Urban Growth Trends and Multi-Hazards in Kathmandu Valley

November 2016

Kathmandu Valley Development Authority
KVDA

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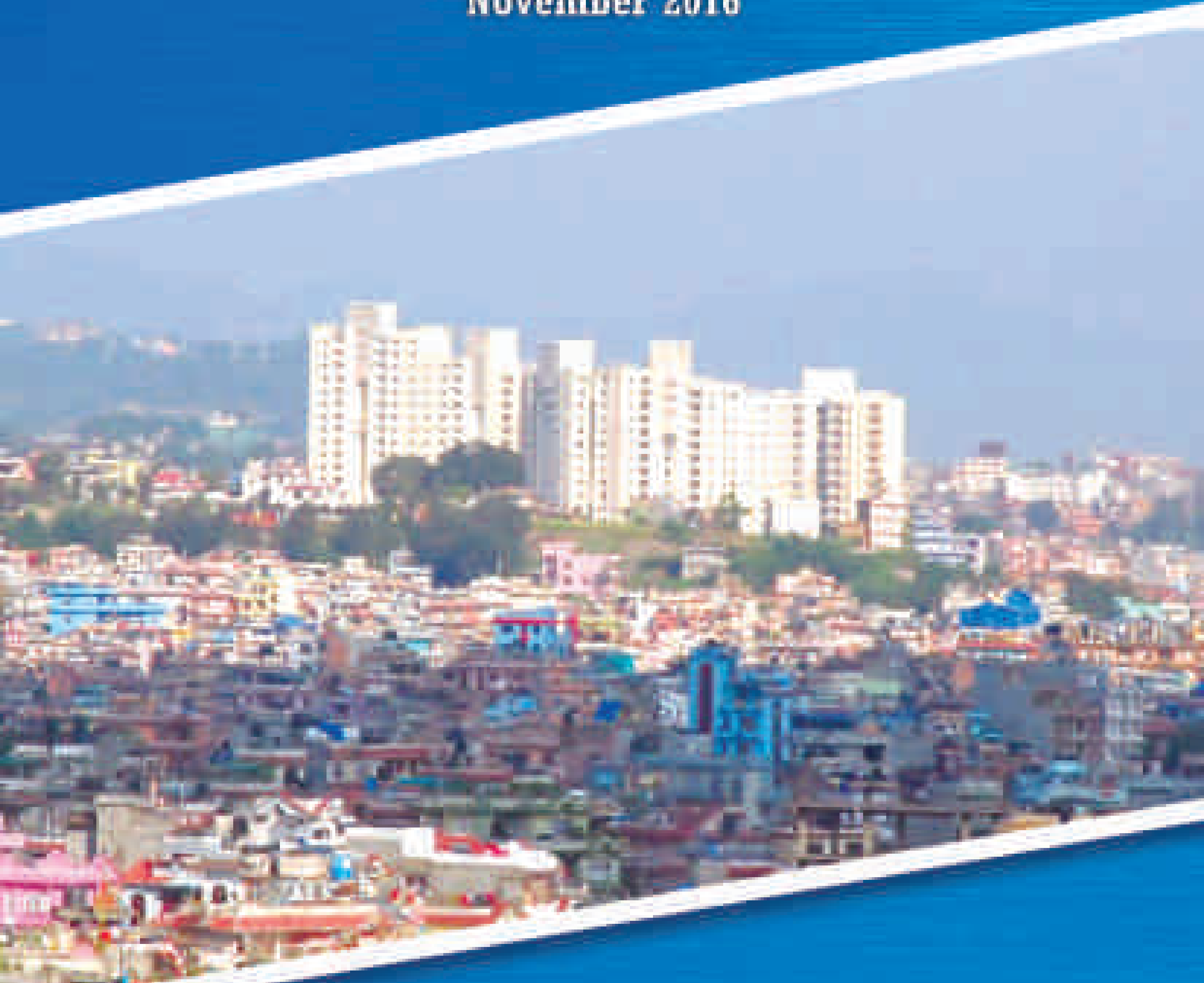

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Urban Growth Trends and Multi-Hazards in Kathmandu Valley
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This report is an outcome of the study "Multi-Hazard and Risk Assessment in Kathmandu Valley" under the assignment "Comprehensive Study of Urban Growth Trend and Forecasting of Land Use in the Kathmandu Valley (PISU/RFP/007/2012)" undertaken for the UNDP/Comprehensive Disaster Risk Management Program (UNDP/CDRMP)" jointly by GENESIS Consultancy (P) Ltd and WELINK Consultants (P) Ltd. The opinions, findings and conclusions expressed herein are those of the consultant/author(s) and do not reflect those of KVDA or UNDP/CDRMP.

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Data Sources and Credits

GIS datasets and their associated attributes used in the study are developed by GENESIS Consultancy (P) Ltd-Welink Consultants (P) Ltd for the study. Building topology and social data were collected during October 2012-January 2013 for the study. Sources of other data and maps are cited in the report.
Authorization from the owner (KVDA) is required for the usage and/or publication of the data in part or whole.

Front Cover

Dense urban built-up and high rise residential apartments in Dhapasi, 23 December 2012, Photo by Anish Joshi.

KATHMANDU VALLEY DEVELOPMENT AUTHORITY

UNDP

50 YEARS

Government of Nepal

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MESSAGE

I am glad to know that the Kathmandu Valley Development Authority is publishing the "URBAN GROWTH TRENDS AND MULTI-HAZARDS IN KATHMANDU VALLEY", which is based on the multi-dimensional study of urban growth trend, multi-hazard and future growth projections. The aim of this document is to provide information to the general people as well as professionals on the urbanization trend and hazard scenarios in Kathmandu Valley.

Recent Gorkha Earthquake of April 2015 and its impact on human life, buildings and settlements have highlighted the importance of hazard assessment of the settlements and vulnerability mitigation measures through risk informed planning process.

This document will be a basic platform for those who are seeking information regarding urban growth trend and hazard scenarios of Kathmandu Valley. It can be instrumental for those working in both public and private sector in order to ensure risk informed planning in their interventions.

