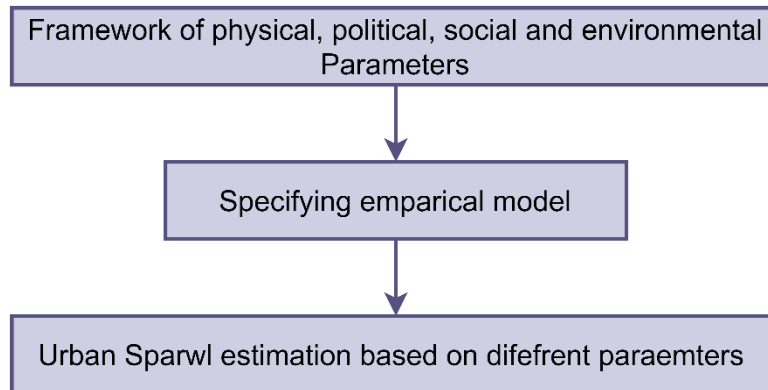


Figure 7: Different stages for measuring urban sprawl (Carruthers & Ulfarsson, 2003).

Different authors were provided stages of urban sprawl in figure 7. Estimation of urban sprawl is based on different parameters such as: total direct, capital facilities, transport facility, sanitation system and water supply facilities, housing and community development, security, fire protection, open space and parks, education, and libraries (Carruthers & Ulfarsson, 2003).

For urban landscape analysis public officials and the general public can use Urban Footprint to help them determine the best scenarios and outcomes for their communities based on scientific research and data from actual places where people live and work (Pravitasari et al., 2018). By looking at current land use plans in their communities, users can see where new residents, buildings, and urban amenities could be located if the population grows in the future.

### 1.7.5 Characteristics of Sprawl

Various theories explain the phenomenon of sprawl, ranging from development aesthetics to local street patterns (Galster et al., 2001). In spite of the lack of an agreed-upon definition, literature suggests a few characteristics that can help us understand and even quantify the occurrence of sprawling land development. These are a few examples:

**1) Low-density, single family dwellings:** The most commonly cited characteristic of sprawl is the proliferation of large-lot residential housing developments (Knaap & Talen, 2005). That consume vast amounts of previously-vacant or productive land (Song & Knaap, 2004). The

number of dwelling units per neighborhood, median lot size, or median floor space for single-family homes can all serve as indicators of density (Song, 2005).

**2) Automobile dependency even for short trip:** As a result of sprawling development patterns that separate land uses and create large distances between dwelling units, residents must rely on automobiles instead of public transportation. Cul-de-sacs dominate street patterns in these neighborhoods, which creates a lack of connectivity and makes it difficult to get around on foot or bike to nearby attractions (Benfield et al., 1999). Auto dependence also promotes the development of homogeneous neighborhoods with a lack of variety in land uses (Song & Knaap, 2004).

**3) Spiraling growth outward from existing urban centers:** Low-density development rapidly spreading away from more compact urban centers is another way to describe sprawl. In the United States, about 80% of newly constructed housing acreage is located outside of urban areas, and 94% of this land is divided into lots of 1 acre or more (Heimlich & Anderson, 2001).

**4) Leapfrogging patterns of development:** Dispersed development is another well-known characteristic of sprawl. It favors the development of parcels located further out in the countryside over vacant lands adjacent to existing development (Torrens & Alberti, 2000). Leapfrogging results in an ad hoc development pattern that uses up a lot of land.

**5) Strip Development "Ribbon" development:** Another prominent feature of sprawl is the development of roads that extend outward from urban centers, housing or commercial properties (Tsai, 2005). Homes located near rural highways pose a traffic safety risk; commercial strips containing fast food chains and large retail outlets cater to car access and are frequently surrounded by parking lots.

**6) Undefined edge between urban and rural areas:** The line between urban and rural areas is becoming increasingly blurred as residential development spreads outward from urban areas

(Heimlich & Anderson, 2001). This type of development is frequently linked to the encroachment of open space and agricultural lands.

It's important to remember that sprawling development patterns are tied to the surrounding urban-suburban environment. In Houston, low-density housing may mean one thing and in a small town in coastal Maine, it may mean something else. Additionally, one development project or neighborhood does not automatically lead to sprawl; rather, sprawling development must be examined as a regional pattern. as an overarching development pattern.

### **1.7.6 Land Use Land Cover**

The terms land use and land cover are frequently used interchangeably, each term has a distinct meaning. Land cover is anything that covers the ground's surface, such as vegetation, urban infrastructure, water, or bare soil. By identifying the land cover, we can use that data as a starting point for other activities like thematic mapping and change detection analysis. This is a term that describes the use of land, such as recreation, wildlife habitat, or farming (Mallupattu & Sreenivasula Reddy, 2013). LULC has crucial relation to topography, lithology, soil type, rainfall, socio-cultural practices, and relative location all influence land cover in different ways. As previously stated, land use planning relies on a variety of different factors. Land use planning also involves the abstraction of a feature and grouping it into the appropriate category. Classification is a methodical approach to classifying things into different groups, adding appropriate clusters, and assigning a relationship between those groups.

### **1.7.7 Cellular automata**

Cellular automata (CA) are a computational method, capable of simulating growth process by describing a complex system through a set of simple rules (Mantelas et al., 2008). It was designed for simulation of hypothetical urban growth in future. This model consists of a set of

rules that describe the spatial interaction of cells and a set of parameters that lead to explore different urban forms. CA ability in the simulation of urban growth, land use change and population expansion had become suitable for simulating complex geographical process (Feng et al., 2011). Space is tessellated into grid cells with initial state  $C_{ij}^{t=0}$ , state of cell (l, j) at time t + $\Delta t$  can be expressed as:

$$C_{ij}^{t+\Delta t} = F (C_{ij}^t, O_{ij}^t, R)$$

Where;

$C_{ij}^t$  is the cell state at time t

$O_{ij}^t$  is the state of cell in its neighborhood

R represents transition rules

$\Delta t$  is small

By using this equation and transition matrix will generate the Urban Growth Model (UGM).

### **1.7.8 Analytical Hierarchy Process (AHP) and Multi-Criteria Decision Analysis (MCDM)**

The analytic hierarchy process, a structured technique for dealing with complex decisions, was used to structure flood causative factors in the application of multi-criteria decision analysis. Theoretically, the AHP aids decision makers in finding the solution that best suits their needs and understanding of the problem, rather than prescribing a correct decision. The implication here is that AHP is a decision-making approach based on people's genuine ability to make critical decisions. To perform the AHP the goal of the project should be identified which in this case is land use suitability for present and future built up. A number of Criteria or parameters are fixed to be ranked accordingly. Following Figure 8 shows the general structure of analytical hierarchy process.

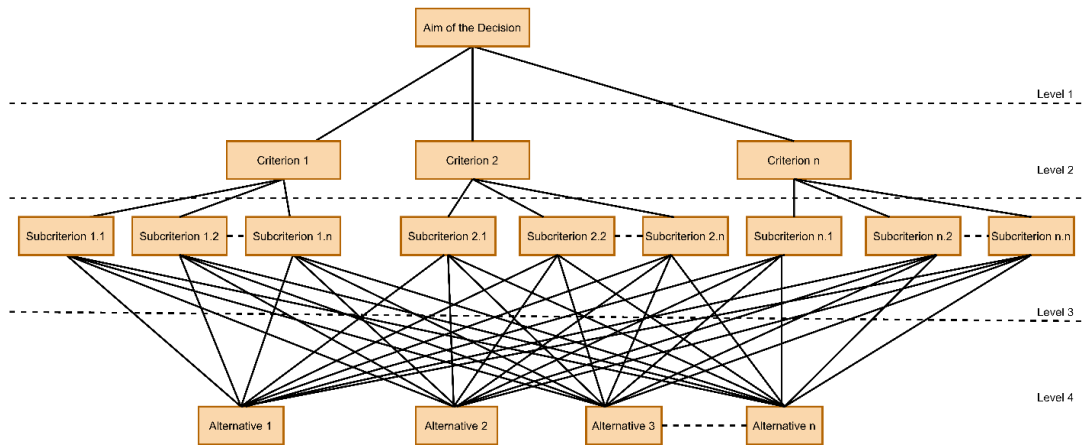


Figure 8: The general structure of AHP for MCDM, modified from (Wątróbski et al., 2016)

Once the hierarchy has been constructed, the expert(s) and participants use AHP to establish priorities for all of the hierarchy's nodes. It's a great way to gather and process information from experts and participants at the same time. According to its architecture, priorities are distributed in a hierarchical manner, with the values of those priorities being determined by the information entered by process users, as shown in the following table. Multiple pairwise comparisons in AHP are based on a standardized comparison scale with nine levels. Psychologists have determined that a person can compare and consistently rank a maximum of nine objects simultaneously. Pairwise decisions are based on the best available information and the decision maker's knowledge and experience.

Multiple pairwise comparisons in AHP are based on a standardized comparison scale with nine levels. A person can compare and rank up to nine different objects at once, so psychologists decided to use that number. Pairwise decisions are based on the best available information and the decision maker's knowledge and experience. The importance level (priority weight) for each of the selected parameters are given below in Table 1.

Table 1: Priority weight for each selected parameters (Saaty, 2008)

Intensity of importance	Definition	Description
1	Equally important	Two factors contribute equally to the objective.
3	Moderately more important	Experience and judgement slightly favor one over the other.
5	Strongly more important	Experience and judgment strongly favor one over the other.
7	Very strong more important	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice.
9	Extremely more important	The evidence favoring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed.
Reciprocal of above	If an element I has one of the above numbers assigned to it when compared with element j, then j has the reciprocal value when compared with i	
Ratios (1.1-1.9)	If the activities(elements) are very close	May be difficult to assign the best value, but when compared with other contrasting activities (elements) the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities (elements).

There are four steps to the AHP process: build a decision tree; determine the relative importance of attributes and sub-attributes; weigh each alternative against each attribute; and verify that the subjective evaluations are consistent. Each alternative is evaluated and its overall weight is calculated (Schoenherr et al., 2008). The process of AHP can be summarized in four steps: construct the decision hierarchy; determine the relative importance of attributes and sub-attributes; evaluate each alternative and calculate its overall weight in regard to each attribute,

and check the consistency of the subjective evaluations. T. Let  $C_j \{c_j \mid j= 0,1, \dots, n\}$  be the set of criteria. The result of the pairwise comparison on  $n$  criteria can be summarized in an  $(n \times n)$  evaluation matrix  $A$  in which every element  $a_{ij} \{i, j=0,1,2,3..n\}$  is the quotient of weights of the criteria, as given in Equation (1)

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}, a_{ii} = 1, a_{ji} = 1/a_{ij}, a_{ij} \neq 0 \quad (1)$$

The relative weights are given by the right eigenvector ( $w$ ) corresponding to the largest eigen value  $\lambda_{max}$  ( $\lambda$ ) as in Equation (2).

$$A_w = \lambda_{max} w \text{ -----} (2)$$

The final consistency ratio (CR), usage of which lets the user to conclude whether the evaluations are sufficiently consistent, is calculated as the ratio of the  $CI$  and the random index ( $RI$ ), as expressed in Equation (3). The values of  $RI$  are tabulated in the following table (V. Ammarapala et al., 2018).

$$CR = CI / RI \text{ -----} (3)$$

Random index ( $RI$ ) used to compute consistency ratios ( $CR$ ) which is presented in Table 2.

Table 2: Random Index (Saaty, 2008)

N	1	2	3	4	5	6	7	8	9	10
Random index (RI)	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

In this analysis maximum threshold of the CR is 10 percent, and in case of exceedance a three-step procedure is followed

- i) find the instance where the decision maker's judgment is the most erratic

- ii) determine a range of values to which the inconsistent judgment can be changed in order to reduce the associated inconsistency,
- iii) and ask the decision maker to reconsider the judgment to a "reasonable value."

Table 2's random index is created by averaging the CI of a randomly generated reciprocal matrix. The measurement of consistency can be used to assess the consistency of decision-makers and the overall hierarchy (Schoenherr et al., 2008). The above AHP steps (Figure 9) can be summarized into five fundamental steps as follows (Wang & Yang, 2007).

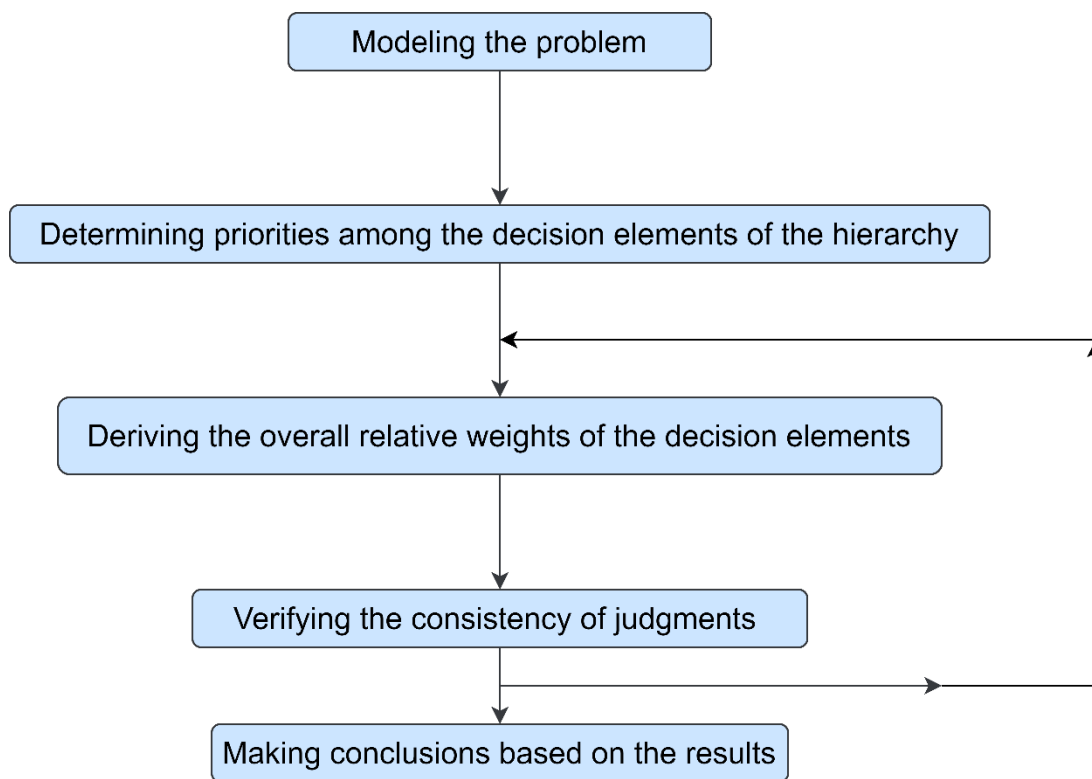


Figure 9: AHP steps (Wang & Yang, 2007)

### Step 1: Modeling the problem

The first step entails stating the issue, broadening the scope of the problem's objectives by taking into account all stakeholders, goals, and the resulting outcomes, and identifying decision elements such as alternatives and criteria or decision rules.

In a hierarchical decision-making process, the decision elements are arranged into four categories: goal, criterion, sub-criterion, and alternative. This is considered the most critical step in the AHP process (Zahedi, 1986). The overall goal (i.e., level 1) occupies the highest position in the hierarchy, such as the objective of selecting the best alternative. It's important to remember that the decision rules or criteria that help you achieve your overall goal are found at the second (i.e. level 2) level of the hierarchy. This level can be increased in complexity based on the level of detail considered for each decision rule or criterion. The alternatives that the decision analyst or maker will select are found at the lowest level (i.e. level 3).

### **Step 2: Determining Priorities among the Decision Elements of the Hierarchy**

This step involves using a pairwise comparison technique and a rating scale of relative importance to collect ratings for each of the criteria and alternatives. Using the pairwise comparison method presented in a matrix, this step solicits input from experts and/or stakeholders to determine the relative importance of one criteria or alternative to another (Saaty, 2008). The number of comparisons for the decision elements (i.e. criteria or alternatives) in a specific level is derived from  $(\text{Number of comparisons} = n(n - 1)/2)$  (Vaidya & Kumar, 2006). Each comparison (e.g., Criteria 1 versus Criteria 2 or Alternative 1 versus Alternative 2) is rated by a group of experts using the scale developed by Saaty, (2008) for a pairwise comparison technique. It's common practice to use a questionnaire and geometric mean to arrive at an overall solution when reaching a consensus among a group (Teknomo, 2017).

### **Step 3: Deriving the Overall Relative Weights of the Decision Elements**

Using a pairwise comparison matrix for the criteria and for the alternatives, the relative importance of each criterion and the relative importance of each alternative to the criteria are determined in this step (Step 2). For each criterion and alternative, normalized values are

calculated and normalized principal eigenvectors or priority vectors are determined. This is accomplished by: (herein also referred to as relative weights). In order to arrive at the normalized values for each criterion and alternative in the matrices, the value of each cell is divided by the sum of the columns. For each criterion and alternative, this procedure yields a column total of one. Next, the weighted averages are computed for each matrix's rows. The resulting values show the relative importance of the criteria in relation to the goal, and the relative importance of the alternatives in relation to the criteria. The relative weights of the alternatives are calculated by multiplying the relative weight of each criterion by the relative weight of the alternative for that criterion (Teknomo, 2017). If the expert opinions are in agreement, the decision makers can use the overall relative weights of the options to make their choice.

#### **Steps 4 and 5: Verifying the Consistency of Judgments and Making Conclusions Based on the Results**

Before making a decision, these steps are essential for determining the consistency of the evaluation. Instead of computing overall relative weights for all alternatives, it would be preferable to first calculate CRs for all matrices (i.e., criteria and alternatives) before moving on to computing those overall relative weights. Calculate each criterion or alternative's maximum eigenvalue, consistency index, consistency ratio, and normalized values. According to Saaty, (2008), if the ratio is greater than 0.1, the set of judgments may be too inconsistent to be relied upon. As a result, a CR of less than 0.1 percent (or 10 percent) is acceptable. When the results are inconsistent, the procedure is repeated until the CR falls within the desired range. The results are then used by decision makers to reach a decision.

#### **1.7.9 Land Suitability analysis for built – up area**

Nepal faces numerous challenges in urban planning, including where to locate public amenities like open space and parks. The assessment of land suitability is a foundation for maximizing

the use of available land resources for sustainable agricultural production. There are different factors which plays crucial roles for land suitability analysis for built up area. These factors are: (i) Physical factor (ii) Accessibility factor (iii) Social Factor (iv) Economic Factor (v) Environmental factor. The subsequent investigation for a suitable site was carried out using five major factors, and the combination of these five criteria has assisted in the identification of various possible locations for future development (Saha & Roy, 2021).

- i) **Physical factor:** Elevation, slope, aspect are the fundamental parameter for setting up urban and settlements in hilly and terai region. The land having steep slope is not suitable for settlements (Saha & Roy, 2021). Due to land slide at rainy season and high construction costs steep lands are not suitable for built – up area. So plain regions are suitable for settlements. For most of the development projects like: road accessibility, water supply, sewer line, city hall, open space and parks, high rise buildings, shopping malls, hotels etc. are suitable for flat area and it should be examined properly.
- ii) **Accessibility factor:** Better connectivity of transport network with the entire metropolitan city and other locations are the prime requirements of settlements commercial purposes. proximity to the transport facilities (road, railways, airport) play vital role to influence people who frequently use this service (Saha & Roy, 2021). Road construction is costly, so the government builds new roads in areas where there are many settlements. This encourages residents to choose an area with good road connectivity before moving there.
- iii) **Social factor:** Every people' s has wish to find out a residence where socially favourable for them. Also important in new built-up development is the population and housing density, because people prefer to live in a less crowded area rather than one that is congested and congested.

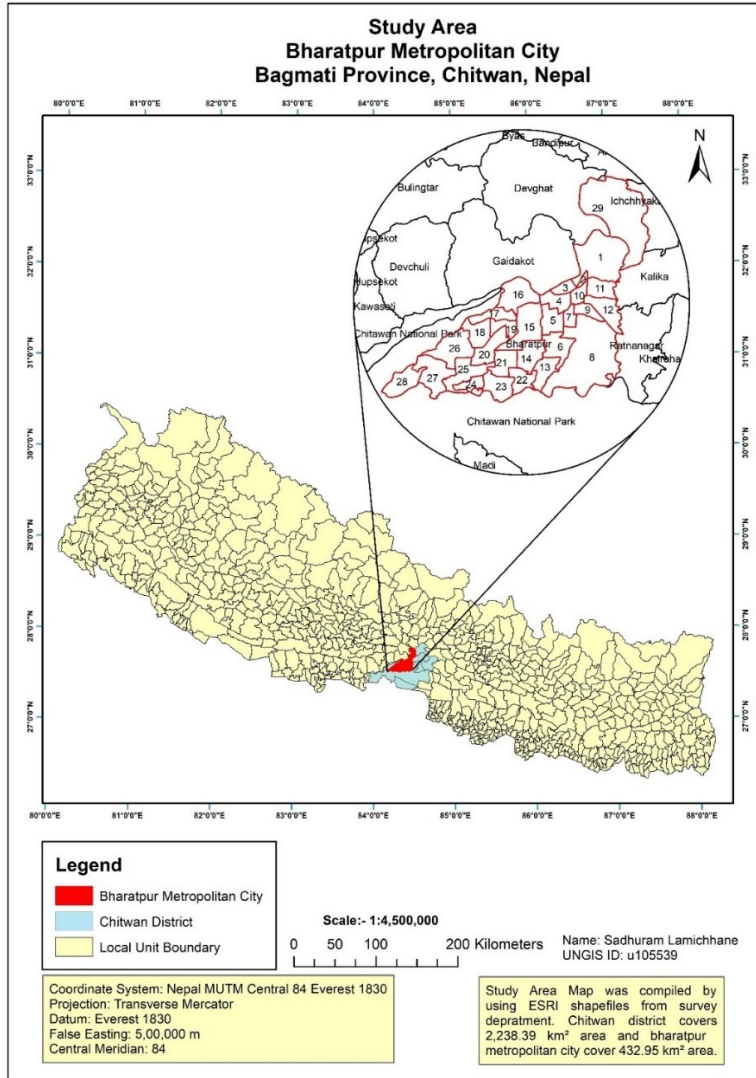
- iv) **Economic factor:** Many people wish to commercial center near to their residence in city area. Most people in these cities want to buy a plot for a lower price that is typically located outside of the city center, while only a small percentage want to buy in the city for any price in order to take advantage of the city's civic amenities (Saha & Roy, 2021). Nevertheless, for the general public, land price is an important determinant of new housing construction.
- v) **Environmental factor:** it plays crucial role for identifying suitable locations for most of the development activities. Most of the construction projects have been implemented by preserving the environment. Builders and government entities should run the development projects by protecting the forest, lakes and water bodies, valleys and mountains, natural heritages etc. So, land use land cover, distance from river and water bodies, distance from canals should be taken to identify the built – up suitability.

## 1.8 Location of the Study Area

### 1.8.1 Geography

Bharatpur is a city in Nepal that's expanding at a rapid pace. It is located on the Narayani River's left bank and is a commercial hub for the Chitwan district and the central region of Nepal. It's in the middle of the Kathmandu-Birganj (North-South) road corridor, on the Mahendra Highway.

The proximity of this city to Kathmandu (146 km), Pokhara (126 km), Butwal (114 km), Ghorahi (275 km), Birganj (128 km), Hetauda (78 km) and Prithivi Narayan (Gorkha) (67 km) has increased the importance of its advantageous geographical location. Bharatpur is well-connected via road and air, with daily flights to Kathmandu and Pokhara. Study area map is presented in Map 1.



Map 1: Study area map

It lies between 84° 09' 41" & 84° 29' 05" east longitude and 27° 32' 58" & 27° 45' 40" North latitude. Ratnanagar Municipality, Chitwan district covers 2,238.39 km<sup>2</sup> (864.25 sq mi), and in 2011 had a population of 579,984 (279,087 male and 300,897 female) people (CBS, 2011). Bharatpur metropolitan city is largest city of Nepal after Kathmandu, is its administrative center and it covers 432.95 Sq. Km. According to CBS 2011 total population of BMC are 280,502. Male and Female population of BMC are 134,001 and 146,501 respectively.

### 1.8.2 Climate

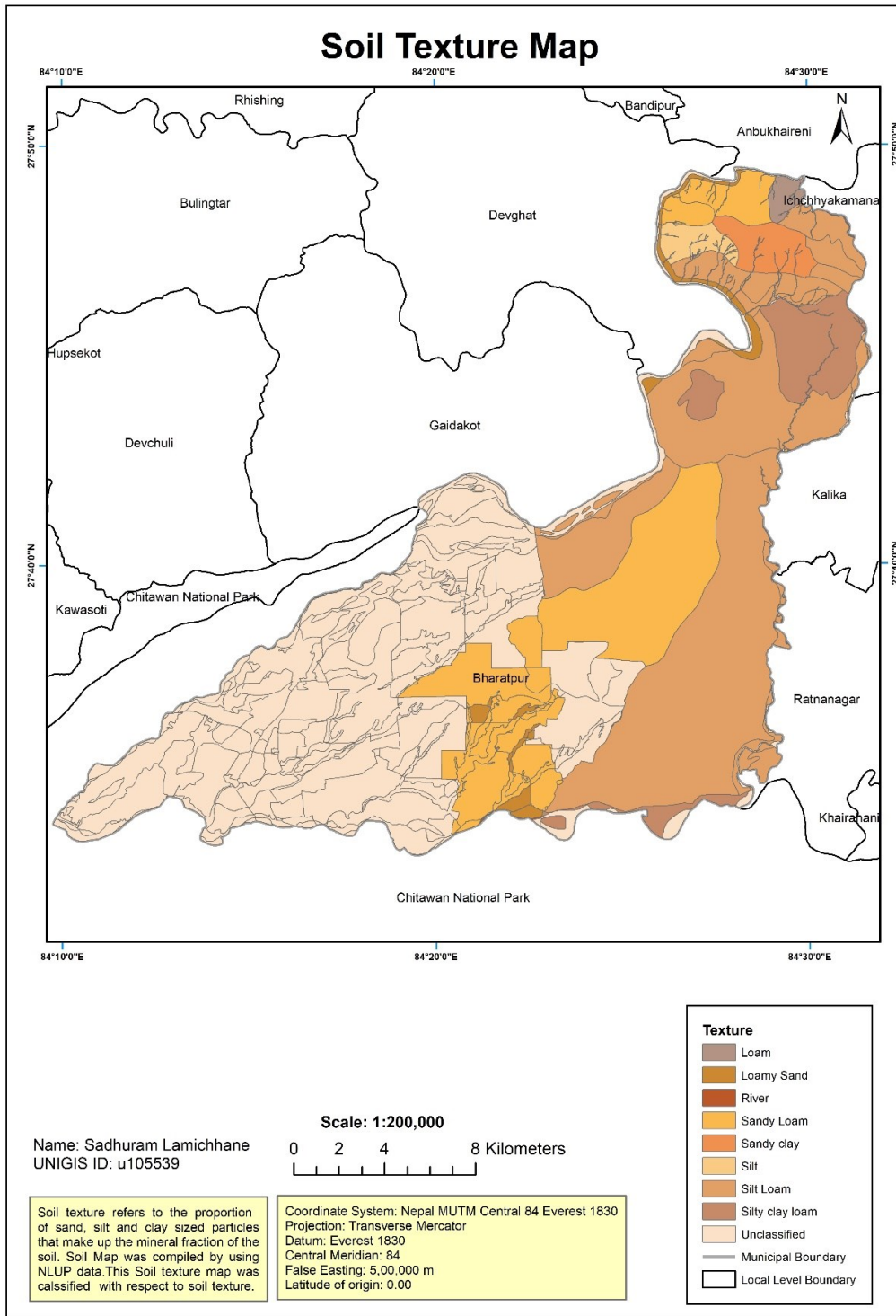
Bharatpur Metropolitan City has climatic variations, which is associated with the diverse nature of its topography and altitude pronounced by terai and hilly regions formed by various rivers and lakes. A mild climate characterizes the area, with days that are warm but not oppressive. Summers have significantly more rain than winters. Bharatpur has an annual average temperature of 25°C. This area receives approximately 1500 millimeters of rain per year which is presented in Table 3.

Table 3: Annual climate data of BMC

Average Rainfall	1500 mm
Average Temperature	25 °C
Lowest Temperature	10 °C
Highest Temperature	40°C

### 1.8.3 Soil

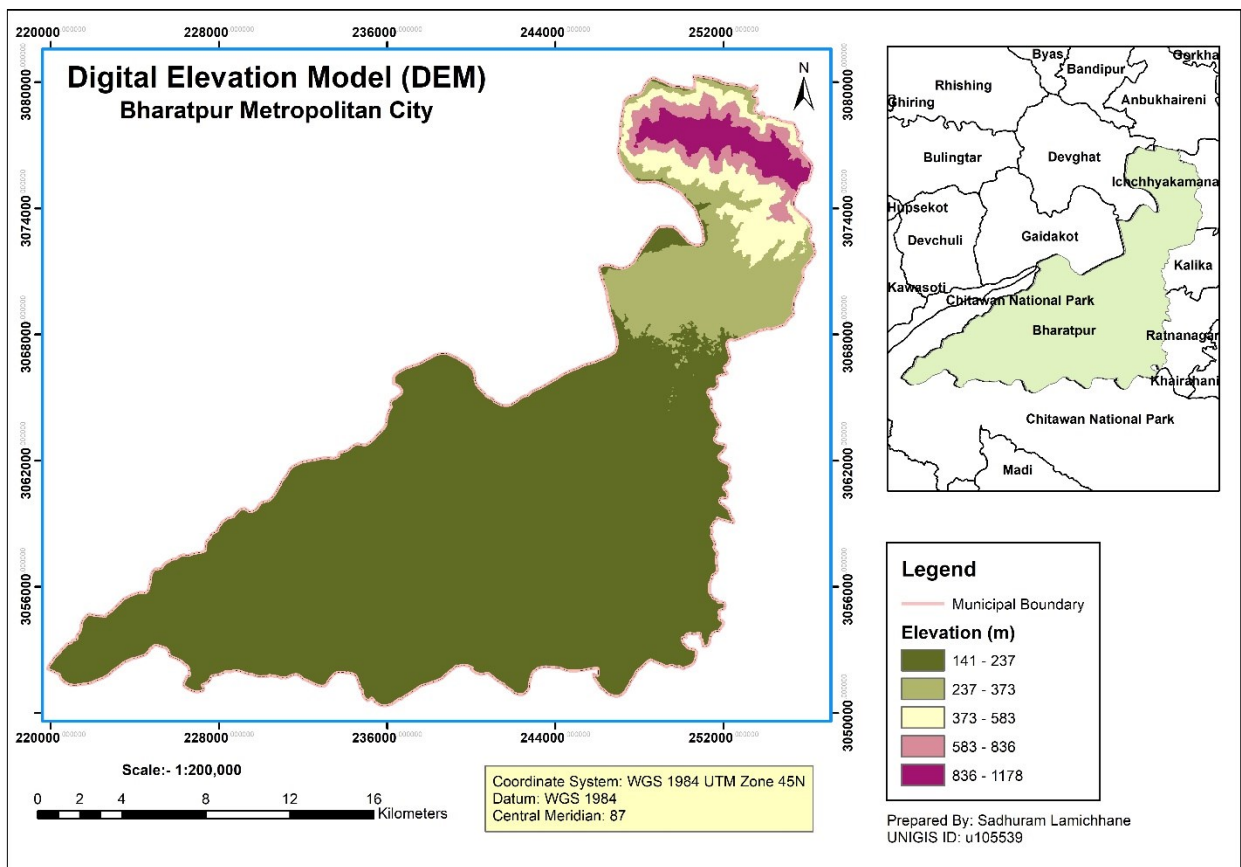
Nepal is a land of extremes; its physiography ranges from alluvial plains in the tropical lowlands to very rugged and permanently snow- and ice-covered high mountains. Nepal is home to many of the world's highest mountain peaks. Tropical and temperate agriculture can be found just a few kilometers apart due to the wide range of climatic conditions. Topography dominates soil formation in such landscapes, resulting in wide variations in soil characteristics, distribution, and depth. Soil texture map of BMC is presented below Map 2. Soil taxonomy map is presented in Appendix III.



Map 2: Soil Texture Map

### 1.8.4 Physiography

Bharatpur is located on the Narayani river's bank and the topography is made up of alluvial soils deposited by the Narayani river, the altitude of Bharatpur municipality varies from 141 meters above sea level to 1178 meters above sea level. Fluvial deposits formed Bharatpur's land, which is flat along the river's banks but gradually rises to the east and north. Elevation map of BMC is presented below in Map 3.



Map 3: Digital Elevation model

Most of the area of this municipality covers lowest elevation. Ward No. 29 cover most of the highest altitude area. Variability of slope measurement was performed by suing DEM data and reclassification of slope map in ArcGIS, which is shown below in Table 4.

Table 4: Slope ranges

Slope ranges	Area (Sq. km)	Area (%)
<3.46°	327.02	75.53
3.46° - 11.46°	58.30	13.47
11.46° - 22.93°	20.03	4.63
22.93° - 35.20°	18.12	4.18
>35.20°	9.48	2.19
Total	432.95	100

### 1.8.5 Social and Cultural Diversity

Total population of the BMC is 280, 502. There are more than 20 ethnic groups in the municipality. The major ethnic groups are Brahman (34.31%), Chhetri (12.61%), Dalit (9%), Gurung (8.73%), Newar (6.15%) etc. Among the more than 10 spoken languages in the municipality 77.83% speak Nepali, 5.17% speak Tharu and 4.21% speak Gurung. BMC has multidimensional cultural heritage, cultural diversities of various ethnic, tribal, and social groups inhabiting different altitudes, and it shows various forms: music and dance, art and craft, folklores and folktales, languages and literature; philosophy and religion, festivals and celebrations; and foods and drinks. Religions practiced in Gandaki Province are: Hinduism, Buddhism, Islam, Christianity, Jainism, Sikhism, Bon, ancestor worship and animism. The majority of peoples are different religions have in harmony through centuries. Devghat, a Hindu pilgrimage site on the banks of the Narayani River and the Kali River Junction, can be found in Ward No. 1 of the City of San Francisco. There are numerous Hindu temples and caves to explore in this area. Due to the two main holy rivers, Devghat is a popular tourist destination as well.

