Using Remotely Sensed Imagery to Examine Changing Urban Land Cover Across Time and Topography: A Study of Nepal's Kathmandu Valley

Rajesh Sigdel

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USING REMOTELY SENSED IMAGERY TO EXAMINE CHANGING URBAN LAND COVER ACROSS TIME AND TOPOGRAPHY: A STUDY OF NEPAL’S KATHMANDU VALLEY

by

Rajesh Sigdel

A thesis submitted to the Graduate College in partial fulfillment of the requirements for the degree of Master of Science Geography Western Michigan University April 2019

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Rajesh Sigdel
USING REMOTELY SENSED IMAGERY TO EXAMINE CHANGING URBAN LAND COVER ACROSS TIME AND TOPOGRAPHY:
A STUDY OF NEPAL’S KATHMANDU VALLEY

Rajesh Sigdel, M.S.

Western Michigan University, 2019

The Kathmandu Valley, located in Nepal, is the most rapidly growing demographic region in the country. With this demographic transformation, urban land is also expanding within the valley. It is important to understand the rate and extent of urban land cover change for effective land use planning. This study analyzed the urban land cover change in the Kathmandu Valley in 1990, 2006, and 2018 using remote sensing. It also analyzed the shift in the urban topography of the valley during the same period. Landsat 5 and Landsat 8 were used to study the transformation of urban land cover in the valley. A supervised maximum likelihood classification method was utilized for the delineation of the urban areas. A slope raster file was overlaid with urban land cover to understand the changing topography of the valley. This study found that the urban land cover of the valley increased by 227% between 1990 and 2018. The valley experienced an outward expansion of urban growth which emerged from the central business districts. Similarly, the results indicate that there is a noticeable shift in urban development in the valley, with development now expanding from the flat lands to steeper sloped areas. Historical developments, economic activities, political instability in the country, the centralized government, and the valley’s status as a hub of education and technology were identified as the key drivers of urban growth.
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CHAPTER I

INTRODUCTION

Land use/land cover (LULC) has been changing in an unprecedented rate throughout the world (Turner et al., 1994; Watson et al., 1996; Dewan & Yamaguchi, 2009). Most of the LULC change has been attributed to human activities (Foley et al., 2005; Goldewijk, 2001; Meyer & Turner, 1992). The increase in human population is a major reason for the modification of LULC through urbanization and agriculture expansion as global human population has surpassed 7.68 billion (Worldmeters, 2019). This growth has significantly impacted natural ecosystems and radically changed land cover as humans use natural resources to meet growing multiple needs. For instance, global cropland and pasture increased 5.5-fold and 6.6-fold, respectively, over the past 300 years (Goldewijk, 2001). About 3% of the earth’s land surface has already been converted into urban areas (Dewan & Yamaguchi, 2009). It is projected that two-thirds of the world’s population will live in urban areas by 2060 (United Nations, 2014). Unfortunately, urbanization has been accompanied by a decline of native habitats (Alphan, 2003), a reduction in the services of remaining ecosystems (Imhoff et al., 2004), an increase in temperature of cities, (Olson et al., 2001; Imhoff, 2010), and a decline in air quality throughout many parts of the world (Martin, 2008; Lyons & Husar, 1976; Ramachandran, 2007). The LULC modifications such as the encroachment of urban areas into other LULC categories have a pervasive impact, especially on developing countries (Dewan et al., 2012; McMichael, 2000) as the urban areas in those countries are growing five times faster than those in the developed countries due to the change in economy (Lo´pez et al., 2001). This is particularly true within Hindu Kush Himalayan countries which have already witnessed massive changes in their LULC, especially rapid
increases in urban built up areas, for example in Nepal (Gautam et al., 2003), Pakistan (Qasim et al., 2011), India (Rao & Pant, 2001), and Bangladesh (Dewan & Yamaguchi, 2009).

Information about land use and land cover change such as change to urban built up land is necessary for optimal distribution of resources (Liu et al., 2012). Remote sensing technology helps provide rapid and precise information about the extent of each land cover type. Land use /land cover maps of various times provide us information such as vegetation condition (Lunetta et al., 2006), urban sprawl (Irwin & Bockstael, 2007), urban housing density and its distribution (Irwin & Bockstael, 2007). This information can support decision making to urban planning and resource management.

Remote sensing has been widely used in monitoring and analyzing land cover change. For example, Schneider et al. (2009) developed global urban maps using satellite imagery. Dahl (2004) used remote sensing to monitor wetlands habitat change. Landsat data are freely available and of moderate resolutions after mid-1980s. Seto et al. (2002) used Landsat Thematic Mapper (TM) data to monitor Pearl River Delta in China. Furthermore, Elmqvist and Khatir (2007) used remote sensing to study the dynamics of agricultural expansion in the Sahel of Sudan. This information helps in assessment of potential environmental impacts (Rozario et al., 2016) and planning strategies (Porter-Bolland et al., 2007).

The Kathmandu Valley, located in Nepal, is the most rapidly growing demographic region in Nepal (Thapa and Murayama, 2010). It is important to understand the rate and extent of urban land cover for effective land use planning. Land use planning refers to scientific and orderly disposition of land for economic and social purposes. A proper urban land cover map helps in hazard zoning (Fell et al., 2008). Land use exhibits unique temporal (time) and spatial (space) variability (Yang & Lo, 2002). Although there have been studies done to map the land
cover of Nepal in the past, the literature lacks the current urban land cover map of the valley. For example, International Development for Integrated Mountain Development (ICIMOD) has been playing a crucial role in mapping the land cover dynamics of Nepal. ICIMOD conducted detailed land cover classifications of Nepal for the years of 1990, 2000, and 2010. These maps were prepared for the development of baseline information for future environmental management and land use planning (ICIMOD, 2013). Landsat TM images with 30 m resolution were used for the development of those maps and the results show significant changes in land cover types. These studies, carried out for the complete geographic extent of Nepal, utilized coarser classification techniques and tended to be more general than the classifications done in smaller area. Classifications done over large geographic extent exhibit biases in urban and suburban areas and might be less accurate than that in fine spatial –scales (Smith et al., 2010). Rimal (2011) also studied the land cover of Kathmandu City and Lalitpur City from 1976 to 2009 and reported rapid increases in the urban land cover. They used Markov Chain Analysis to predict the 2017 land cover. However, their study did not cover Bhaktapur City within the valley. Similarly, Thapa and Murayama (2011) also conducted a study of urban land cover of 2010 and predicted the future change in 2020. This study also excluded some parts of the valley. The Kathmandu Valley (comprised of Kathmandu District, Bhaktapur District, and Lalitpur District) is the major social, political, economic and cultural hub of the country (Pant & Dangol, 2009) and therefore, should be studied as a whole. Hence, this research will seek to understand the changes in the spatial extent of urban land cover of the entire Kathmandu Valley. The purpose of the study is to understand the growth rate in urban area from 1990 to 2006 and from 2006 to 2018, so as to compare urban land cover changes between the 1990 – 2006 and the 2006 – 2018. The specific objectives of this study are to:
1) Collect ground truth data and relevant DEM, land use maps, and social economic data;

2) Classify urban land cover for the periods of 1990, 2006, and 2018 by Landsat TM images;

3) Analyze the patterns of the urban expansion for the period of 1990-2018;

4) Understand the causes/drivers of the urban land cover change in the study area.

Rationale for choosing 1990 to 2018 time period

The year of 1990 was important, both politically and economically, for Nepal. Nepal not only gained multiparty democracy in this year, but also started the free market economic liberalization of the country. This economic liberalization increased Gross Domestic Product (GDP) of the country (World Bank, 2002), and it is hypothesized that change in urban land cover was directly related to the growth in GDP (Wu et al., 2013). Similarly, the Maoist Party, which had been conducting armed struggles to replace the government before this, signed a comprehensive peace agreement in 2006, which was a major milestone for the long term peace process in the country. Kathmandu Valley was the major hotspot for those important events and brought diverse groups from rural areas to participate in this political transition (Routledge, 2010). This had led to the planned residential developments in the fringe and rural areas along with significant expansion of transportation network and commercial land use.

Definition of terms

Remote sensing refers to the monitoring of earth resources without physically touching it (Lillesand et al., 2014). In this study, remote sensing means the acquisition of land surface information by Landsat TM images.
Spatial resolution means the pixel size covering the land surface. The spatial resolution of Landsat TM is 30m (except for thermal and panchromatic bands), meaning a pixel covers 30m X 30m of ground surface. Another key term in remote sensing is the temporal resolution. Temporal resolution refers to the frequency to which a satellite sensor captures a feature of the earth surface with respect to time. There is a tradeoff between the temporal and spatial resolution. Satellites having high temporal resolutions covers larger areas with low spatial resolution (Lillesand et al., 2014).

Land cover is defined as what is actual on the land surface. For example, forest, water, built up areas, and diverse types of vegetation. Whereas land use is defined as how humans use the land. For example, forest parks, agriculture, and so forth (Anderson, 1976). The objective of the image classification is to categorize all pixels of the image into appropriate land cover classes or themes (Lillesand et al., 2014). There are many land cover classification schemes used for worldwide research and planning activities. The Anderson 1976 land use/land cover classification system (Anderson, 1976) is one of the most widely used globally. Level 1 of the Anderson classification system consists of 9 land cover classes (Table 1). This study utilizes the Anderson classification Level 1 system. After the classification, all the pixels except pixels belonging to “developed” class were converted into null values to separate urban land cover from non-urban areas in this study.
Table 1: Anderson land use/land cover classification system.