I would like to encourage the practitioners, technical persons, planners and designers to refer to this document as a vital source of information and would like to request for the media persons too for highlighting the usefulness of this document for planned urban development of Kathmandu Valley.

I would like to acknowledge the efforts made by the staffs of Kathmandu Valley Development Authority, who have given their valuable inputs and guidance. Likewise, I would also like to thank United Nations Development Programme (UNDP/CDRMP) for their support to prepare this document.

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MESSAGE

Kathmandu Valley Development Authority (KVDA)- planning, developing, monitoring, regulating and prohibiting agency-has a mandate to prepare and implement integrated physical development plan for Kathmandu Valley, which encompasses twenty two municipalities with estimated permanent population of three million and floating population of another two and a half millions. It's mission is the develop "Kathmandu Valley as a Safe, Clean, Organized, prosperous and Elegant (SCOPE) National Capital Region", so as to foster the global image of Kathmandu Valley as a "livable city with the synergy and harmonization of nature, society and culture".

KVDA is mandated to prepare and implement an integrated physical development plan for Kathmandu Valley. While spatially planning any urban area, the basic thing to do is the population growth analysis through which it has been found that the annual growth rate of nationwide population is 1.35%, annual population growth rate in the Kathmandu valley is 4.63% and maximum growth rate observed in urbanizing new municipalities of Kathmandu Valley is 5.7%. Kathmandu Valley is located in the area with various kinds of risks and hence risk sensitive landuse planning is essential for the valley. This publication which is going to be launched is the basic study of urban growth trends and multi hazards of Kathmandu Valley.

I am pleased to know that the KVDA is publishing the "URBAN GROWTH TRENDS AND MULTI-HAZARDS IN KATHMANDU VALLEY", which is based on the multi-dimensional study of urban growth trends, multi-hazard analysis and future growth projections. The aim of this document is to provide information to the general people as well as professionals on the urbanization trend and hazard scenarios in Kathmandu Valley.

I would like to acknowledge the efforts made by the Development Commissioner, District Commissioners and all staff of KVDA who have given their valuable inputs and guidance. I would also like to thank United Nations Development Programme (UNDP/CDRMP) for their support to prepare this document.

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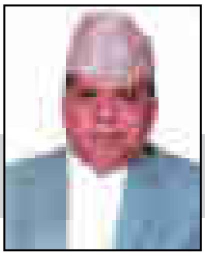


FOREWORD

Kathmandu Valley Development Authority (KVDA) has embarked upon a mission 'to establish Kathmandu Valley as a Safe, Clean, Organized, Prosperous and Elegant National Capital Region' to foster the global image of Kathmandu Valley as a livable city with the synergy and harmonization of nature, society and culture. With this overarching mission, KVDA, with the support of UNDP/CDRMP, has developed Risk Sensitive Land Use Plan (RSLUP) of Kathmandu Valley and its municipalities during 2014-2015 and seeks to implement the plan in an integrated and inclusive manner. The RSLUP vision accentuates building of resilient communities through conservation of heritage, sustainability of ecology and ensuring social equity.

This technical publication is a joint contribution of KVDA and UNDP/CDRMP to highlight the approach methodology and outcomes of the multi-dimensional study of urban growth trends, multi-hazard and future growth projections under different scenarios in Kathmandu Valley undertaken during 2012-2013. The aim of this publication is to sensitize general readers on the urbanization and hazard scenarios in Kathmandu Valley as well as to disseminate information to planners, engineers and academia on the technical aspects of spatial modelling applications in urban planning and design.

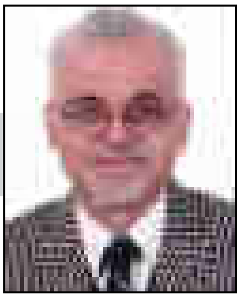
On the behalf of KVDA, I would like to gratefully acknowledge UNDP/Comprehensive Disaster Risk Management Programme's continual support to KVDA towards building a resilient Kathmandu Valley. My humble appreciation also goes to the Ministry of Urban Development for continual support and coordination. I thank the study team of GENESIS Consultancy (P) Ltd. and WeLINK Consultant (P) Ltd. for their innovative method and technically sound study outputs.

I would like to thank Mr. Yogeshwar Krishna Parajuli, former Development Commissioner, for his initiation and his valuable guidance in shaping this document. Likewise, the staffs of Kathmandu Valley Development Authority, who have given their valuable feedback and inputs, also deserve recognition. Last, but not the least, I would also like to extend my gratitude to all the professionals, who were engaged in the process of preparation of this document for giving it a final shape. On behalf of KVDA, I also convey that the digital data and information developed by this study is made available publically through KVDA's web portal for wider users to be benefitted.

Dr. Bhai Kaji Tiwari
Development Commissioner
Kathmandu Valley Development Authority

Dr. Bhaikaji Tiwari
Development Commissioner

FOREWORD



The development of Risk Sensitive Land Use Plan (RSLUP) was corroborated by a comprehensive and multi-faceted study of urban growth trends, drivers of changes, multi-hazard assessment and future growth projections. Scientific study of these urban scenarios in Kathmandu Valley and their spatial modelling using advance Earth Observation and Geo-Information Science methods has developed a comprehensive information for evidence based planning of Kathmandu Valley. Per se this 'spatially enabled decision supports' in planning of safe Kathmandu Valley has set an exemplary case of risk sensitive spatial planning that can be replicated and up-scaled throughout the country for building resilient and safe cities.

This publication is an abridge form of three interdependent study reports on urban growth, multi-hazard and future growth projections whose specific outputs are deemed more relevant on the aftermath of the April 2015 earthquake. The readers are informed that the study was based on geotechnical, population and other data of the period 2012-2013, therefore may not correlate with the impacts made by the April 2015 earthquake. Similar study is now being undertaken by as international team adopting similar scientific methods and the baseline data from this study. KVDA advises the readers that this publication reflects the ongoing process of developing urban information of Kathmandu Valley for evidence based planning and will be further refined from the subsequent studies and researches.