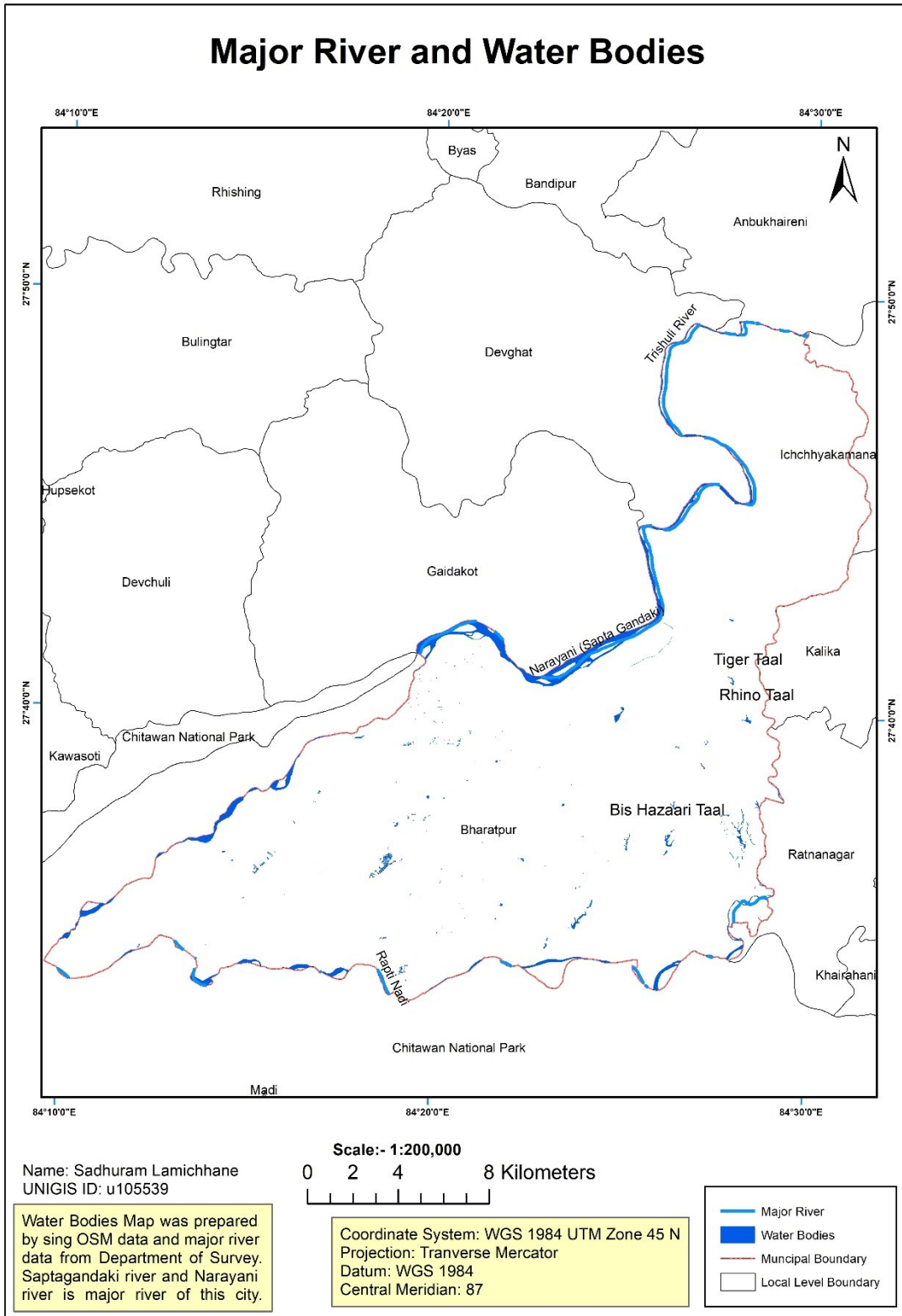
### 1.8.6 Economy

Bharatpur's economy has traditionally been based on agriculture. Small-scale processing industries are also present in the city. These industries mostly deal with the food surpluses from the Chitwan district itself. Their goods are shipped to major Nepalese cities like Kathmandu

and Pokhara, respectively (Business360, 2018). The poultry industry is growing in the district, producing a significant amount of poultry products for the country and providing a significant amount of jobs in the Chitwan area. Honey, mushrooms, and flowers are just a few of the city's other specialty items. Education and health care make up a large portion of the country's economy. Chitwan National Park, nearby, is home to one-horned rhinos, elephants, Royal Bengal tigers, crocodiles, and deer, among other wild animals. After Kathmandu and Pokhara, this is Nepal's most popular tourist destination. Since 1983, the park has been protected as a UNESCO World Heritage Site (WIKIPEDIA, 2018). Chitwan District in Nepal is connected to Nawalpur District by the Narayani Bridge, which spans the Bhote Koshi River. Picnic spots like Nagarban in the Narayani river, which has a few small islands, are very popular.

#### **1.8.7 Major River and Water Bodies**

Narayani and rapti river are major source of water in BMC. There are numerous lakes at Bharatpur city. In Bharatpur's southern suburbs, the Narayani River runs north to south (WIKIPEDIA, 2018). The Rapti River, which runs east-west through Bharatpur, meets the Chitwan National Park's northern border as it flows through the region. Major rivers and water bodies in Bharatpur metropolitan city is presented below. "Twenty thousand lakes" (Bishazari Tal) is a region in south Bharatpur. The lake is a popular spot for bird watching, and it also has a large number of crocodiles living in it. In the vicinity of Chitwan National Park, Bishazari Tal is 5 kilometers (3 miles) south of Bharatpur's city center, Chaubiskothi. The lake's closest chok (square) is Pandeyghumti, at only 0.62 kilometers (0.37 miles). Major rivers and water bodies is presented in Map 4.



Map 4: Major rivers and water bodies

## CHAPTER 2: METHODOLOGY

### 2.1 Data Acquisition

Data have been acquired from different sources. Firstly, Landsat imageries and digital elevation model from USGS Landsat collection sources (<https://earthexplorer.usgs.gov>), Administrative boundary shapefiles was acquired from Survey Department of Nepal (<https://dos.gov.np>) and (<http://nationalgeoportal.gov.np/>). Secondary data acquired from Bharatpur Metropolitan City (<https://bharatpurmun.gov.np/>), statistical data acquired from Central Bureau of Statistics (CBS) (<https://www.npc.gov.np/>), parent soil data, soil texture data acquired from National Soil Science Research Center NARC (<https://soil.narc.gov.np/soil/soilmap/>). Road network data was acquired from HIMS department of road (<https://dor.gov.np/home/page/hims-and-ict-unit>).

#### 2.1.1 Satellite Data

Landsat 4 – 5 TM imageries for 1990, 2000, 2010 and Landsat 8 (OLI/TIRS) for 2020 with path/row 142/41, having 30m ground resolution was downloaded and extracted by administrative boundary of BMC. Detail band description is shown below. Landsat 4-5 Thematic Mapper (TM) images include seven spectral bands with a spatial resolution of 30 meters for Bands 1 to 5 and 7. Its spatial resolution is 120 meters, but its pixel size is resampled to 30 meters for Band 6 (thermal infrared). The scene spans 170 kilometers north-south and 183 kilometers east-west (106 mi by 114 mi). : Landsat TM 5 band description is described in Table 5.

Table 5: Landsat TM 5 band description

Landsat Missions: Landsat 5 TM
Image acquisition date: 4/16/1990, 12/05/2000 and 12/3/2010
Ground Sampling Interval (pixel size): 30 m reflective, 120 m thermal
Path/Row: 142/41

<b>Band</b>	<b>Wavelength (µm)</b>	<b>Resolution(m)</b>
Band 1 - Visible	0.45-0.52	30
Band 2 - Visible	0.52-0.60	30
Band 3 - Visible	0.63-0.69	30
Band 4 - NIR	0.76-0.90	30
Band 5 - NIR	1.55-1.75	30
Band 6 - Thermal	10.40-12.50	120 (30)
Band 7 - MIR	2.08-2.35	30

Source: (<https://earthexplorer.usgs.gov>)

Images from the Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) have a spatial resolution of 30 meters for Bands 1 to 7 and 9, respectively which is presented in Table 6. New band 1 (ultra-blue) is beneficial for coastal and aerosol studies. With the addition of band 9, it will be easier to spot cirrus clouds. Band 8 (panchromatic) has a resolution of 15 meters. More precise surface temperatures can be obtained by using thermal bands 10 and 11, which are collected at a distance of 100 meters. The scene spans 170 kilometers north-south and 183 kilometers east-west (106 mi by 114 mi).

Table 6: Landsat 8 band description

Landsat Missions: Landsat 8 OLI/TIRS		
Image acquisition date: 11/28/2020		
Path/Row: 142/41		
<b>Band</b>	<b>Wavelength (µm)</b>	<b>Resolution(m)</b>
Band 1 - Coastal aerosol	0.43-0.45	30
Band 2 - Blue	0.45-0.51	30
Band 3 - Green	0.53-0.59	30
Band 4 - Red	0.64-0.67	30
Band 5 - Near Infrared (NIR)	0.85-0.88	30
Band 6 - SWIR 1	1.57-1.65	30
Band 7 - SWIR 2	2.11-2.29	30

Band 8 - Panchromatic	0.50-0.68	15
Band 9 - Cirrus	1.36-1.38	30
Band 10 - Thermal Infrared (TIRS) 1	10.6-11.19	100
Band 11 - Thermal Infrared (TIRS) 2	11.50-12.51	100

Source: (<https://earthexplorer.usgs.gov>)

### 2.1.2 Digital Elevation Model

Elevation data acquired from (<https://earthexplorer.usgs.gov>) is presented in Table 7. There is an open data set available for download from SRTM 1 Arc-Second Global, which provides global coverage for void-filled data at a resolution of one arc-second (30 meters). There may be voids in some tiles even after a recolor. Earth Explorer's coverage map can be used to see if an area of interest is covered. There is a 2 arc-second by 1 arc-second sampling resolution for tiles north and south of 50° north latitude.

Table 7: SRTM DEM description

Data Set Attribute	Attribute Value
Entity ID	SRTM1N27E083V3, SRTM1N27E084V3
Acquisition Date	2/11/2000
Publication Date	9/23/2014
Resolution	1-ARC
Date Updated	1/2/2015
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

## 2.2 Software Used

- i) **ArcGIS:** As part of the ArcGIS family of products, Esri creates and maintains client and server software, as well as online geospatial information system services. Before

becoming ArcGIS, ARC/INFO was an open-source GIS system that could be used via the command line to perform various tasks with data.

- ii) **ERDAS IMAGINE:** ERDAS IMAGINE is a geospatial and other imagery, as well as vector data, processing software package. Erdas is also capable of handling hyperspectral and LiDAR imagery from various sensors. A 3D viewing module (VirtualGIS) is also available from Erdas, as is a vector modeling module.
- iii) **QGIS:** Open-source desktop geographic information system QGIS allows to view, edit, and analyze geospatial data on a variety of platforms.
- iv) **TerrSet Geospatial Monitoring and Modeling Software:** To analyze and display geospatial digital data, Clark Labs at Clark University developed TerrSet, a geographic information system (GIS) and remote sensing software system (RSS). TerrSet is a PC grid-based system that provides researchers and scientists with tools for analyzing earth system dynamics and making effective and responsible environmental management, sustainable resource development, and equitable resource allocation decisions.
- v) **Urban Landscape Analysis Tool (ULAT):** Undeveloped lands in close proximity to developed areas are at risk of degradation, which is why the Urban Landscape Analysis Tool (ULAT) was created. Land cover data for a particular city can be analyzed using the tool over a variety of time periods. Two maps will be created for each period, one showing the built-up area's density classes and the undeveloped land that has been degraded due to its proximity to the built-up area. Additionally, the tool will classify development that occurs between two consecutive time periods based on how close it is to already existing development.

## 2.3 Data Processing and Analysis

The following methodology describing the process of data preparation, analysis and determination of the result for this study, which is presented in Figure 10.

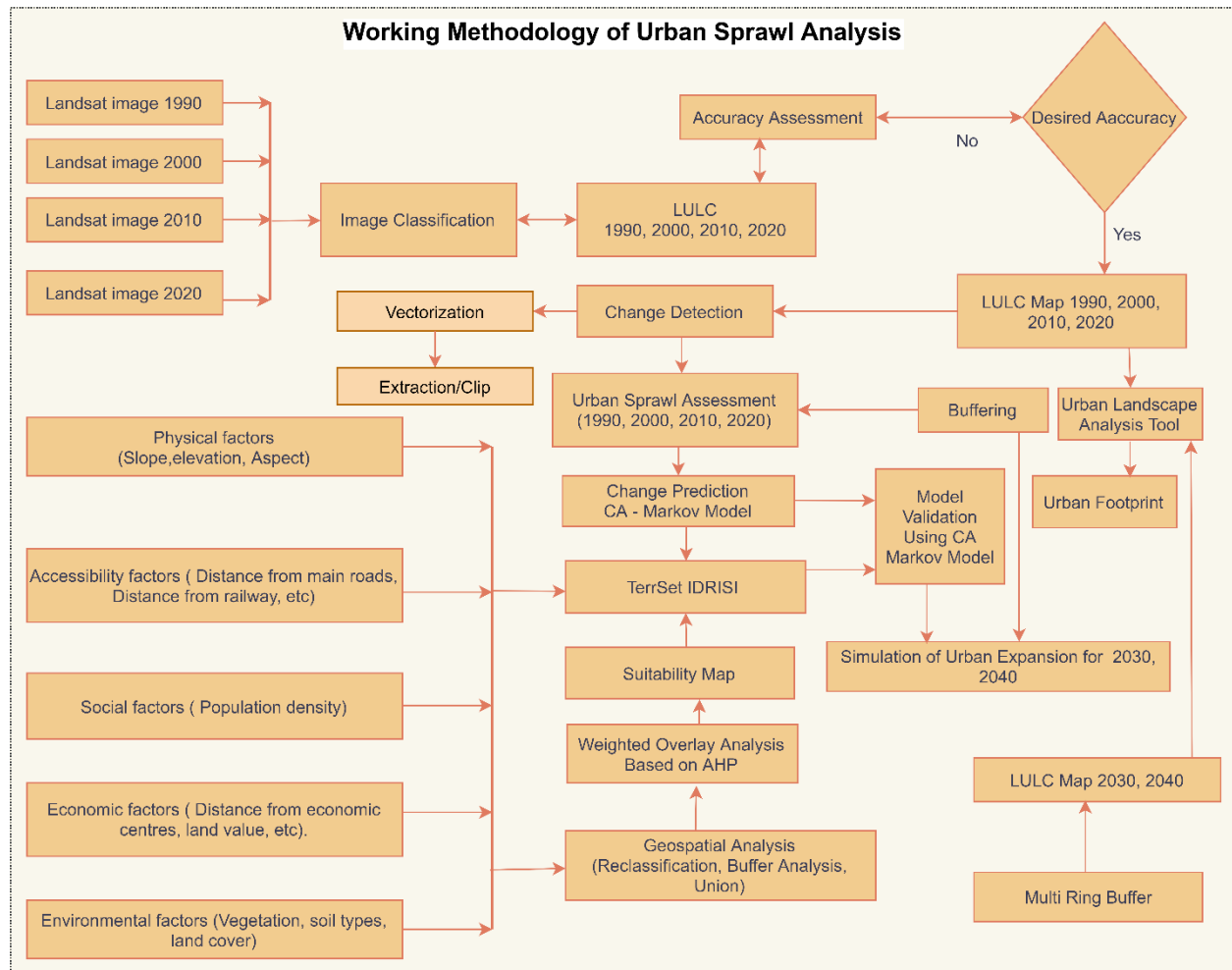


Figure 10: Schematic presentation of Methodology (Koirala, 2018; Parry et al., 2018; Jafari et al., 2016)

Land use land cover pattern and change detection during 1990 – 2020 was analysis by processing and classification of Landsat imageries using ERDAS IMAGINE and ArcGIS software. Accuracy assessment for all these years were Modeled land use land cover maps for 2030 and 2040 was prepared by using previous years land use land cover maps. Urban

footprint maps were derived from urban landscape analysis tool. Suitability analysis for built up area was determined by analytical hierarchy process (AHP).

### **2.3.1. Preprocessing of Satellite data**

Preprocessing of satellite data includes following steps.

- i) Band Composition: Composition of bands for Landsat 5 TM was composite by using “Composite” tools in ArcMap 10.3.
- ii) Extraction: Downloaded satellite imageries tiles were extracted by using tools “Extract by Mask” in ArcMap 10.3. Visualization of extracted imageries was performed by changing true color and false color combinations.
- iii) Reprojection: Extracted imageries was reproject from GCS\_WGS\_1984 to WGS\_1984\_UTM\_Zone\_45N.

### **2.3.2. Image Classification**

Landsat 5 TM imageries and Landsat 8 OLI/TIRS imageries can be easily classified using supervised pixel-based classification. Creating training areas for various classes in pixel-based supervised classification with manual editing. Manual editing was conduct for better classification. These imageries were classified into five classes they are: Agriculture land, Barren land, Built – up area, Forest land and water bodies. Classified imageries were compared to google earth imageries at that time. After comparison, classified imageries were reclassified for area calculation. Finally, land use land cover map for years 1990, 2000, 2010 and 2020 were prepared by following process in Figure 11.

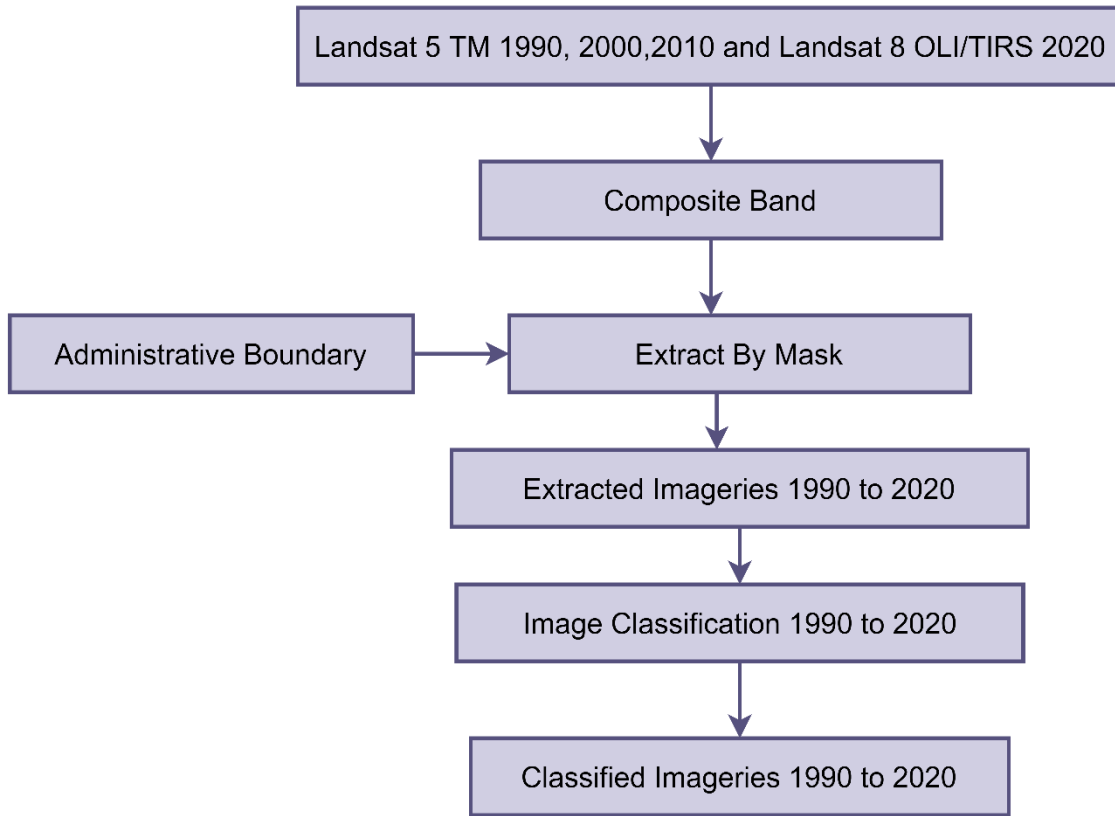


Figure 11: Image classification process (Dhingra & Kumar, 2019)

### 2.3.3. Accuracy Assessment

Image classification generates a raster file with class labels on each of the raster elements. Because image classification relies on samples from different classes, the actual quality of the images must be verified and quantified afterward. There are a number of sampling approaches that can be used to do this, but the most common one compares the classification results to a true world class (Janssen et al., 2001). In order to compare, an error matrix is generated from which various accuracy measures can be calculated.

Field observations yield the "true world class," which is preferable. Sources of a higher assumption are sometimes assumed. Using a reference source, class types are identified and compared to class types claimed on a classified map. Between reference and classification, it

shows the ratio of equally classified pixels to pixels that have not been equally classified. It has a value range of 0 to 1 (there is no agreement between reference and classification) (complete agreement between reference and classification). The following formula can be used to estimate the accuracy of your measurements:

$$\text{Total Accuracy} = \text{number of correct plots} / \text{total number of plots}$$

The Kappa statistic measures the difference between the actual and expected levels of agreement, where K represents the chance for agreement. It does this by contrasting the classification outcome with a fictitious assignment to a new class. The reference pixels are assumed to be dispersed spatially at random.

$$\hat{K} = \frac{\text{observed accuracy} - \text{chance agreement}}{1 - \text{chance agreement}}$$

#### 2.3.4. Change Detection

Land use land cover changes during 1990 to 2020 was performed by intersection of two LULC maps after vectorization of classified raster imageries. Following classes in Table 8 were obtained after intersection of two LULC maps.

Table 8: Change detection classes

Classified Classes	Change Classes	Change
Agriculture Land	Agriculture Land	Agriculture Land - Agriculture Land
Agriculture Land	Barren Land	Agriculture Land - Barren Land
Agriculture Land	Built-up Area	Agriculture Land - Built-up Area
Agriculture Land	Forest Land	Agriculture Land - Forest Land
Agriculture Land	Water Bodies	Agriculture Land - Water Bodies
Barren Land	Agriculture Land	Barren Land - Agriculture Land
Barren Land	Barren Land	Barren Land - Barren Land
Barren Land	Built-up Area	Barren Land - Built-up Area
Barren Land	Forest Land	Barren Land - Forest Land
Barren Land	Water Bodies	Barren Land - Water Bodies
Built-up Area	Agriculture Land	Built-up Area - Agriculture Land
Built-up Area	Barren Land	Built-up Area - Barren Land

Built-up Area	Built-up Area	Built-up Area - Built-up Area
Built-up Area	Forest Land	Built-up Area - Forest Land
Built-up Area	Water Bodies	Built-up Area - Water Bodies
Forest Land	Agriculture Land	Forest Land - Agriculture Land
Forest Land	Barren Land	Forest Land - Barren Land
Forest Land	Built-up Area	Forest Land - Built-up Area
Forest Land	Forest Land	Forest Land - Forest Land
Forest Land	Water Bodies	Forest Land - Water Bodies
Water Bodies	Agriculture Land	Water Bodies - Agriculture Land
Water Bodies	Barren Land	Water Bodies - Barren Land
Water Bodies	Built-up Area	Water Bodies - Built-up Area
Water Bodies	Forest Land	Water Bodies - Forest Land
Water Bodies	Water Bodies	Water Bodies - Water Bodies

### 2.3.4. Urban Sprawl Assessment

After determined the Land use land cover change between 1990 to 2020 sprawl assessment was performed by different ways they are (i) Measuring urban sprawl types with multi ring buffer (ii) Urban footprint measurement. Zero point was set near hakim chowk of BMC. 5 km incremental multiring buffer was created with reference to zero point. Level of sprawl was identified in each of 5 km incremental ring buffer, which shows spatial pattern of built – up area. The graph of incremental buffer versus built up area described better picture of urban spatial concentration and dispersion.

Types of urban sprawl in metropolitan city for each year was determined by “Urban Landscape Analysis Tool”. LULC map were reclassified into three classes they are: urban, water and other data (Pravitasari et al., 2018). Reclassified image was inserted ULAT, which generated three different output maps they are: urban footprint map, urban area map and new development land cover map. Overall workflow for urban sprawl assessment is given below in Figure 12.

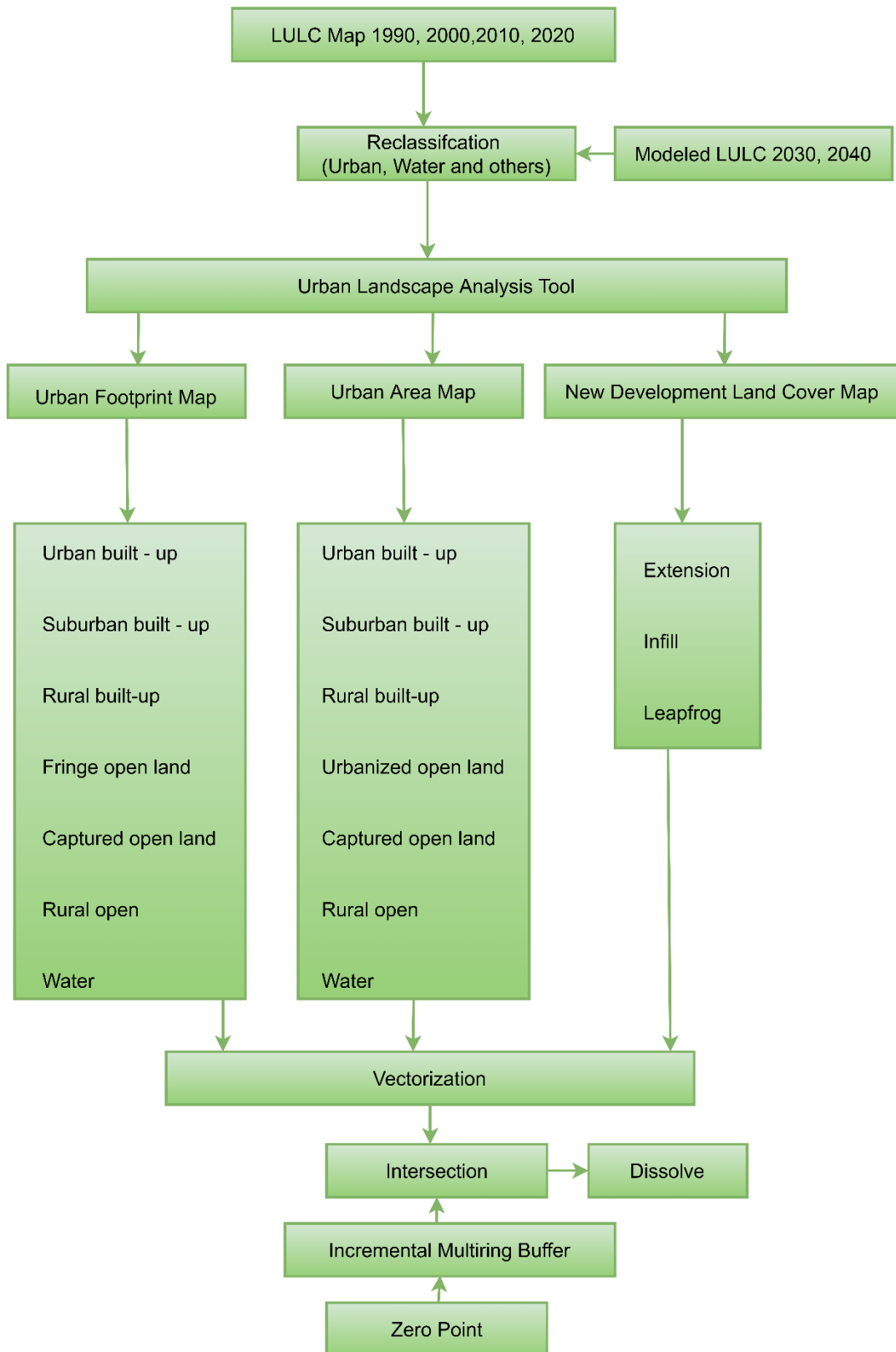


Figure 12: Workflow for urban sprawl assessment (Koirala, 2018)

## 2.4 Land Suitability Analysis for Built – up Area

### 2.4.1 AHP Workflow and Computations

The following steps summarize the process of generating the normalized relative importance weights for the parameters at level 2, level 3 and creating the model.

**a) Modelling the problem:** In order to achieve the project's goal, the first step is to set the parameters, which takes into account all stakeholders, goals, and the resulting outcomes. The decision elements are arranged in a hierarchical structure that includes the goal, criteria, and sub-criteria. Slope, Elevation, Stream Network, Soil, Precipitation, and Land Cover were all modeled. The different types of criteria are grouped together as sub-criterion. As far as AHP goes, this is the most critical step.

**b) Deriving the overall weight of the criteria and sub-criteria using Logical Decisions**

**Software Version 7.2:** Here, ratings are gathered for all criteria and sub-criteria using a pairwise comparison technique and a scale of relative importance (see Table), as shown in Table. Following the pairwise comparison, the relative importance weights of the criteria are normalized in terms of the goal's attainment and the relative importance weights of the sub-criteria are determined with respect to the criteria. This method was primarily used to calculate the weight, which ensures that all of the other variables are also unbiased. We used logical decision software to calculate NRIW. The process generally includes a visit to the field and a questionnaire for comparing all the elements to reach a group consensus. The importance of each parameter was determined by ranking each one. There are three ways to calculate NRIW in this program: by using NRIW as a vector and by using the Eigen value consistency index and Eigen value consistency ratio as inputs. The CR must be less than 10% for the computed NRIW to be valid. It is an iterative process if the process is repeated until it meets the requirements which is presented in Figure 13.

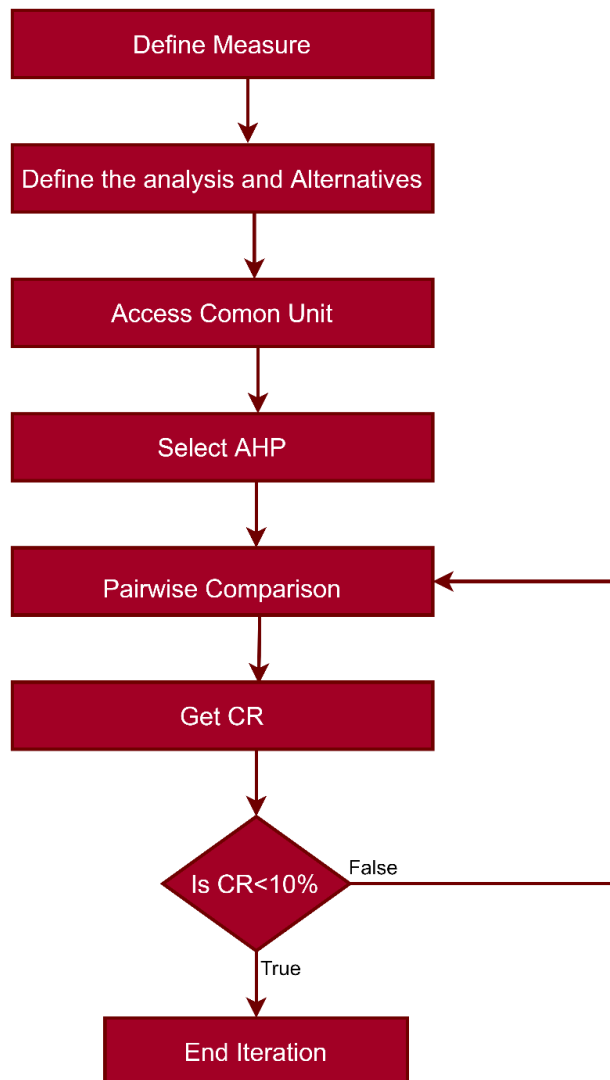


Figure 13: Workflow for Computation using AHP (Saha & Roy, 2021)

In the table below, the diagonal elements show the Normalized Relative Importance Weight, and the largest Eigen value, consistency index, and consistency ratio are all found in the top left corner. In the beginning, the software needs to define the measurement, and then the analysis and alternatives must be specified. The access Common Unit menu consists of different analysis access such as AHP, adjusted AHP, ideal AHP, and Balance Beam Method. We were able to gain access to AHP as one of these. Then we created a pairwise comparison matrix for all of the major parameters and sub-classes. The process came to an end when the

iteration process reached an acceptable CR value. The NRIW is computed for main criteria (Level 2) is given below. Which shows comparison matrix for selected parameters: Physical factor (slope, elevation, aspect etc.), Accessibility factor (distance from main road, distance from railway, etc.), Social factor (population density), Economic factor (distance from economic centers, land value), Environmental factor (vegetation, soil types, land cover). In this study each parameter from five major criteria were taken for suitability analysis.

Table 9: Comparison matrix For Selected Parameters for Level-2 Hierarchy Iteration 1

	Physic	Access	Social	Econo	Environ	GEO	Normaliz
Physic	1	0.25	1.6	1.7	0.33	0.743	0.136
Access	4	1	2	0.33	0.25	0.922	0.169
Social	0.62	0.5	1	0.5	0.5	0.600	0.110
Econo	0.58	3	2	1	1	1.286	0.236
Environ	3	4	2	1	1	1.888	0.347
	9.21	8.75	8.6	4.53	3.08	5.440	1

$$\Delta\text{Max} \Rightarrow (9.21 * 0.14) + (8.75 * 0.17) + (8.6 * 0.11) + (4.53 * 0.24) + (3.08 * 0.35) = 5.83, \text{ CI} \\ \Rightarrow (5.83-5) / 5-1 = 0.2082, \text{ CR} = \text{CI}/\text{RI} \Rightarrow \text{CR} \Rightarrow 0.21/1.12=0.1859 = 18.59\% > 10\%$$

Table 10: Comparison matrix For Selected Parameters for Level-2 Hierarchy Iteration 2

	Physic	Access	Social	Econo	Environ	GEO	Normaliz
Physic	1	0.33	1.3	1.5	0.33	0.736	0.135
Access	3	1	2	0.33	0.25	0.870	0.160
Social	0.76	0.5	1	0.5	0.5	0.626	0.115
Econo	0.66	3	2	1	1	1.319	0.242
Environ	3	4	2	1	1	1.888	0.347
	8.43	8.83	8.3	4.33	3.08	5.440	1

$$\Delta\text{Max} \Rightarrow (8.44 * 0.14) + (8.83 * 0.16) + (8.3 * 0.12) + (4.33 * 0.24) + (3.08 * 0.35) = 5.63, \text{ CI} \\ \Rightarrow (5.63-5) / 5-1 = 0.15, \text{ CR} = \text{CI}/\text{RI} \Rightarrow \text{CR} \Rightarrow 0.16/1.12=0.14091 = 14.09\% > 10\%$$

Table 11: Comparison matrix For Selected Parameters for Level-2 Hierarchy Iteration 3

	Physic	Access	Social	Econo	Environ	GEO	Normaliz
Physic	1	0.33	1.1	1.3	0.33	0.692	0.126
Access	3	1	1.5	1.3	0.33	1.142	0.208
Social	0.90	0.66	1	0.5	0.5	0.685	0.125
Econo	0.76	0.76	2	1	0.5	0.900	0.164
Environ	3	3	2	2	1	2.047	0.374
	8.67	5.76	7.6	6.1	2.66	5.468	1

$\Delta Max \Rightarrow (8.68 * 0.13) + (5.77 * 0.21) + (7.6 * 0.13) + (6.1 * 0.16) + (2.67 * 0.37) = 5.25$ ,  $CI \Rightarrow (5.26-5) / 5-1 = 0.0649$ ,  $CR = CI/RI \Rightarrow CR \Rightarrow 0.06/1.12 = 0.0579739098205975 = 5.79\% < 10\%$

In similar manner NRIW for parameter subclasses also identified iteratively. Saha & Roy, (2021) classified nine sub-criteria for five classes. Summary of criteria, sub-criteria, suitability level, ranking of sub-criteria and weightage of criteria is shown below. Among all the mentioned sub criterion for physical factor, I took slope for sub criterion. Slope was classified in to five classes which is presented in Table 12.