<table>
<thead>
<tr>
<th>Level I</th>
<th>Level II</th>
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<tbody>
<tr>
<td>1. Urban or Built up Land</td>
<td>11. Residential</td>
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<td>12. Commercial and Services</td>
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<td></td>
<td>13. Industrial</td>
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<td>14. Transportation, Communications and Utilities</td>
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<td>16. Mixed Urban or Built-up Land</td>
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<td>17. Other Urban or Built-up Land</td>
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<td></td>
<td>22. Orchards, Groves, Vineyards, and Nurseries</td>
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<td></td>
<td>23. Confined Feeding Operations</td>
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<td></td>
<td>24. Other Agriculture Land</td>
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<td>3. Rangeland</td>
<td>31. Herbaceous Rangeland</td>
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<td>32. Shrub and Brush Rangeland</td>
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<td></td>
<td>33. Mixed Rangeland</td>
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<td>4. Forest Land</td>
<td>41. Deciduous Forest Land</td>
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<td></td>
<td>42. Evergreen Forest Land</td>
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<td>43. Mixed Forest Land</td>
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<td>5. Water</td>
<td>51. Streams and Canals</td>
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<td>52. Lakes</td>
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<td>53. Reservoirs</td>
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<td>7. Barren Land</td>
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<td>72. Beaches</td>
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<td>73. Sandy Areas Other than Beaches</td>
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<td></td>
<td>74. Bare Exposed Rock</td>
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<td>75. Strip Mines, Quarries, and Gravel Pits</td>
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<td>76. Transitional Areas</td>
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<td>77. Mixed Barren Land</td>
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<td>8. Tundra</td>
<td>81. Shrub and Brush Tundra</td>
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<td></td>
<td>82. Herbaceous Tundra</td>
</tr>
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<td>83. Bare Ground</td>
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<td>84. Wet Tundra</td>
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<td>85. Mixed Tundra</td>
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<tr>
<td>9. Perennial Snow or Ice</td>
<td>91. Perennial Snowfields</td>
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<td></td>
<td>92. Glaciers</td>
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CHAPTER II

LITERATURE REVIEW

It has been noted that urban land cover has been rapidly expanding within the Kathmandu Valley over the past few decades (Ishtiaque et al., 2017), and that there are many drivers behind this change. In order to make sense of this change, it is first important to establish a fuller picture of the drivers that fuel it. Many drivers of LULC change have been noted in the research record, but there are a few categories of change that seem to be altering the valley to a greater degree than others; these drivers include economic liberalization, the Maoist movement, the peace process and tourism. This section discusses different drivers of urban land cover change in the Kathmandu Valley.

**Economic Liberalization in 1990**

Economic conditions are one of the major drivers of LULC change. Jain et al. (2016) reported that the economic reforms of 1991 in India was one of the main drivers of unprecedented rate of LULC change. Nepal entered into a new era of economic liberalization after its achievement of democracy in 1990. Before 1990, the country was ruled by a “Panchayat” system, which is a party-less self-governing system under the king. The king had the highest and absolute authority, and civil liberties and press freedom were curtailed. Nepal achieved its democracy after a successful people’s movement. It should be noted that before 1990, Nepal was inside a closed door under the Panchayat system. The peoples’ movement did not only bring reform in the country, but also opened its gate to the global market.

Although Nepal had signed treaty with World Bank and International Monetary Fund (IMF) in 1986 and 1989 to deregulate the domestic market and promote greater international trade, the true economic liberalization of Nepal was not carried out until the passing of the
Industrial Act in 1990 (Sakya, 2010). The Act guided the nation to market-based capitalism, although the ruling parties were inclined towards the Marxist-Leninist philosophy. Nepal also reduced international tariff and non-tariff barriers to trade significantly. There were various laws and policies made after the liberalization to promote the free market concept. The country established the Foreign Investment and Technology Transfer Act in 1996. The main objective of the Act was to help foreign business ventures to invest in the Nepalese market without the need for having a Nepali business partner. The act also helped reduce unnecessary controls on capital repatriation (Sakya, 2010). Similarly, Nepal also established an Industrial Promotion Board in 1997 whose main objective was to help ensure that the policies of free market were implemented throughout the country. The economic liberalization combined with the democratic people’s movement not only provided an opportunity to compete in market-based competitive capitalism, it also brought profound change in the social organization of the country.

As a consequence of these change, economic dependency of Nepal became much more complex and closer with its neighboring country of India. Exports to and imports from India increased significantly, the number of tourists visiting Nepal from India also grew significantly, and Nepal’s economic performance improved as measured by increase in per capita income throughout the 1990s. According to the World Bank (2002), economic liberalization and macroeconomic stability were the two major factors for this improvement.

Increases in economy and GDP could lead to increase in the conversion of land to urban areas. Wu et al. (2013) reported that urban land cover of Hangzhou metropolitan area was positively correlated with changes in Gross Domestic Product. Similarly, Deng et al. (2010) also reported a similar relationship between GDP and urban development in China in their study. However, Karmacharya (2001) pointed out that the economic growth of Nepal was not sustained
after 1996. He pointed out that the benefits of the globalization were not fully materialized in Nepal. Many of the infant industries in Nepal simply could not compete in the global market. Karmacharya also pointed out that the service industry was one of the back buttresses of rapid economic growth from 1990 to 1995. It should be pointed out that the majority of service industries were located within Kathmandu Valley. However, the service sector was not backed up by the strong domestic production of expended services (Karmacharya, 2001). Similarly, the distribution of income, generated from entering the liberal market, was very unequal. Urban areas took most of the share of the increase in revenues and income, putting rural areas suffered due to migration. This income disparity put more pressure on the urban areas. Lambin et al. (2001) pointed out that the integration in the global market through globalization always leads to the rapid change in land use and land cover change. This is especially true in developing countries whose economies is nascent and there are lots of opportunities for exploitation. Kathmandu is one of example of rapid urban land use change after the implementation of the economic liberalization policy in the country.

**The Maoist movement in Nepal**

Civil war may also be one of the drivers of urbanization (Fay & Opal, 1999). There was a wide income gap between the income of urban and peri-urban Kathmandu and rural districts of Nepal. Murshed and Gates (2005) reported that many of the far western districts has average income of less than 25 % of Kathmandu, which led to civil war in the country. After the liberalization of economy in Nepal in 1990, some of the political parties in Nepal were not happy with the economic and political situation of the country. The Maoist insurgency or Maoist revolution armed war was fought from 1996 to 2006, between the Communist Party of Nepal (CPN) and the government of Nepal. According to CPN, one of the main reason for the war was
due to the disparity of income and wealth among people in the nation. The wealth was largely centered in urban centers, especially in the Kathmandu Valley, and the government of Nepal basically neglected the rural population. The war resulted in deaths over 17,000 people including civilians, army personals, and the members of CPN party (Hutt, 2004).

The movement or the war was launched from the rural areas (Pettigrew & Shneiderman, 2004). Cities were often regarded as a safe place from the war. The movement was stronger in the districts and villages with rates of poverty and inequality (Hatlebakk, 2010). Relatively rich people, and higher caste people felt insecure to live in village. Although Nepal was a Hindu Kingdom, the country has a deep seated caste system within the society. Maoist party established their own “Jan Sarkar” in their bastion villages. One of the primary objective of the movement was to remove caste system in the country. Higher caste people tended to incline away from the ideology of the party. According to the party, Jar Sarkar is the government of people. Maoist party had formed their own judicial system as well. During the war, the economic progress of the rural areas almost halted to full stop as the engines of growth such as banks, and other financial institutions were targeted in the war by the both parties. The war displaced thousands of people from rural place to urban areas. Relatively rich people and higher caste people moved to cities as way to escape from the war as they were targeted by the party.

Beyond economic upheaval, urbanization in the Kathmandu Valley is also directly related to the Maoist (CPN) war and the people’s movement in the country. Rural areas were heavily affected by the war between the government of Nepal and CPN party. People migrated to the urban areas like the Kathmandu Valley to escape the war and to get jobs (Adhikari, 2012).

Many people also migrated to cities as they found themselves targeted by the CPN for not accepting the Maoist ideology. Much of the government power resided in the cities, especially
Kathmandu Valley since the rural areas were controlled by the forces sympathetic to Maoist movement. This led to the heterogeneous distribution of the country’s resources. The Kathmandu Valley became a major hotspot for any political incidents. The valley was very important both politically and economically (Sharma, 2006). These factors helped draw large population to the valley from rural and fringe areas into the valley, thus increasing the rate of urbanization in the valley.

**Peace process**

Nepal entered into a new era after the Maoist party decided to put an end into an armed struggle and to participate in the merging democratic movement. When the then king of Nepal, Gynendra Bir Bikram Shaha took direct control of the government of Nepal in 2005, the Maoist party and 7 other major political parties formed an alliance and called for a nationwide strike through the country. The King banned all political parties citing that they failed to control or solve the Maoist insurgency. The leaders of the political parties were arrested and media outlets were also suppressed by the King. Protestors and cadres from the all the political parties demonstrated in all the major cities of the country. The Royal Palace was also located within the Kathmandu Valley, hence, the political parties focused their energy for protest in the Kathmandu Valley to apply more pressure on the king for reform (Wagle, 2006). There is evidence that people from villages were imported/brought to the Kathmandu Valley for the strike. The nineteen days of strike/protest ended after the King formally stepped down from power and the political parties took control over the government once again. The 10-years long Maoist war formally ended in 2006 with the signing of a comprehensive peace agreement between the newly formed government of Nepal and the Maoist party. The peace agreement not only stopped the
violence, but also brought the insurgent Maoist party into ballet from bullets (von Einsiedel, 2012; Upreti, 2012).

The year of 2006 also marked another important event in the history of Nepal. After the Maoist party put their arms and ammunitions to the rest, they participated into an election to produce a new constitution for the country. The new constitution replaced the king with a presidential form of government. Although ceremonial, the presidential form of government played a major role in reshaping the urban centers of Nepal. Once again, all the major activities such as the constitutional assembly happened within the Kathmandu Valley, putting the valley into the center once again. Routledge (2008) noted that urban places such as Kathmandu offered key spaces to bring diverse groups from rural areas to participate in the democratic movement. According to Routledge (2008), these urban places provides suitable sites for the mass mobilization of citizens during protests against the King.

Tourism in the Kathmandu Valley

Previous research has shown that tourism is another drivers of urbanization. Qian et al. (2012) reported that tourism can cause significant expansion of the urban built up environment. Nepal is a popular destination for mountain climbers, trekkers, religious pilgrims, and for many other types of people who wants to enjoy authentic rural village lifestyles. Tourism is one of the main sectors for the country. The Kathmandu Valley serves as the only one international gateway for tourist coming to visit Nepal via airplane. At present, Nepal has only one international airport till now, Tribhuvan International Airport and it is located in the Kathmandu city. Hence, Kathmandu is the first destination of the tourists visiting Nepal via airplanes.