This study has significantly contributed in developing the new Long Term Development Concept Plan (2020-2035) of KV, formulating the Strategic Development Master Plan (2015-2035) and has also supported the ongoing Kathmandu Sustainable Urban Transportation Plan and the Transportation Master Plan. Therefore, the significance of this study's outputs cannon be undervalued.

In person, my sincere appreciation goes to these individuals who have directly and indirectly contributed to make this study publishable; Mr. Vijaya Singh, UNDP; Mr. Ramraj Narasimhan, Mr. Krishna Raj Kaphle, Mr. Naresh Giri, , Dr. Kirti Kusum Joshi, and Ms. Afrin Khan from UNDP/CDRMP; the study team of Mr. David Irwin, Mr. Saroj Basnet, Mr. Kamal Raj Pandey, Mr. Anish Joshi, Mr. Gaurab Dawadi, Ms. Sunita Duwal, Mr. Biplob Rakhal, Mr. Dinee Tamang, Dr. Tirtha Adhikari, Dr. Pradeep Paudyal and Dr. Rama Mohan Pokharel from GENESIS-WeLINK; and the members of review committee Mr. Bimal Rijal and Mr. Narayan Prasad Bhandari.

I also thank KVDA team members Dr. Bhai Kaji Tiwari, Deputy Commissioner; Mr. Karuna Ratna Shakya, Senior Divisional Engineer; Mr. Keshab Neupane, Administration Chief for their coordination and support. Last but not the least, I thank my dynamic team of urban planners and support staff which includes Ms. Hisila Manandhar, Ms. Jeny Shrestha, Ms. Nilima Shrestha, Mr. Bhagawat Bhakta Khokhali, Ms. Ritu Shrestha and Mr. Shadev Khadka for their review of the outputs and support during the study period.

Mr. Yogeshwar Krishna Parajuli
Former Development Commissioner
Kathmandu Valley Development Authority

EXECUTIVE SUMMARY

Kathmandu Valley Development Authority (KVDA) and *GoN/Ministry of Urban Development (MoUD)* with the support of UNDP's *Comprehensive Disaster Risk Management Programme (CDRMP),* a comprehensive study was undertaken during 2012-2013 to assess the existing urban growth trend, assess potential scenarios of multi-hazards and project future land use scenarios in Kathmandu Valley (KV). The study investigated and spatially modelled the projected future land use under the current context of the 'drivers of changes', probability of multi-hazard scenarios, current land use and planning policies so as to give a clearer picture of the current and future trends of the urban expansion. This study aimed to develop a comprehensive information base to understand and model the disaster risk and its interaction with the urbanization of KV to support formulation of effective *'Risk Sensitive Land Use Plan (RSLUP)'*. The devastating earthquake of 25th April 2015 and its aftershocks has further highlighted the need of risk sensitive land use planning for safe building practices and development in KV. This report publication has aimed to shed lights on the process of developing background information and scenario modelling of urban growth and multi-hazards in KV to sensitize the stakeholders, academicians, researchers, urban development practitioners and professionals. This report is an abridged version of three individual report volumes presenting the urban growth, multi-hazards and future projections under this study.

This study was undertaken in a three pronged approach *viz.* the assessment of urban growth and multi-hazard scenarios to understand disaster risk and its implications on rapid urban growth in KV; assessment of current building practices in the form of bye-laws to understand existing regulatory framework for use of land for urban development; and assessment for safe and sustainable urban growth regions with strategic policy recommendations for developing *RSLUP.* This report presents the outputs of urban growth and multi-hazard study to understand urbanizing trends and implications of hazard risks in KV.

Urban Growth Pattern and Trends

Under this study, the first component investigated the *Urban Growth Pattern in Kathmandu Valley* in order to assess the urban expansion and its spatial pattern over the period of last four decades (1970-2010). This study further assessed in details, the spatial pattern of urban land use and its transitions over the period of 1990-2010. The spatial pattern and transition analysis supported to understand the trend of transition and spatial correlation of the *'drivers'* influencing the *'rural-urban'* transformation. The changes in urban growth and its trend over the past decades was analysed using temporal series of LANDSAT TM/MSS imageries at decadal intervals over the period of last 40 years (1970-2010). The urban growth analysis showed the built-up has grown from 31 percent during 1970-1980, 89 percent during 1980-1990 to 125 percent and 191 percent during the decades of 1990-2000 and 2000-2010 respectively. This 191 percent explosion during the last decade coincides with the 10 years insurgency period attributing to mass internal displacement and in migration to the urban centres, especially the KV. The trend of urban expansion and land use conversion has most intensely been directed towards the northwest part of the valley, where the urbanizing VDCs like Dhapasi, Manamaiju, Gongabu, Ichangu-Narayan and non- urbanizing VDCs Tokha Saraswati has undergone major change during last decade. The land use change model also predicted the major change in the north-west direction of the valley for further years in the future if the current trend is permitted.