Table 12: Slope classification for AHP calculation

Slope ranges	Class
<5°	Very Low
5° - 10°	Low
10° - 20°	Medium
20° - 30°	High
>30°	Very High

Table 13: Normalized Relative Importance Weight for Level-3 for Slope

	V.Low	Low	Mediu	High	V.High	GEO	Normaliz
V.Low	1	2	3	5	7	2.913	0.445
Low	0.5	1	2	3	4	1.643	0.251
Mediu	0.33	0.5	1	3	3	1.084	0.165
High	0.2	0.33	0.33	1	2	0.536	0.082
V.High	0.14	0.25	0.33	0.5	1	0.358	0.054
	2.17	4.08	6.66	12.5	17	6.537	1

$\Delta_{Max} \Rightarrow (2.18 * 0.45) + (4.08 * 0.25) + (6.67 * 0.17) + (12.5 * 0.08) + (17 * 0.05) = 5.0616$ ,  $CI \Rightarrow (5.06-5) / 5-1 = 0.0154$ ,  $CR = CI/RI \Rightarrow CR \Rightarrow 0.02/1.12 = 0.01376 = 1.37 \% < 10\%$

For accessibility factor, I choose distance from road for sub criterion. Distance from road was classified in to five classes. Which is tabulated below in Table 15.

Table 14: Distance from road classification

Distance (m)	Class
<500	Very Near
500 – 1000	Near
1000 – 1500	Medium
1500 – 2000	Far
>2000	Very Far

Table 15: Normalized Relative Importance Weight for Level-3 for Distance from road

	V.Near	Near	Mediu	Far	V.Far	GEO	Normaliz
V.Near	1	1.1	1.8	3	5	1.970	0.344
Near	0.90	1	1.5	1.7	4	1.561	0.273
Mediu	0.55	0.66	1	1.8	2	1.059	0.185
Far	0.33	0.58	0.55	1	1.1	0.654	0.114
V.Far	0.2	0.25	0.5	0.90	1	0.469	0.082
	2.99	3.60	5.35	8.40	13.1	5.714	1

$\Delta_{Max} \Rightarrow (3 * 0.34) + (3.6 * 0.27) + (5.36 * 0.19) + (8.41 * 0.1) + (13.1 * 0.08) = 5.04$ ,  $CI \Rightarrow (5.05-5) / 5-1 = 0.0124$ ,  $CR = CI/RI \Rightarrow CR \Rightarrow 0.01/1.12 = 0.0111 = 1.11 \% < 10\%$

For social factor, I choose population density for sub criterion. Population density was classified in to five classes. Which is tabulated below.

Table 16: Classification of population density

Population density (/Sq.km)	Class
<300	Very Low
300 – 900	Low
900 – 2700	Medium
2700 – 5000	High
>5000	Very High

Table 17: Normalized Relative Importance Weight for Level-3 for population density

	V.Low	Low	Mediu	High	V.High	GEO	Normaliz
V.Low	1	2	3	4	5	2.605	0.442
Low	0.5	1	2	1.5	1.4	1.159	0.196
Mediu	0.33	0.5	1	1.3	3	0.917	0.155
High	0.25	0.66	0.76	1	1.1	0.675	0.114
V.High	0.2	0.71	0.33	0.90	1	0.533	0.090
	2.28	4.88	7.10	8.70	11.5	5.892	1

$\Delta_{Max} \Rightarrow (2.28 * 0.44) + (4.88 * 0.2) + (7.1 * 0.16) + (8.71 * 0.11) + (11.5 * 0.09) = 5.11$ ,  $CI \Rightarrow (5.12-5) / 5-1 = 0.0292$ ,  $CR = CI/RI \Rightarrow CR \Rightarrow 0.03/1.12 = 0.0261 = 2.61\% < 10\%$

For economic factor, I choose distance from economic centers for sub criterion. Distance from economic centers was classified in to five classes. Which is tabulated below.

Table 18: Distance from distance from economic centers

Distance (m)	Class
<500	Very Near
500 – 1000	Near
1000 – 2000	Medium
2000 – 3000	Far
>3000	Very Far

Table 19: NRIW for Level-3 for distance from economic centers

	V.Near	Near	Mediu	Far	V.Far	GEO	Normaliz
V.Near	1	1.1	1.8	2	3	1.970	0.344
Near	0.90	1	1.5	1.7	3	1.561	0.273
Mediu	0.55	0.66	1	1.8	2	1.059	0.185
Far	0.33	0.58	0.55	1	1.1	0.654	0.114
V.Far	0.2	0.25	0.5	0.90	1	0.469	0.082
	2.99	3.60	5.35	8.40	13.1	5.714	1

$\Delta_{Max} \Rightarrow (2.28 * 0.44) + (4.88 * 0.2) + (7.1 * 0.16) + (8.71 * 0.11) + (11.5 * 0.09) = 5.11$ ,  $CI \Rightarrow (5.12-5) / 5-1 = 0.0292$ ,  $CR = CI/RI \Rightarrow CR \Rightarrow 0.03/1.12 = 0.0261 = 2.61\% < 10\%$

For environmental factor, I choose Land Use Land Cover for sub criterion. LULC was classified in to five classes. Which is tabulated below.

Table 20: Normalized Relative Importance Weight for Level-3 for LULC

	Agricult	Barren	Built up	Forest	Water	GEO	Normaliz
Agricult	1	2	0.5	2	5	1.584	0.257
Barren	0.5	1	2	3	7	1.838	0.299
Built up	2	0.5	1	2	7	1.695	0.275
Forest	0.5	0.33	0.5	1	3	0.757	0.123
Water	0.2	0.14	0.14	0.33	1	0.267	0.043
	4.2	3.97	4.14	8.33	23	6.143	1

$$\Delta_{Max} \Rightarrow (4.2 * 0.26) + (3.98 * 0.3) + (4.14 * 0.28) + (8.33 * 0.12) + (23 * 0.04) = 5.44, CI \Rightarrow (5.44-5) / 5-1 = 0.1111, CR = CI/RI \Rightarrow CR \Rightarrow 0.11/1.12 = 0.0992 = 9.92\% < 10\%$$

### 2.4.2 Model Building

It was necessary to reclassify the parameter raster and compute their weights before creating the final model. We used GIS model builder with toolbox customization to prepare the model. A weighted sum tool is used to combine several rasters by multiplying their weights by each other and adding the results.

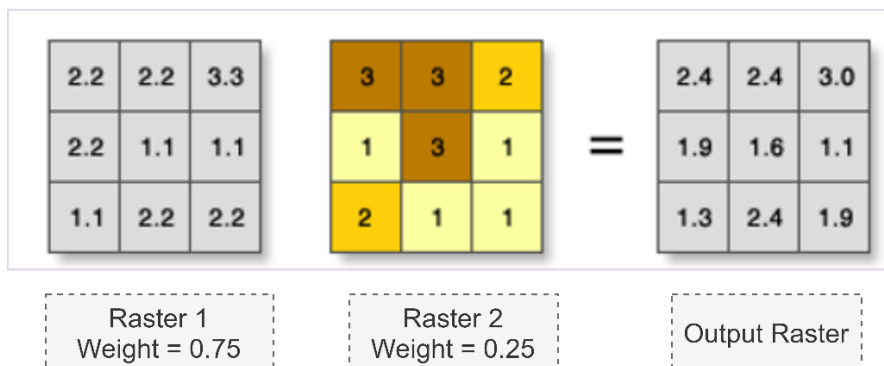


Figure 14: Illustration of weighted sum

In Figure 14, the cell values are multiplied by their weight factor, and the results are added together to create the output raster. For example, consider the upper left cell. The values for the two inputs become  $(2.2 \times 0.75) = 1.65$  and  $(3 \times 0.25) = 0.75$ . The sum of 1.65 and 0.75 is 2.4.

The tool has following usages:

- A useful way to add several rasters together is to input multiple rasters and set all weights equal to 1. Input raster can be integer or floating point.
- The weight values can be any positive or negative decimal value. It is not restricted to a relative percentage nor does it need to be equal to 1.0.
- The weight will be applied to the specified field for the input raster. Fields can be of type short or long integer, double or float.

In the model builder parameter were raster maps and their weight value, field for computation and weight are specified as shown in following Table 21.

Table 21: Specification of input raster, field and weight in Model Builder

<b>Factor</b>	<b>Raster</b>	<b>Field</b>	<b>Weight</b>
Physical factor	Reclassified slope	Value	0.126
Accessibility factor	Reclassified distance from road	Value	0.208
Social factor	Reclassified population density	Value	0.125
Economic factor	Reclassified distance from economic centers	Value	0.164
Environmental factor	Reclassified land use land cover	Value	0.374

After determining the weight for each factor, final model was prepared. Final output raster was prepared by using weighted overlay analysis in GIS. Which is presented below in Figure 15.

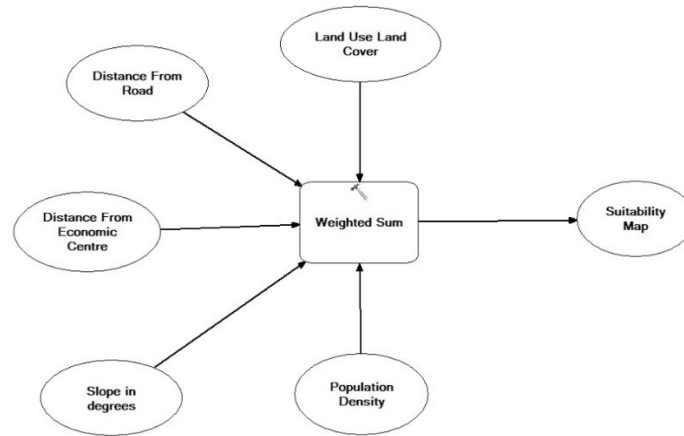


Figure 15: Final Model for suitability analysis on GIS

Mathematically,

$$\text{Land suitability model for built – up} = W1 * \text{slope} + W2 * \text{distance from road} + W3 * \text{population density} + W4 * \text{distance from economic center} + W5 * \text{LULC}$$

In this model the coefficients W1, W2, W3.... W5 are the computed from comparison matrix and Eigen vector using Analytic Hierarchy Process and the model parameters like precipitation, slope etc. are reclassified raster map of the respective parameter. Hence,

$$\text{Land suitability model for built – up} = 0.126 * \text{slope} + 0.208 * \text{distance from road} + 0.125 * \text{population density} + 0.164 * \text{distance from economic center} + 0.374 * \text{LULC}$$

Where the weights for the variables like slope, LULC etc. are also computed using AHP methodology. Their value ranges from 0 to 1 in general but their weight is converted to integer by multiplying each by thousand to avoid floating point value during reclassification as indicated in Appendix I.

## 2.5 Urban Sprawl Extent Modeling

Urban sprawl during 1990 to 2020 was performed by determining the change detection, urban landscape analysis and urban sprawl pattern with 5km incremental ring buffer analysis. One of

main objectives of this study is predict future land use land cover of BMC. Prediction of future urban sprawl extent was performed by using TerrSet Geospatial Monitoring and Modeling Software. Land Change Modeler (LCM) is one of the main parts of this software. LCM is fully integrated to TerrSet software, which contained innovative land planning and decision system. LCM easily simplifies the more complexity of land cover change analysis.

LCM enables to quickly analyze changes in land cover, empirically model relations to explain variables and scenarios for land changes. LULC change analysis was done by determining the changes between 1990 to 2020.

Firstly, urban sprawl changes and transition modelling from 1990 to 2010 was performed by CA Markov chain analysis. The implication of the CA-Markov model divides the total area into a cell grid, representing an integrated area with a grid or raster grid, representing a finite state (Kityuttachai et al., 2013). By using transition model, land cover changes and variables, modeled land use land cover map for 2020 was prepared. Such variables are six rasters: Digital Elevation Model (DEM), Slope, Aspect, Distance from River, Distance from Road and Suitability map. Validation of modeled land use land cover 2020 map was done.

By using earlier land cover image for LULC 2010 and later land cover change for LULC 2020, transition potential was determined and land cover change prediction for 2030 was performed. In similar manner urban extent for 2040 was prepared.

## Chapter 3: Result

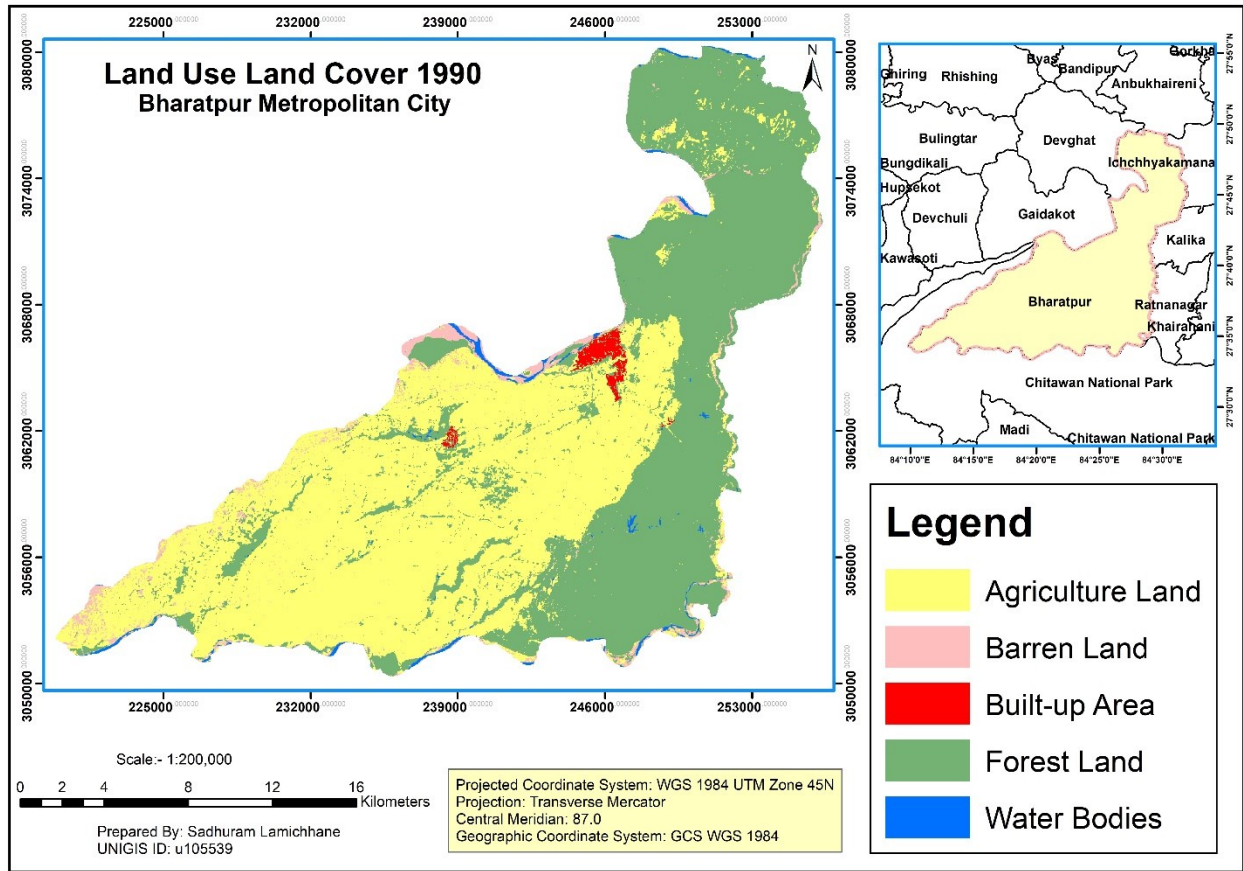
This chapter includes result of land use land cover pattern from 1990 to 2020, urban landscape analysis, sprawl types with incremental ring buffer, urban footprint, suitability analysis and predicted land use land cover for 2030 and 2040 with CA – Markov chain analysis.

### 3.1 Land Use Land Cover

Details explanation of classification of Landsat imageries from 1990 to 2020 was mentioned in chapter 2.3.2. Six different LULC maps were classified in each of five categories they are: (i) Agriculture land, (ii) Barren land, (iii) Built – up area, (iv) Forest land and (v) Water bodies. Each LULC maps was validate by performed accuracy assessment. All years LULC maps are presented below.

#### 3.1.1 BMC Land Use Land Cover Map 1990

Land use land cover maps of 1990 is depicted below in (Map 5). Agriculture and cultivated land is the most dominant land in this metropolitan city. Which occupies 221.88 km<sup>2</sup> land out of 432.95 km<sup>2</sup>. Which is 51.25% of total land in BMC. Forest Land is second dominant land which cover 192.08 km<sup>2</sup> area, which is 44.36 % of total area. Barren land is third dominant land which occupies 12.14 km<sup>2</sup> area, which is 2.80% of total land use land cover. Water Bodies is fourth dominant land cover, which occupies 3.56 km<sup>2</sup> area, which is 0.82% of its total LULC. Last and least dominant land cover is Built – up area, which occupies 3.29 km<sup>2</sup> area, which is 0.76% of total LULC. Above explanation concludes that built – up area occupies small area in this metropolitan city at 1990. Land use land cover map of 1990 is presented below in Map 5 .



Map 5: BMC Land use land cover 1990

Land use land cover area for each category is tabulated and summarize below in Table 22.

Table 22: Land use land cover area of 1990

Year	1990	
	Area (Sq. Km)	Area (%)
Agriculture Land	221.88	51.25
Barren Land	12.14	2.80
Built-up Area	3.29	0.76
Forest Land	192.08	44.36
Water Bodies	3.56	0.82

For more visual interpretation for land cover areas for each category of 1990 is presented in pie – chart, which is shown below Figure 16.

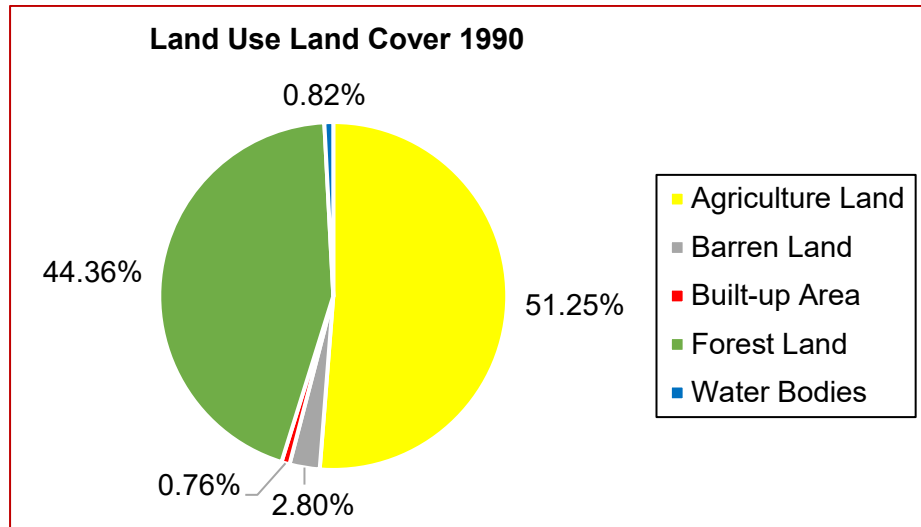


Figure 16: 1990 land cover area with Pie – chart

Overall accuracy for this LULC map was obtained is 86.32% and kappa coefficient is 0.82. The Kappa Index can have values in the range of -1 to 1. The lower it is the more random the classification result is and the higher the index is, the less random the classification. User accuracy and producer accuracy for LULC 1990 is presented below Table 23.

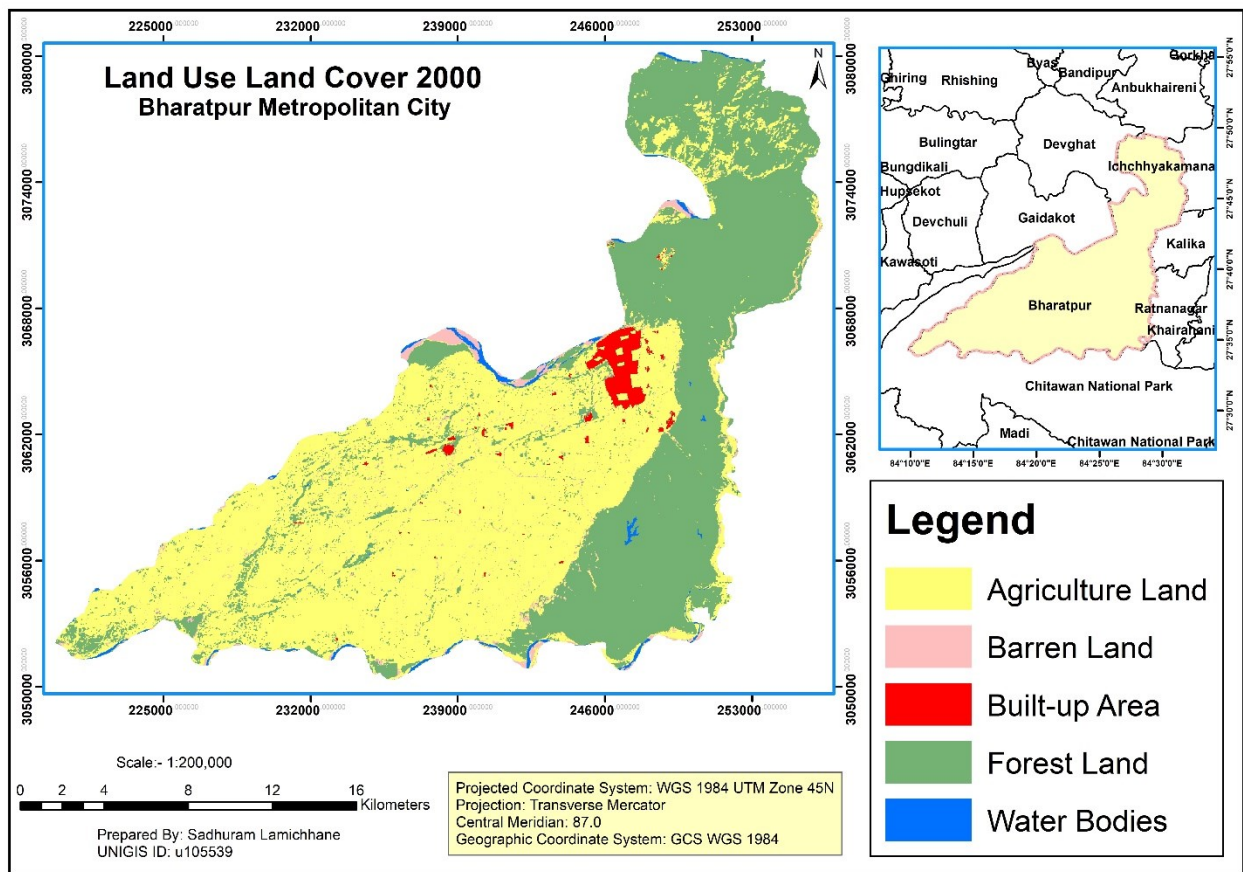
Table 23: Accuracy assessment table of LULC 1990

Accuracy Assessment of LULC 1990								
Classes	Water Bodies	Forest Land	Built - up area	Barren Land	Agriculture Land	Total	User Accuracy	Kappa
Water Bodies	24	1	0	1	0	26	<b>0.92</b>	0
Forest Land	2	45	1	2	4	54	<b>0.83</b>	0
Built - up area	0	0	28	1	2	31	<b>0.90</b>	0
Barren Land	1	2	0	33	4	40	<b>0.83</b>	0
Agriculture Land	0	3	2	3	53	61	<b>0.87</b>	0
Total	27	51	31	40	63	212	0	0
Producer Accuracy	<b>0.89</b>	<b>0.88</b>	<b>0.90</b>	<b>0.83</b>	<b>0.84</b>	0	0	0
Kappa	0	0	0	0	0	0	0	<b>0.82</b>

### 3.1.2 BMC Land Use Land Cover Map 2000

Spatial distribution of land use land cover 2000 is presented below in (Map 6). Agriculture and cultivated land is the most dominant land in this metropolitan city. Which occupies 238.38 km<sup>2</sup> land out of 432.95 km<sup>2</sup>. Which is 55.06% of total land in BMC. Forest Land is second dominant

land which cover 174.98 km<sup>2</sup> area, which is 40.42% of total area. Barren land is third dominant land which occupies 8.92 km<sup>2</sup> area, which is 2.06% of total land use land cover. Built – up area is fourth dominant land cover, which occupies 6.79 km<sup>2</sup> area, which is 1.57% of its total LULC. Last and least dominant land cover is Water Bodies, which occupies 3.87 km<sup>2</sup> area, which is 0.89% of total LULC. Above explanation concludes that built – up area occupies second last small area in this metropolitan city at 1990. Land use land cover map of 2000 is presented below in Map 6.



Map 6: BMC Land use land cover 2000

Land use land cover area for each category is tabulated and summarize below in table 24.

Table 24: Land use land cover area of 2000

Year	2000	
Name	Area (Sq. Km)	Area (%)
Agriculture Land	238.38	55.06
Barren Land	8.92	2.06
Built-up Area	6.79	1.57
Forest Land	174.98	40.42
Water Bodies	3.87	0.89

For more visual interpretation for land cover areas for each category of 2000 is presented in pie – chart, which is shown below in Figure 17.

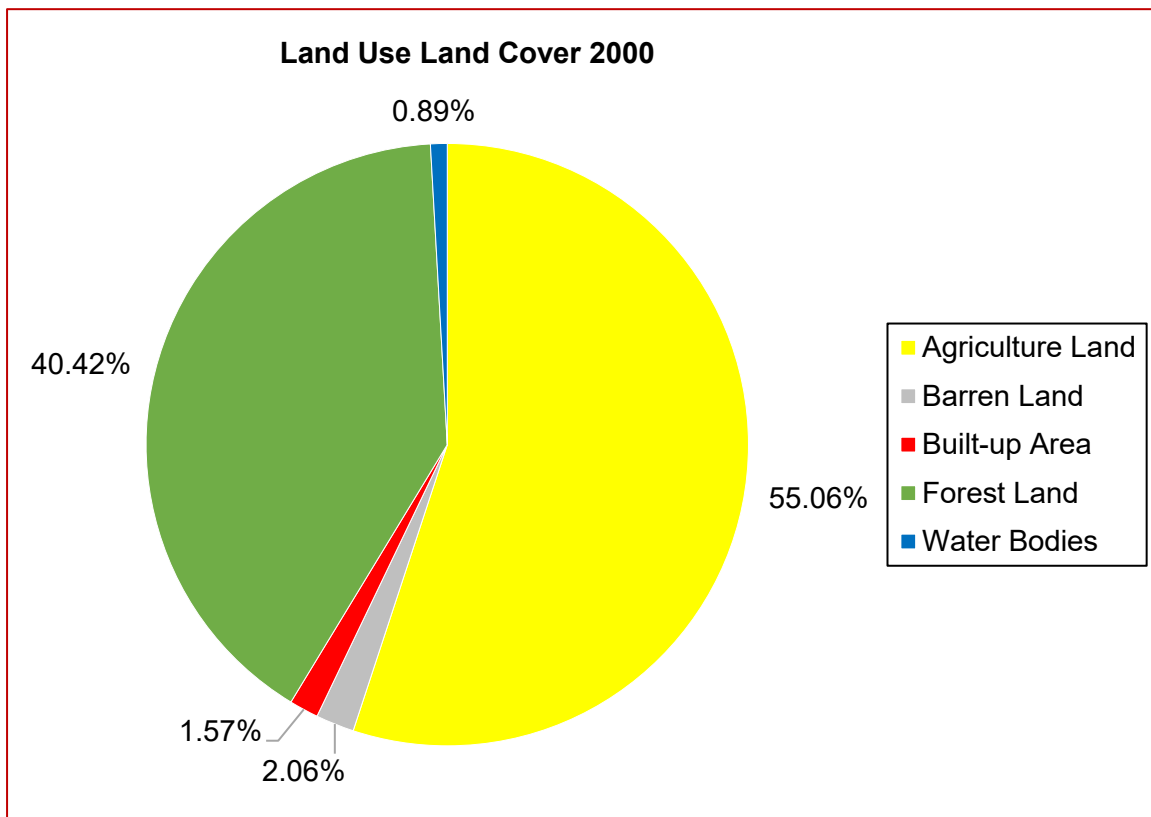


Figure 17: 2000 land cover area with Pie – chart

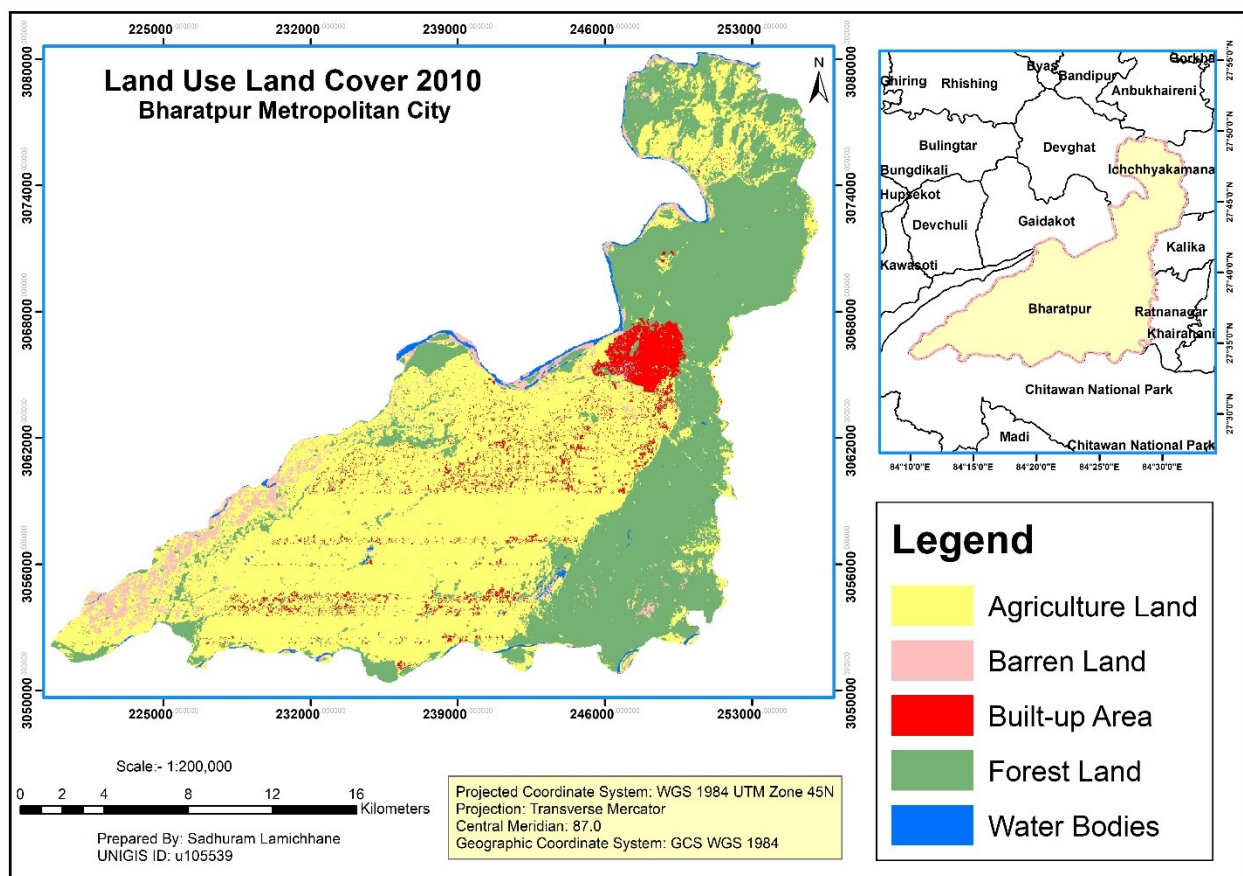
Overall accuracy for this LULC map was obtained is 89.01% and kappa coefficient is 0.86. User accuracy and producer accuracy for LULC 2000 is presented below in Table 25.

Table 25: Accuracy assessment table of LULC 2000

<b>Accuracy Assessment of LULC 2000</b>								
Classes	Forest Land	Water Bodies	Agriculture Land	Barren Land	Built - up area	Total	User Accuracy	Kappa
Forest Land	34	0	1	1	2	38	<b>0.89</b>	0
Water Bodies	0	18	0	0	1	19	<b>0.95</b>	0
Agriculture Land	4	3	60	4	2	73	<b>0.82</b>	0
Barren Land	1	1	0	25	0	27	<b>0.93</b>	0
Built - up area	0	0	0	1	33	34	<b>0.97</b>	0
Total	39	22	61	31	38	191	0	0
Producer Accuracy	<b>0.87</b>	<b>0.82</b>	<b>0.98</b>	<b>0.81</b>	<b>0.87</b>	0	0	0
Kappa	0	0	0	0	0	0	0	<b>0.86</b>

### 3.1.3 BMC Land Use Land Cover Map 2010

Spatial distribution of land use land cover 2010 is presented below in (Map 7). Agriculture and cultivated land is the most dominant land in this metropolitan city. Which occupies 233.08 km<sup>2</sup> land out of 432.95 km<sup>2</sup>. Which is 53.84% of total land in BMC. Forest Land is second dominant land which cover 159.70 km<sup>2</sup> area, which is 36.89% of total area. Barren land is third dominant land which occupies 18.18 km<sup>2</sup> area, which is 4.20% of total land use land cover. Built – up area is fourth dominant land cover, which occupies 17. 28 km<sup>2</sup> area, which is 3.99 % of its total LULC. Last and least dominant land cover is Water Bodies, which occupies 4.71 km<sup>2</sup> area, which is 1.09% of total LULC. Above explanation concludes that built – up area occupies second last small area in this metropolitan city at 2010. Land use land cover map of 2010 is presented below in Map 7.



Map 7: BMC land use land cover 2010

Land use land cover area for each category is tabulated and summarize below in Table 26.

Table 26: Land use land cover area of 2010

Year	2010	
	Area (Sq. Km)	Area (%)
Agriculture Land	233.08	53.84
Barren Land	18.18	4.20
Built-up Area	17.28	3.99
Forest Land	159.70	36.89
Water Bodies	4.71	1.09

For more visual interpretation for land cover areas for each category of 2010 is presented in pie – chart, which is shown below in Figure 18.