According to the data from the Ministry of Tourism of Nepal, the number of tourists visiting Nepal has increased from 1991 to 2017 (Figure 1). About three hundred thousand
tourists visited Nepal in 1991 and the figure jumped to around nine hundred thousand in the year of 2017. Nepal celebrated “Nepal Visit 1998” in 1998 as the year drew more tourists in compared with the previous years. However, there is a steep decline in the number of tourists visiting Nepal from 2000 to 2006. This is correlated with the intense Maoist armed struggle in the country (Bhattarai et al., 2005). After the peace process in 2006, tourists’ number also started to increase. Most of the tourists prefer to stay few days in the Kathmandu Valley, before heading towards the other parts of nation. This creates an employment opportunity in the valley, and draws large number in-migration from the rural parts of the country. However, the devastating Earthquake in 2015 caused a sharp decline in tourist in the country.

Figure 1: Number of tourists visiting Nepal from 1991 to 2017.
**Landsat satellites**

Though there are many ways that LULC can be analyzed and visualized, remote sensing techniques are among the best outlets for studying LULC. The use of remote sensing to study land cover change has been documented through many case studies and applied research programs. NASA’s Landsat satellite program in particular is a valuable source of open and accessible remote sensing data that can provide high quality imagery for analysis. Different classification techniques can be used with Landsat imagery to provide a full accounting of land cover change. The following section of this literature review will provide a foundational understanding of these subjects and demonstrate their relevance to this research. This section will first explain Landsat 5 and Landsat 8. This will be followed by a section that details the use of remote sensing by other researchers to study urban land cover change. This section will conclude by describing a selection of relevant image classification techniques and the history of study of land cover change in the Kathmandu Valley.

Landsat satellites are earth observing satellites launched by the National Aeronautics and Space Administration (NASA) and administered by the United States Geological Survey (USGS). Landsat 5 and Landsat 8 were launched on 1984 and 2013 respectively. Landsat 5 has both the Thematic Mapper (TM) and Multispectral Scanner (MSS) and Landsat 8 has the Operational Land Imager (OLI) and the Thermal Infrared Sensor. Both of the satellites have a spatial resolution of 30 m (except for panchromatic and thermal bands). The Landsat 5 TM sensor has 7 bands (Table 2; Source: USGS), whereas Landsat OLI has 9 bands (Table 3). Both the satellites have a temporal resolution of 16 days. This study utilizes Landsat 5 TM and Landsat 8 OLI remotely sensed data.
Table 2: Band designation of Thematic Mapper sensor in Landsat 5.

<table>
<thead>
<tr>
<th>Bands</th>
<th>Wavelength (micrometers)</th>
<th>Resolution (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1 - Blue</td>
<td>0.45 - 0.52</td>
<td>30</td>
</tr>
<tr>
<td>Band 2 - Green</td>
<td>0.52 - 0.60</td>
<td>30</td>
</tr>
<tr>
<td>Band 3 - Red</td>
<td>0.63 - 0.69</td>
<td>30</td>
</tr>
<tr>
<td>Band 4 - Near Infrared (NIR)</td>
<td>0.76 - 0.90</td>
<td>30</td>
</tr>
<tr>
<td>Band 5 - Short Wave Infrared (SWIR) 1</td>
<td>1.55 - 1.75</td>
<td>30</td>
</tr>
<tr>
<td>Band 6 - Thermal</td>
<td>10.40 - 12.50</td>
<td>120</td>
</tr>
<tr>
<td>Band 7 - Short Wave Infrared (SWIR) 2</td>
<td>2.08 - 2.35</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 3: Band designation of Operational Land Imager sensor in Landsat 8.

<table>
<thead>
<tr>
<th>Bands</th>
<th>Wavelength (micrometers)</th>
<th>Resolution (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1 - Ultra Blue (coastal/aerosol)</td>
<td>0.435 - 0.451</td>
<td>30</td>
</tr>
<tr>
<td>band 2 - Blue</td>
<td>0.452 - 0.512</td>
<td>30</td>
</tr>
<tr>
<td>Band 3 - Green</td>
<td>0.533 - 0.590</td>
<td>30</td>
</tr>
<tr>
<td>Band 4 - Red</td>
<td>0.636 - 0.673</td>
<td>30</td>
</tr>
<tr>
<td>Band 5 - Near Infrared (NIR)</td>
<td>0.851 - 0.879</td>
<td>30</td>
</tr>
<tr>
<td>Band 6 - Shortwave Infrared (SWIR) 2</td>
<td>1.566 - 1.651</td>
<td>30</td>
</tr>
<tr>
<td>Band 7 - Shortwave Infrared (SWIR) 2</td>
<td>2.107 - 2.294</td>
<td>30</td>
</tr>
<tr>
<td>Band 8 - Panchromatic</td>
<td>0.503 - 0.676</td>
<td>15</td>
</tr>
<tr>
<td>Band 9 - Cirrus</td>
<td>1.363 - 1.384</td>
<td>30</td>
</tr>
<tr>
<td>Band 10 - Thermal Infrared (TIRS) 1</td>
<td>10.60 - 11.19</td>
<td>100 * (30)</td>
</tr>
<tr>
<td>Band 11 - Thermal Infrared (TIRS) 2</td>
<td>11.50 - 12.51</td>
<td>100 * (30)</td>
</tr>
</tbody>
</table>

**Use of remote sensing to study urban land cover**

Hundreds of researchers have used remote sensing to detect urban change. For example, Weng (2001) used remote sensing technique to study the urban expansion in the Zhujiang Delta of South China from 1989 to 1997. Land cover of the Delta experienced a rapid change due to
accelerated economic activity. The researchers analyzed band 2 (green), band 3 (red) and band 4 (near-infrared) of multitemporal Landsat TM data. A supervised classification approach paried with the maximum likelihood algorithm was utilized to classify the images into urban land, barren land, crop land, horticulture farms, dike-pond land, forests, and water bodies. The accuracy of the classification ranged from 85.43% to 90.57%. The researcher also analyzed the urban growth pattern by using a GIS-based modelling approach and reported significant increases in urban land cover during the study period. The study also found out that the urban expansion was inversely related to the distance from major road. Specifically, urban expansion in Zhujiang Delta declined as the distance increased away from a major road.

Similarly, Yuan et al. (2005) also used Landsat TM data to monitor the land cover of seven counties within the Twin Cities Metropolitan Area of Minnesota. They combined late spring and summer images to distinguish bare soil and annual crops. They also used reference data to improve the accuracy of the study. A post classification approach was utilized, to reduce the classification errors caused by the similar spectral responses from bare soil and impervious surfaces such as urban land using GIS. They employed hybrid supervised and unsupervised classification technique for the change detection procedures. In their study, the root mean square error (a measure of accuracy) was less than 0.25 pixel. The researchers used different method for the accuracy assessment. They compared their classification results with the Natural Resources Inventory classification schemes using the $\chi^2$ statistical test. Their overall land cover classification accuracy averaged 94%. The researchers also emphasized the important use of the 3x3 majority filter tool in the study to smooth the classification results. Their research showed that the urban land cover is growing rapidly in seven counties of Twin Cities Metropolitan Area of Minnesota.
A different approach is taken by Mundia and Aniya (2005) to study the urban land cover in Nairobi of Kenya. They combined three Landsat images together with socio-economic data to understand the spatial dynamics of the land cover change. Multispectral scanner, Thematic Mapper and Enhanced Thematic Mapper plus (ETM+) data were used to study the land cover change of the city from 1976 to 2000. They used the Iterative Self-Organizing Data Analysis (also known as ISODATA) algorithm technique, which is an unsupervised classification technique, in ERDAS Imagine. ISODATA does not require any training samples as inputs. Landsat data were rectified according to the Clarke 1880 spheroid and UTM projections. The images were properly georectified using 10 ground control points. They adopted the Anderson classification design in their study to classify land cover. The overall accuracy (Kappa index) was about 0.86. Their results indicated that the urban built up area expanded by about 47 sq. km from 1976 to 2000. Using socioeconomic data of various years (from 1975 to 2002) after post classification revealed that economic growth was the key factor in urban expansion. Their results also showed that the growing network of roads played significant role in spatial distribution of urban built area.

Lu and Weng (2004) also emphasized the importance of Landsat data to study impervious land cover. They examined the characteristics of urban land cover using spectral mixture analysis by employing ETM+ images. The images of Indianapolis in the US state of Indiana was chosen as a study site by the researchers. They transformed the values from the images into principal components after applying minimum noise fraction transformation to the data. For land covers’ end members: shade, green vegetation, impervious surface, and soils, were selected as the inputs. The researchers employed a maximum likelihood classification algorithm along with spectral mixture analysis in the study. After applying 3 x 3 focal window, they were
able to achieve up to 86% accuracy. Their results indicated that Landsat data are very useful to study urban land cover.

A different algorithm, the Spectral angle mapper (SAM) was used by Girouard et al. (2004) to study the usefulness of Landsat TM data for Landsat thematic mapper data for geological mapping in Central Jebilet of Morocco. Their purpose was to compare Quickbird and Landsat data using SAM. They corrected the atmospheric effects on images using the Herman transfer radiative code. They applied Principal Component (PC) transformation as a guide for their end member selection to train SAM classification algorithm. One of the interesting things to point out from their study is that although Quickbird data has a high spatial resolution compared to TM data from Landsat, Quickbird did not provide good results compared to TM because of its low spectral resolution. Although Landsat data has medium spatial resolution, Quickbird data has only 4 spectral resolutions whereas Landsat data has 7 spectral resolutions. Hence, Landsat outperformed Quickbird in geological mapping in Central Jebilet of Moracco.