Further detailed analysis of urbanization trends in the decades between 1990-2010 using very high resolution aerial photographs (1992) and satellite imageries (IKONOS 2001, GeoEye 2012) showed drastic changes in urban morphology of KV. This change can be attributed to various socio-political and economic factors. Influenced by these factors and accelerated by haphazard and unplanned development, the built-up has increased from 38 sq. km in 1990 to 119 sq. km in 2012 over the period of 22 years, a staggering 211 percent increase. Consequently, cultivated land has decreased from 421 sq.km to 342 sq.km, a decrease of 19 percent over the period of 22 years. Within the built-up category, the proportion of mixed residential/commercial has increased by 524 percent and that of residential has increased by 331 percent over the last two decades. This unprecedented growth in the mixed residential/ commercial and commercial land indicating drastic increase in constructions of new building for residential and small scale commercial purposes, generally an extended business for consumer goods supplies. In 2012, the built-up area covered 16 percent of the total area of the KV, agriculture area covered 47 percent and forests/vegetation covered 35 percent. The trend of change in built-up area apparently showed that the rate was higher in the central parts of the KV during the earlier decades. In the later decades the rate of urban growth is found to have increased in peripheral regions, protruding to urbanizing VDCs. The decade of 1990s showed a significant increase in built-up (51%) in ward number 20 of Lalitpur Sub Metropolitan City (LSMC), which was closely followed by ward numbers 12 and 5 of LSMC and 2 and 10 of Kathmandu Metropolitan City (KMC), which were within the range of 40 to 50 percent. Among the VDC's, Gongabu showed highest built-up rate (12%), closely followed by Jorpati, Dhapasi, Sitapaila and Manamaiju. Between 2000 and 2010, growth rate of built-up was high for many parts of valley, especially in urban fringes. Ward number 4 of KMC and 9 of Kirtipur Municipality hit the highest growth rate of 62 percent, In addition to the ward numbers 3, 5, 6 and 7 of KMC, Dhapasi and Gongabu VDCs also showed an increase in built-up above 50 percent. Ward numbers 10 of Kirtipur Municipality, 3, 7 and 8 of LSMC, 5 and 7 of Madhyapur Thimi Municipality also showed remarkable built-up growth, well above 30 percent. Built-up growth of Jorpati, Mahankal and Manamaiju VDCs were also above 30 percent. Other VDC showing remarkable change in built-up areas were Satungal, Sitapaila, Kapan, Gothatar, Tinthana and Imadol, which were in the range of 20 to 30 percent.

Consequently the population has also seen rapid growth between the census decades of 1981-2011. The total population of KV in the census year 2011 was 2,468,316 with the annual growth rate of 4.63 percent. The maximum annual growth rate of 5.7 percent with the increasing trend was observed in the urbanizing VDCs inside the valley. The decreasing trend of annual population growth was observed in the KMC, LSMC and Bhaktapur Municipality in the consecutive census years from 1981 to 2011. Increasing growth trend was observed in Kirtipur Municipality with annual growth from 2.7 to 5.1 percent; and Madhyapur Thimi Municipality with annual growth from 4.1 percent to 5.8 percent. The population for 2020 and 2030 of KV projected using geometric growth method indicated 3,794,866 and 6,249,958 respectively.

Drivers of Urban Growth

The rapid urban growth in KV is attributed to various socio-political, economical and development factors, so called "the drivers" of changes. In the context of KV, these drivers have had significant influences since 1970s, as being the capital city and the economical hub of the country. The in-migration from surrounding and remote districts seeking economic opportunities, the political instability and internal conflict during the decade of 1996-2006, ensuing political turmoil after 2006 have somehow directly or indirectly influenced the socio-economic and development trends of the KV. Various factors pertaining to socio-economy, demography and development have influenced this growth trend. These factors are multi-dimensional in nature and are catalysts to the other factors as well as influence the impacts of other factors. In this study, these drivers were derived through Key Informant Interviews with prominent experts in urban planning and development using Analytic Hierarchy Process (AHP) method and spatially modelled using Logistic Regression (LR) of decadal land use change (1990-2012) and other spatial aspects. Indicators of drivers (or their proxy indicators) pertaining to economic opportunities; bio-physical conditions; existing road networks and planned major developments; access to infrastructure and services; land market; building construction pattern; plans and policies were spatio-temporally modelled for the decades of 1990-2012 and their impacts assessed using Logistic Regression (LR).

Based on the LR model, the major determinants with negative correlation with urban growth were distance to existing urban cluster and distance to minor roads (coefficient of -21.6 and -19.2), indicating that the probability of urban growth is higher in the areas closer to these variables. Thus, the model shows that urban growth of the valley has been controlled by road accessibility which is contributing to the spatial pattern of linear urban development along the road networks. The LR model also showed negative relationship between presence of institutions and urban growth. An area tends to have higher probability of urban growth if there no institution which seems logical as urban growth in institutional area is very low or almost nil. Degree of slope has also a negative influence on the growth of settlement which is because of the fact that most of the urban growth is occurring in relatively flat area than in surrounding elevated lands. Similarly, other distance related factors such as distance to ring road, distance to major road, distance to river, distance to municipal boundary, forest and distance to airport have also negative association with urban growth.

Population density had a positive influence in urban growth, with an odds rate of 43.9 and coefficient 3.78. This indicates that the probability of urban growth is 43.9 times larger when the population density is increased by one unit. Similarly, the positive spatial interaction between road density and urban growth reflects that urbanization trend in KV is highly dependent on road accessibility. The probability of urban development is increased by 3.8 times for every unit increase in road density in a particular area in KV. Other factors like proportion of agricultural land in a neighbourhood, distance to rural settlement and distance to school were also positively associated with urban growth.

Multi-hazard Assessment

The second component investigated the *Multi-hazard Scenarios* in order to assess the seismic, flood, liquefaction, landslide and industrial and environmental hazards and their composite impacts in the existing built-up and projected built-up scenarios in the KV. This assessment modeled and mapped different hazard scenarios and assess the vulnerabilities of the population and built-up. The modelling was based on soil geotechnical data, hydrological flow measurements supported by field investigations and sound scientific base to map the locations and extent of multi-hazard scenario pertaining to earthquake, flood, landslide, industrial and environmental hazards.

Seismic Hazard

Under this study, seismic hazard is modelled and assessed following an empirical approach where ground motion at a particular place is generated based on the regional seismicity model, an attenuation model, and a site response model. The ground motion is represented by the *Peak Ground Acceleration* (PGA), which defines the maximum acceleration experienced by the soil during the scenario earthquake. Seismic intensity in modified Mercalli scale (MMI) is computed from the obtained PGA values at corresponding site to show the earthquake hazard for a particular scenario earthquake. For KV, scenario earthquakes of 1833 Sindhupalchok Earthquake (M_w=7.8), 1934 Nepal-Bihar Earthquake (M_w=8.4), hypothetical earthquake source along Main Boundary Thrust (MBT) (M_w=8.0) and hypothetical Chobhar Local Earthquake (M_w=6.5) were considered for modelling. The ground model was prepared on the basis of 104 numbers of borehole logs distributed in the KV. An empirical relationship between standard penetration test (SPT) N-value and shear wave velocity (V_s) is adopted from previous study based on field and lab experiments, specifically for Kathmandu. In this study, PGA values were calculated at each borehole location for each different scenario earthquakes, where SPT and/or shear wave velocity (V_s) values were available. The calculated PGA was spatially modelled using geostatistical tools, particularly, Ordinary Kriging in prediction and Sequential Gaussian Simulation (SGSIM) was used in simulation of predicted results covering the KV.