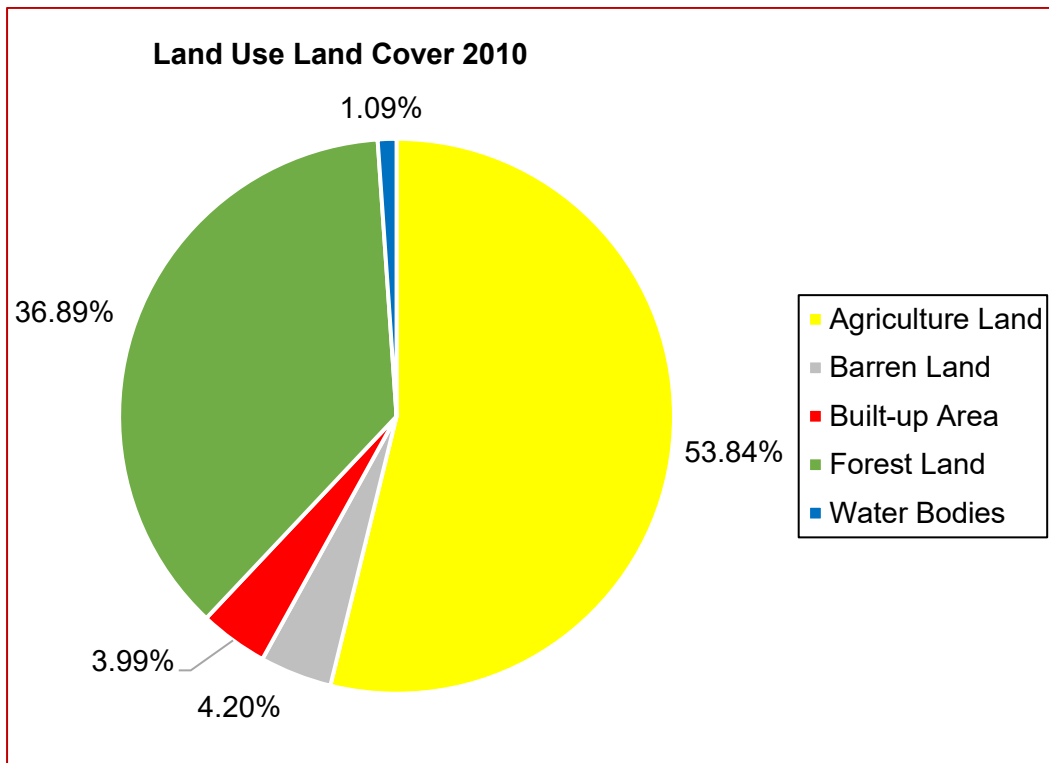


Figure 18: 2010 land cover area with Pie – chart

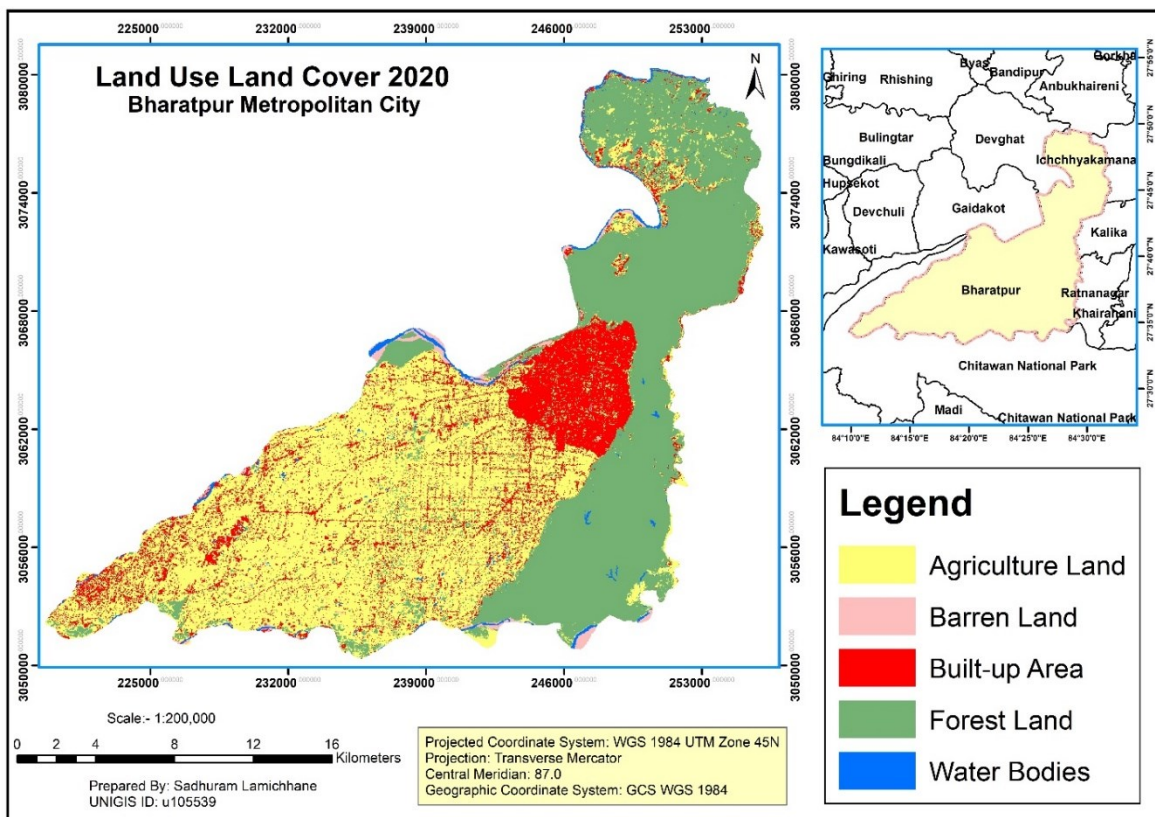
Overall accuracy for this LULC map was obtained is 87.57% and kappa coefficient is 0.84. User accuracy and producer accuracy for LULC 2010 is presented below in Table 27.

Table 27: Accuracy assessment table of LULC 2010

Accuracy Assessment of LULC 2010								
Classes	Forest Land	Water Bodies	Agriculture Land	Barren Land	Built - up area	Total	User Accuracy	Kappa
Forest Land	35	4	1	2	0	42	<b>0.83</b>	0
Water Bodies	0	26	1	1	0	28	<b>0.93</b>	0
Agriculture Land	3	0	38	1	5	47	<b>0.81</b>	0
Barren Land	2	0	0	27	0	29	<b>0.93</b>	0
Built - up area	0	0	3	0	36	39	<b>0.92</b>	0
Total	40	30	43	31	41	185	0	0
Producer Accuracy	<b>0.88</b>	<b>0.87</b>	<b>0.88</b>	<b>0.87</b>	<b>0.88</b>	0	0	0
Kappa	0	0	0	0	0	0	0	<b>0.84</b>

### 3.1.4 BMC Land Use Land Cover Map 2020

Spatial distribution of land use land cover 2020 is presented below in (Map 8). Agriculture and cultivated land is the most dominant land in this metropolitan city. Which occupies 193.90 km<sup>2</sup> land out of 432.95 km<sup>2</sup>. Which is 44.79% of total land in BMC. Forest Land is second dominant land which cover 164.02 km<sup>2</sup> area, which is 37.88% of total area. Built – up area is third dominant land which occupies 64.32 km<sup>2</sup> area, which is 14.86% of total land use land cover. Water Bodies is fourth dominant land cover, which occupies 5.84 km<sup>2</sup> area, which is 1.35 % of its total LULC. Last and least dominant land cover is Barren land, which occupies 4.88 km<sup>2</sup> area, which is 1.13% of total LULC. Above explanation concludes that built – up area occupies second last small area in this metropolitan city at 2010. Land use land cover map of 2020 is presented below Map 8.



Map 8: BMC land use land cover 202

Land use land cover area for each category is tabulated and summarize below in table 28.

Table 28: Land use land cover area of 2020

Year	2020	
Name	Area (Sq. Km)	Area (%)
Agriculture Land	193.90	44.79
Barren Land	4.88	1.13
Built-up Area	64.32	14.86
Forest Land	164.02	37.88
Water Bodies	5.84	1.35

For more visual interpretation for land cover areas for each category of 2020 is presented in pie – chart, which is shown below in Figure 19.

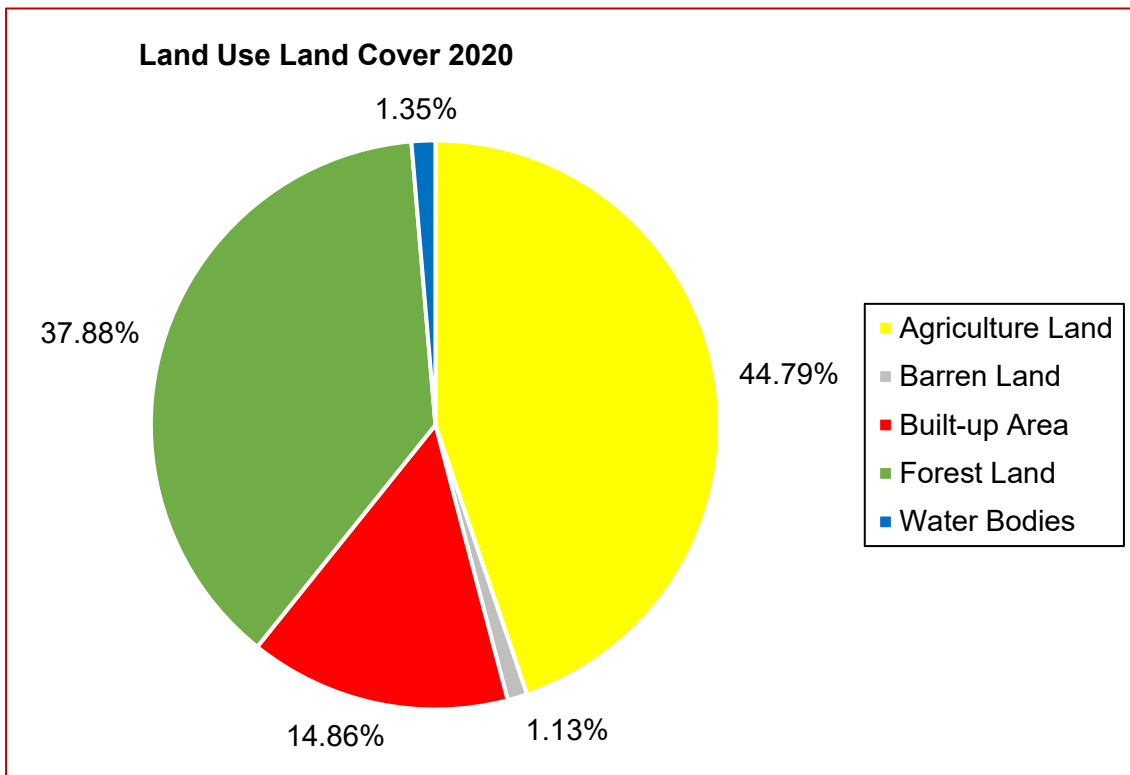


Figure 19: 2020 land cover area with Pie – chart

Overall accuracy for this LULC map was obtained is 89.66% and kappa coefficient is 0.87. User accuracy and producer accuracy for LULC 2010 is presented below Table 29.

Table 29: Accuracy assessment table of LULC 2020

<b>Accuracy Assessment of LULC 2020</b>								
Classes	Forest Land	Water Bodies	Agriculture Land	Barren Land	Built - up area	Total	User Accuracy	Kappa
Forest Land	55	1	0	2	1	59	<b>0.93</b>	0
Water Bodies	0	32	1	0	0	33	<b>0.97</b>	0
Agriculture Land	4	0	67	3	5	79	<b>0.85</b>	0
Barren Land	2	1	0	28	2	33	<b>0.85</b>	0
Built - up area	1	1	3	0	52	57	<b>0.91</b>	0
Total	62	35	71	33	60	261	0	0
Producer Accuracy	<b>0.89</b>	<b>0.91</b>	<b>0.94</b>	<b>0.85</b>	<b>0.87</b>	0	0	0
Kappa	0	0	0	0	0	0	0	<b>0.87</b>

Spatial distribution of land use land cover from 1990 to 2020 was depicted above (map 5 – map 8). Those maps depict there was rapid increment of built – up area in each decade. Total Built – up area determined for 1990, 2000, 2010 and 2020 was 0.76 %, 1.57 %, 3.99 %, and 14.86 % respectively. It seems urban sprawl in BMC goes rapidly in each year. Agricultural land was found to decreased in last two decades but forest land found to be increased in 2020. Barren land was found to increased in 2010 but it decreases in 2020. Water bodies found to be slightly changes near river corridor. Forest land also decreased in last two decades. Summarization of land use land cover for each year is presented below in Figure 20.

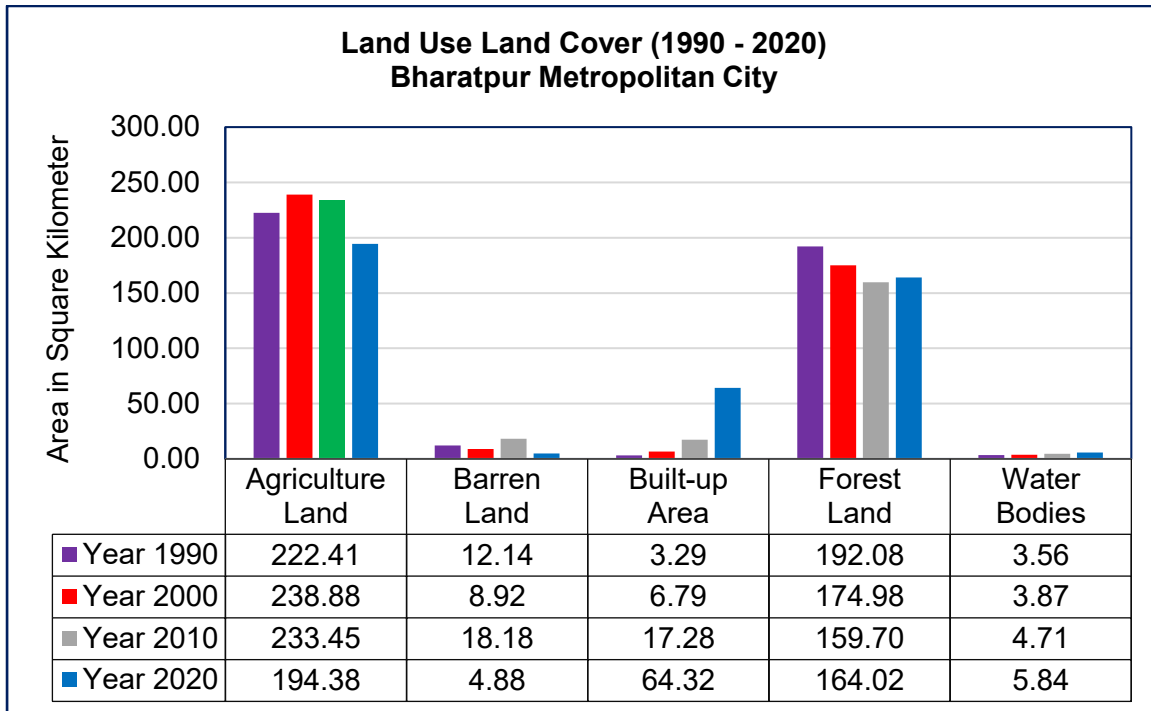


Figure 20: BMC Land use land cover from 1990 to 2020

### 3.2 Land Use Land Cover change

Land use land cover of BMC from 1990 to 2020 was presented in (maps 5 – map 8) and figure 21, it reflects significant increase in built – up area. Built up area obtained at the years 1990, 2000, 2010 and 2020 were 3.29 km<sup>2</sup>, 6.79 km<sup>2</sup>, 17.28 km<sup>2</sup>, and 64.32 km<sup>2</sup> respectively. At the study year 2020 built up area increases more than three times than study year 2010.

Built – up area increased with degradation of agriculture land, forest land and barren land near river corridor. Agriculture land changes from 1990 to 2020 were 221.88 km<sup>2</sup>, 238.38 km<sup>2</sup>, 233.08 km<sup>2</sup>, and 193.90 km<sup>2</sup> during the study period. It seems most of the agriculture land changes from 2010 to 2020. Change detection during study period was determined using geospatial analysis tool. Land cover changes from 1990 to 2020 is presented below in Table 30.

Table 30: Land cover changes from 1990 to 2020

Change Classes	LULC Change 1990 to 2000	LULC Change 2000 to 2010	LULC Change 2010 to 2020
	Area (Sq. km)	Area (Sq. km)	Area (Sq. km)
Agriculture Land - Agriculture Land	201.66	195.86	163.87
Agriculture Land - Barren Land	3.19	10.50	1.75
Agriculture Land - Built-up Area	3.47	13.46	45.57
Agriculture Land - Forest Land	13.52	14.55	21.28
Agriculture Land - Water Bodies	0.29	0.74	0.76
Barren Land - Agriculture Land	6.40	3.94	8.66
Barren Land - Barren Land	2.78	1.53	1.94
Barren Land - Built-up Area	0.15	0.31	4.53
Barren Land - Forest Land	1.63	1.72	1.86
Barren Land - Water Bodies	0.81	0.22	1.06
Built-up Area - Agriculture Land	0.88	3.27	6.36
Built-up Area - Barren Land	0.02	0.55	0.11
Built-up Area - Built-up Area	2.17	2.42	10.19
Built-up Area - Forest Land	0.22	0.55	0.61
Built-up Area - Water Bodies	0.00	0.00	0.01
Forest Land - Agriculture Land	28.92	27.49	14.71
Forest Land - Barren Land	2.31	2.70	0.55
Forest Land - Built-up Area	1.00	1.08	3.65
Forest Land - Forest Land	158.62	139.81	139.16
Forest Land - Water Bodies	0.77	0.56	1.40
Water Bodies - Agriculture Land	0.59	0.36	0.44
Water Bodies - Barren Land	0.42	0.60	0.44
Water Bodies - Built-up Area	0.00	0.00	0.28
Water Bodies - Forest Land	0.56	0.51	0.91
Water Bodies - Water Bodies	1.78	1.02	2.37

Land cover changes (Agriculture Land - Built-up Area) during study period (1990 – 2020) is shown below in Figure 21. During the study period of years from 1990 to 2000, 3.47 km<sup>2</sup> agriculture land changes to built-up area. From 2000 to 2010, 13.46 km<sup>2</sup> agriculture land changes to built-up area. From 2010 to 2020, 45.57 km<sup>2</sup> agriculture land changes to built-up area.

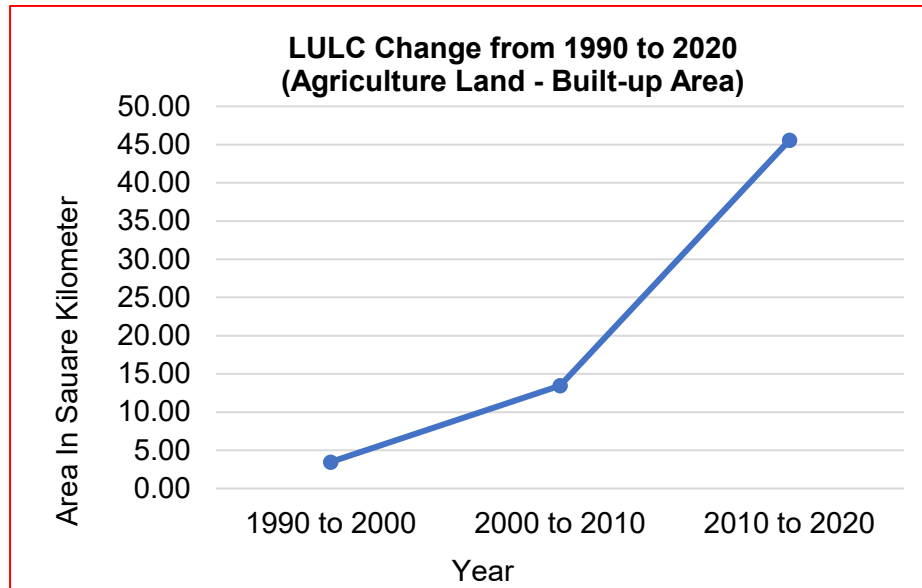
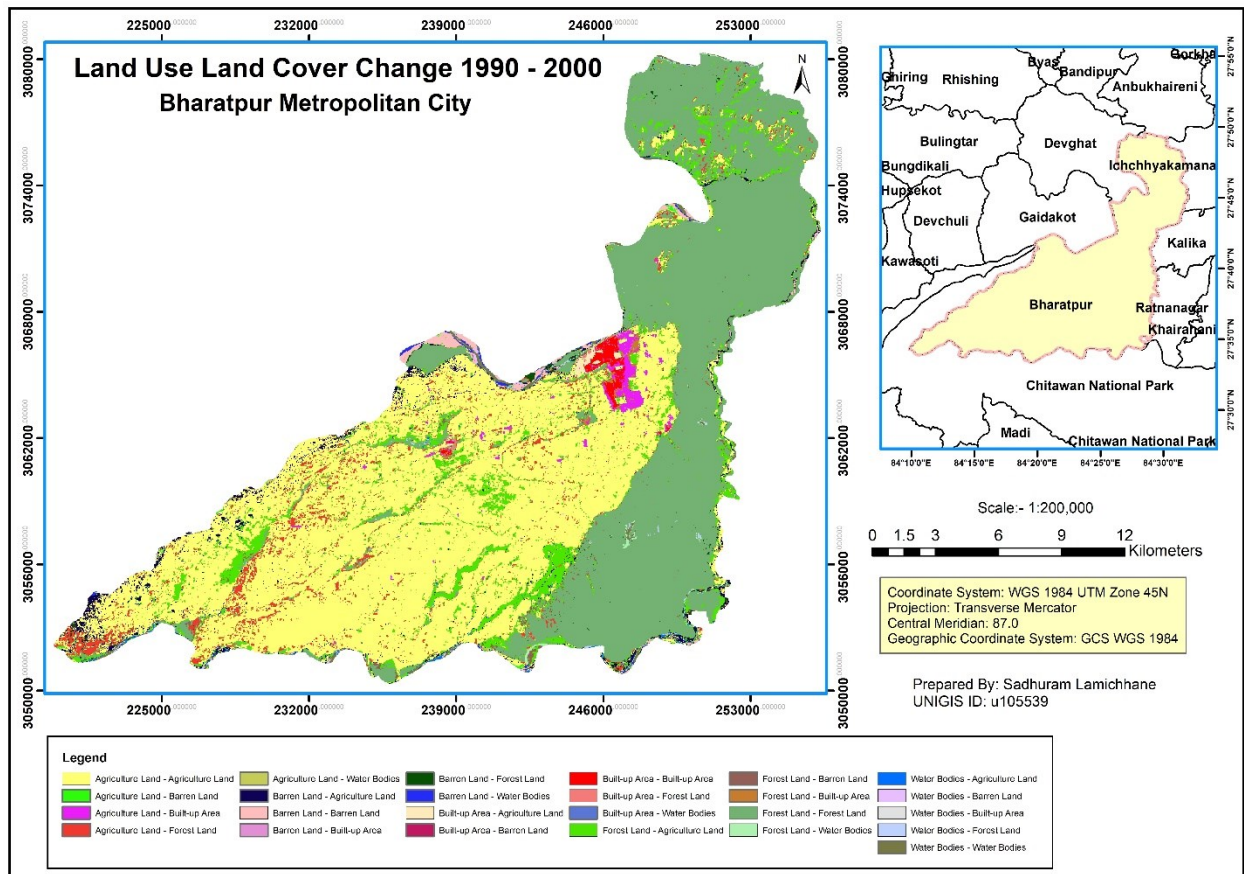


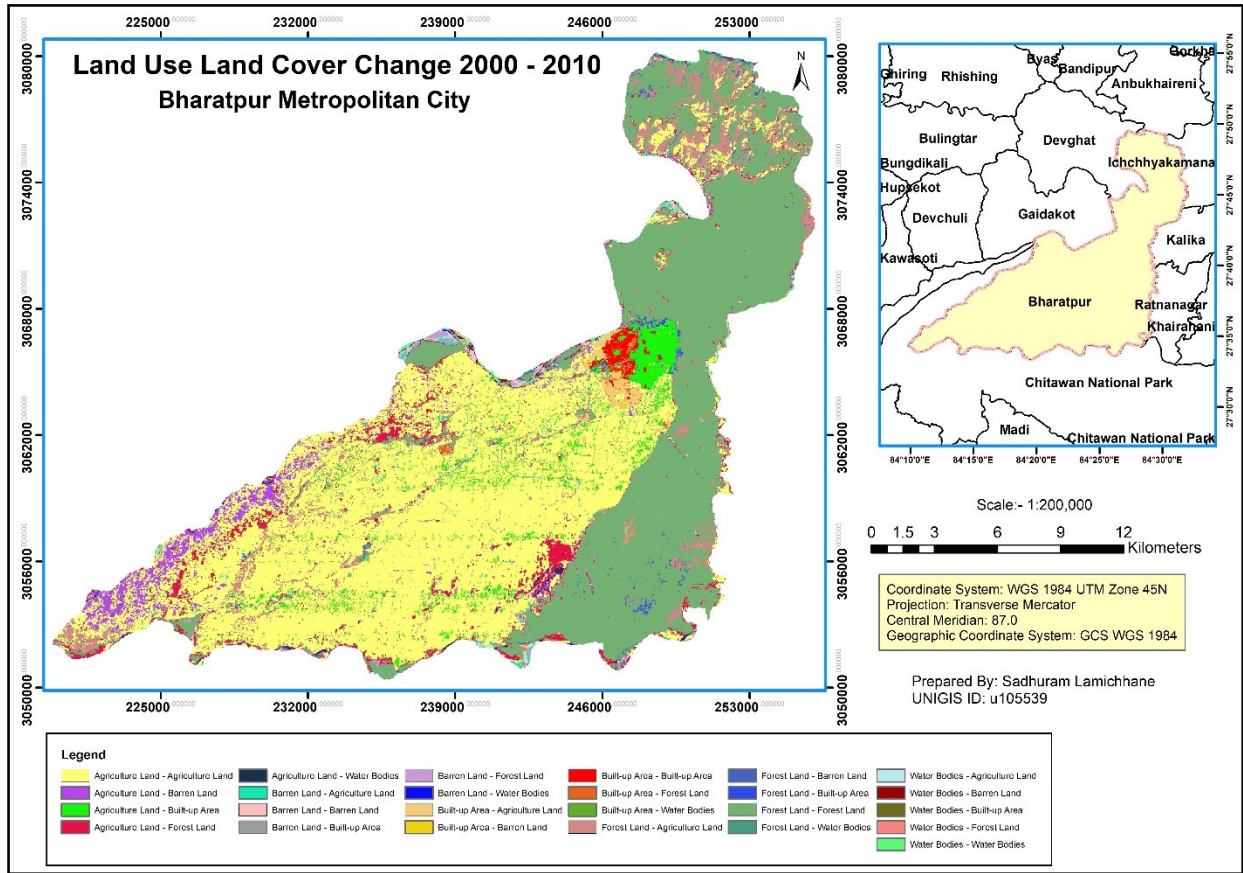
Figure 21: Agriculture Land - Built-up Area changes during 1990 – 2020

28.92 km<sup>2</sup> of forest land changes to agriculture land from 1990 to 2000. In similar manner 27.49 km<sup>2</sup> forest land changes to agriculture land changes to agriculture land from 2000 to 2010. 14.71 km<sup>2</sup> forest land changes to agriculture land from 2010 to 2020. So, these data sheet shows that most of the forest land goes to agriculture purpose during 1990 to 2020. The result shows during 1990 to 2010, 0.46 km<sup>2</sup> barren land was takeovers by public and during 2010 to 2020, 4.53 km<sup>2</sup> barren land was takeovers by public. Most of the rural agriculture area was rapidly urbanized during study period. 6.40 km<sup>2</sup> barren land changes to agriculture land. 201.66 km<sup>2</sup> agricultural land, 2.78 km<sup>2</sup> barren land, 2.17 km<sup>2</sup> built – up area, 158.62 km<sup>2</sup> forest land and 1.78 km<sup>2</sup> water bodies remain same during 1990 to 2000. Land cover changes map from 1990 to 2000 is presented below in Map 9.



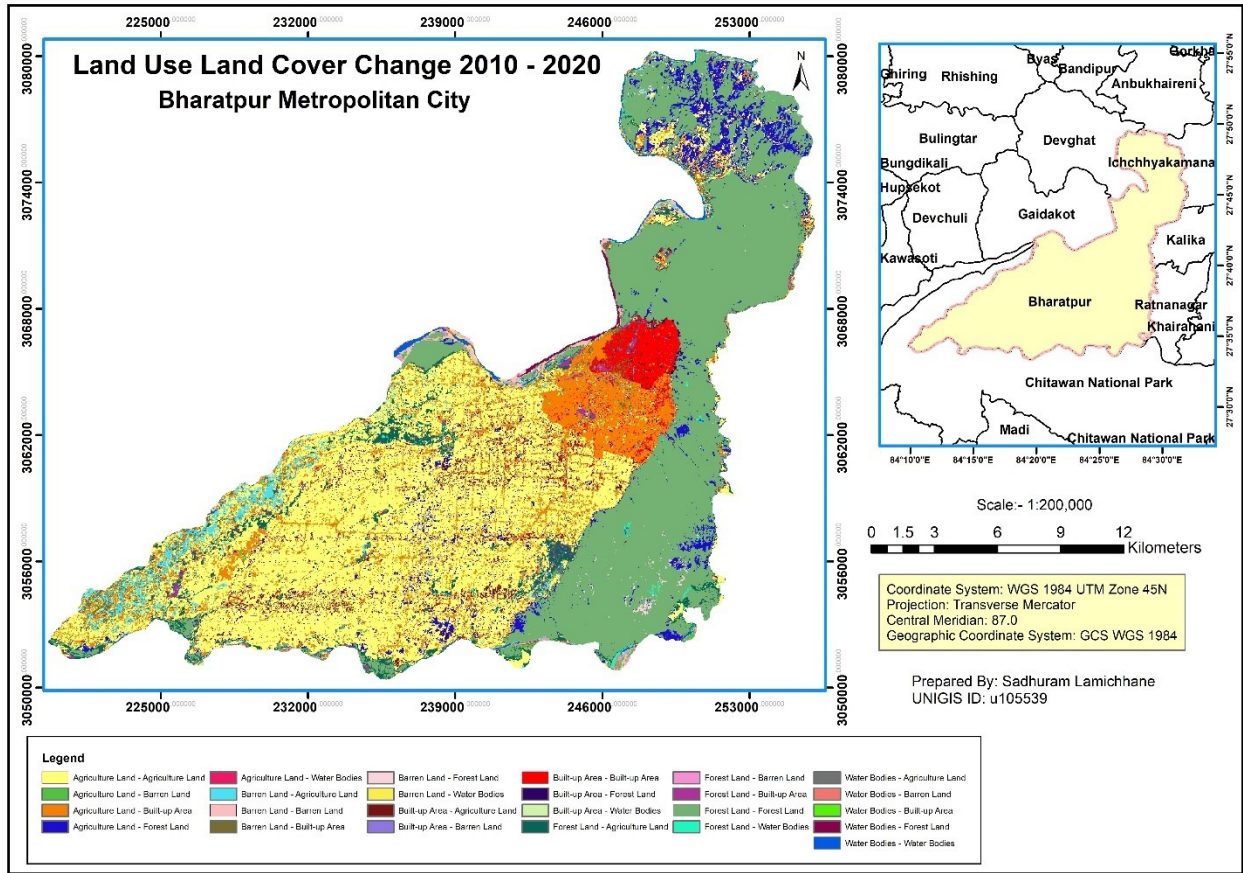
Map 9: Land use land cover changes 1990 to 2000

195.86 km<sup>2</sup> agricultural land, 1.53 km<sup>2</sup> barren land, 2.42 km<sup>2</sup> built – up area, 139.81 km<sup>2</sup> forest land and 1.02 km<sup>2</sup> water bodies remain same during 2000 to 2010. 10.50 km<sup>2</sup> agricultural land changes to barren land, 13.46 km<sup>2</sup> agricultural land changes to built up area. 27.49 km<sup>2</sup> forest land changes to agriculture land during 2000 to 2010. Land cover changes map from 2000 to 2010 is presented below Map 10.



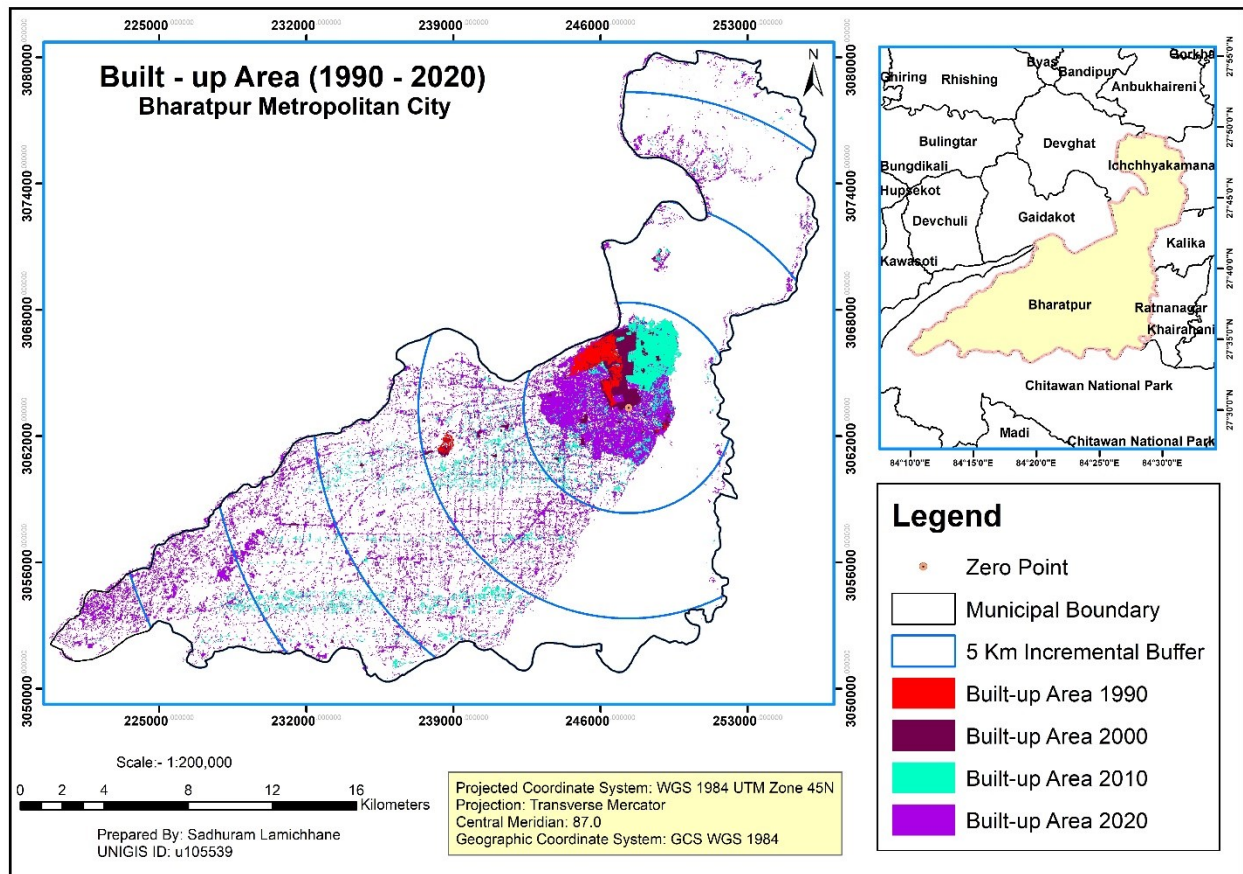
Map 10: Land use land cover changes 2000 to 2010

163.87 km<sup>2</sup> agricultural land, 1.94 km<sup>2</sup> barren land, 10.19 km<sup>2</sup> built – up area, 139.16 km<sup>2</sup> forest land and 2.37 km<sup>2</sup> water bodies remain same during 2010 to 2020. 1.75 km<sup>2</sup> agricultural land changes to barren land, 45.57 km<sup>2</sup> agricultural land changes to built – up area, 21.28 km<sup>2</sup> agricultural land changes to forest land 14.71 km<sup>2</sup> forest land changes to agriculture land during 2010 to 2020. Land cover changes map from 2010 to 2020 is presented below Map 11.