Sarvestani et al. (2011) studied three decades of urban growth in the city of Shiraz, Iran using remote sensing. This study uses Landsat MSS, Landsat TM, and Landsat ETM+, along with SPOT 4 to study the urban cover change from 1976 to 2005. They applied supervised classifications to all the images to classify them into four classes urban built-up area, vegetated land, bare land, and water. The kappa index ranged from 0.88 to 0.95. Urban areas grew by 181% over the period of three decades. The researchers coupled the results of the classification with population data, obtained from United Nations and Iranian censuses, for various years and reported that the population growth rate and the city growth rate in area were very close. Their results also revealed that the vegetated areas per capita decreased from 60.50 m$^2$ to 31.36 m$^2$ and
recommended including protection and development of vegetation area in a comprehensive master plan of the city to preserve the quality of life of the residents.

A similar approach is taken by Rawat and Kumar (2015) to study land use/land cover change of the Hawalbagh block of Almora district in Uttarakhand, India from 1990 to 2010. They also utilized Landsat TM data for the change detection. Supervised maximum likelihood classification technique was employed in ERDAS Imagine software to categorize into vegetation, agriculture, barren land, built-up, and water body. The overall accuracy of the classification was 90.29% for 1990 and 92.13% for 2010 data. Built up area increased from 2.72 km$^2$ to 12.20 km$^2$. Unlike other studies, the researchers reported that the vegetation of Hawalbagh block also increased by 9.39 km$^2$ from 1990 to 2010. They attributed afforestation programs promoted by the government as a major factor for the increase of vegetation.

Islam et al. (2018) also employed maximum likelihood classification technique to study change detection by using multi temporal Landsat 5 TM and Landsat 8 OLI remotely sensed data in Chunati wildlife sanctuary, Bangladesh. The scholars considered 2005 as a base year and examined the change from 2005 to 2015. The scholars categorized the images into sixteen different classes, and the accuracy ranged from 83 percent to 100 percent. Natural forest preserves decreased by 1911 ha. The researchers attributed this change to intense pressures from the growth of surrounding populations. The researchers warned that the fragmented land could affect natural habitat of Asian elephant and other wildlife.

**Image classification techniques**

The primary objective of image classification is to convert the digital numbers of the images, collected by satellite sensors, into land cover classes, also known as themes. Several image classification method exists for image processing. Image classification techniques can be
grouped into two types: pixel based classification, and object based classification technique (Schowengerdt, 2012). In pixel based classification, an algorithm is applied to the individual pixels. Whereas in object based classification, pixels are grouped to form objects. Image texture, pixel proximity, feature size, shape, repetition, and context are taken into account in object-oriented classification (Lillesand, 2014), whereas only spectral information is used in pixel based classification method. When using Landsat data, the classification results between pixel based and object based are not always statistically significant (Duro et al., 2012; Dingle & King, 2011). Several researchers have used pixel based classification to study urban areas around the globe (for example, Zha et al., 2003; Muñoz-Marí et al., 2007; Erbek et al., 2004; Alphan, 2003). This study employs pixel based classification technique. There are various classification algorithms for the pixel based classification technique. They generally fall under three categories: supervised, unsupervised, and hybrid classification technique. These three types are revised in the next sections.

Unsupervised classification: The unsupervised classification method converts digital numbers of the image without the utilization of training samples. The user does not provide sample classes as an input. Unsupervised classification assumes that the digital numbers of same land cover types are close to each other in vector space, and so the digital numbers belonging to different land cover classes are well separated (Lillesand et al., 2014).

Supervised classification: This technique is most often applied in quantitative analysis of remotely sensed images (Richards, 2013). In supervised classification, spectral domain are segmented into regions that are associated with particular types of ground cover (Richards, 2013). There are three steps in supervised classification. (a.) the researchers identifies the pure spectra of various land cover or themes, as a set of training samples, either from the field work or
from aerial imagery (b.) the training sample is then used to classify images to produce thematic LULC maps (c.) finally, accuracy assessment is conducted on the classified/thematic maps.

There are several classification algorithms that may be found in the literature within the supervised classification technique. For example, there is a minimum distance to means classifier, a Parallelepiped classifier, and a Gaussian maximum likelihood classification (Lillesand, 2014). The Gaussian maximum likelihood classification, also known as the maximum likelihood method, is the most commonly used algorithm to classify images. This classification algorithm evaluates the variance and covariance of the spectral domain of the image (Lillesand, 2014). However, it is assumed that the probability density function of digital numbers of each category of image, are assumed to be normally distributed. The probability density functions generated from the training samples are used to classify unknown/unidentified pixels of the image. The probability of any given pixels of falling into each class is computed, and computer program assigns that pixel into the category that has the highest probability of accurate classification.

Hybrid classification: The hybrid classification routine uses the combination of both supervised and unsupervised classification techniques.

This type of classification is employed when there is complex variability in the spectral response of land cover in the remotely sensed data (Lillesand et al., 2014). This type of classification is suitable for feature reduction, and feature selection and is often combined with guided clustering (Phillips et al., 2009).

Hundreds of researchers around the globe have used maximum likelihood classification techniques in their research (for example: Suhura et al., 2018; Alfa et al., 2018; Mukhopadhyay et al., 2018; Camilleri et al., 2017). The maximum likelihood method consumes less computing
time as compared to non-parametric methods such as backpropagation neural networks (Paola & Schowenderdt, 1995). Many researchers have reported more than 80 percent accuracy when employing this algorithm in their studies (for example: Otukei & Blaschke, 2010; Erbek et al., 2004; Karan et al., 2016). For my study of urban land change in the Kathmandu Valley of Nepal, I used the maximum likelihood classification technique to classify remotely sensed data into thematic classes.

**Land cover mapping in the Kathmandu Valley, Nepal**

Thapa (2009) studied the land cover change of the Kathmandu Valley from 1967 to 2000 using remotely sensed data. He used images acquired by the Corona satellite (1m² resolution) for 1967. However, these high resolution images were only available for a very limited area of the valley (Thapa, 2009). Similarly, the researcher used MSS 30m² resolution to study the urban cover in 2000. The researcher classified the image into six land cover types: shrubs, forest, water, urban/built up area, open space, and agriculture areas. Urban/ built up areas occupied only 2.94 percent of the total area of the valley. In 2000, the urban area increased to 14 percent of the total. Another significant change was noticed in forest shrub land cover. Shrubs occupied 19.81 percent in 1967 and this land cover declined to 10.44 percent in 2000. From personal interviews, the researcher found that there were very few houses along the road in 1967, and the changed areas was agricultural land. The scholar reported that with the extension of roads in the valley, the rural agricultural landscape gradually changed to a peri-urban landscape.

The International Centre for Integrated Mountain Development (ICIMOD) conducted a land cover classification study of Nepal in 1990 (ICIMOD, 2014), in 2000 and in 2010 (ICIMOD, 2013). For all the years, Landsat Thematic Mapper data (30m² resolution) was used for the LULC classification. They used the Geographic Object Based Image Analysis technique
to classify land cover of whole country. The remotely sensed images were classified into eight
different classes: forest, shrubs, grass, agriculture, bare areas, water bodies, snow, and built ups.
According to the study, about 45.15% of Nepal was covered by forest and 25.41% was covered
by agriculture in 1990. Forest land cover was reduced to 41.9% in 2010, however, agricultural
land increased to 27.32% in 2010. About 0.32 percent of the entire country was covered by built
up/urban areas in 2010. According to ICIMOD, the land cover study of Nepal in 2010 is the first
and most complete national land cover classification conducted in the country.

A clip was performed using ICIMOD’s national land cover dataset for the years of 1990,
2000 and 2010, in order to extract the land cover of the Kathmandu Valley specifically. This
simple geospatial procedure was conducted in order to demonstrate how the valley’s land cover
changed over time. In 1990, some 50.75% of the valley was covered in forest and 36.5% was
covered in agricultural land, with negligible amounts of barren land, grassland and shrubland
(Table 4). At this point in time, urban built-up area accounted for 10.88% of the land within the
valley. By 2000, the percentage of forested and agricultural lands had decreased slightly with
47.23% of land being classified as forest and 35.85% being classified as agricultural land. Built-
up urban areas had increased to 14.1% of the total land, roughly corresponding with the amount
of forested and agricultural land lost. By 2010, the built up area of the valley had increased to
18.47%, and forested and agricultural land had decreased to 45.9% and 33.48% respectively. The
decline of agriculture and forested lands represents a major change in the land cover of the
valley, and demonstrates very much the impact of humans on the environment. The built up
areas are expanding at the expense of agricultural and forestland in the Kathmandu Valley.
Table 4: ICIMOD classification of the land cover of the Kathmandu Valley.

<table>
<thead>
<tr>
<th></th>
<th>1990 Km²</th>
<th>1990 %</th>
<th>2000 Km²</th>
<th>2000 %</th>
<th>2010 Km²</th>
<th>2010 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural area</td>
<td>341.62</td>
<td>36.65</td>
<td>334.12</td>
<td>35.85</td>
<td>312.10</td>
<td>33.48</td>
</tr>
<tr>
<td>Barren area</td>
<td>1.15</td>
<td>0.12</td>
<td>1.65</td>
<td>0.18</td>
<td>1.97</td>
<td>0.21</td>
</tr>
<tr>
<td>Built-up area</td>
<td>101.41</td>
<td>10.88</td>
<td>131.45</td>
<td>14.1</td>
<td>172.17</td>
<td>18.47</td>
</tr>
<tr>
<td>Forest</td>
<td>473.00</td>
<td>50.75</td>
<td>440.17</td>
<td>47.23</td>
<td>427.84</td>
<td>45.90</td>
</tr>
<tr>
<td>Grassland</td>
<td>12.70</td>
<td>1.36</td>
<td>22.03</td>
<td>2.36</td>
<td>16.76</td>
<td>1.79</td>
</tr>
<tr>
<td>Shrubland</td>
<td>0.84</td>
<td>0.09</td>
<td>1.54</td>
<td>0.17</td>
<td>0.66</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Source: ICIMOD.