The shear wave velocity and predominant period of earthquake were calculated only in soft sedimentary deposits of the valley because there was no borehole data information in the bedrocks and alluvial fan deposits. The variation of shear wave velocity in the valley sediments ranges from 154 m/s to 300 m/s, while it increases in alluvial soil and bedrocks. The longest predominant period of earthquake in the valley sediments ranges from 0.4 to 0.8 second, implying that buildings with 4 to 8 storeys, are more likely to be affected during the earthquake. The PGA distribution for the 1833 Sindhupalchok earthquake scenario shows the KV sediments would experience PGA range of 342–497 gal (i.e., 0.35g–0.51g). Kalimati, Balkhu and Suryabinayak areas would experience maximum horizontal acceleration. *Similarly,* the reoccurrence of 1934 Nepal-Bihar earthquake would create the PGA ranging from 142 gal to 206 gal in KV. Areas in Kalimati, Kuleshwor, and Suryabinayak would experience the maximum ground acceleration. The PGA distribution for the MBT scenario earthquake shows that the PGA values ranges from 380 gal to 703 gal in the valley sediments. The maximum ground acceleration would be experienced in Kalimati, Balkhu, Bungmati, Suryabinayak, and neighbouring regions. The local earthquake scenario would experience PGA of 354–929 gal with maximum ground acceleration experienced in Kalimati, Balkhu, and Sanepa area. From all the four scenario earthquakes, the regions in the vicinity of Kalimati and Suryabinayak are highly hazardous in terms of seismicity.

Liquefaction Hazard

Liquefaction associated with earthquake is also pertinent as the KV is filled up with unconsolidated to semi-consolidated sediments highly susceptible to liquefaction. Liquefaction susceptibility assessment and mapping was done for KV based on sediment physical properties, ground water table, age of sedimentary deposits, historic records of liquefaction, surface and sub-surface geological conditions, thickness of individual soil layers, SPT

N-Values from borehole logs and estimated ground motion threshold of different scenario earthquakes. Stochastic simulation was performed to generate the spatial distribution of liquefaction potential values in the soft sedimentary deposits of the KV for four different liquefaction susceptibility scenarios for each scenario of earthquake. The liquefaction susceptibility map generated for the 1833 Sindhupalchok earthquake showed that the areas in the vicinity of Kalimati, Nakhu, Suryabinayak, Thimi, Lazimpat, and Tokha would experience high to liquefaction. Most of the valley sediments would be moderately liquefied due to such earthquake. The liquefaction susceptibility map for 1934 Nepal-Bihar earthquake showed Rabibhavan, Kalimati, and Teku area including Thamel and Gyaneshwor area would experience moderate to high liquefaction. Most of valley sediments lie under low susceptibility zone if the 1934 earthquake reoccurred. Similarly, most of the valley sediments would be affected by high liquefaction if an earthquake scenario occurred in the MBT. Some areas in the vicinity of Solteemode, Kalimati, Teku, Lainchaur, Tokha in Kathmandu, Dhobighat, and Nakhhu in Lalitpur, and Thimi, and Suryabinayak area of Bhaktapur would face very high degree of liquefaction. Tribhuvan International Airport (TIA) lies under moderate susceptible zone. For the local earthquake scenario, high and very high liquefaction susceptible zones are dominant in the soft sediments of the KV. The areas having bedrocks and alluvial fan deposits on the basement could only be safe if such earthquake occurred in the valley.

Flood Hazard

Though not in the scale and extent of a disaster, floods are frequently occurring in KV impacting the urban landscape and human activities. Particularly, during the monsoon, situation becomes more sensitive when the water from other major rivers in the valley pours into the mainstream of Bagmati. These major rivers in the KV are Manohara, Hanumante, Kodku, Dhobi, Bishnumati, Mahadev Nakkhu, Balkhu and Godavari rivers that flows through KV and confluences into the Bagmati River. In recent years, these rivers has experience higher frequency of flood/ flash flood events primarily due to change in precipitation intensities, poor drainage conditions, poor constructions of river training and drainage works. Encroachment of river flood plains with buildings and constructions have led to frequent flooding and loss of properties in various parts of the KV. The projection of rainfall pattern in KV using A1B climate change scenario model shows negative rainfall trends of (-) 4.4531mm per year decrease from 2000 to 2030; but positive trends of (+) 2.5249 mm per year increase from 2030s to 2060s. Contrarily the A2 scenario shows increase rainfall trend (+) 7.6222 mm and (+) 12.854 mm per year from 2000 to2030s and 2030s to 2060s respectively. It means after 2030, rainfall will increase in KV. This higher rainfall intensities indicates higher frequency and occurrences of flood events.