Map 11: Land use land cover changes 2000 to 2010

In 2011 total population of Chitwan was 579,984 and total population of the BMC is 280, 502 (CBS, 2011). Population rate of BMC increase rapidly during these years. Almost 49% of chitwan population occupies by bharatpur metropolitan city. Fertile land, better education, health and transportation facility attracted the rural people for migration in this area. Summarization of built – up area changes from 1990 to 2020 is presented in Map 12.



Map 12: BMC built – up area changes from 1990 to 2020

### 3.3 Types of Urban Sprawl

Urban sprawl can be categorized into three classes based on the extent of urban sprawl they area: expansion, infill and leapfrog (Angel et al., 2007; Batty et al., 2003; Besussi et al., 2010). Urban sprawl type was identified by using Urban Landscape Analysis Tool (ULAT). ULAT, which generated three different output maps they are: urban footprint map, urban area map and new development land cover map. Calculation of ULAT based on develop area with different densities. it also identifies undeveloped area which is close to proximity of developed area (Jason, 2009). It can analyze multi – year land cover maps of city. One of the output map from ULAT is new development map. New development map was classified into three different classes they are: (i) infill, (ii) extension, and (iii) leapfrog.

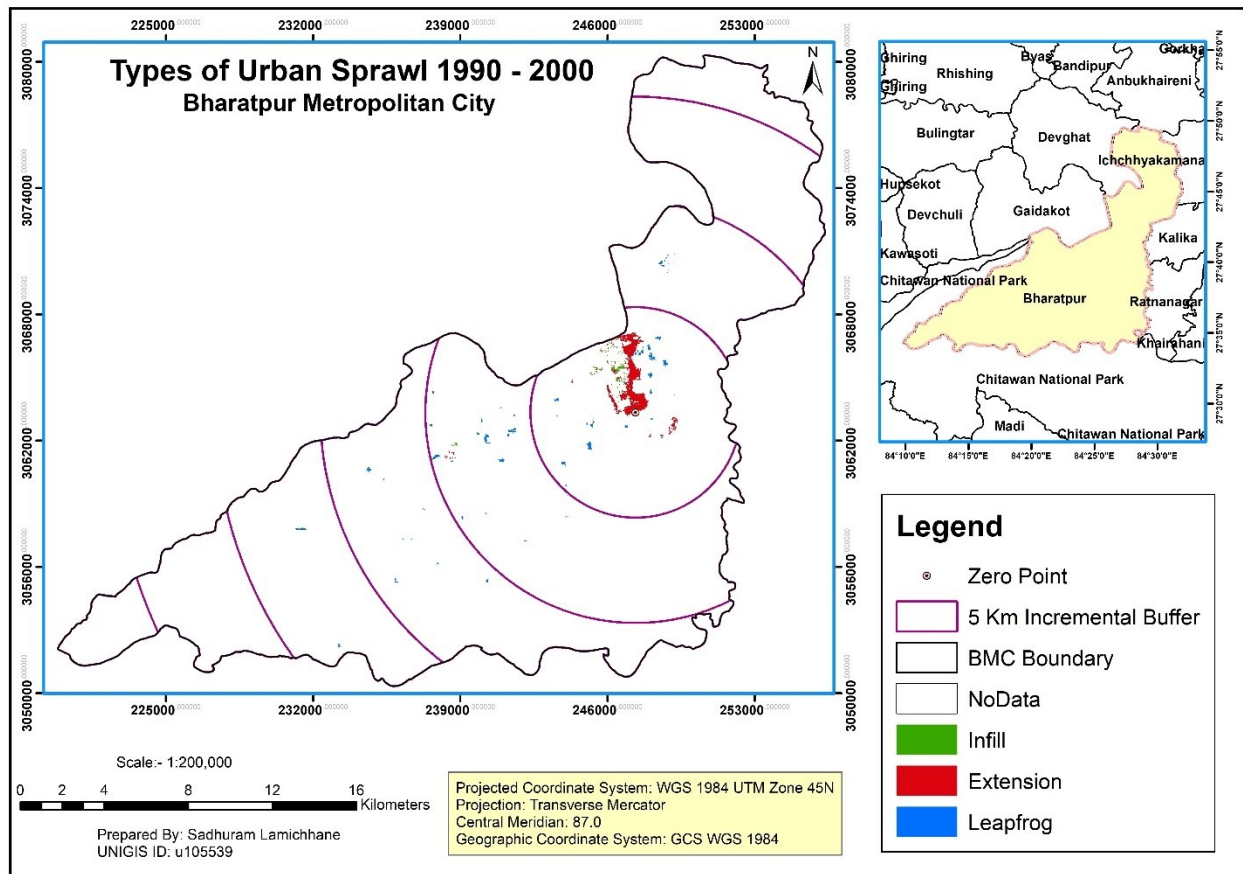
Infill type growth refers to new types of development in open area within the existing urban area newly developed pixels in urbanized open area in the preceding period of time as well as in the previous period as well (Angel et al., 2007).

Second type of sprawl is extension: it refers to the newly built development area, which overlaps with the current urban footprint, which represent newly developed pixels in the open fringes of the previous period.

Third type of urban sprawl is leapfrog: it is the type of development of a newly constructed area which is not overlapping with existing urban areas newly developed pixels outside the previously open rural areas. It favors the development of parcels located further out in the countryside over vacant lands adjacent to existing development (Torrens & Alberti, 2000). Leapfrogging results in an ad hoc development pattern that uses up a lot of land. Types of urban sprawl map are presented in following figures.

### **3.3.1 Types of Urban Sprawl from 1990 to 2000**

Urban sprawl types from 1990 to 2000 was depicted in (Map 13). Expansion type of growth existing between infill and leapfrog development. Types of urban growth with areas was shown below in figure 22. Out of total urbanization during 1990 to 2000, 0.28 km<sup>2</sup> newly developed pixels in urbanized open area which is infill. Maximum area of urbanization is extension which is 2.50 km<sup>2</sup>.



Map 13: Types of urban sprawl (1990 – 2000)

During the decade 1990 to 2010, most of the urban expansion due to “extension” type expansion within 5 km buffer zone from zero point. 2.47 km<sup>2</sup> area was detected extension type urban growth with 5km proximity and 0.03 km<sup>2</sup> area was detected at (5 – 10) km proximity range. 0.26 km<sup>2</sup> growth area were obtained due to “infill” type of expansion at (0 – 5) km proximity range. Leapfrogging type of urban sprawl were detected from 0 km to 20 km proximity range, 0.39 km<sup>2</sup>. So, mostly all the expansion within (0 – 5) km buffer zone.

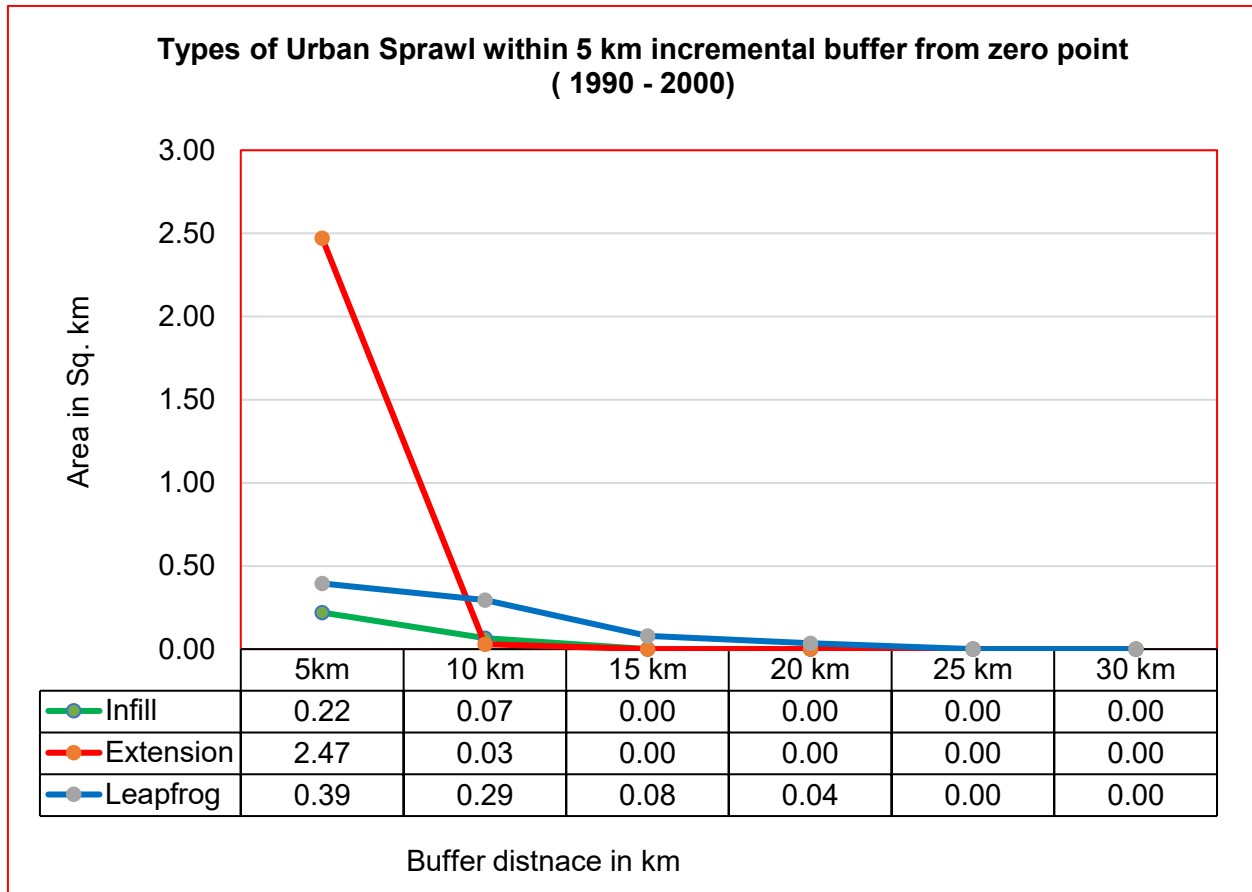
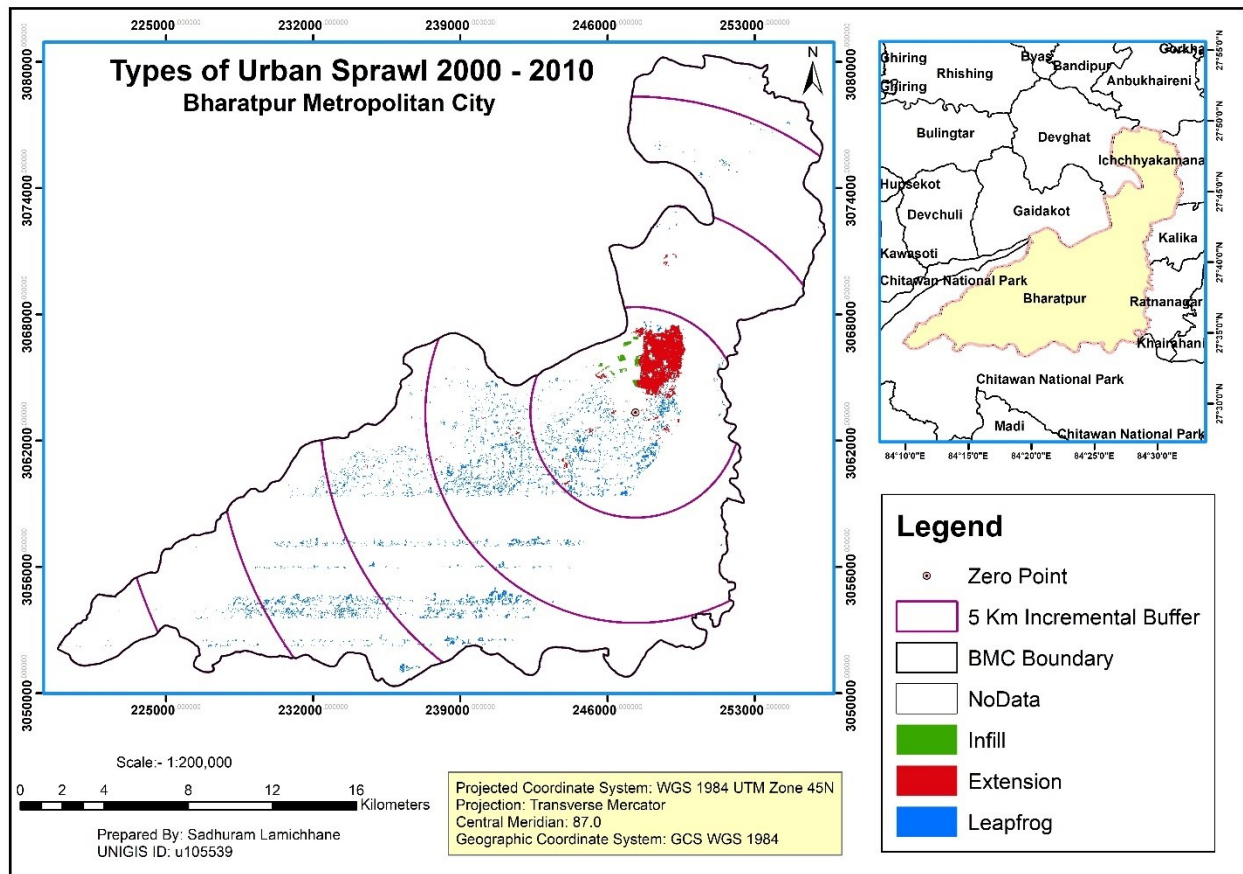


Figure 22: Types of Urban Sprawl within 5 km incremental buffer (1990 - 2000)

### 3.3.2 Types of Urban Sprawl from 2000 to 2010

Urban sprawl types from 2000 to 2010 was depicted in (Map 14). Expansion type of growth existing between infill and leapfrog development. Out of total urbanization during 2000 to 2010, 0.40 km<sup>2</sup> newly developed pixels in urbanized open area which is infill. Maximum area of urbanization is extension which is 5.50 km<sup>2</sup>. During the decade 2000 to 2010, most of the urban expansion due to “extension” type expansion within 5 km buffer zone from zero point. 5.40 km<sup>2</sup> area was detected extension type urban growth with 5km proximity and 0.09 km<sup>2</sup> area was detected at (5 – 10) km proximity range.



Map 14: Types of urban sprawl (2000 – 2010)

0.40 km<sup>2</sup> growth area were obtained due to “infill” type of expansion at (0 – 5) km proximity range and there was no any infill type of sprawl at (10 – 30) km buffer range. Leapfrogging type of urban sprawl were detected at (0 – 5) km proximity range was 2.21 km<sup>2</sup>, at (5 -10 km) the growth area was 2.03 km<sup>2</sup>. So, most of the leapfrog type growth was detected from 2000 to 2010. Mostly the infill type urban sprawl detected at BMC ward 2, 3 10 and 11. Extension type of sprawl mostly detected at BMC ward 1, 2, 10,11. Here, we can see that ward 10 and 11 has both type of urban expansion. Leapfrog type of sprawl was detected at Fulbari, Gitanagar, Shivanagar, Patihani and mangalpur. Types of urban growth with areas was shown below in figure 23.

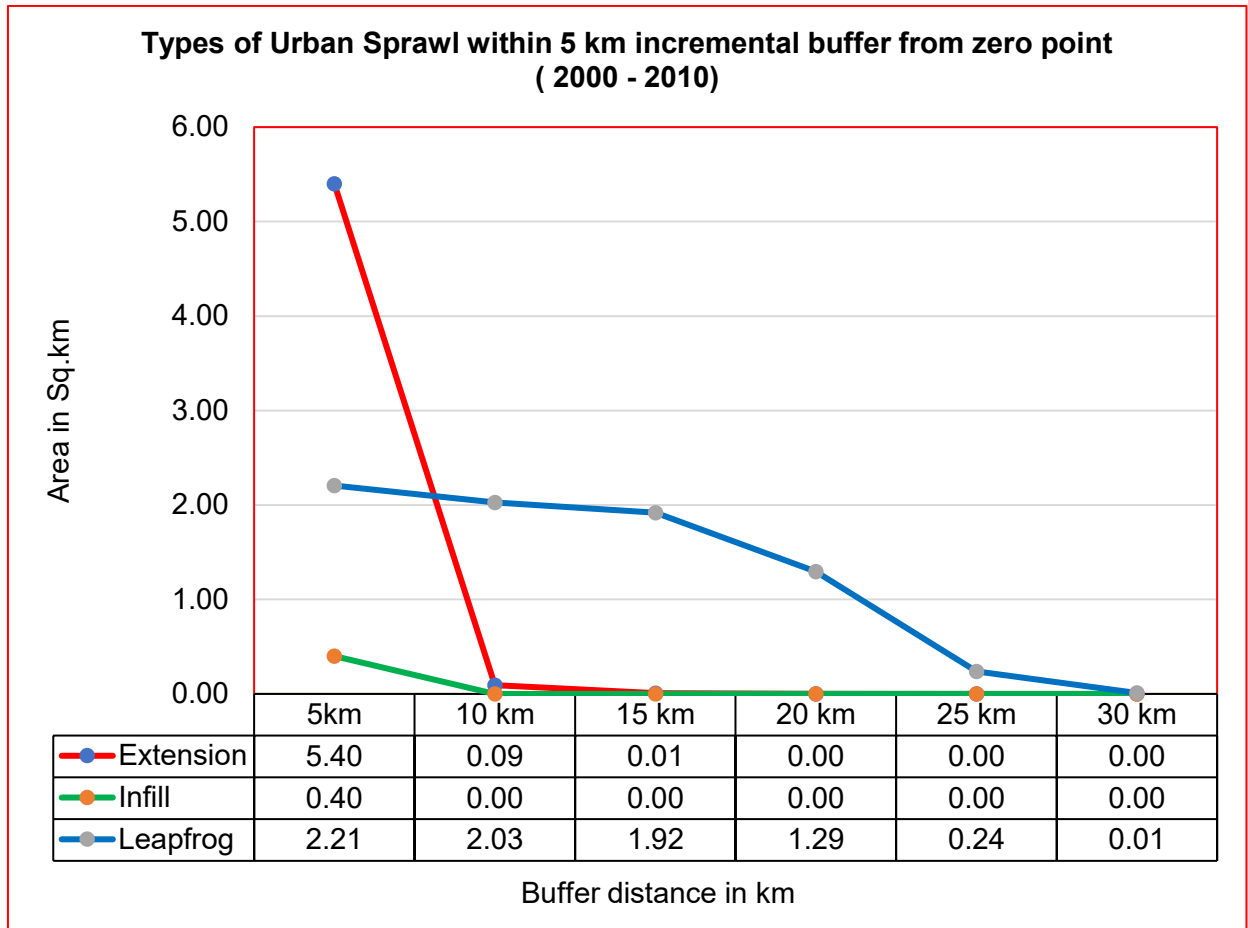
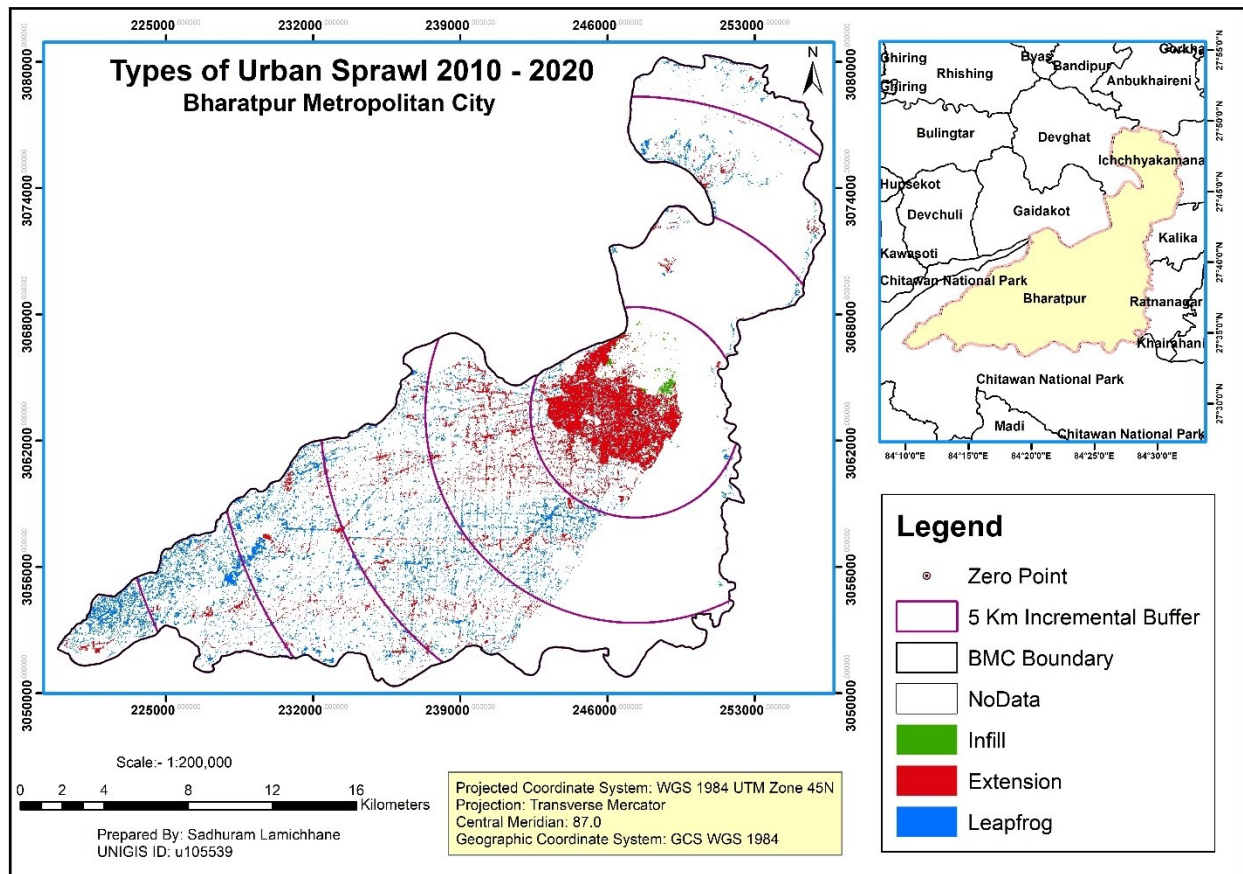


Figure 23: Types of Urban Sprawl within 5 km incremental buffer (2000 - 2010)

### 3.3.3 Types of Urban Sprawl from 2010 to 2020

Urban sprawl types from 2010 to 2020 is presented in (Map 15). Expansion type of growth existing between infill and leapfrog development. Out of total urbanization during 2010 to 2020, 0.56 km<sup>2</sup> newly developed pixels in urbanized open area which is infill. Maximum area of urbanization is extension which is 26.80 km<sup>2</sup>. During the decade 2010 to 2020, most of the urban expansion due to “extension” type expansion within 5 km buffer zone from zero point. 18.97 km<sup>2</sup> area was detected extension type urban growth with 5km proximity and 3.57 km<sup>2</sup> area was detected at (5 – 10) km proximity range.



Map 15: Types of urban sprawl (2010 – 2020)

0.55 km<sup>2</sup> growth area were obtained due to “infill” type of expansion at (0 – 5) km proximity range and there was no any infill type of sprawl at (10 – 30) km buffer range. Leapfrogging type of urban sprawl were detected at (0 – 5) km proximity range was 0.66 km<sup>2</sup>, at (5 -10 km) the growth area was 3.95 km<sup>2</sup>. So, most of the leapfrog type growth was detected from 2000 to 2010. Out of total growth 20.01 km<sup>2</sup> area was obtained as leapfrog. Most of the new settlement area was obtained at (5- 30) km proximity range. Due to rapid construction and widening of urban road, infill type of expansion occurred in newly constructed and widened roads. It seems most of the rural open land and agricultural land was used for new settlement. Mostly the infill type urban sprawl detected at BMC ward 2 and 11. Extension type of sprawl mostly detected at BMC ward 3, 4, 7, 8, 9, 10, 11,12. Here, we can see that ward 11 has both type of urban

expansion. Leapfrog type of sprawl was detected at Fulbari, Gitanagar, Shivanagar, Patihani and mangalpur. Types of urban growth with areas was shown below in figure 24.

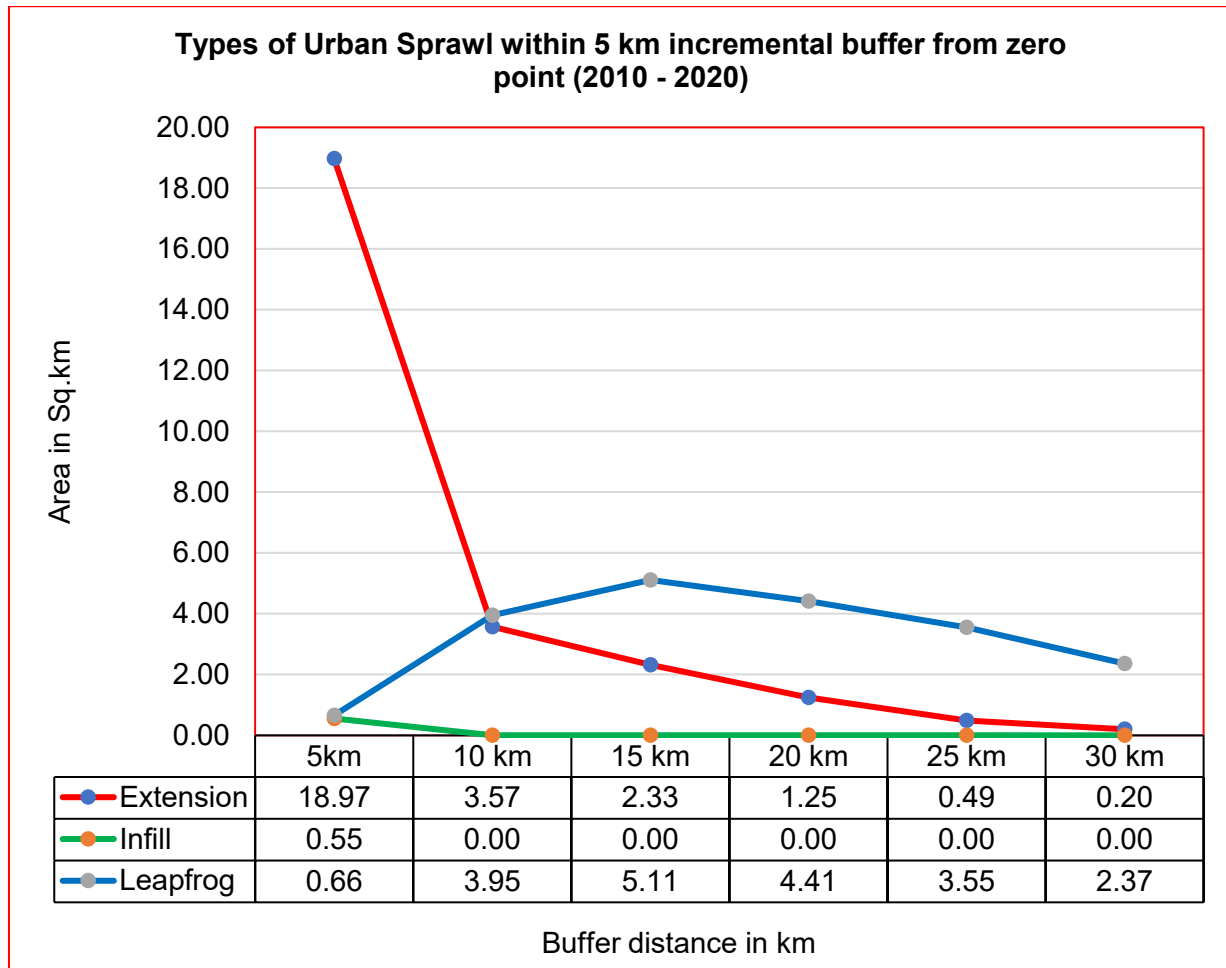
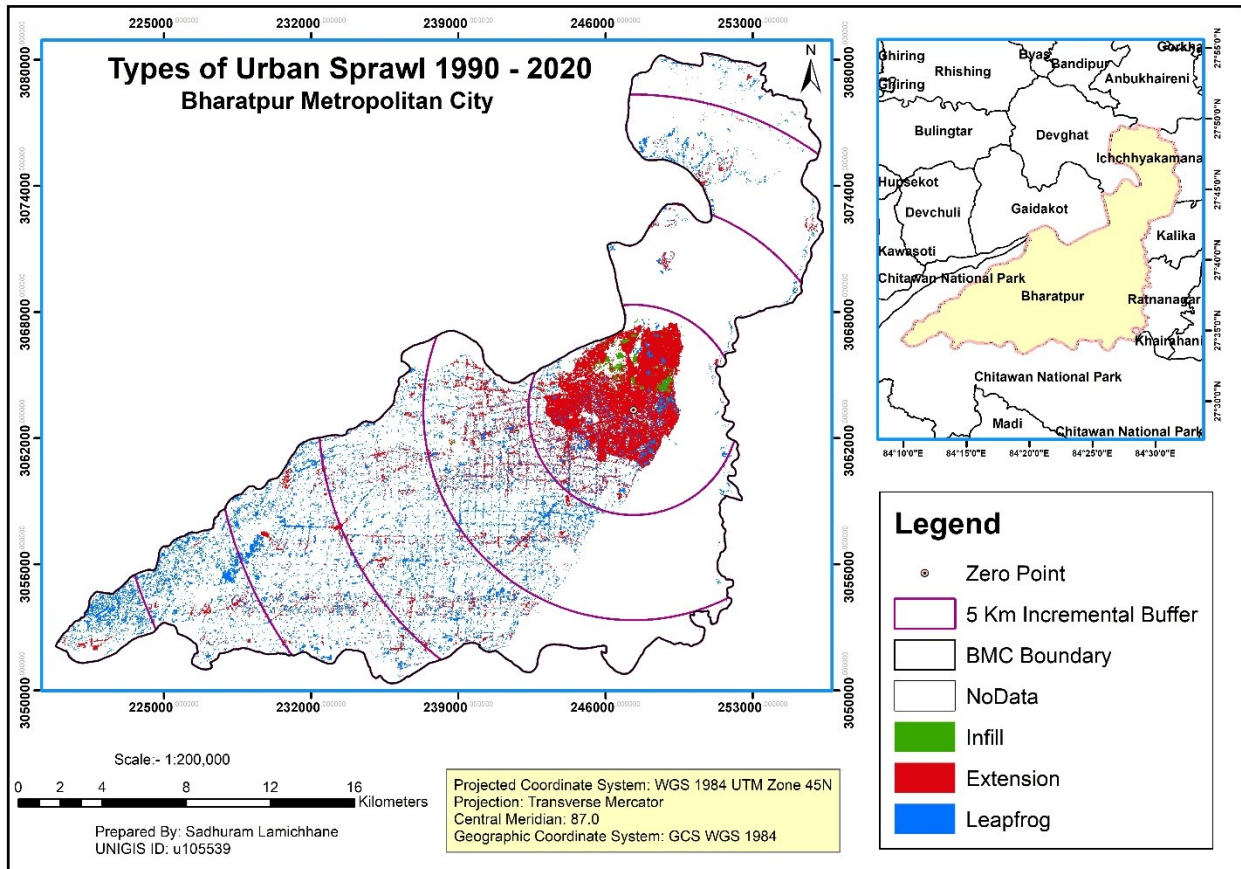


Figure 24: Types of Urban Sprawl within 5 km incremental buffer (2010 - 2020)

The reason behind the rapid urban growth from 2010 to 2020 due to land value, transportation and education facility, federalism, tourism, commercialization in suburbs and rural open area. Chitwan national park, narayani corridor, sauraha, numerous lakes are the main sources of attraction for domestic and international tourist. Better hospitality and green environment of this city increases domestic and international tourism day by day.

### 3.3.4 Types of Urban Sprawl from 1990 to 2020

Urban sprawl types from 1990 to 2020 is presented below in map 16 and figure 25 with incremental buffer area.



Map 16: Types of urban sprawl (1990 – 2020)

Out of total urbanization during 1990 to 2020, 8.94 km<sup>2</sup> newly developed pixels in urbanized open area which is infill. Maximum area of urbanization is extension which is 103.48 km<sup>2</sup>. During the decades 1990 to 2020, most of the urban expansion due to “extension” type expansion within 5 km buffer zone from zero point. 32.03 km<sup>2</sup> area was detected extension type urban growth with 5km proximity, 21.21 km<sup>2</sup> area was detected at (5 – 10) km proximity range, 22.17 km<sup>2</sup> area was detected at (10 – 15) km proximity range and 18.53 km<sup>2</sup> area was detected at (15 – 20) km proximity range.

Most of the land of this city was arable and suitable for cereal crops. But due to rapid migration from rural areas most of the arable agriculture and cultivated land was transformed to built – up area. Mostly leapfrog expansion had greater impact on cultivated and bare land. Within the proximity of 0 to 30 km buffer range extension leapfrog types of development was main dominating type of urban sprawl.