There are several other previous land cover classification projects for Nepal done in the past. However, few have focused on Kathmandu Valley as a prime study site. For example, Bishop (1990) studied the land cover change from 1950 to 1972 of Karnali zone, in far western Nepal, using Landsat imagery. Similarly, Thapa and Weber (1990) used topographic maps to analyze the land cover change of upper Pokhara Valley. These studies all indicate an increase in urban landscapes in major cities of Nepal. Several researchers have also analyzed the snow cover/glacial extend of Nepal. For example, Maskey et al. (2011), Midriak (2009), Kuhle (2014) and Shea et al. (2014) all studied these issues. These studies also showed a decreasing trend in the snow cover in Himalayan range of Nepal.

Thapa and Murayama (2010) provide one of the few studies that predicted the future land cover of the Kathmandu Valley. The researchers first generated 1978, 1991, and 2000 land cover maps of Kathmandu, using 30m Landsat data, and employed cellular automata technique to extrapolate the urban development pattern of the Kathmandu Valley from 2010 to 2020. They included biophysical, infrastructure, and social factors, such as a digital elevation model, distance to rivers, distance to industrial estates from residential area, distance to roads from residential area, and the annual population growth rate, to predict the land use change of the valley. Their results predicted that the built up area of the valley will continue to increase both by
in filling of the open land inside the core area, as well as the rapid outward expansion of the built up areas. They predicted that the future expansion will take place in eastern and southern direction within valley. They also acknowledged that the future urban development will be influenced by the existing roads network and the complex topography of the valley.

Similarly, Rimal (2011) used Markov chain analysis to predict the 2017 land cover of Kathmandu city, and Lalitpur city (excluding Bhaktapur city also with in the valley). Markov chain analysis is a stochastic process that is useful for future prediction based on the present conditions and the history of the state. At first, the scholar studied the land cover of Kathmandu city, and Lalitpur city of Nepal from 1976 to 2009 using Landstat MSS, TM and ETM+ data and found out that the urban built up areas of the two cities increased from 10.90 km$^2$ in 1976 to 43.10 km$^2$ in 2009. This increase in the built up area is correlated with the decrease in forest cover and water body. The cultivated land of the cities also decreased from 38.40 sq. km in 1976 to 17.30 sq. km in 2009. He then applied a Markov chain analysis model in the study site. The probability model showed that the urban land of the two metro cities will increase by 3.60 km$^2$ from 2009 to 2017.

All of the above studies showed that the land use and land cover of many places throughout Nepal has been changing at a rapid pace. Remote sensing and GIS has proven to be a valuable tool in understanding the spatial and temporal scales of land use and land cover changes. Given the incredible rate of land use change which was observed during the field visit, in summer 2018, there is an urgency to document and measure urban land.
CHAPTER III
MATERIALS AND METHODS

This chapter first describes the study area, and then transitions into datasets used for this thesis. Finally, it discusses image classification technique and accuracy assessment of the image classification.

Study area

The Kathmandu Valley, located in the central part of Nepal (Figure 2), lies in $85^\circ 15'$ East longitude and $27^\circ 37'$ North, is the most densely populated region of the country. It lies within the central hill region and comprises of three districts: Kathmandu District, Bhaktapur District, and Lalitpur District, with each covering an area of 395 km$^2$, 119 km$^2$, and 385 km$^2$, respectively. Kathmandu District consist of eleven municipalities (including Kathmandu City), Lalitpur District consists of six municipalities (including Lalitpur City), and Bhaktapur District consists of four municipalities (including Bhaktapur City) (Figure 2).

The valley is bowl shaped and surrounded by hills with elevations ranging from 1,500 m to 2,800 m (Gurung, 2014). According to the report published by the World Bank, the Kathmandu Valley is the fastest growing metropolitan region in the South Asia with a 4 percent annual growth rate (Muzzini & Aparicio, 2013). Other amenities such as adequate infrastructure and employment opportunities are not being developed at the same pace as the population growth rate (Haack & Rafter, 2006). According to Muzzini and Aparicio (2013), the core of the valley has a stabilized population but the peripheral portions of the valley are experiencing rapid unstrained growth. In the hills of the valley, temperate/cool temperate climatic conditions are prevalent whereas a subtropical climate is dominant in the basin. The maximum mean temperature of the valley is $35.6^\circ$ C for the month of April and minimum mean temperature is –
3° in January, with an annual average humidity of 75% (Pant & Dangol, 2009). Due to its cool climate and fertile soil, historically, the valley is very productive in agriculture (ICIMOD, 1993). The valley floor is intensely cultivated and terrace farming is prevalent in the hilly areas of the valley. The crops in the valley are rice, wheat, barely. The valley is drained by the Bagmati River Watershed. Kathmandu City and Lalitpur City are connected by a 27 km ring road which circles the two cities. Industrial areas blend together with the residential and commercial districts in the valley. The valley hosts many industrial businesses such as cement factories and brick factories. Due to its bowl shape and low wind speed, the air is not quickly dispersed in the valley. Hence, air particulates produced from the factories and road resuspension often exceed the World Health Organization’s Air Quality guidelines (Haack & Rafter, 2006). This is called temperature inversion. The population of the valley was 1,105,379 in 1991 and is projected to be 2,877,255 by 2020 (Central Bureau of Statistics, 2016).
Figure 2: Location of the Kathmandu Valley in Nepal.
Datasets

Landsat images: Landsat has a long history of continuously monitoring earth features and has a moderate resolution of 30 m. and are used for urban land cover change studies (Alberti et al., 2004; Xian and Crane, 2006; Zhang 2002)

Nepal experiences monsoon starting from July until the end of October, which causes many images to be covered by clouds. Kondo et al. (2005) reported that the aerosols such as NO$_2$, and O$_3$ are higher in the winter season in the Kathmandu Valley. Aerosols and clouds present difficulty in isolating path radiance from the top of atmosphere radiance and affect the Landsat scene quality (Ichoku et al., 2004; Liang et al., 2001). Hence, images of post winter seasons are appropriate for LULC change detection. All the images were acquired for the month of March or April to reduce phenological bias. The Landsat images have been atmospherically corrected by United States Geological Survey (USGS) with Landsat Ecosystem Disturbance Adaptive Processing System and the L8SR algorithm. Surface reflectance products are generated and radiometrically corrected by USGS using specialized software “Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS)” developed by NASA. Images with less than 10 percent cloud cover of Landsat 5 TM and Landsat 8 Optical Land Imager (OLI) were downloaded from the USGS website (https://earthexplorer.usgs.gov/). Surface reflectance imageries (Level 2) instead of Level 1 were downloaded for the years of 1990, 2006, and 2018 (Table 5).
Table 5: Summary of the satellite data.

<table>
<thead>
<tr>
<th>Year</th>
<th>Satellite</th>
<th>Sensor</th>
<th>No. of scenes</th>
<th>Acquisition date</th>
<th>Data type</th>
<th>Path /Row</th>
<th>Cloud Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>Landsat 8</td>
<td>Operational Land Imager</td>
<td>7</td>
<td>3/21/2018</td>
<td>Level 2</td>
<td>141/41</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>2006</td>
<td>Landsat 5</td>
<td>Thematic Mapper</td>
<td>6</td>
<td>4/3/2006</td>
<td>Level 2</td>
<td>141/42</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>1990</td>
<td>Landsat 5</td>
<td>Thematic Mapper</td>
<td>6</td>
<td>4/9/1990</td>
<td>Level 2</td>
<td>141/43</td>
<td>&lt;10%</td>
</tr>
</tbody>
</table>

- Scene id of 2018: LC08_L1TP_141041_20180321_20180403_01_T1
- Scene id of 2006: LT05_L1TP_141041_20060304_20161122_01_T1
- Scene id of 1990: LT05_L1TP_141041_19900409_20170131_01_T1

Field data collection

During the summer of 2018, a field visit of the valley was conducted. Thirty Geographic Positioning points (GPS) were collected during the field visit (Table 6). These points were used for generation of training samples and accuracy assessment.
### Table 6: GPS points collected from field visit in the Kathmandu Valley during summer 2018.

<table>
<thead>
<tr>
<th>No.</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Land cover</th>
<th>No.</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Land cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27.73649</td>
<td>85.329603</td>
<td>Built up</td>
<td>16</td>
<td>27.69744</td>
<td>85.336739</td>
<td>Open water</td>
</tr>
<tr>
<td>2</td>
<td>27.740659</td>
<td>85.327619</td>
<td>Built up</td>
<td>17</td>
<td>27.6797</td>
<td>85.305297</td>
<td>Built up</td>
</tr>
<tr>
<td>3</td>
<td>27.737346</td>
<td>85.298046</td>
<td>Forest</td>
<td>18</td>
<td>27.684697</td>
<td>85.286008</td>
<td>Built up</td>
</tr>
<tr>
<td>4</td>
<td>27.647835</td>
<td>85.330869</td>
<td>Agriculture</td>
<td>19</td>
<td>27.518261</td>
<td>85.299153</td>
<td>Forest</td>
</tr>
<tr>
<td>5</td>
<td>27.654484</td>
<td>85.322486</td>
<td>Agriculture</td>
<td>20</td>
<td>27.604864</td>
<td>85.330423</td>
<td>Forest</td>
</tr>
<tr>
<td>6</td>
<td>27.644046</td>
<td>85.347305</td>
<td>Fallow land</td>
<td>21</td>
<td>27.609183</td>
<td>85.32549</td>
<td>Open space</td>
</tr>
<tr>
<td>7</td>
<td>27.525124</td>
<td>85.321047</td>
<td>Fallow land</td>
<td>22</td>
<td>27.663278</td>
<td>85.438516</td>
<td>Open space</td>
</tr>
<tr>
<td>8</td>
<td>27.621172</td>
<td>85.286147</td>
<td>Forest</td>
<td>23</td>
<td>27.665986</td>
<td>85.442131</td>
<td>Forest</td>
</tr>
<tr>
<td>9</td>
<td>27.665685</td>
<td>85.268094</td>
<td>Built up</td>
<td>24</td>
<td>27.732715</td>
<td>85.396778</td>
<td>Open water</td>
</tr>
<tr>
<td>10</td>
<td>27.710664</td>
<td>85.325914</td>
<td>Open water</td>
<td>25</td>
<td>27.597659</td>
<td>85.375714</td>
<td>Built up</td>
</tr>
<tr>
<td>11</td>
<td>27.779331</td>
<td>85.359859</td>
<td>Built up</td>
<td>26</td>
<td>27.585029</td>
<td>85.331478</td>
<td>Built up</td>
</tr>
<tr>
<td>12</td>
<td>27.763522</td>
<td>85.366198</td>
<td>Agriculture</td>
<td>27</td>
<td>27.632322</td>
<td>85.325239</td>
<td>Vegetation</td>
</tr>
<tr>
<td>13</td>
<td>27.661527</td>
<td>85.312833</td>
<td>Built up</td>
<td>28</td>
<td>27.630121</td>
<td>85.316767</td>
<td>Open space</td>
</tr>
<tr>
<td>14</td>
<td>27.66039</td>
<td>85.30987</td>
<td>Built up</td>
<td>29</td>
<td>27.51116</td>
<td>85.330087</td>
<td>Open space</td>
</tr>
<tr>
<td>15</td>
<td>27.662182</td>
<td>85.317056</td>
<td>Road</td>
<td>30</td>
<td>27.592151</td>
<td>85.299984</td>
<td>Open space</td>
</tr>
</tbody>
</table>

### Image processing and classification

For this study, the Gaussian maximum likelihood classification method (MLCA) was selected for the classification of all of the Landsat images. Many researchers have used MLCA...
and reported high accuracy rates for the classifications (for example: Otukei & Blaschke, 2010; Sarvestani et al., 2011; Rawat and Kumar, 2015; Islam et al., 2018).