Flood scenario in KV was modelled through hydrological and hydrodynamic modelling. The hydrological modelling involved collection of river discharge and cross-section observations at various locations in the rivers of KV. This discharge measured data were used for model calibration, validation and application for flood frequency analysis in Gumbel's methods. The stream flow gauging stations at Sundarijal, Gaurighat Tika Bhairab and Khokan within the catchment area of the Bagmati River basin were analysed for determining average river discharge from 1992 to 2009. For flood prediction analysis HEC- HMS model and Tank model were used along with the measured extreme flood data from gauging station for flood frequency analysis. The flood frequency analysis used Gumbel method for prediction of rainfall and flood peaks in different return period. Flood hazard assessment and mapping was done for the estimation of flood inundation extent area and the depth of inundation for different return periods. The assessment was done using hydrological analysis for rainfall-runoff modelling and hydrodynamic modelling to analysis water surface profile. Rainfall-runoff simulation was done using HEC-HMS and HEC-GeoHMS tools. Hydro-dynamic modelling was done by one-dimensional hydraulic calculations for a full network of natural and constructed channels calculation of water surface profiles for both steady and unsteady gradually varied flow. This was done using cross-sections for river and flood plain including left and right bank locations and flow paths, roughness coefficients (Manning's n), and contraction and expansion coefficients. Flood flow modelling was done by calibration of Manning's coefficient for various land cover classes, hydraulic analysis and modelling of river X-section, simulation of profile for given return period and discharge, simulation of the profile in steady state flow method (in HecRAS).

Analysis result showed maximum inundation depth in different return periods of the flood in KV at different rivers. For 50 years return period, major flooding is foreseen in Dhobi Khola with estimated 5,312 buildings affected by inundation with at least 5 buildings up to 5 m depth. Bagmati and Bishnumati rivers are also likely to cause submergence of 3,806 and 2,2295 buildings respectively. For 100 years return period, flood in Dhobi Khola, is likely to affect 5,425 buildings, Bagmati River flood is likely to affect 4,153 buildings and the Bishnumati flooding is likely to affect 2,313 buildings. Similarly for 200 years return period, Dhobi Khola, Bagmati and Bishnumati Khola are likely to affect more buildings than other smaller rivers in the KV.

Analysis of flood simulations in different return periods and the extent of the inundation areas clearly indicates buildings built in the flood plains of Dhobi Khola, in Kapan VDC and KMC are effected. Bagmati River inundates the buildings in Jorpati and KMC, Bishnumati Khola floods effect the buildings in rivers in Khadka Bhadrakali, Tokha Saraswoti, Dhapasi, Gongabu, Manamiaju and KMC. Buildings in Imadol, Harisiddhi, LSMC and Dhapakhel are likely to be affected by the floods in Kodhku Khola. Certain areas along the Bagmati are also affected within LSMC.

Landslide Hazard

Landslide hazard assessment and mapping in KV was done by identifying and mapping the historic and existing landslides in the valley to model landslide susceptibility due to prevailing soil, terrain, and catchment area triggered by rainfall. With visual interpretation of high resolution aerial photographs and satellite image of the year 1990, 2000 and 2012, mapping with ground observations, the scenario of landslide in KV was found in an increasing trend. Slope stability analysis and modelling was done using (Stability Index Mapping–SINMAP), considering infinite slope stability approach to give stability of slope based on slope gradient, soil and geological characteristics along with hydrological parameter such as '*Topographic Wetness*'. For SINMAP modelling, DEM of 20m was used along with landslide inventory points collected from satellite image of different time period. Geological map, Land System map and few soil profiles data of Land Resource Mapping Project (LRMP) were been used as base data to set the soil parameter. With 352 number of landslide inventory points, DEM and assigned soil parameter, the SINMAP model derived the topographic Wetness Index map that showed the saturation index in steady state hydrologic condition in the valley to map the susceptibility zone of landslides in six range of stability index.

Vulnerability to the buildings are roads were assessed for existing landslide and land slide potential based on the mapping of existing landslides and potential landslide areas. Mapped buildings were assessed for landslide vulnerability based on their proximity to the existing active landslides and modelled landslide potential maps. There were altogether 352 existing active landslides in the slopes of KV with total of 326 individual buildings in their near vicinity (within 50 m), which were found vulnerable to slope failure. The landslide susceptibility and vulnerability analysis showed total of 1,414 buildings in high susceptible zone, 8,667 buildings in moderate susceptibility zone and 22,544 buildings in low susceptible zones of landslide throughout the KV. Buildings in KMC, Nanglebhare, Jitpur Phedi, KM, Lele, Lapsiphedi, Chaling, Nagarkot and Bageshowri VDCs are at higher exposure levels to landslide. Buildings in Ghusel VDCs are at very high exposure levels to landslide susceptibility (279 buildings).

Environment Hazard

Under this study, assessment of environmental hazards was limited to the impacts of brick kilns based on primary data collection and field observations. Brick kilns were introduced in KV in around 2050 with the growing demand for building houses and it grew in numbers to more than 200 In KV. Traditional clamp kiln were slowly replaced following ban of moving chimney bull's trench kiln in BS 2059 due to growing pollution and improved brick kiln were introduced. There were about 112 fixed chimney brick kilns in KV; 108 bull's trench kiln (Natural draught and Forced Draught), 2 Vertical Shaft Brick Kiln (VSBK) and 2 Hoffman Kiln, located at the outskirts of ring road and concentrated mainly in Bhaktapur and Madhyapur Municipality in the East, Lalitpur Municipality in the South and Thankot in the West. Smoke emissions affecting the health and soil extraction from agricultural land are the two hazardous environmental impacts of brick kilns in the KV.

The health concerns arise from the smoke emissions from brick kilns which consists of harmful gases such as CO, CO_2, NO_2, SO_2, SO_3 and particle emissions which are the causes of respiratory diseases, headaches and irritation of eyes. People living at close proximity to the brick kiln and at the same level of elevation as chimney height face higher level of emissions and for longer duration. It has been observed that many of the people living in the 250m to 500m zone around the brick kilns in Bhaktapur district and Dakshinkali VDC of Kathmandu district show higher frequency of respiratory problems, black spot in the sputum and common cold with few cases of eye irritation and headache more frequent during morning and evening.

The removal of topsoil for urban uses mainly for construction brick is growing rapidly due to increased urbanization and industrialization. On average a brick kiln extracts soil from an area of 133 ropanies of prime agriculture land and during the season produces on average 49 lakhs bricks. The volume of soil extracted by a single brick kiln is around 6,000 cu. m. The extraction of soft top-soil required for brick production is causing an alarming loss of prime agriculture land in the KV. Besides these impacts, there is also the loss of habitat of microorganisms living in the soil, destruction of ecosystem that are directly linked to the soil and the microorganisms inhabiting the soil. In some rare cases, the over extraction of soil has caused landslides along road and structural failures in houses near soil extraction sites.