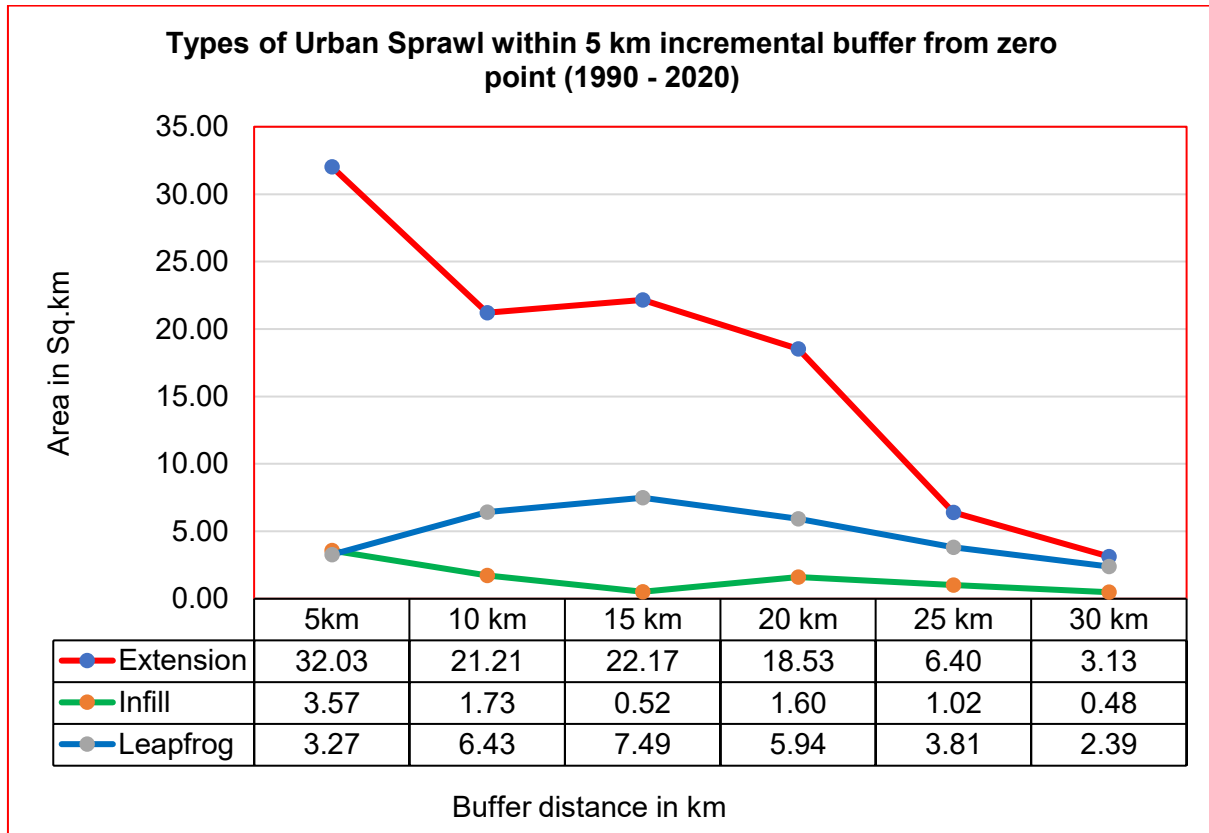


Figure 25: Types of Urban Sprawl within 5 km incremental buffer (1990 - 2020)

Urban Landscape Analysis Tool also generate “Urban footprint map”. Urban footprint shows the impact that development has on the city's open countryside. This map contains seven project area categories based on different value of urbanization and attributes of land cover. There was increment of built – up during time span 1990 – 2020. Urbanization of rural settlements has increased during the study period. This increment of rural settlements in this city due to rapid urbanization in rural areas, land price, extension of services towards the rural

areas. Detailed information about urban footprint during 1990 – 2020 is presented below in Figure 26 and urban footprint map during study period is depicted in Appendix II.

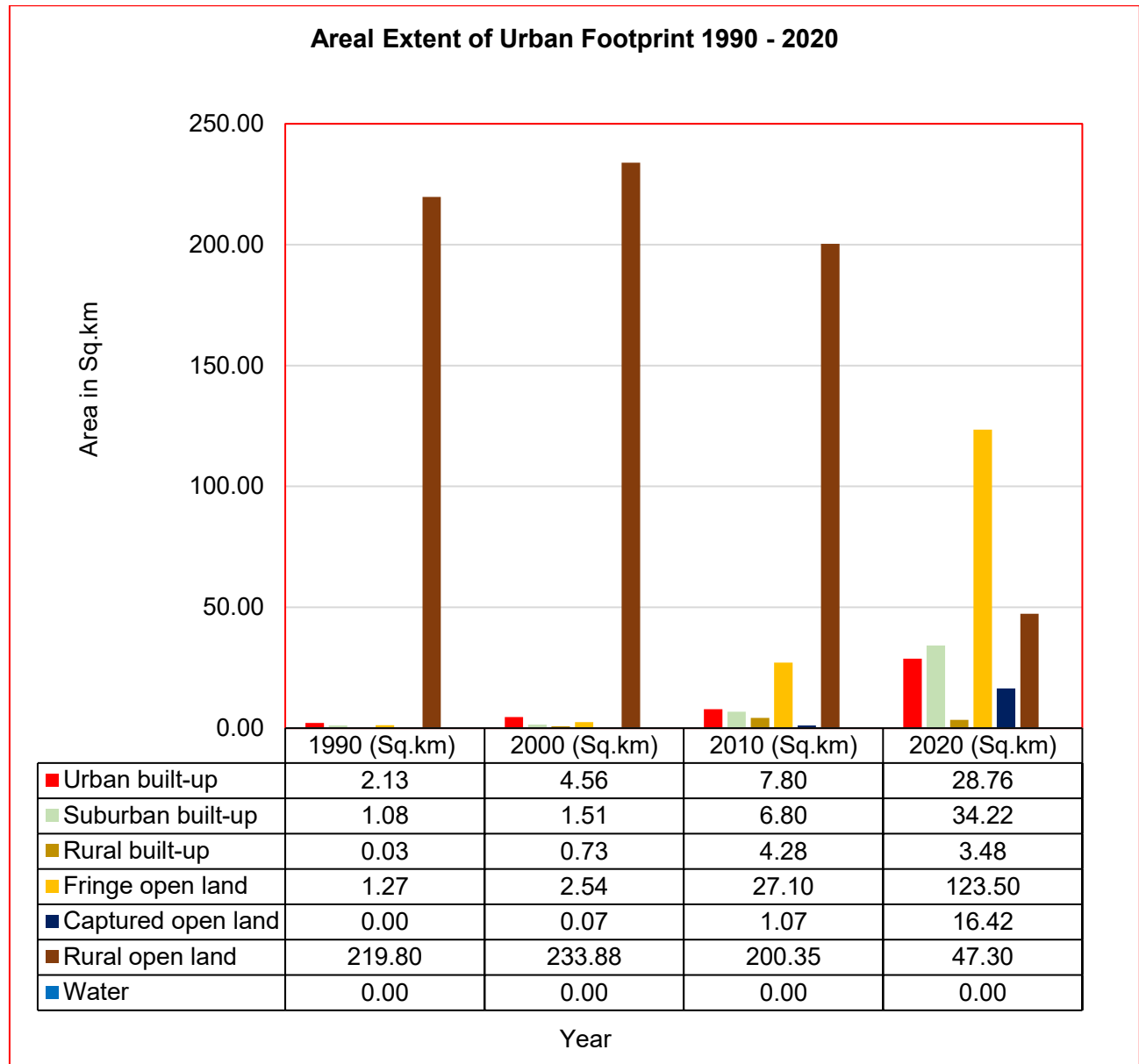


Figure 26: Areal Extent of Urban Footprint (1990 - 2020)

The seven urbanized classes impact the different level of urbanization. Rural open land was rapidly decrease during 2010 – 2020 due to new settlements. There was drastic change of urbanized area in this metropolitan city. Slight changes of urban built – up, suburban built – up,

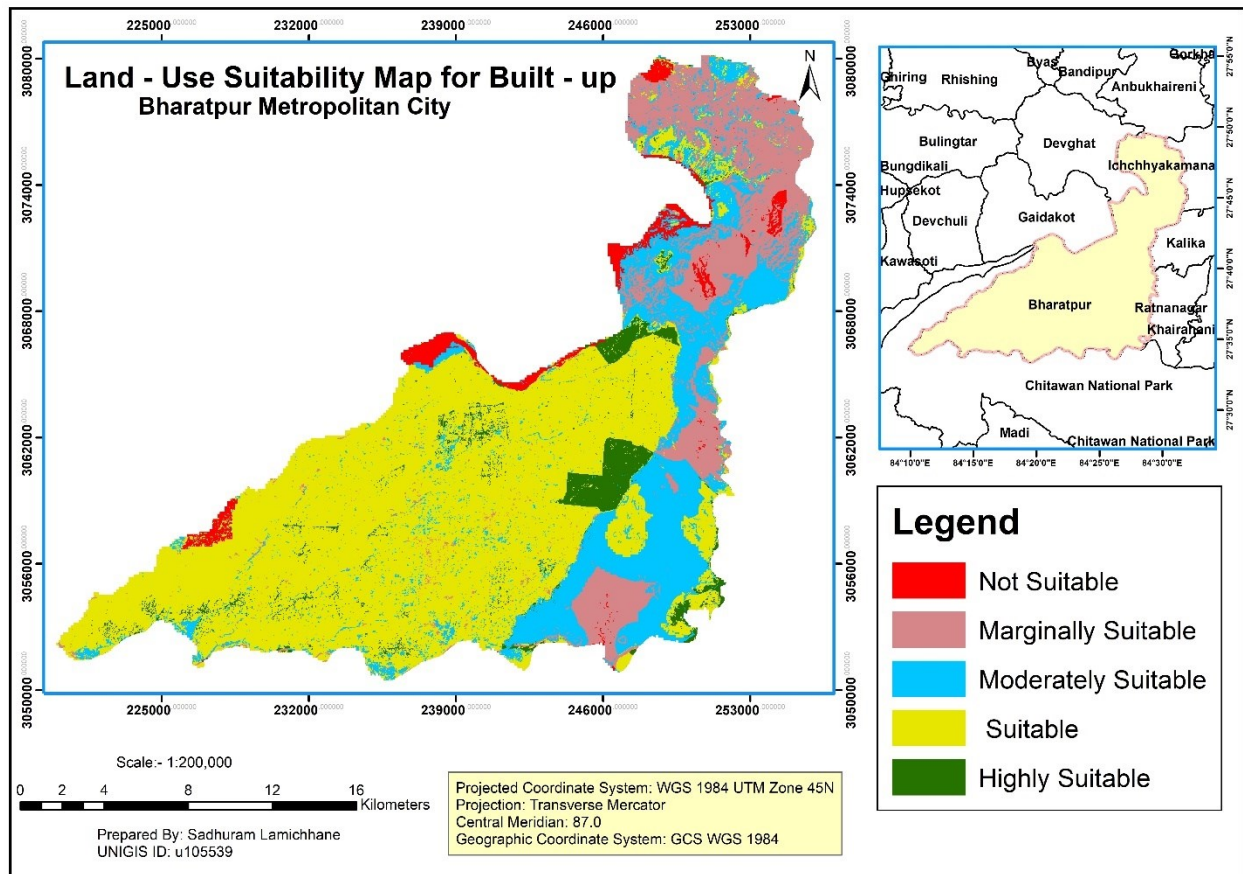
rural built – up during the study year 1990 to 2010. There were huge amount of land cover classes changes from 2010 to 2020. Urban built-up area at 1990 was 2.13 km<sup>2</sup>, at 2020 it increases to 28.76 km<sup>2</sup>. Fringe open land from 1990 to 2000 has slight changes but from decades 2000 to 2020 it has drastic change. 2.54 km<sup>2</sup> to 123.50 km<sup>2</sup>.

### **3.4 Urban Sprawl Modeling for 2030 and 2040**

Urban sprawl extent modelling for 2030 and 2040 was performed with the TerrSet Geospatial Monitoring and Modeling Software. Land Change Modeler (LCM) used for modeling future land use land cover analysis in bharatpur metropolitan city. Detailed process for LULC prediction for 20340 and 2040 was explained at chapter 2.4 Urban Sprawl Extent Modeling. LULC change analysis during 1990 to 2020 was performed at chapter 3.2 map (9 – 11). Change probability grid for 2010 and 2020 was generated with help of LCM and with the application of CA – Markov chain analysis land cover change prediction was performed in TerrSet IDRISI software. The model of implication CA-Markov divides the whole area into cell grid or grid; this is an integrated area with a grid or raster grid, representing a finite state set (Kityuttachai et al., 2013). Cell size for output predicted raster is 30m×30 m. Various parameter for urban extent prediction are DEM, slope, distance from road, distance from river, aspect, suitability map for built up.

#### **3.4.1 Suitability Analysis for Built – up area**

Suitability analysis for built – up was performed by6 analytical hierarchy process (AHP). Importance and weightage of five factors: (i) Physical factor (ii) Accessibility factor (iii) Social factor (iv) Economic factor (v) Environmental factor were analyzed by field observation and questionnaire survey with local people. All selected raster was reclassified with cell size 30m×30m. Detailed description of AHP process was mentioned was chapter 2.4 and chapter 2.4.1. Final suitability map was prepared with weighted overlay analysis in ArcGIS. Final suitability map for built – up is presented below.



Map 17: Suitability map for built – up area development

Suitability map for built up area was depicted in map 17. Out of total area 14.97 km<sup>2</sup> obtained as not suitable for built – up, which is 3.46% of total study area. Mostly the not suitable area is located at and near water bodies, higher elevated land, near Narayanghat - Mugling Highway. So, this area is restricted for new construction for settlements. Maximum villages of ward no 1, 3, 16, 26, 29 have shown unsuitable land for built – up. Jugedi, Dasdhunga, bhorle, devghat area have shown not suitable. 73.53 km<sup>2</sup> area was obtained marginally suitable area for built – up which is 16.98% of total study area. Most of the marginally suitable area is located at dense forest zone, this is not better choice for settlements. Maximum villages of ward no 1, 8, 11, 12 and 29 have shown marginally suitable area. Further construction for built – up will harm and destroy the aesthetic area, dense forest and vegetated area. 81.96 km<sup>2</sup> area was obtained as

moderately suitable which is 18.93% of total area. Maximum villages of ward no 1, 8, 11, 12, 16, 22, 23, 27 and 29 have shown as moderately suitable class. But for these villages are located at moderately suitable category. Which is apart from the existing facilities and nearer to forest and river. 243.32 km<sup>2</sup> area was obtained as suitable for built – up which is 56.20% of total area. But most of the area covered by suitable category are agriculture/cultivated area and has better accessibility of road. Maximum village of shivanagar, patihani, meghauli, gitanagar, jyotinagar have shown suitable area for built – up and 19.17 km<sup>2</sup> area was obtained as highly suitable for built up which is 4.43% of study area. Most of the area of this category has already dense settlements. Suitability classes with area ins presented in Figure 27.

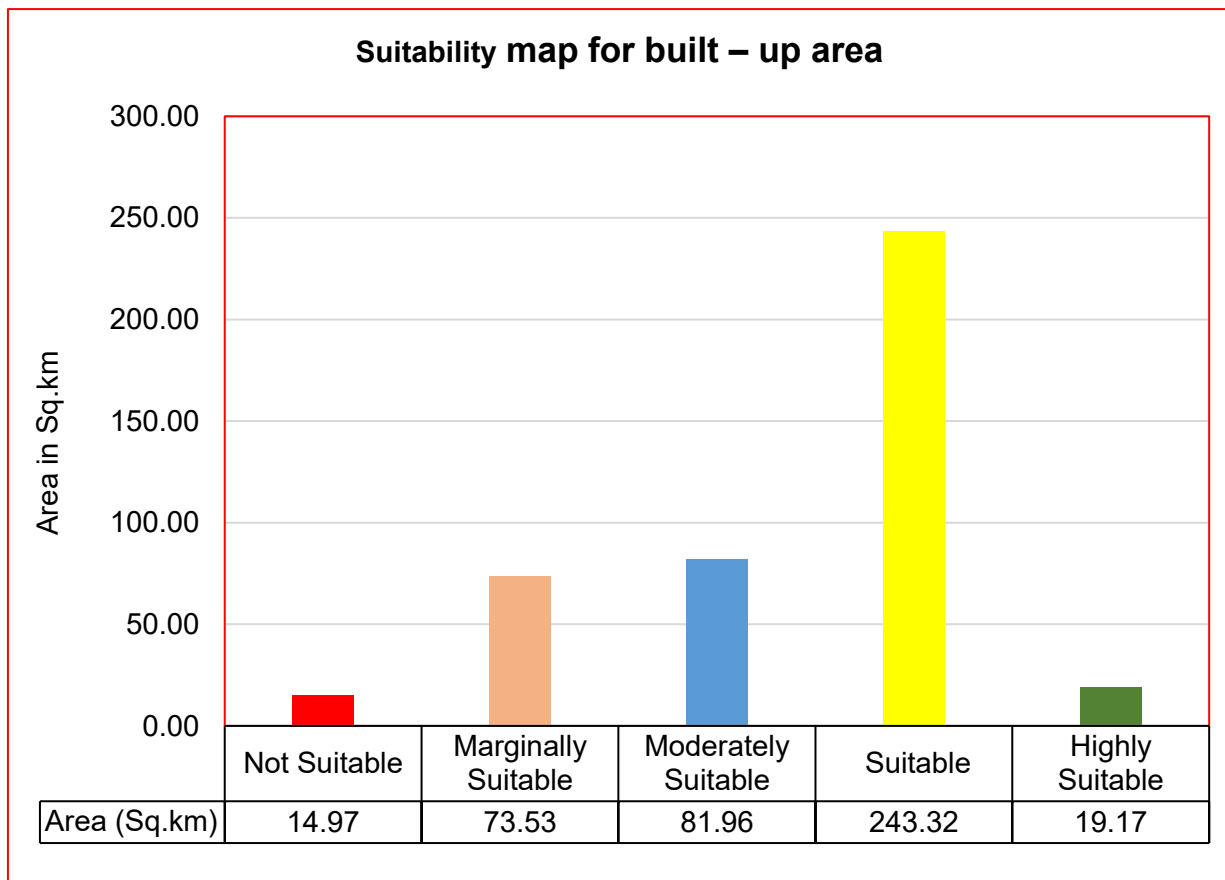
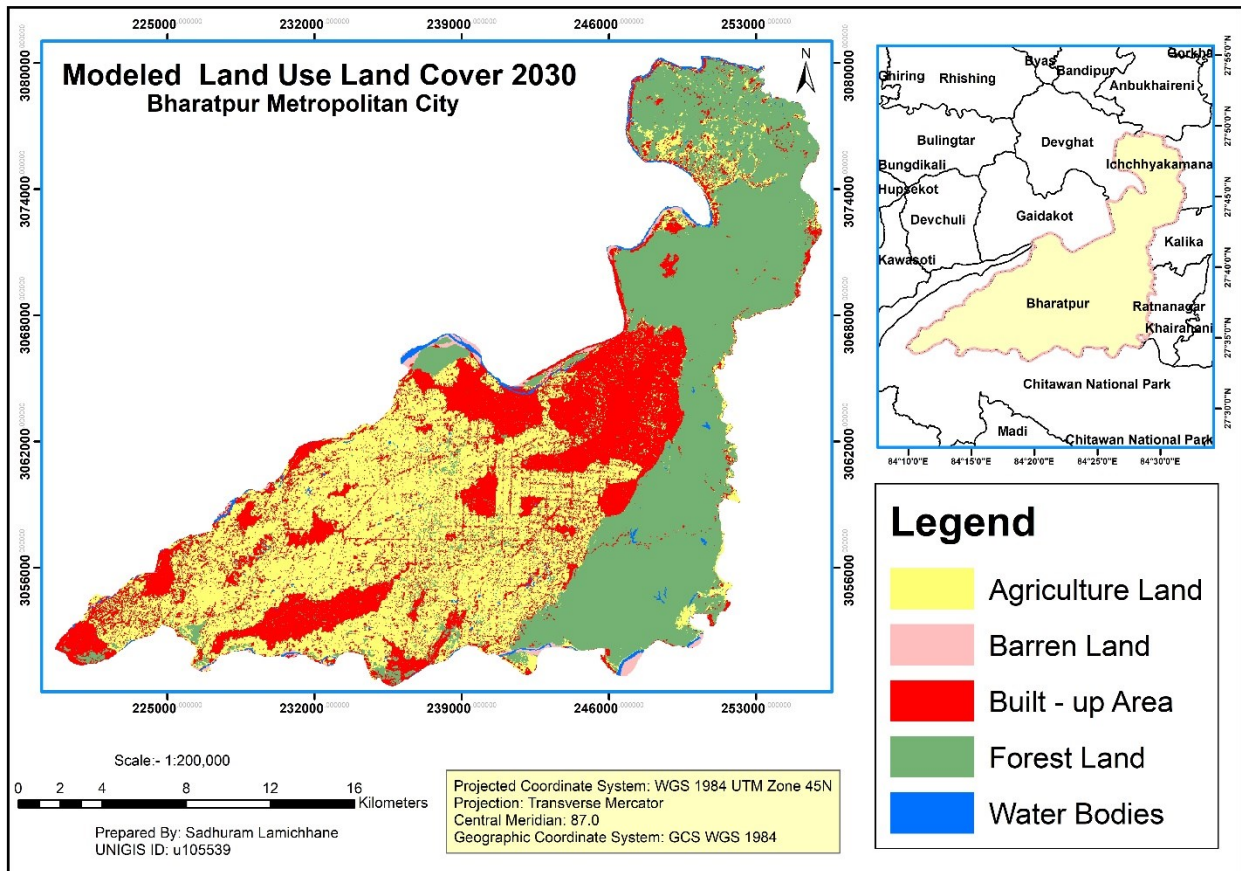


Figure 27: Suitability map for built – up area

### 3.4.1 Land Use Land Cover Modeling of 2030 and 2040

#### 3.4.1.1 Land Use Land Cover Modeling of 2030

LULC map for 2030 was generated by using LULC map of 2010 and 2020 as base year. LULC 2010 implied as application of state time ( $t_1$ ) and modeled LULC 2020 implied as model state time ( $t_2$ ) for land cover prediction of 2030. CA – Markovian method used for land cover prediction for 2030. Transition potential and transition area matrix was analyzed during the study period 2010 to 2020. Following maps 18 represents modeled LULC of BMC 2030.



Map 18: Modeled land use land cover map 2030

Modeled land use land cover map of 2030 was depicted in (Map 18). Forest land was obtained the most dominant land in this metropolitan city. Which occupies 160.29 km<sup>2</sup> land out of 432.95

km<sup>2</sup>. Which is 37.02% of total land in BMC. Agricultural land is second dominant land which cover 149.98 km<sup>2</sup> area, which is 34.64% of total area. Built – up area is third dominant land which occupies 113.25 km<sup>2</sup> area, which is 26.16% of total land use land cover. Water Bodies is fourth dominant land cover, which occupies 5.78 km<sup>2</sup> area, which is 1.33% of its total LULC. Last and least dominant land cover is barren land, which occupies 3.65 km<sup>2</sup> area, which is 0.84% of total LULC. Above explanation concludes that bare and open land occupies small area in this modeled LULC map of BMC 2030.

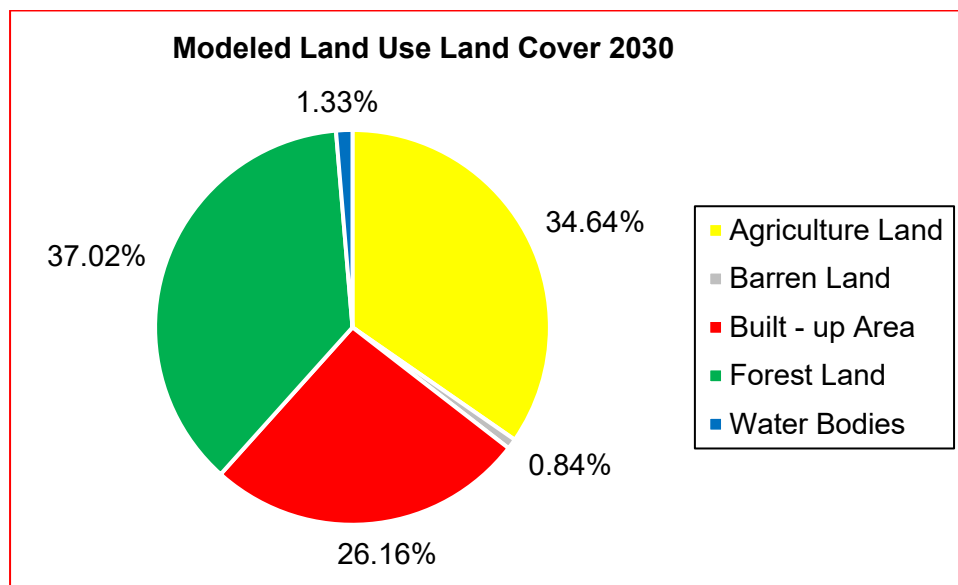


Figure 28: 2030 modeled land cover area with Pie – chart

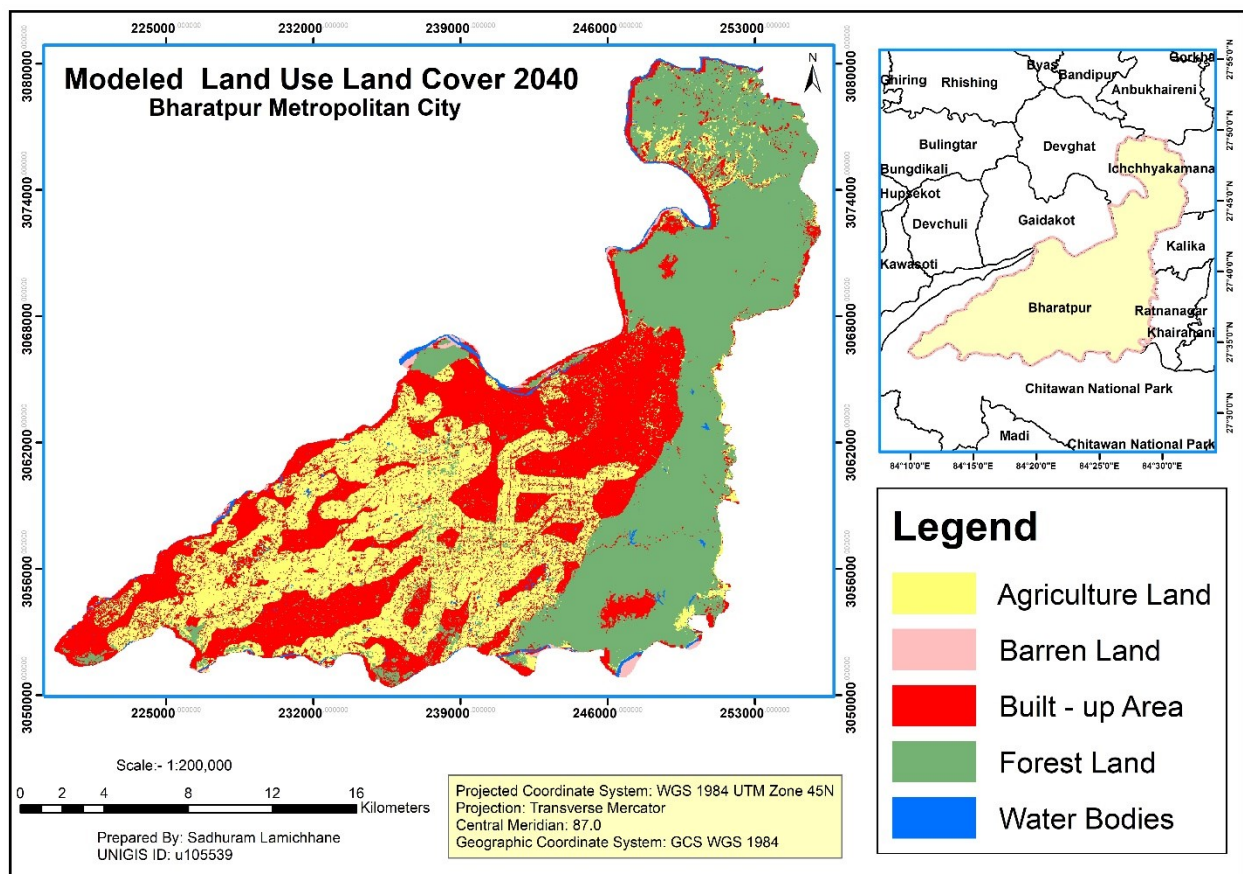
Map 18 and figure 28 demonstrates the drastic changes between different land cover. There was significant increment of built – up area. In 1990 built – up area in BMC was 3.29 km<sup>2</sup>, in 2000 built – up area increases two times which is obtained 6.79 km<sup>2</sup>, in 2010 it increases to 17.28 km<sup>2</sup>, and finally in 2020 its increase 3.5 times which is 64.32 km<sup>2</sup>.

During the study period 1990 to 2030, built up area expected to increase by more than two folds. We can assume that, there will be substantial decreases in agricultural and cultivated land, forest land and barren land. Agriculture land is expected to decreases by 23%, barren

land is expected to decrease by 25%, forest land expected to decrease by 2% and water bodies expected to decrease by 1%, whereas built-up area is expected to increase by 76%. During these periods agriculture land and bare land will contribute to settlements for new construction.

### 3.4.1.2 Land Use Land Cover Modeling of 2040

LULC map for 2040 was generated by using LULC map of 2020 and modeled 2030 as base year. LULC 2020 implied as application of state time ( $t_1$ ) and modeled LULC 2030 implied as model state time ( $t_2$ ) for land cover prediction of 2040. CA – Markovian method used for land cover prediction for 2040. Transition potential and transition area matrix was analyzed during the study period 2020 to 2030. Following maps 19 represents modeled LULC of BMC 2040.



Map 19: Modeled land use land cover map 2040

Modeled land use land cover map of 2040 was presented in (Map 19). Forest land was obtained the most dominant land in this metropolitan city. Which occupies 146.37 km<sup>2</sup> land out of 432.95 km<sup>2</sup>. Which is 36.12% of total land in BMC. Built – up area is second dominant land which cover 149.33 km<sup>2</sup> area, which is 34.49% of total area.

Agricultural land is third dominant land which occupies 118.78 km<sup>2</sup> area, which is 27.43% of total land use land cover. Water Bodies is fourth dominant land cover, which occupies 5.78 km<sup>2</sup> area, which is 1.33% of its total LULC. Last and least dominant land cover is barren land, which occupies 2.70 km<sup>2</sup> area, which is 0.62% of total LULC. Above explanation concludes that bare and open land occupies small area in this modeled LULC map of BMC 2040.

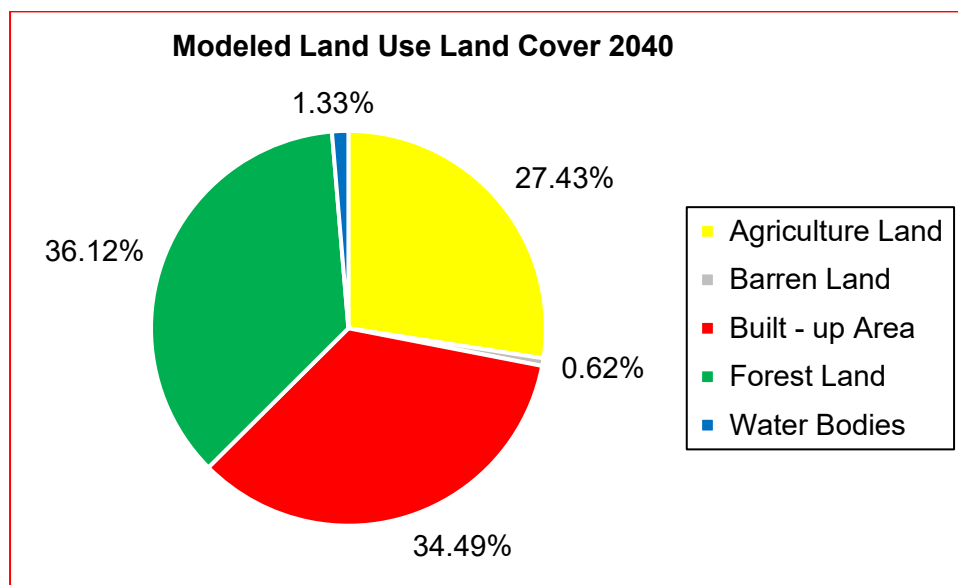


Figure 29: 2040 modeled land cover area with Pie – chart

Map 19 and figure 29 shows the significant changes between different land cover. There was significant increment of built – up area.

In 1990 built – up area in BMC was 3.29 km<sup>2</sup>, in 2000 built – up area increases two times which is obtained 6.79 km<sup>2</sup>, in 2010 it increases to 17.28 km<sup>2</sup>, and finally in 2020 its increase 3.5 times which is 64.32 km<sup>2</sup>. During the study period 1990 to 2040, built up area expected to increase

by more than two folds. We can assume that, there will be substantial decreases in agricultural and cultivated land, forest land and barren land. Agriculture land is expected to decrease by 39% than 2020 LULC and 21% by predicted 2030 LULC. Barren land is expected to decrease by 45% than 2020 LULC and 26% by predicted 2030 LULC.

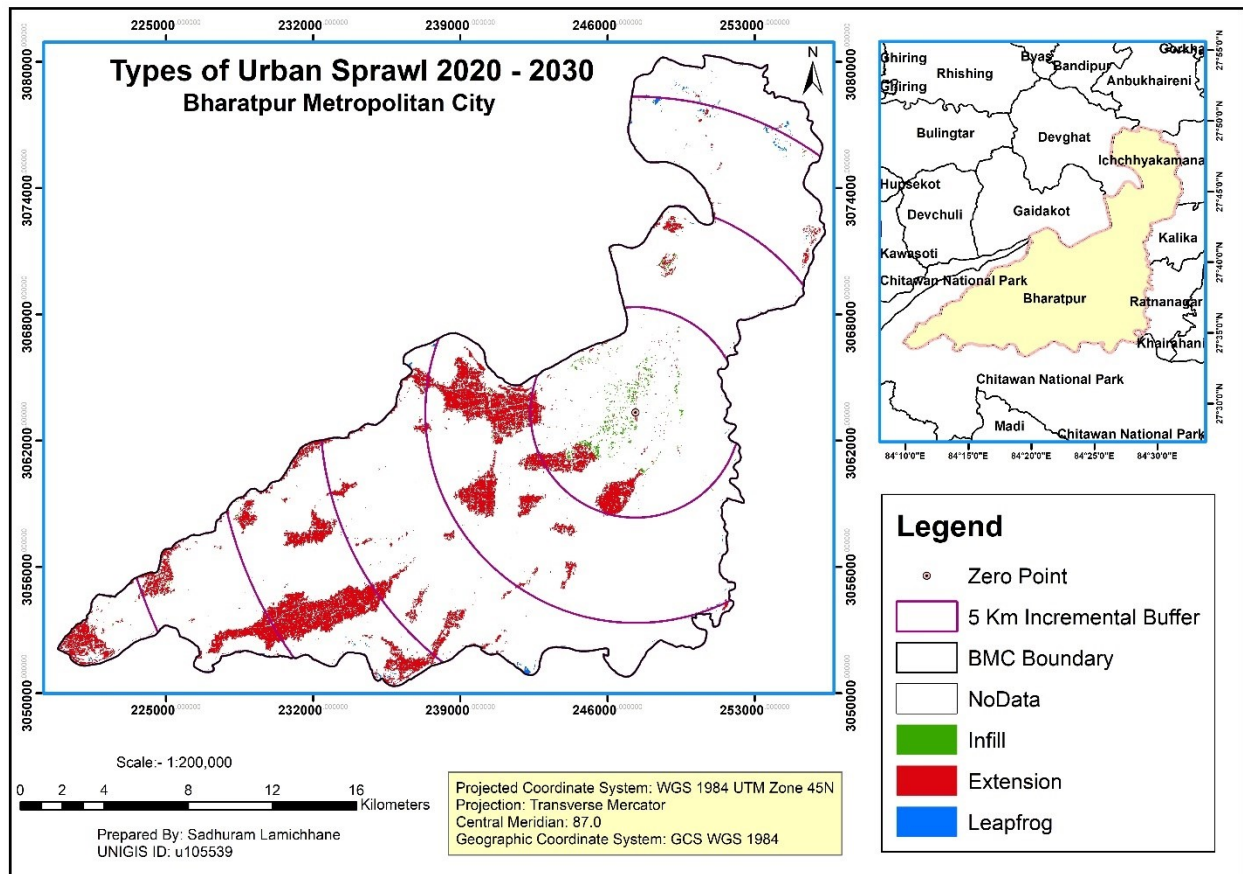
Forest land expected to decrease by 5% than 2020 LULC and 2% by predicted 2030 LULC and water bodies expected to decrease by 1% than 2020 LULC and 0% by predicted 2030 LULC. Whereas built – up area is expected to increase by 132% than 2020 LULC and 32% by predicted 2030 LULC. During these periods agriculture land and bare land will contribute to settlements for new construction.