A shapefile of the districts of Nepal was downloaded from the website of the Humanitarian data exchange (https://data.humdata.org), an open data sharing platform managed by the United Nations Office for the Coordination of Humanitarian Affairs (European Commission, 2018). Using the query tool in ArcGIS, the boundary of the Kathmandu Valley was extracted from the districts shapefile and then was converted into a shapefile only representing the masked portion included in the research. Similarly, the Digital Elevation Model (DEM) of Nepal was also downloaded from Humanitarian Data Exchange website.

The Landsat images were mosaicked using ArcGIS 10.5 (ESRI, 2010). After excluding thermal and panchromatic bands, the images were then clipped in the ArcGIS environment using the Kathmandu Valley boundary. For display purpose, a false color composite (Figure 3) of the Landsat (band 4, band 3, and band 2) was used because it highlights vegetation and built up areas. Vegetation appears in bright red, urban areas in cyan blue and the soil appears in brown colors.

A supervised maximum likelihood classification was used (see Figure 4). This involves three stages: the training stage, classification stage, and the output stage. (Fu et al., 2014). After visually identifying different land cover types and also using the ground control points collected from the field, training data were created. Roads and waterbodies in the image were used to help identify the training sites. The training data were used as an input for the maximum likelihood technique to classify the land cover types. The maximum likelihood classification assigns pixels that have the highest probability of belonging to that class. The Anderson classification scheme Level 1 (1976) (see Table 1) was used for the classification scheme. After the classification, all
other classes, except built up classes, were converted into null values so as to mask out areas of urban land cover. Urban land cover and bare soil have the similar spectral signatures (Zha et al., 2003). Much effort was made to separate the urban built up areas from the barren soil/land by trying to select only pure spectra during the training stage. However, some areas within the study area required manual editing due to this misclassification between barren soil and urban land cover.

Figure 3: False color composite of Landsat 8 image of the Kathmandu Valley.
Several researchers have reported topography as a significant factor affecting urban growth. For example, Li et al. (2013) studied urban expansion in Beijing from 1972 to 2010 and reported that slope had negative effect on urban expansion of the city over the past forty years. Similarly, Batisani and Yarnal (2009) studied effects of slope in Centre County of Pennsylvania from 1993 to 2000 and found that slope had a negative effect at the suburban area. Hence, the topographic analysis of the urban land cover of the Kathmandu Valley was conducted to see if a similar pattern exists in the valley.

The workflow of the topographic analysis is shown in Figure 5. The digital elevation model (30 m resolution) was first clipped using the Kathmandu Valley boundary shapefile. The clipped raster file was then converted into slope raster file in degrees (Figure 6). Data representing urban land cover for each year (of 1990, 2006, and 2018) were used to clip the slope raster file. Using the Sample tool in ArcGIS, the digital numbers of the slope file was extracted.
into a .dbf file. The file was then converted into csv format. Histograms were computed to display the change in the topography of the urban landscapes of 1990, 2006, and 2018.

![Workflow of the topographic analysis](image)

**Figure 5:** Workflow of the topographic analysis.

**3 dimensional model**

For increased visualization of urban growth at different elevations and slop grades, a 3-dimensional model was designed to illustrate these dimensions. The elevation data, through a digital elevation model was placed into a projected coordinate system (UTM-45 N) and then visualized within the ArcScene software. Using the base heights feature, specifically the floating on a custom surface function, a 3-dimensional visualization was created. Urban land use pixels for 1990 and 2018 were then overlaid on this surface.
Figure 6: Slope raster file of the Kathmandu Valley (Source: Author).
Post classification smoothing and accuracy assessment

Classified data often exhibits a salts and pepper appearance, especially when pixel-by-pixel classification methods are applied (Lillesand, 2014). Hence, post classification refinement was used to improve the accuracy of the classification method. Geographic Information Systems (GIS) provides an excellent platform for facilitating the post classification smoothing process. The use of a majority filter is one of the means of classification smoothing. A 3 x 3-pixel majority filter was applied to the classified data. A moving window is passed through the classified data. The pixel value is then replaced by the majority class within the moving window (Lillesand, 2014).

An accuracy assessment was performed on this classification, which helps users calculate the percentage of the image that was correctly classified when compared to the real world (Story & Congalton, 1986). Accuracy assessments points were randomly generated in the ArcMap using a stratified random sampling technique. For 1990, 90 points were randomly generated, and for 2006, 100 points were generated, and for 2018, 100 points were generated. Ground truth was then conducted to find the accuracy of the classified maps. The time slider of Google Earth was utilized for 1990, and 2006. Shapefiles were converted into Keyhole Markup language (KML) to import into Google Earth pro for the accuracy assessment. A non-parametric Kappa test was used to measure the accuracy of the classified map as it considers all the elements in the error matrix.

A non-parametric Kappa test (Eq.1) is used to measure the accuracy of each classified map as it considers all the elements in the error matrix. This study also employs the post classification detection technique. A confusion matrix is created using points classified as land
cover, and points from ground cover. The Kappa Value is computed as follows (Congalton, 1991).

\[
Kappa = \frac{(Observed - Expected Agreement)}{(1 - Expected Agreement)}
\]  

(Eq.1)

Kappa values reflect the difference between actual agreement and agreement by chance for the land cover classification. Kappa values ranging from 0.61 to 1.00 are considered to be good to excellent (McHugh, 2012).
CHAPTER IV
RESULTS AND DISCUSSION

This chapter discusses the results of the classification and accuracy assessment of the classification. It then transitions into the topographic analysis of the urban land cover. Finally, it identifies the drivers of the urban land cover change in the Kathmandu Valley.

Classified images and accuracy assessments

The classified urban land cover map of the Kathmandu Valley for the years 1990, 2006, and 2018 are shown in Figures 7, 8, and 9, respectively. The combined overlaid urban land cover map of 1990, 2006, and 2018 is shown in Figure 10.

The user accuracy ranged from 86% to 97% and the producer accuracy ranged from 92% to 94% (Table 7). The achieved overall classification accuracies were 92%, 93%, and 93% and overall Kappa statistics were 0.84, 0.86, and 0.84, respectively for the classification of 1990, 2006, and 2018 images. The overall accuracy more than 80% and the kappa value more than 0.80 are considered very good (Anderson, 1976; Lucas et al., 1994; Congalton et al., 1991).

Table 7: Error matrix for 1990, 2006, and 2018 classified images.

<table>
<thead>
<tr>
<th>Year</th>
<th>Class name</th>
<th>Urban</th>
<th>Non - urban</th>
<th>Total</th>
<th>User accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>Urban</td>
<td>33</td>
<td>4</td>
<td>37</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>Non - Urban</td>
<td>3</td>
<td>50</td>
<td>53</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>36</td>
<td>54</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Producer accuracy</td>
<td>0.92</td>
<td>0.93</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Classification accuracy</td>
<td>92%</td>
<td>Kappa Statistics</td>
<td>0.84</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>Urban</td>
<td>44</td>
<td>3</td>
<td>47</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>Non - urban</td>
<td>4</td>
<td>49</td>
<td>53</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>48</td>
<td>52</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Producer accuracy</td>
<td>0.92</td>
<td>0.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Classification accuracy</td>
<td>93%</td>
<td>Kappa Statistics</td>
<td>0.86</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>Urban</td>
<td>30</td>
<td>5</td>
<td>35</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>Non - Urban</td>
<td>2</td>
<td>63</td>
<td>65</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>32</td>
<td>68</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Producer accuracy</td>
<td>0.94</td>
<td>0.93</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Classification accuracy</td>
<td>93%</td>
<td>Kappa Statistics</td>
<td>0.84</td>
<td></td>
</tr>
</tbody>
</table>
Figure 7: Urban land cover map of the Kathmandu Valley of 1990.
Figure 8: Urban land cover map of the Kathmandu Valley of 2006.
Figure 9: Urban land cover map of the Kathmandu Valley of 2018.
Figure 10: Overlay map of the urban land cover of the Kathmandu Valley of 1990, 2006, and 2018.
Urban land cover estimates for the Kathmandu Valley for 1990, 2006, and 2018 are summarized in Table 8, Table 9 and Figure 11. The results indicate that in 1990 approximately 9.53% of the Kathmandu Valley was in urban land cover class. In 2006 this percentage markedly increased to 15.67%, and by 2018 urban land made up 31.8% of the valley’s land cover. By 2006, the urban area infilled completely within the central business district and began to expand outside of its boundaries. This outward urban growth was speculatively caused by the rising price of land closer to the city center, because all land within the central business districts is increasingly expensive compared to areas outside of the ring road (Toffin, 2010). The growth of industry at the margins of the city limits has also contributed to this growth (Thapa et al, 2009). There are two major industrial estates in the region, Balajau and Patan, and a growing number of industrial zones along the major highways of the periphery (Thapa et al, 2008). With the growth of industry, many residents who traditionally would have looked for work in the heart of Kathmandu now have the ability to work and live on the outskirts of the city. This urban shift in land uses has contributed to urban sprawl. Similarly, the total percentage change in urban area between 1990 and 2018 was 227.12%. When this is broken down between 1990 and 2006, the total percentage change was 64.27% for the first sixteen years, while between 2006 and 2018, this figure increased to 99.14%. This growth in urban development seems to correspond at par with Nepal’s total GDP growth from the 1990s to present. Since Kathmandu is the capital city of Nepal, it is not unsurprising that growth within the Kathmandu Valley has been so outsized.