Industrial Hazard

Industrial hazards studied under study are possible events of Boiling Liquid Expanding Vapour Explosion (BLEVE) and Vapour Cloud Explosion (VCE) likely to originate from gas stations, gas distribution centers and petrol stations which has the possibility to cause loss of life and property in the built-up settlements of KV. The vulnerability of the surrounding based on the types of existing buildings, their functional use and their proximity to the gas stations and LPG tank distribution centres were assessed. Most of the structures built in the KV are cement mortar and cement buildings with high probability of complete damage in scenario of BLEVE. Total of 4 LPG tank distribution centres, gas stations and petroleum reserves were surveyed within the KV for the scenario of BLEVE and VCE analysis. The modelling of the BLEVE scenario for the petroleum stations and gas depos showed that areas surrounding Sinamangal, Ghattaghar, Balaju and Thankot were more likely to suffer high damage and loss of life and property than other areas.

Land Use and Urban Growth Projection

The third component built on the studies of land use-land use change trends and its driving factors to project the future land use for the decades of 2020 and 2030 based on the cases of 'business-as-usual', perceived implementation of 'Long Term Development Concept Plan-2020' and the envisioned new development plan of the KV, integrating the scenarios of multi-hazards.

The projection of growth in KV was based on the probabilistic growth pattern which relied on dominant drivers or catalysts for urban expansion witnessed over time in the KV. It was observed that built-up areas in 2012 land use map was 10,537 hectares which is projected to increase to 16,219 hectares in 2020 and 21,378 hectares in 2030 (as per LR model), if the current trend of urban growth is left unabated (business-as-usual). It is estimated that at each decade approximately 6,000 hectares of arable land in KV will be converted into the built-up area. From the predicted maps of 2020 and 2030 for business-as-usual model, it can be observed that urban growth is expected to occur as diffusion growth extending from already built up areas in an infilling and expansion manner. The urban area of the valley is expected to increase to 162.2 km^2 in 2020 which is almost 1.5 times of the current built-up area. Moreover it is estimated that during 2030 the urban area of the valley will be 213.8 km^2 which is twice as much as present built-up area.

The results from Long Term Development Concept Plan 2020 envisaged model suggests that the probability of urban growth in future will be driven by biophysical factors, proximity factors and neighbourhood factors which can have either positive or negative correlation with urban growth. If regulations in growth control is put into action in compliance to the LTDCP 2020 recommendations, it is expected that urban growth will be significantly low i.e. in 2020 there will be 118.2 km^2 built-up area which is around 1.07 times of existing built-up area. Similarly, during 2030 it is expected to increase by 1.2 times (i.e. 131.1 km^2).

ABBREVIATIONS

BM	Bhaktapur Municipality
CBS	Central Bureau of Statistics
CC	Climate Change
CDRMP	Comprehensive Disaster Risk Management Programme
DRR	Disaster Risk Reduction
DRR	Disaster Risk Reduction
GIS	Geographical Information System
GLOF	Glacial Lake Outburst Flood
IPCC	Inter-governmental Panel on Climate Change
KM	Kirtipur Municipality
KMC	Kathmandu Metropolitan City
KV	Kathmandu Valley
KVDA	Kathmandu Valley Development Authority
LSMC	Lalitpur Sub-Metropolitan City
MTM	Madhyapur Thimi Municipality
RSLUP	Risk Sensitive Land Use Planning
UNDP	United Nations Development Program
VDC	Village Development Committee
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
mg/L	Milligram per liter
sq.km	Square Kilometer
BLEVE	Boiling Liquid Expanding Vapour Explosion
VCE	Vapour Cloud Explosion

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1. INTRODUCTION

1.1. Background

Under the auspices of *Kathmandu Valley Development Authority (KVDA*) and *GoN/Ministry of Urban Development (MoUD)* with the support of UNDP's *Comprehensive Disaster Risk Management Programme (CDRMP),* a comprehensive study was undertaken during 2012-2013 to assess the existing urban growth trend, assess potential scenarios of multi-hazards and project future land use scenarios in Kathmandu Valley (KV). The study investigated and spatially modelled the projected future land use under the current context of the 'drivers of changes', probability of multi-hazard scenarios, current land use and planning policies so as to give a clearer picture of the current and future trends of the urban expansion. These assessments were aimed to support formulation and implementation of effective *'Risk Sensitive Land Use Plan (RSLUP)'* in KV. This study was undertaken in a three pronged approach *viz.* the assessment of urban growth and multi-hazard scenarios to understand disaster risk and its implications on rapid urban growth in KV; assessment of current building practices in the form of bye-laws to understand existing regulatory framework for use of land for urban development; and assessment for safe and sustainable urban growth regions with strategic policy recommendations for developing *RSLUP.* This report presents the outputs of urban growth and multi-hazard scenarios to understand disaster risk in KV.

Under this study, the first component investigated the *Urban Growth Pattern in Kathmandu Valley* in order to assess the urban expansion and its spatial pattern over the period of last four decades (1970-2010). This study further assessed in details, the spatial pattern of urban land use and its transitions over the period of 1990-2010. The spatial pattern and transition analysis supported to understand the trend of transition and spatial correlation of the *'drivers'* influencing the *'rural-urban'* transformation.

The second component investigated the *Multi-hazard Scenarios* in order to assess the seismic, flood, liquefaction, landslide, industrial and environmental hazards and their composite impacts in the existing built-up and projected built-up scenarios in the KV. This assessment modeled and mapped different hazard scenarios and assess the vulnerabilities of the population and built-up. The assessment and modelling was based on soil geotechnical data, hydrological flow measurements supported by field investigations and sound scientific base to map the locations and extent of multi-hazard scenario pertaining to earthquake, flood, landslide, industrial and environmental hazards.
The third component built on the studies of land use-land use change trends and its driving factors to project the future land use for the decades of 2020 and 2030 based on the cases of 'business-as-usual', perceived implementation of 'Long Term Development Concept Plan-2020' and the envisioned new development plan of the KV, integrating the scenarios of multi-hazards.