### **3.5 Types of Urban Sprawl from 2020 to 2040**

Urban sprawl from 2020 to 2040 was generated by Urban Landscape Analysis Tool. Firstly, LULC map of 2020, modeled LULC 2030 and 2040 was introduced to ULAT. Two new development maps and three urban footprint maps were generated. Types of urban sprawl from 2020 to 2040 are presented below.

#### **3.5.1 Types of Urban Sprawl from 2020 to 2030**

Urban sprawl during the study period 2020 to 2030 is depicted below in map 20 and fig 30. This map represents different categories of urban expansion they are: (i) infill (ii) extension (iii) leapfrog development.



Map 20: Types of urban sprawl (2020 – 2030)

During the decade 2020 to 2030, most of the urban expansion due to “extension” type expansion within 10 km buffer zone from zero point. 12.04 km<sup>2</sup> area was detected extension type urban growth with 10 km proximity and 11.83 km<sup>2</sup> area was detected at (10 – 15) km proximity range. 0.96 km<sup>2</sup> growth area were obtained due to “infill” type of expansion at (0 – 5) km proximity range.

Leapfrogging type of urban sprawl were detected from 0 km to 30 km proximity range, 0.44 km<sup>2</sup>. So, mostly all the expansion within (0 – 10) km buffer zone. Out of total urban expansion 46 km<sup>2</sup> is extension type of urban expansion. The red patches represent extension type of urban growth, most of agriculture rural development, fringe open land has contribution to new

development. Mostly sub urban built – up, rural open land within 10 km and 15 km buffer zone. Extension of new development was expected to 0 km to 30 km.

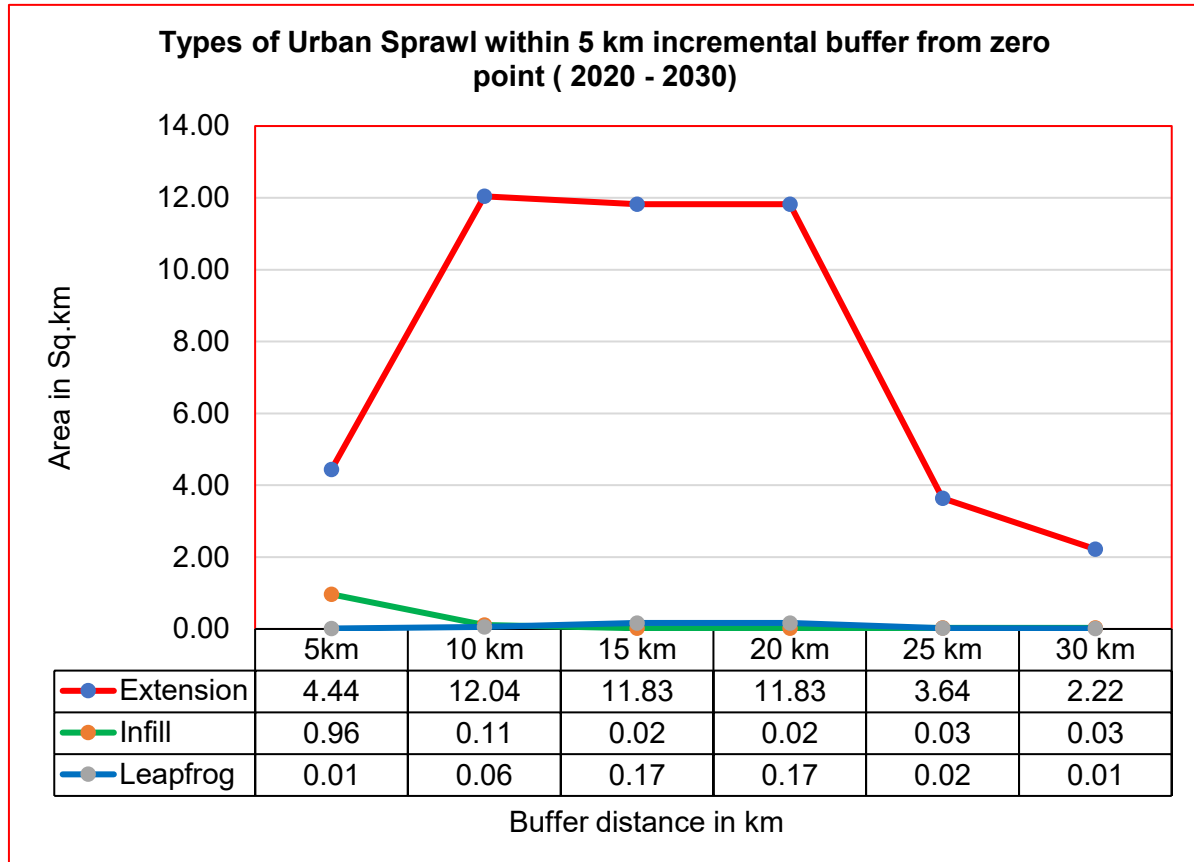
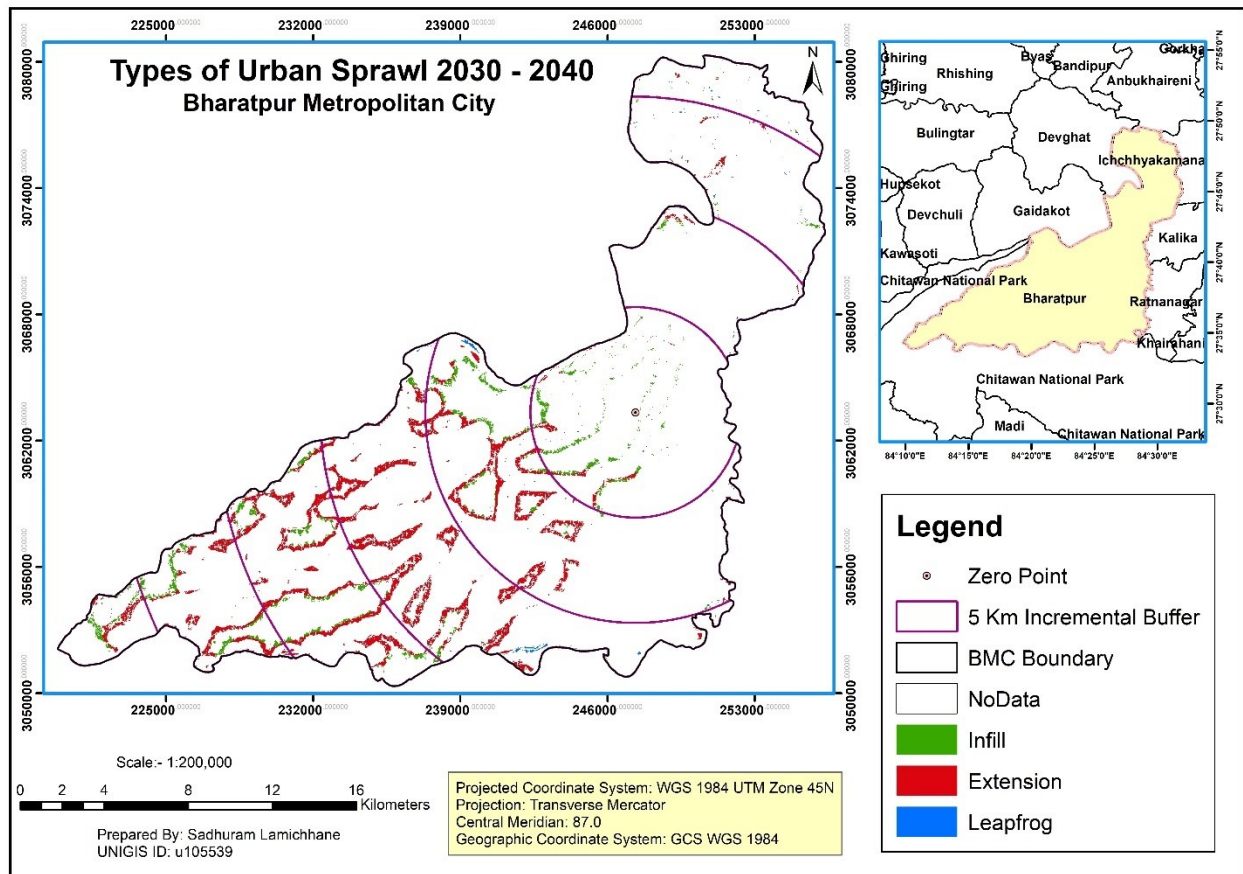


Figure 30: Types of Urban Sprawl within 5 km incremental buffer (2020 - 2030)

### 3.5.2 Types of Urban Sprawl from 2030 to 2040

Urban sprawl during the study period 2030 to 2040 is depicted below in map 21 and fig 31. This map represents different categories of urban expansion they are: (i) infill (ii) extension (iii) leapfrog development.



Map 21: Types of urban sprawl (2030 – 2040)

During the decade 2030 to 2040, most of the urban expansion due to “extension” type expansion within 15 km buffer zone from zero point. 8.01 km<sup>2</sup> area was detected extension type urban growth with (10 - 15) km proximity and 5.48 km<sup>2</sup> area was detected at (5 – 10) km proximity range. 1.43 km<sup>2</sup> growth area were obtained due to “infill” type of expansion at (0 – 5) km proximity range.

Leapfrogging type of urban sprawl were detected from 0 km to 30 km proximity range, 0.34 km<sup>2</sup>. So, mostly all the expansion within (0 – 20) km buffer zone. Out of total urban expansion 22.67 km<sup>2</sup> is extension type of urban expansion. The red patches represent extension type of urban growth, most of agriculture rural development, fringe open land has contribution to new

development. Mostly sub urban built – up, rural open land within 10 km and 15 km buffer zone. Extension of new development was expected to 0 km to 30 km.

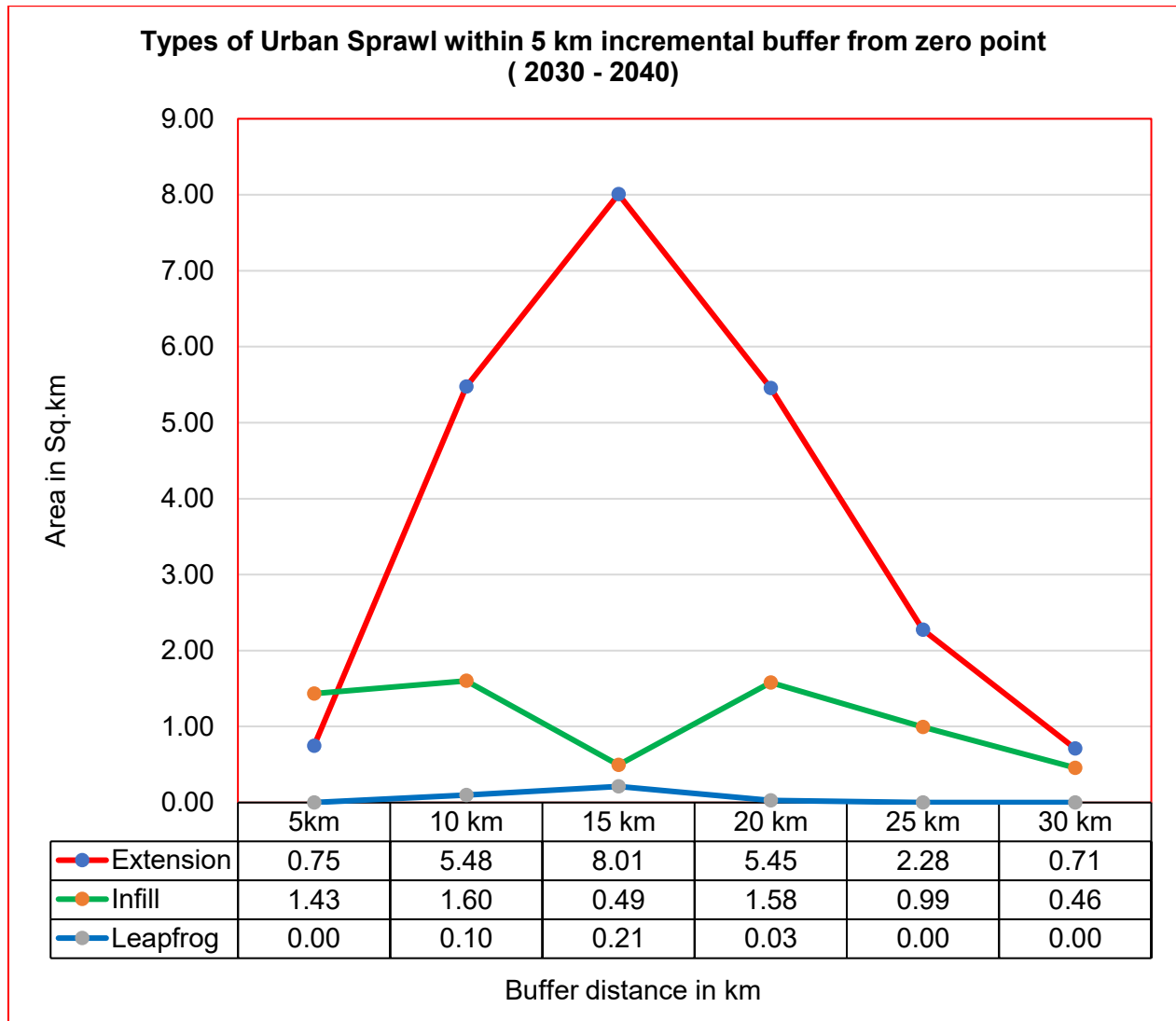


Figure 31: Types of Urban Sprawl within 5 km incremental buffer (2030 - 2040)

Urban Landscape Analysis Tool also generate “Urban footprint map”. Urban footprint shows the impact that development has on the city's open countryside. There was increment of built – up during time span 2020 – 2040. Urbanization of rural settlements has increased during the study period. This increment of rural settlements in this city due to rapid urbanization in rural areas, land price, extension of services towards the rural areas. Detailed information about

urban footprint during 2020 – 2040 is presented below Figure 32 and urban footprint map during study period is depicted in Appendix I.

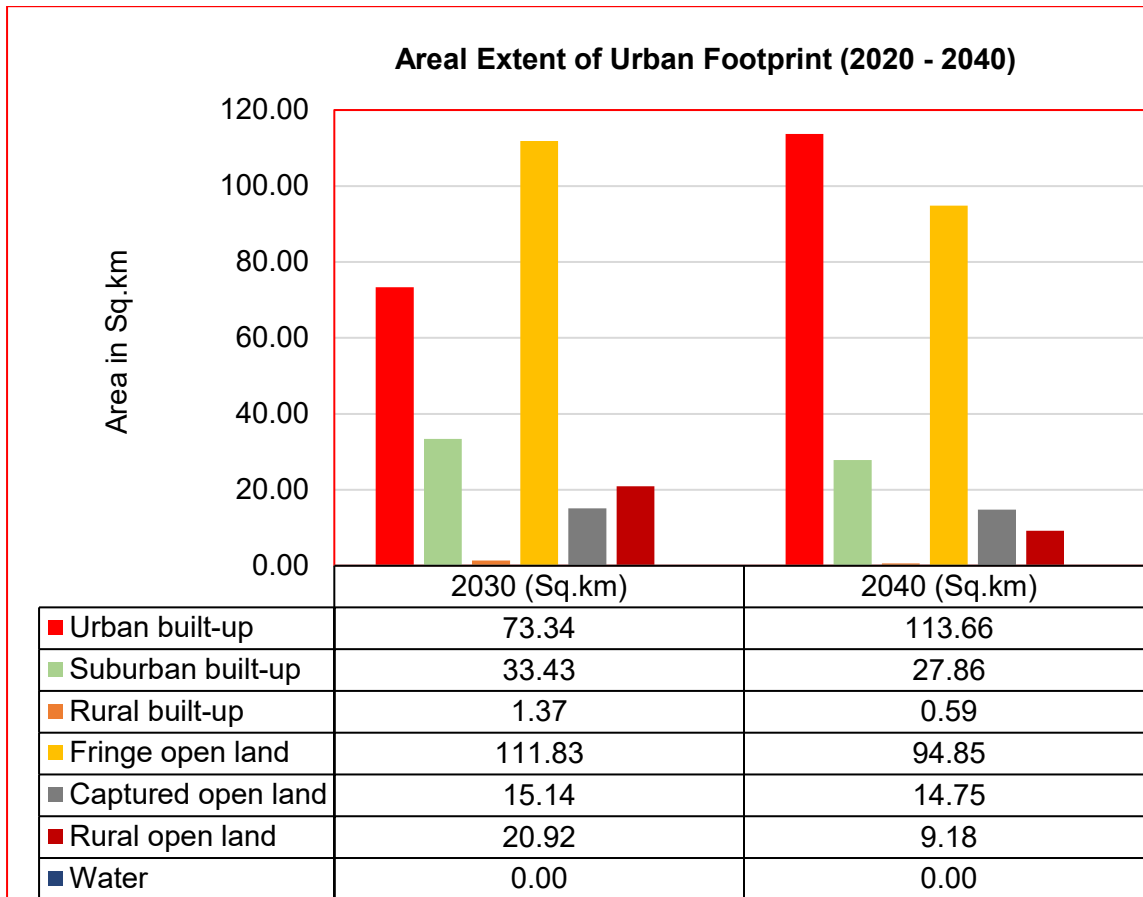
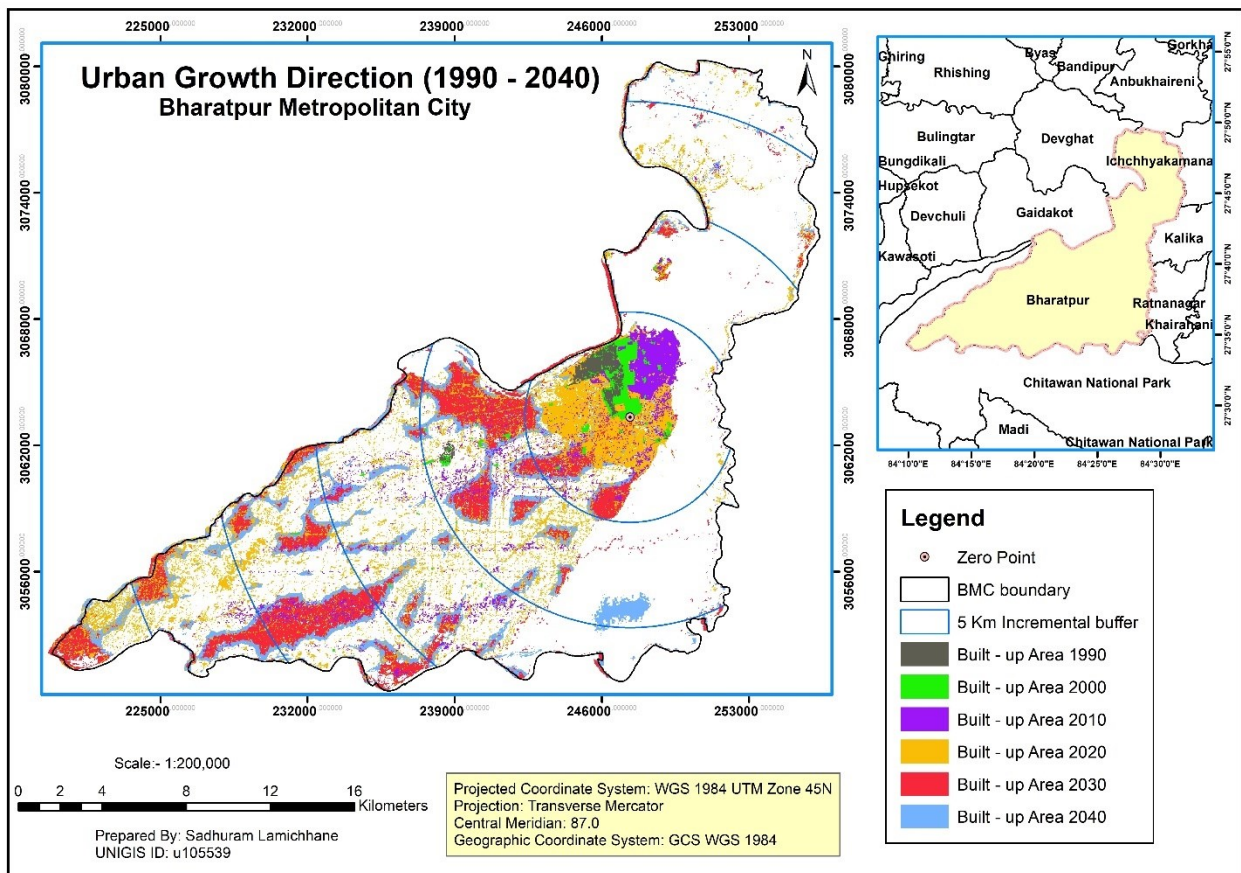


Figure 32: Areal extent of urban footprint (2030 - 2040)

There was drastic change of urbanized area in this metropolitan city. Slight changes of urban built – up, suburban built – up, rural built – up during the study year 2020 to 2040. There were huge amount of land cover classes changes from 2020 to 2040. Urban built-up area at 1990 was 2.13 km<sup>2</sup>, at 2020 it increases to 28.76 km<sup>2</sup>. In 2040 built – up area expected to 149.33 km<sup>2</sup>. Fringe open land from 2020 to 2040 has slight changes but from decades 2000 to 2020 it has drastic change. 111.83 km<sup>2</sup> to 94.85 km<sup>2</sup>.

### 3.6 Direction of Urban Sprawl

During the study period 1990 to 2000, mostly the urban expansion area was located at north – east and north – west area. From 2000 to 2010 there was medium expansion of new settlements mostly in south – west and south – east zone from zero point. Direction of urban growth from 1990 to 2040 is depicted in map 22.



Map 22: Direction of urban growth (1990 – 2040)

During 2010 to 2020 mostly the new built – up area seemed to be concentrated to south – west and south – east zone from zero point. New expansion area during these periods are: Gitanagar, Jyotinagar, Patihani, Dibyanagar, Sukranagar, Kadhaghari, Cement factory, Gondryang, Sajha tole, Dharma chowk, Ramghat, shivaghat. During these decades due to

highest land value, expansion of urban road and national highway, increment of urban facility in rural area of this city helps to increase huge amounts of settlements.

During these periods Devastating Nepal earthquake 2015 was happened. Due to this earthquake thousands of Nepalese were made homeless with entire villages flattened. Most of the people in hilly area like: Gorkha, Tanahun, Lamjung, Nuwakot, Sindhupalchowk are homeless. Most of the people was migrated from rural area to terai and valley region like: Chitwan, Kathmandu etc. (Rafferty, 2021).

Land price played vital role for rapid urban sprawl development during these years. Most of the area near urban road, highways has highest land value. Out of total area of this city, more than 80% area covered by gentle slope. Many quarry sites are nearer to city. So, excavation and construction material cost for building was less than hilly areas. Also, maximum area are fertile and suitable for cereal crops. Due to this reason, thousands of rural citizen were attracted to migrate in this city. Thus agriculture, cultivated and bare land were fragmented haphazardly and converted to settlement areas.

## Chapter 4: Conclusion and Recommendations

### 4.1 Conclusion

Urban sprawl analysis during the study period 1990 to 2040 in Bharatpur Metropolitan City was performed. The major objective of this study was to identify the sprawl analysis during six decades using RS/GIS technology and techniques. Also, delineated suitability for present and future built – up area with integration of weighted multiple rasters. Urban expansion type and urban footprint was demonstrated. Spatial distribution of the built – up area has demonstrated quickly grown, disoriented, low efficiencies, and scattered spatial distribution features.

Mostly the new construction seemed at suburbs, rural open land. Built – up areas occupied 3.29 km<sup>2</sup> in 1990, 6.79 km<sup>2</sup> in 2000, whereas built – up area contributed at 17.28 km<sup>2</sup> in 2010, 64.32 km<sup>2</sup> in 2020. Built – up areas increased by more than three folds compare to 2010. Agriculture and cultivated area decreased from 222.41 km<sup>2</sup> to 194.38 km<sup>2</sup>. 28.03 km<sup>2</sup> agriculture area was degraded during three decades. Bare and open land decreased from 12.14 km<sup>2</sup> to 4.88 km<sup>2</sup> during 1990 to 2020. It seems agriculture land and barren land has greater contribution to new development for built – up.

Behind the result haphazard and uncontrolled urbanization degrade the agriculture and bare land of this city. Urban footprint map during study years showed most of the new development were detected at south – east and south – west zone from zero point. Mostly the outward urban growth from the main city from 2010 to 2020. Different types of urban sprawl analysis within multiring buffer demonstrated, high rate of urban expansion has obtained in the proximity of (0 – 5) km. it concludes that densification of settlement area near by existing built – up area and transformation of open and agriculture land to new settlement. drastic change of urbanized area in this metropolitan city. Slight changes of urban built – up, suburban built – up, rural built

– up during the study year 1990 to 2010. There were huge amount of land cover classes changes from 2010 to 2020.

Extension and leapfrogging are two major forms of urban sprawl and which is closely related to BMC municipal division in their respective area distribution characteristics. The wards having high contribution of extension, infilling and leapfrogging form of urban expansion were distributed in south – east and south – west zone from main city.

Arable and suitable for cereal crops, most of the land in this city. However, the majority of agriculture and farm land has been transformed into a built-up area, thanks to rapid migration from rural areas. The expansion of leapfrogs mostly influenced the cultivated and bare soil. Leapfrog development types were the main dominant type of urban scope within a distance of between 0 and 30 km of buffer rage.

Due to distribution of government facilities and physical infrastructure development, infill types of expansion contribute existing dense settlement areas. The calculated frequency of leapfrogging type of expansion has strong relations to whole urban expansion process. Infilling types of expansion support to edge type of expansion in the main urban areas. Leapfrogging type of development contributes expansion at the low elevation area. Extension types of sprawl contribute high rate of expansion during the past four decades. For the development of quality of life, balance must be maintained in population growth and urbanization.

## 4.2 Recommendations

This research work described and deals with urban sprawl analysis during six decades. Some recommendations are given below for future research.

- i) Urban sprawl in BMC from 1990 to 2040 is expected to increase by a huge amount. Huge increment of urban sprawl will have a major economic and environmental impact. This result gives better chances for planners, designers, policy makers, politicians to control the haphazard urbanization and preserve the environment. In addition, it is highly advisable to implement the building bylaws and land use plans.
- ii) Due to high population growth and urbanization, BMC faces lots of problems like: drainage facilities, flooding in rainy season, traffic congestion, proper sanitation facilities and unplanned settlements. Without proper land use planning those problems cannot be solved.
- iii) Mostly the river corridor was used for restaurant, residential purpose, dumping site and human encroachment of the river and its banks turned to settlement area. Due to this reason government officials should protect the river banks and natural environment for wildlife and habitats.
- iv) Furthermore, so many environmental impacts like: water pollution, imbalance of biodiversity, rises of temperature, natural disaster, climate change should be studied in future.

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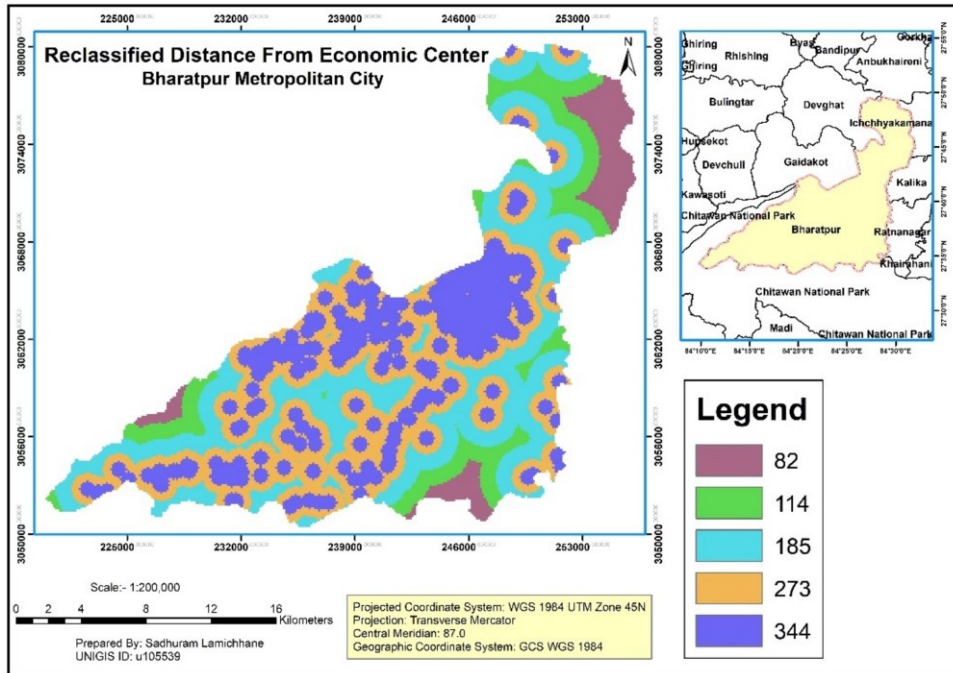
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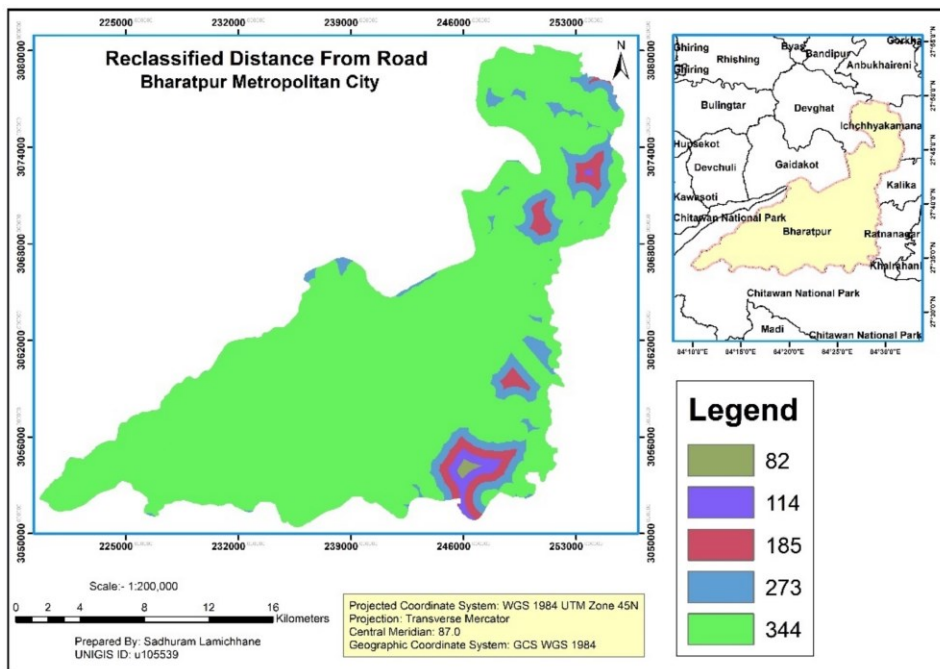
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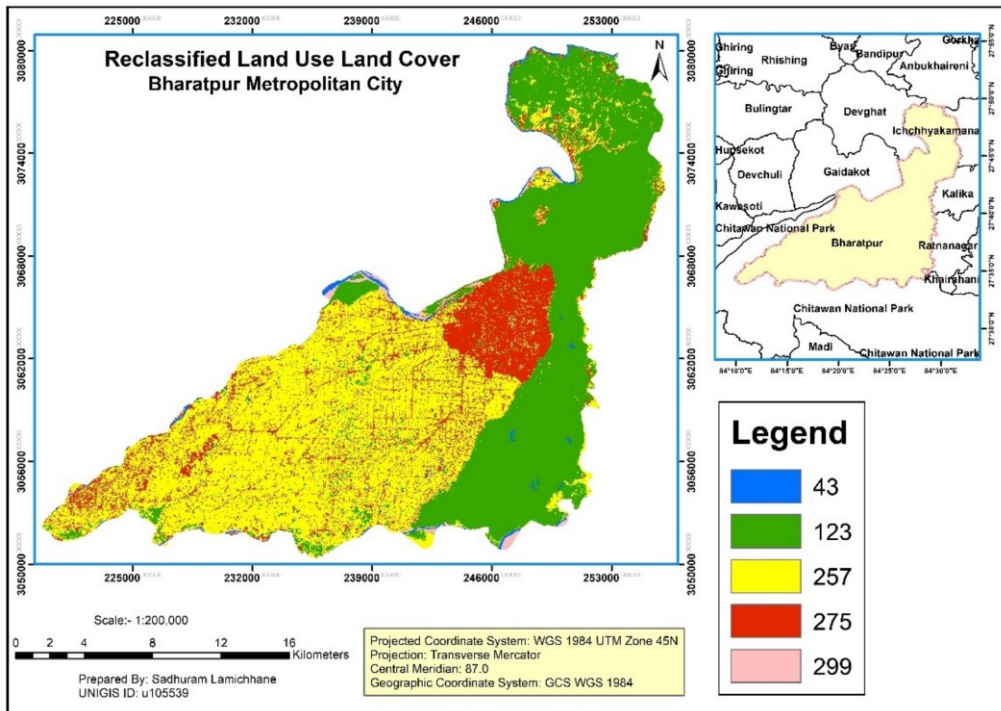
# Appendix I: Reclassified Map