Tables 4.4, 4.5, and 4.6 demonstrate the changes to urban land cover of the individual districts within the Kathmandu Valley between 1990 and 2018. In 1990, all three districts had a low percentage of land in urban development categories compared to the entire surface area of each district.
Table 8: Urban land cover of the Kathmandu Valley.

<table>
<thead>
<tr>
<th>Year</th>
<th>Urban Land Cover</th>
<th>Non-Urban Land Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area in km²</td>
<td>Area in %</td>
</tr>
<tr>
<td>1990</td>
<td>88.96</td>
<td>9.53</td>
</tr>
<tr>
<td>2006</td>
<td>146.13</td>
<td>15.67</td>
</tr>
<tr>
<td>2018</td>
<td>291.01</td>
<td>31.18</td>
</tr>
</tbody>
</table>

Table 9: Change in percentage of the urban land cover of the Kathmandu Valley.

<table>
<thead>
<tr>
<th>Time period</th>
<th>Change in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990 - 2006</td>
<td>64.265</td>
</tr>
<tr>
<td>2006 - 2018</td>
<td>99.14</td>
</tr>
<tr>
<td>1990 -2018</td>
<td>227.12</td>
</tr>
</tbody>
</table>

Source: Calculated by author.

Figure 11: Urban land cover of the Kathmandu Valley in 1990, 2006, and 2018.
The Kathmandu District had the highest amount of urban land of the three districts with 58.18 km\(^2\) or comprised 14.06% of all land in the district in 1990 (Table 10). The Bhaktapur District had 13.39 km\(^2\) of urban land cover, which comprised 10.88% of this district. The Lalitpur District had the lowest urban development with only 17.39 km\(^2\) of urban land cover, which comprised 4.38% of the total district area at the time. By 2006, urban development had ballooned in the Kathmandu District and the Bhaktapur District, while Lalitpur District saw a smaller amount of growth (Table 11). By 2018, 43.98% of the Kathmandu District and 45.01% of the Bhaktapur District were classified as urban, while 13.53% of Lalitpur District was assigned to urban land cover (Table 12). The majority of the brick factories of the Kathmandu Valley are highly concentrated in the Lalitpur and Bhaktapur districts, where factors such as soil, water availability and transportation are more optimal for their production than within the city center of Kathmandu (Haack & Khatiwada, 2007). Kathmandu Valley is experiencing conurbation process where cities in the valley are merging together to form a giant urban area with poly centers. It is important to note that the southern part of the Lalitpur District experienced less urbanization when compared to the other regions of the valley. The Lalitpur District is bigger in size compared to the Kathmandu District and the Bhaktapur District and the southern part of the Lalitpur District is much farther from the central business district and so the land values are lower but transportation and commute are less convenient.

Table 10: Urban land cover of districts in the Kathmandu Valley in 1990.

<table>
<thead>
<tr>
<th></th>
<th>Urban Area</th>
<th>Non - Urban Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area in sq. km</td>
<td>Area in %</td>
</tr>
<tr>
<td>Kathmandu District</td>
<td>58.18</td>
<td>14.06</td>
</tr>
<tr>
<td>Bhaktapur District</td>
<td>13.39</td>
<td>10.88</td>
</tr>
<tr>
<td>Lalitpur District</td>
<td>17.39</td>
<td>4.38</td>
</tr>
</tbody>
</table>

Source: Calculated by author.
Table 11: Urban land cover of districts in the Kathmandu Valley in 2006.

<table>
<thead>
<tr>
<th></th>
<th>Urban Area</th>
<th>Non-Urban Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area in km²</td>
<td>Area in %</td>
</tr>
<tr>
<td>Kathmandu District</td>
<td>89.05</td>
<td>21.53</td>
</tr>
<tr>
<td>Bhaktapur District</td>
<td>27.13</td>
<td>22.04</td>
</tr>
<tr>
<td>Lalitpur District</td>
<td>30.06</td>
<td>7.57</td>
</tr>
</tbody>
</table>

Source: Calculated by author.

Table 12: Urban land cover of districts in the Kathmandu Valley in 2018.

<table>
<thead>
<tr>
<th></th>
<th>Urban Area</th>
<th>Non-Urban Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area in km²</td>
<td>Area in %</td>
</tr>
<tr>
<td>Kathmandu District</td>
<td>181.88</td>
<td>43.98</td>
</tr>
<tr>
<td>Bhaktapur District</td>
<td>55.40</td>
<td>45.01</td>
</tr>
<tr>
<td>Lalitpur District</td>
<td>53.71</td>
<td>13.53</td>
</tr>
</tbody>
</table>

Source: Calculated by author.

In 1990, Kathmandu City comprised the most urban land area of the three urban centers of the valley, with a total of 36.99 km² of urban land cover compared to only 11.60 km² and 2.32 km² in Lalitpur and Bhaktapur cities respectively (Table 13). In total, Kathmandu City had 74.82% of its land area covered in urban land while Lalitpur City had 46.51% and Bhaktapur City had 35.39% of their land covered in urban land cover respectively. By 2006, the percentage and total area of urban cover in all three cities had increased by a significant amount, and by 2018, Kathmandu City was all but completely covered in urban land type with 99.33% of the land being in urban use. This shift over the past two decades represents a marked growth in the valley, which has resulted in the complete infilling of Kathmandu City. The other cities, Lalitpur and Bhaktapur, have experienced even more dramatic growth. Lalitpur City is comprised of 90.40% urban land cover and Bhaktapur City is comprised of 91.52% urban land cover as of 2018. These cities are likely to infill even more in the future.
Table 13: Urban land cover of Kathmandu City, Lalitpur City, and Bhaktapur City.

<table>
<thead>
<tr>
<th></th>
<th>Urban Area in km²</th>
<th>Total Area in km²</th>
<th>% Urban built up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kathmandu City</td>
<td>36.99</td>
<td>49.44</td>
<td>74.82</td>
</tr>
<tr>
<td>Lalitpur City</td>
<td>11.60</td>
<td>24.93</td>
<td>46.51</td>
</tr>
<tr>
<td>Bhaktapur City</td>
<td>2.32</td>
<td>6.55</td>
<td>35.39</td>
</tr>
<tr>
<td>2006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kathmandu City</td>
<td>47.63</td>
<td>49.44</td>
<td>96.35</td>
</tr>
<tr>
<td>Lalitpur City</td>
<td>18.35</td>
<td>24.93</td>
<td>73.58</td>
</tr>
<tr>
<td>Bhaktapur City</td>
<td>4.05</td>
<td>6.55</td>
<td>61.78</td>
</tr>
<tr>
<td>2018</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kathmandu City</td>
<td>49.11</td>
<td>49.44</td>
<td>99.33</td>
</tr>
<tr>
<td>Lalitpur City</td>
<td>22.54</td>
<td>24.93</td>
<td>90.40</td>
</tr>
<tr>
<td>Bhaktapur City</td>
<td>6.00</td>
<td>6.55</td>
<td>91.52</td>
</tr>
</tbody>
</table>

Source: Calculated by author.

The built-up urban area within the valley has grown consistently according to clipped data from ICIMOD. According to ICIMOD classification of the satellite data, in 1990, the urban area of the valley was 10.88%, and in 2000 it increased to 14.1% (Table 14). By 2010 it had increased to 18.47%. This also confirms that the land cover of the valley is expanding at a rapid pace.

Table 14: ICIMOD classification of urban land cover of the valley.

<table>
<thead>
<tr>
<th></th>
<th>km²</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>101.41</td>
<td>10.88</td>
</tr>
<tr>
<td>2000</td>
<td>131.45</td>
<td>14.1</td>
</tr>
<tr>
<td>2010</td>
<td>172.17</td>
<td>18.47</td>
</tr>
</tbody>
</table>

**Topographic analysis**

Since 1990, there has been a noticeable shift of development from the flatter valley bottom of the valley to areas with a steeper slope (Figure 12). This could be a result of there being less flat lands available for development, and the majority of flat lands are proximate to core areas. The flat lands that are closer to the core of the valley are also expensive (Toffín, 2010), and this could be an additional factor that is driving the change in growth patterns.

![Graph showing topographic analysis of the urban land cover of the Kathmandu Valley of 1990, 2006, and 2018.](image)

**Figure 12:** Topographic analysis of the urban land cover of the Kathmandu Valley of 1990, 2006, and 2018.
The 3-dimensional model is shown in Figure 13. The model demonstrated clearly that as urban growth occurred between 1990 and 2018, the amount of growth in steeply sloped areas also increased. Where previously urban growth within the valley occurred only in the flat lands, it can be visualized that newer growth has now occurred at elevations where it has not occurred previously. This lends credence to the notion that as land price has increased, people have had to build in areas where they might not built traditionally.

![Three dimensional image of the Kathmandu Valley.](image)

**Figure 13**: Three dimensional image of the Kathmandu Valley.

**Drivers of urban land cover change**

With the increase of urban land use in the valley, there has also been an increase in the overall population. Table 15 shows the population of the Kathmandu Valley estimated by the Central Bureau of Statistics of Nepal. This growth has been fueled by in-migration from other regions of Nepal (Kumar, 2004). The increasing numbers of migrants to the region has led to an exponential growth in the valley’s population, leading to rapid urbanization. The driving factors behind this immigration to the valley are discussed below.
Table 15: Population of the Kathmandu Valley.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Kathmandu District</td>
<td>675,341</td>
<td>1,081,845</td>
<td>1,276,754</td>
<td>1,744,240</td>
<td>2,011,978</td>
</tr>
<tr>
<td>Bhaktapur District</td>
<td>172,952</td>
<td>225,461</td>
<td>254,074</td>
<td>304,651</td>
<td>340,066</td>
</tr>
<tr>
<td>Lalitpur District</td>
<td>257,086</td>
<td>337,785</td>
<td>381,327</td>
<td>468,132</td>
<td>525,211</td>
</tr>
<tr>
<td>Total</td>
<td>1,105,379</td>
<td>1,645,091</td>
<td>1,912,155</td>
<td>2,517,023</td>
<td>2,877,255</td>
</tr>
</tbody>
</table>

**Historical development**

The Kathmandu Valley has primarily been an agricultural region throughout most of its history. From the earliest records of life in the Kathmandu Valley, dating back to the 5th Century AD, there has been development noted in the region. This development dates back to at least the Lichchhavi period, approximately 400 to 750 CE (Tiwari, 1999). The temples, chaityas, palace squares and monasteries were concentrated in the medieval towns, while the majority of the valley was dominated by agricultural land use (Tiwari, 1999). According to the 1952/54 census, the Kathmandu Valley hosted 82.6 percent of the urban population of the country (Sharma, 2003). The primary driver behind this heavy concentration of population was the agricultural potential of the region (Sharma, 2003). There were no major industrial areas in the Kathmandu Valley until the 1960s. Starting in the 1960s, the development of the valley began to change. At that time, with the aid of the Indian Government, the Balaju and Patan industrial estates were set up (Rahul, 1968). This development slowly changed the land use characteristics of the valley. By 1990, much of the land in the core area of the valley had already been developed because of being the political, cultural, and financial capital of the country (Sharma, 1990).

**Economic hub**

The factors that have fueled migration are many. For many residents, the draw of being close to the country’s economic hub is a major driver. Nepal adopted free market policies in 1990 after achieving a multiparty democracy. This change enforced market based capitalism in
the country and reduced tariff and non-tariff barriers (Khadka, 1998). Kathmandu became the center of these market changes. The region experienced high level changes with respect to its local economy. Another factor that helped fuel these economic changes is the fact that Kathmandu is the main gateway to the remaining country. Nepal’s only international airport is located within the Kathmandu Valley, making it the primary entrance point for tourists and investors alike. With outside capital, investors and tourists as soon as were flooding into the valley, subsequently the job market grew which drew immigrants from other regions of the country.

**Political factors**

Throughout its history, Nepal has been controlled by a monarchial form of government. With the rise of the Maoist Army, people migrated to the capital to escape wars and get jobs (Adhikari, 2012). In 2006, however, this changed when the Maoist insurgency came to the forefront of Nepalese politics and forced the government to change. Today, Nepal is a presidential democratic system with a secular government and a nation-wide focus on growth and opportunity. With this change comes new opportunities for growth and development in the Kathmandu Valley, but also many challenges. Increased immigration to the valley has led to increased economic growth and a booming economy for the region, but it has also led to a housing crisis and the development of a system that does not provide subsidized housing to people who cannot afford increasingly expensive houses/properties (Sharma, 2006).

**Centralized government**

Nepal’s main governmental offices and service centers are confined to the bounds of the Kathmandu Valley. Citizens seeking major services have no choice but to travel to the valley for assistance. Nepal’s legislature, Supreme Courts and Executive Offices are also located in the
valley. For people who need access to these government offices, living in close proximity to these buildings is a priority. For those who need medical care, legal services, and social assistance, living within the valley is also advantageous (Murshed & Gates, 2005). As more people seek to live close to the seat of power in Nepal, the urban areas of the Kathmandu Valley are also experiencing enhanced growth.

**Center of education and technology**

The majority of Nepal’s renowned educational institutions are located in the Kathmandu Valley (Thapa et al., 2008), this includes Tribhuvan University, which draws large numbers of students from across the country to the valley. A 2015 report by Nepal’s Ministry of Education found that students within the valley outperformed their peers in other regions of the county, especially compared to students in rural areas where educational achievement, as measured by standardized tests, has been steadily declining (Ministry of Education, 2015). Rural families with the financial means to do so will send their children to schools in the Kathmandu Valley so that they can receive a higher quality of education. This migration of students is a driver of growth for the valley.
Summary

The factors outlined in this chapter all play a significant role in the expansion of urban development within the Kathmandu Valley. The economic and political centralization of Kathmandu, combined with insurrection in the countryside and a growing gap in technological resources and education sectors have made the Kathmandu Valley the primary hub of activity in Nepal (See Figure 14). All of the growth drivers that are influencing the valley are interrelated and work in concert with one another, creating a system of growth that is fueling rapid change in the region. It is unknown whether or not this growth pattern will continue into the future, but if the same core group of drivers remain in place, the prospects for future development remain positive. It is also unclear if these drivers will remain consistent across each district, and future studies will have to keep this factor in mind when surveying urban growth.
CHAPTER V

CONCLUSIONS

This thesis research aimed to analyze urban change in the three districts of the Kathmandu Valley for the periods of 1990, 2006, and 2018. The study first focused on understanding the change in urban topography of the valley, and then identified different drivers for the urban land cover change. Landsat images were used for the delineation of urban land cover of the valley using a supervised Gaussian maximum likelihood classification. The main findings are as follows:

1. There was a significant increase in urban land cover between 1990 and 2018. The urban land cover increased by 227% from 1990 to 2018. Urban land in 1990 made up only 9.53% of the valley’s land cover. In 2006, the urban land occupied 15.67% of the total land cover. This pattern changed in 2018 and the urban land cover occupied 31.18% of the total land cover. Kathmandu District of the valley was the most urbanized in 1990 with 14.06% of the urban land followed by Bhaktapur and Lalitput with 10.88 percent and 4.38 percent, respectively. By 2018, Kathmandu District and Bhaktapur District were almost equally urbanized with 43.98% and 45.01% of the total land area, respectively. Out of the three Districts, Lalitpur had always been least urbanized. This could be due to the fact that Lalitpur is the largest district and the southern part of the district is very rural with the least number of roads. Kathmandu Valley experienced outward expansion of urban growth emerging from the central business district of the valley and expanded to the perimeter where new industrial estates were being built.

2. Kathmandu Valley is experiencing urbanization process where cities in the valleys are merging together with poly centers. Similarly, there is a noticeable shift of built up areas
from the flat lands of the valley to steeper slope areas from 1990 to 2018. These changes could be attributed to the increasing land prices in the core of the urban center and less flat lands available for the urban development.

3. The growth of urban areas of the valley is correlated with the increase in the valley’s population. Kathmandu valley has always experienced faster development compared to other regions of the valley since the 5th century. This historical development of the valley attracted large population due to its agricultural potential. After the birth of democracy in the country in 1990, the economic liberalization of the country fueled rapid growth in the region. The region benefitted from the market based capitalism. The rise in the Maoist armed struggle also put more pressure in the valley. This led to the immigration of population due to the security threats. As the center of education/technology, the valley also contributed to the rapid urban expansion as many students came to the valley for higher education from the rest of the country.

Implications of the study

Using remotely sensed data affords the scientific community the ability to gather data on regions where in-situ data collection might prove more problematic. Nepal, which is a developing nation, can benefit greatly from using remotely sensed data as this research demonstrates. By classifying urban land cover within the valley and charting its growth over time, both across the flat lands and areas with a steeper slope, this study was able to make new contributions to the understanding of Kathmandu’s dramatic change over the past decades. This body of research is placed within a growing cohort of similar studies from within the region, following up the research of Rawat and Kumar in Uttarakhand, and Islam et al. (2018) in Chunati, Bangladesh. This research is also a successor to the studies of other scientists on land
cover change in Nepal including Thapa and Weber (1990), Maskey et al. (2011) and Shea et al. (2014). This thesis study also acts as a successor to the 2010, ICIMOD study, which featured a comprehensive examination of the land cover for the entirety of Nepal. It is hoped that other members of the academic community will be able to use this research as a baseline for understanding land cover change within Kathmandu, Nepal and the rest of the South Asian region.

The fundamental problems related to the continued growth of Kathmandu Valley in the future are as follows:

1. Profits from developed lands are greater than undeveloped, so when there is available capital, it is logical that land is developed.
2. Only when government restricts development or create a public park system can green space be preserved. It is not a market driven or neo-liberal outcome.
3. Land use decisions must be made by communities, not just those with economic interest or the government.
4. Moving up in steeper slope areas are profitable but in the case of Kathmandu Valley, this can be dangerous because of the vulnerability of the earthquake. A major earthquake seems to occur every 100 years in Nepal. It seems reasonable to expect more earthquakes in the future so that allowing construction of multifamily housing is ever more dangerous.

**Limitations of the study**

Anderson Level 2 classification allows us to classify urban land cover into residential, commercial, and industrial thematic classes. This thesis mapped broad urban land cover type. Industrial, residential, and commercial land cover were lumped together in the urban land cover class. Hence, it is difficult to understand the pattern (whether commercial, or residential, or
industrial) is growing in the Kathmandu Valley. In the regions like Kathmandu Valley where commercial, residential, and industrial are intermixed spatially, it is difficult to separate these classes using Landsat imagery. Similarly, it was quite challenging to acquire base data sets that would have allowed sufficient information to separate commercial, industrial, and residential areas of the Kathmandu Valley. Furthermore, lack of hyperspectral imagery was another issue faced in this study. Additionally, lack of access to socioeconomic data, such as GDP of the Kathmandu Valley, and migration of the population to the valley, prevented quantitative analysis of the drivers of the urban land cover change in this thesis study. Thus this study relied on literature review to understand the drivers of urban land cover change of the Kathmandu Valley. Future studies would need to acquire high resolution remote sensing imagery and base datasets and social economic datasets for more detailed classification of urban change and quantitative analysis of drivers of the urban land cover change to support informed land use planning and decision making in the Kathmandu Valley.
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