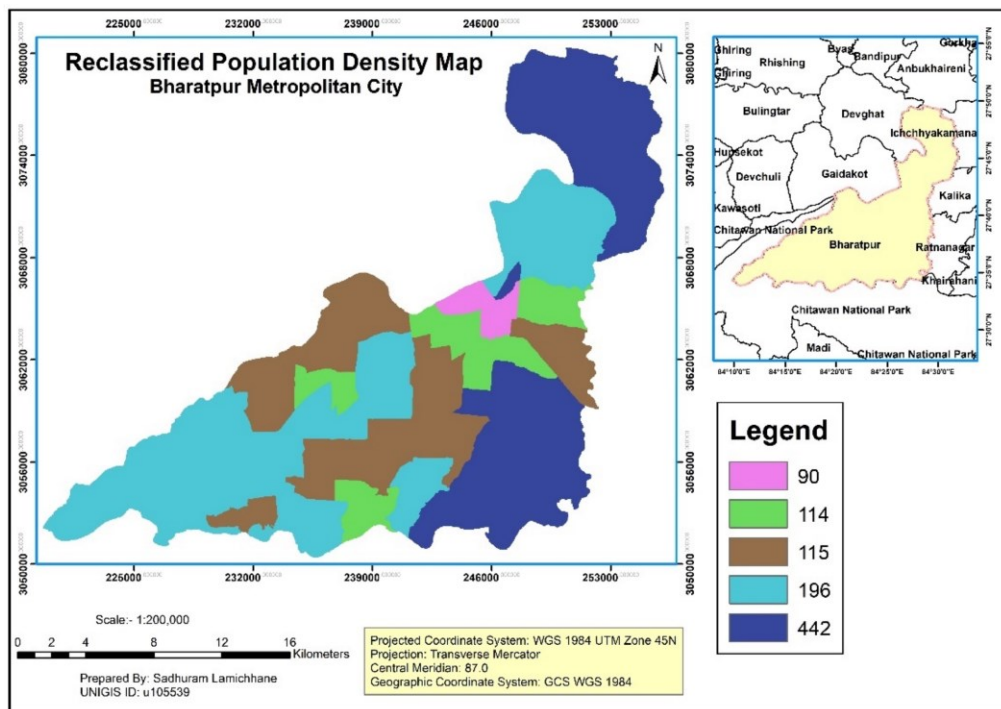
Map A 1: Reclassified distance from economic center map



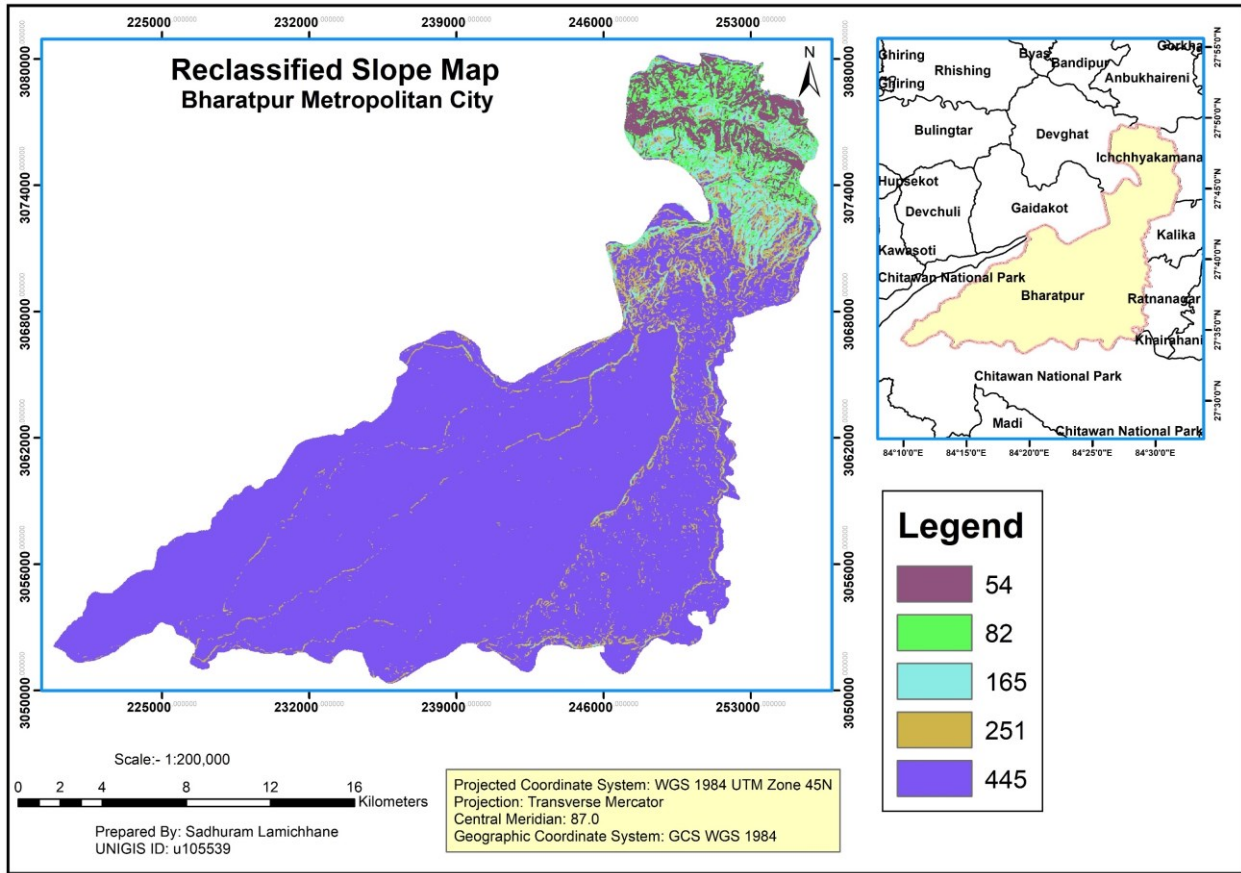
Map A 2: Reclassified distance from road map



Map A 3: Reclassified land use land cover map

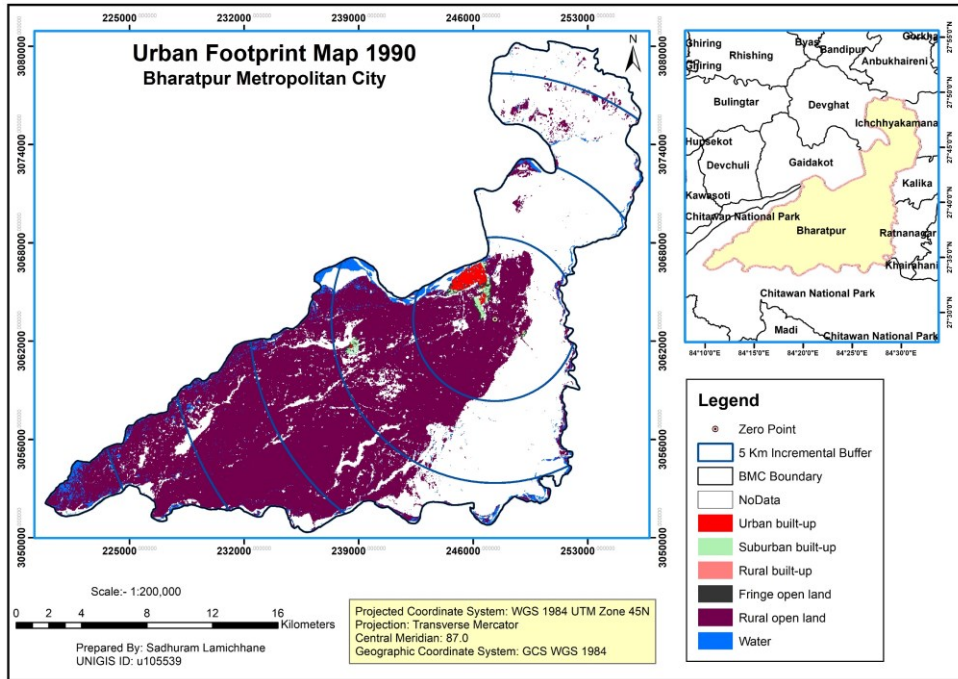


Map A 4: Reclassified population density map

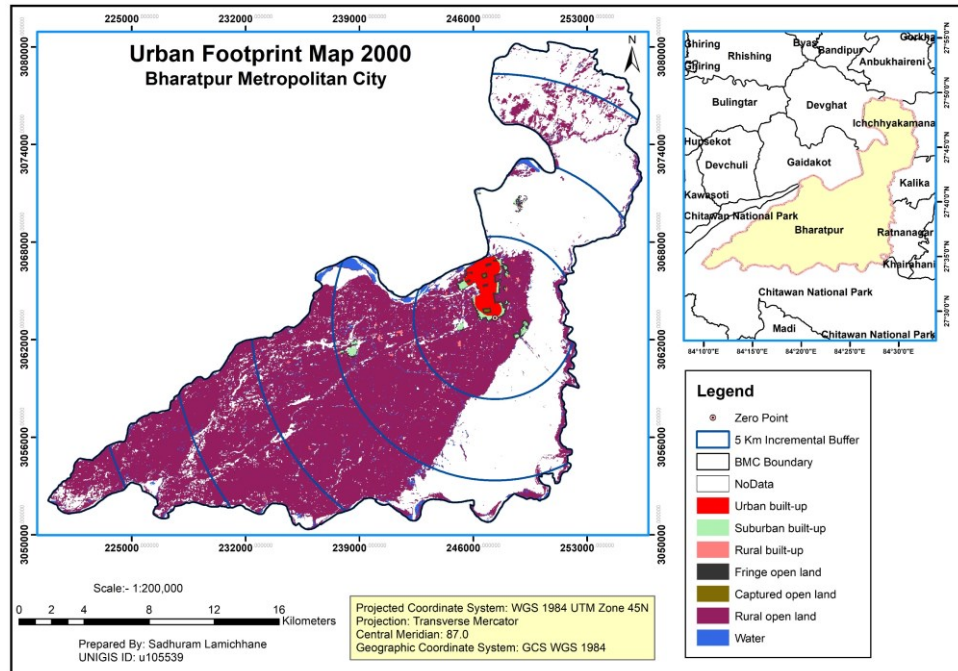


Map A 5: Reclassified slope map

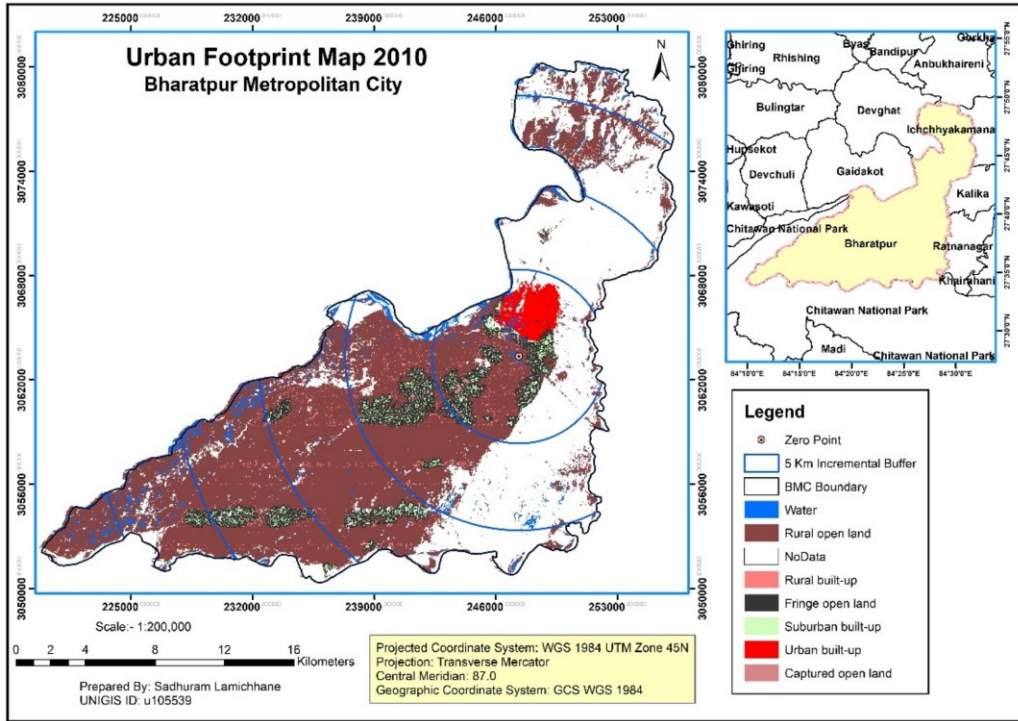
# Appendix II: Urban Footprint Map (1990 – 2040)



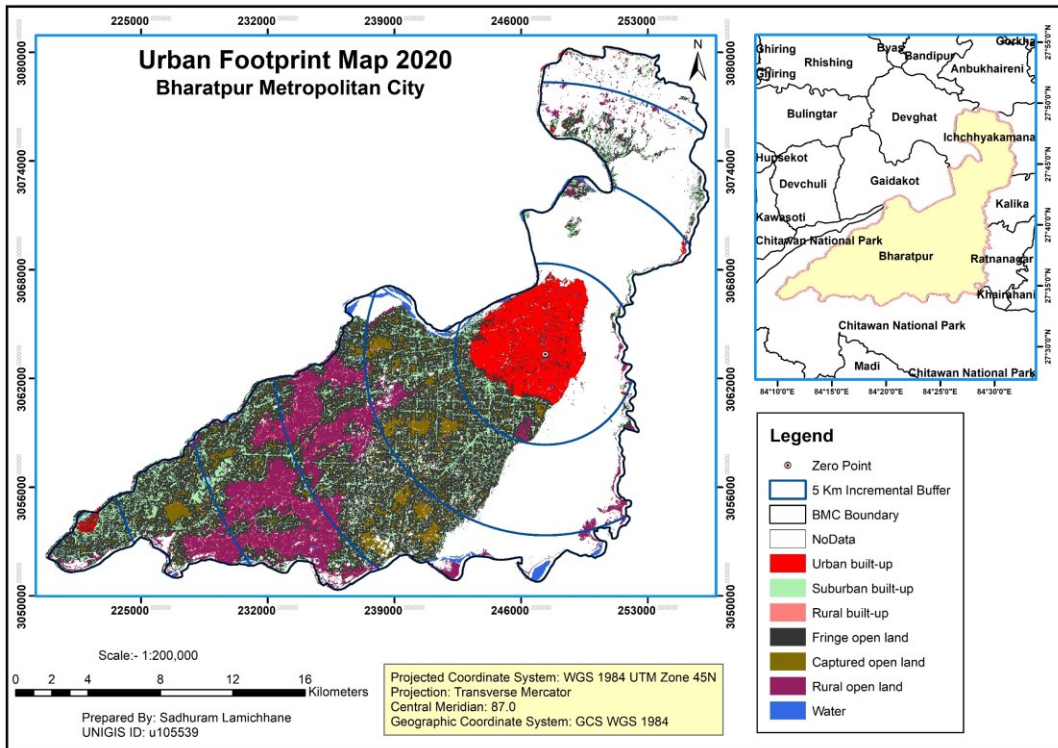
Map B 1: Urban footprint map 1990



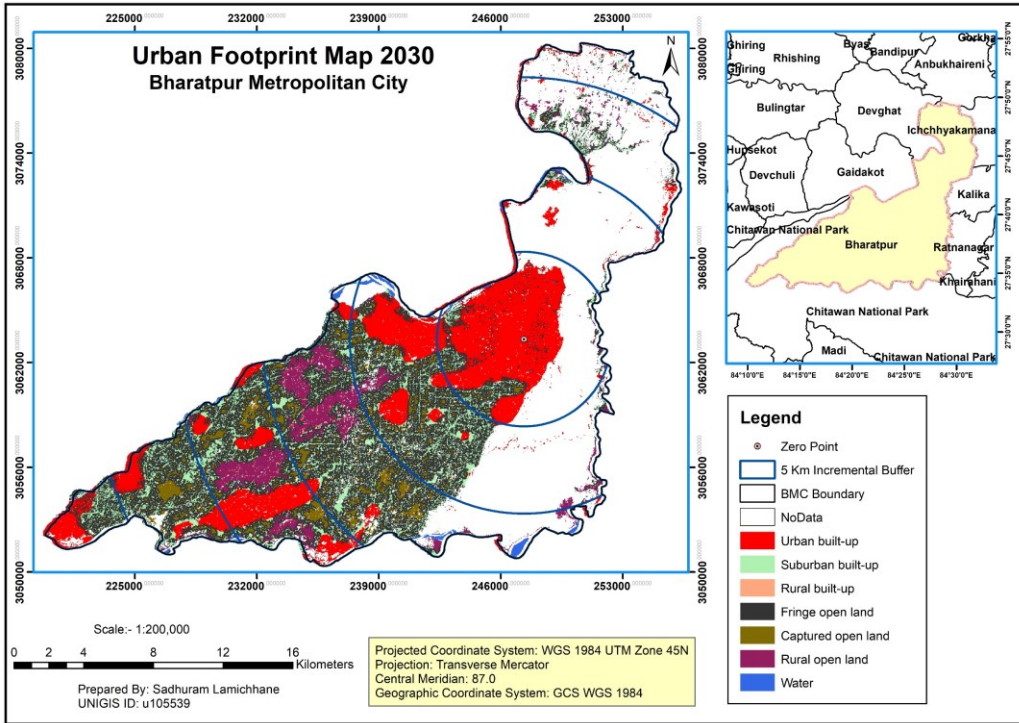
Map B 2: Urban footprint map 2000



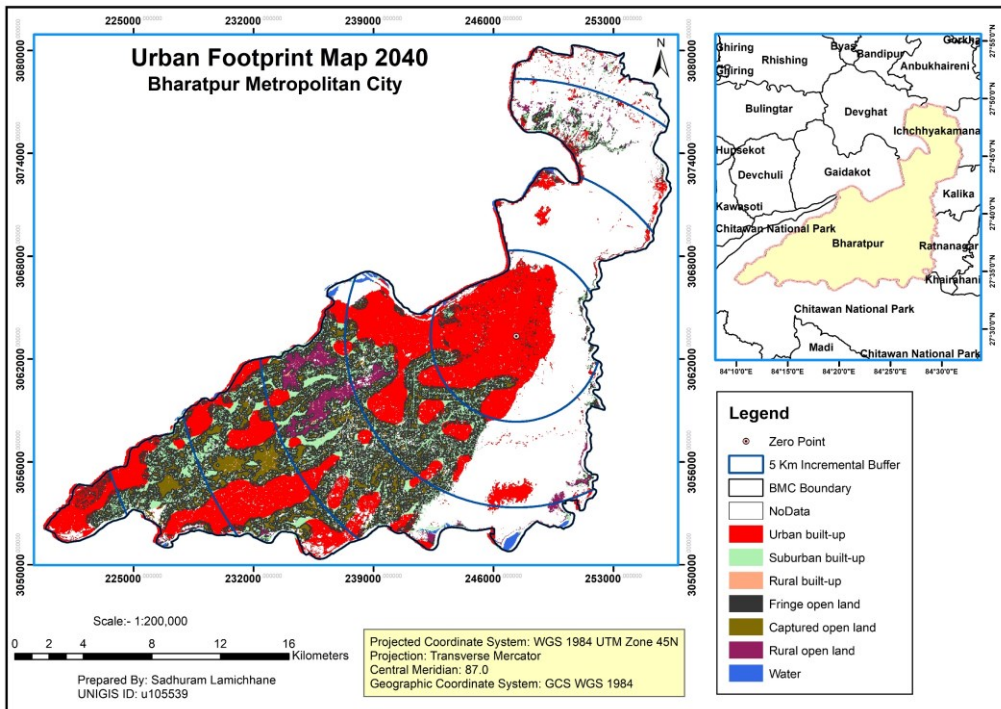
Map B 3: Urban footprint map 2010



Map B 4: Urban footprint map 2020

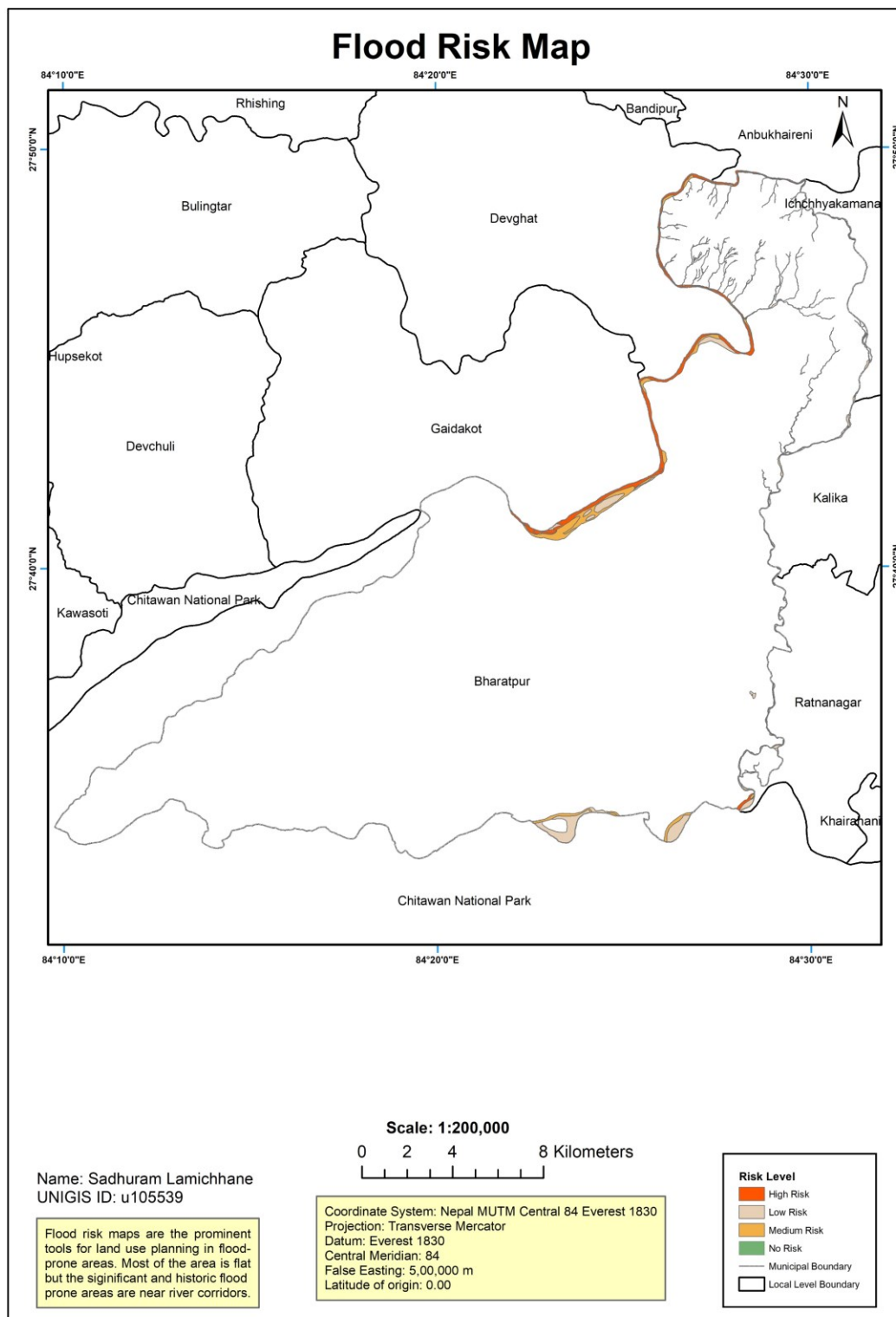


Map B 5: Modeled Urban footprint map 2030

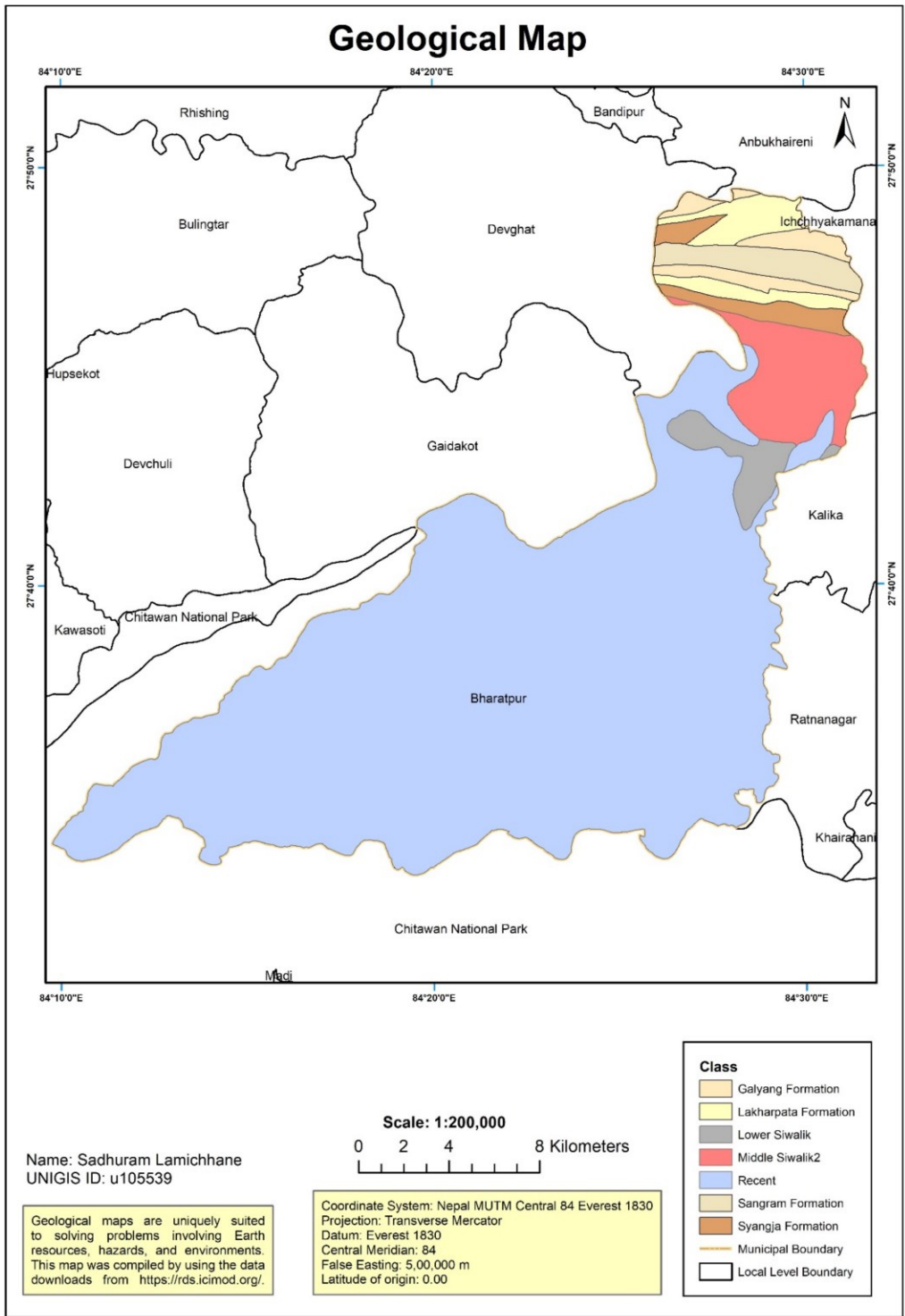


Map B 6: Modeled Urban footprint map 2040

# Appendix III: General Reference Map and Thematic Map

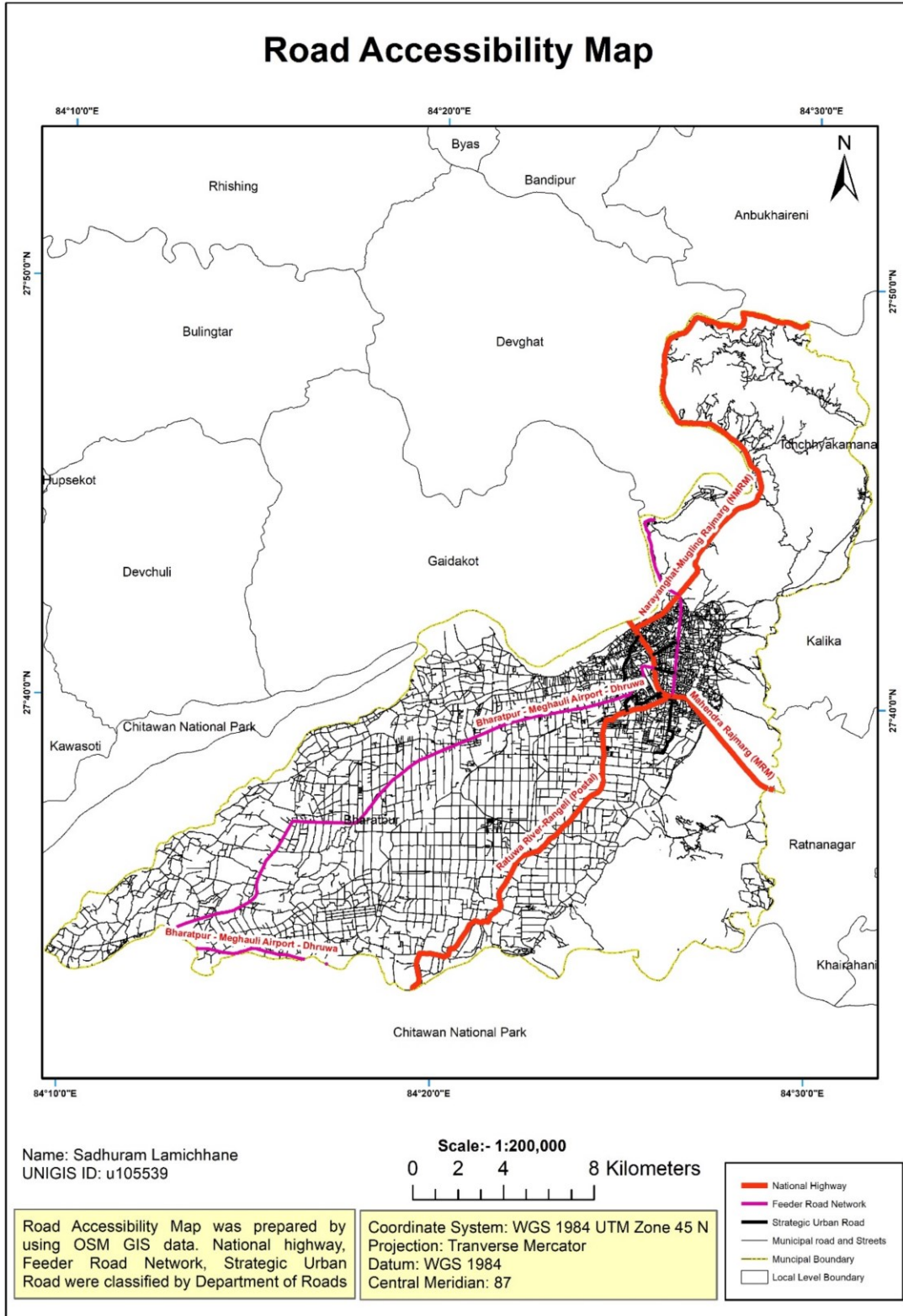


Map C 1: Flood risk map

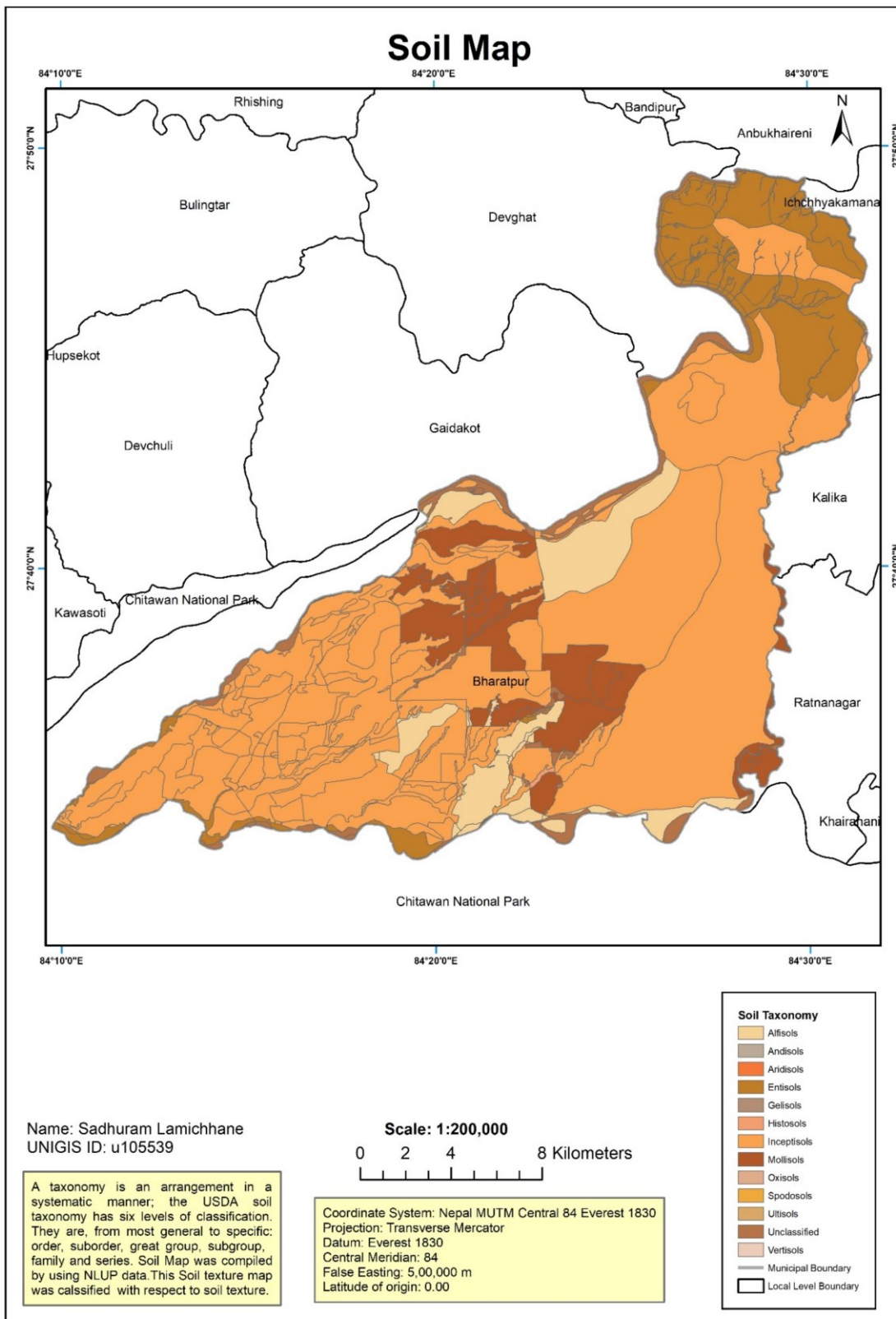


Map C 2: Geological map

# Road Accessibility Map



Map C 3: Road accessibility map



Map C 4: Soil taxonomy map