1.2. Objectives of the Study

The study aimed to develop a comprehensive information base to understand the disaster risk and its interaction with the urbanization of KV. The three interrelated components of the study have their specific objectives and defined outputs to support development of an integrated RSLUP.

The primary objective of '*Urban Growth Pattern in Kathmandu Valley'* was to assess the changes of built-up pattern and transition of urban land use. With this broader objectives, specific objectives were:

- Map and assess historical settlement pattern and decadal land cover/land use changes from 1970 to 2010
- Assess land use change trend and the driving factors of the changes pertaining to socio-economic, population, infrastructure development and other factors
- Assess the changes and trends in building construction pattern and typologies
- Assess the changes in land transactions and land market

The primary objective of the second component *'Multi-hazard and Risk Assessment in KV'* was to assess and model the scenarios of disasters pertaining to earthquake, flood, landslide, industrial and environment hazards and make probabilistic assessment of the vulnerability and risks due to these multi-hazard scenarios. The specific objectives associated with this broader aim were:

- Assessment of regional geology and seismotectonic assessment, surface fault and rapture and seismic zonation mapping
- Liquefaction susceptibility analysis and hazard mapping
- Assessment of soil characteristic, soil movement and landslide hazard mapping
- Analysis of past historic hydro-meteorological scenario; scenario of climate change and flood hazard
- Assessment of environmental hazards and mapping
- Assessment of industrial hazards and mapping of the scenarios
- Assessment of vulnerability and risks to the buildings and population based on sample study

The third component *'Urban Growth Projection'* aimed to project the future urban growth scenarios in KV considering Business-as-usual models to portray possible situations of uncontrolled growth, model proposed by LTDCP 2020 to project regulated development and a new model integrating multi-hazard risk and environmental factors to project potential risk sensitive urban growth. The objectives under this study were:

- Identification of drivers/catalysts of change of land use in KV and determination of its severance on the existing and future growth of KV
- Identification of transition potential of land use in KV through probabilistic artificial intelligence land use change model
- Forecasting of land use and predicting changes in KV under three scenarios of existing trend or Business-as-usual model (BAU), Long Term Development Concept Plan for 2020 envisaged model andd updated long term development plan envisaged model

1.3. Limitations of the Study

Since the undertaking of this study during 2012-2013, the geo-political context of the country and the Kathmandu Valley has changed. More significantly, Kathmandu Valley now has twenty two municipalities with the latest declaration on the September 2015 by the GoN. This study, therefore accounts for the previous 5 municipalities *viz.* Kathmandu Metropolitan City (KMC), Lalitpur Sub-Metropolitan City (LSMC), Bhaktapur Municipality (BMC), Madhyapu Thimi Municipality (MTM) and Kirtipur Municipality (KM) and surrounding 94 urbanizing VDCs in three districts. On the technical aspects, the limitations of the study are briefed hereunder for clarity to the readers.

a) The land use change and urban growth analysis were done using various imageries for the decades of 1990, 2000, 2012. For the decade of 1990, aerial photographs taken during 1992 were used. Similarly for 2000, high resolution IKONOS 1m imagery was used and for 2012, very high resolution GeoEye 1m imagery was used. Different mapping approaches were used for aerial photograph and satellite imagery based land use mapping. Though similar mapping accuracies were achieved, change analysis of land use categories may have encountered certain errors due to the differences in levels of details between the land use classification from aerial photograph (for 1990) and those from the high resolution satellite imageries (for 2000,2012).
b) The urban population growth analysis was based on the National Census data (1981-2001), which may not have accounted for the floating population in the municipalities and VDCs of the valley. Therefore, the population growth pattern and trend analysis have not accounted for the floating populations of these decades.

c) The urban growth analysis and future projections were based on modelling methods, which may not result cent percent accurate results. The growth model and projections also depends on other variables such as land use changes, population growth and its spatial context, influences of different drivers of changes and their spatial contexts. Therefore, this should be considered as an estimated projections with certain assumptions of deviation.

d) The multi-hazard risk assessment study is undertaken based on probabilistic hazard assessment approach adopting scientific base and best practices methodology. However, due to the lack of relevant data in sufficient details, assumptions had to be made in physical modelling of earthquake, landslide and flood. Specific limitations under this assessment were:
   - Due to non-availability of well distributed bore deep hole logs, the study used only 104 boreholes located in the municipalities and surrounding VDCs. These bore holes had varying depth ranging from 20 m to 30m. Scenario seismic hazard and liquefaction modelling is based on shear velocity (Vs) at 20m, therefore the data available from the bore holes are deemed sufficient for the assessment
   - Vulnerability to the elements and risk were assessed for the representative sample set only and is up-scaled to model for KV, reliability and sensitivity analysis of the upscaling method has not been tested, therefore this probabilistic assessment may yield some uncertainty.
   - Forest fire hazard was not done under this study due to lack of sufficient data on wind and its temporal variation.

1.4. Context and Rationale

1.4.1. Urban Growth, Climate Change and Hazard Vulnerability

Cities in the developing world are facing increased risk of disasters, and the potential of economic and human losses from natural hazards is being exacerbated by the rate of unplanned urban expansion and influenced by the quality of urban management (Dickson et al. 2012). Nepal's demographic transformation is characterized by fast-growing population densities in the Kathmandu Valley, along the main highways and close to the border with India (Muzzini and Aparicio 2013). Various studies have indicated the annual rate of population growth in KV is 4.3 percent in the past decade with the highest growth up to 6.5 percent in the VDCs in the KV, making the population growth rate in the valley one of the highest in the sub-continent. The total population in the valley is estimated to be 2,544,908 (CBS 2011) with an estimated projection of 3,995,152 and 6,698,665 in the years 2020 and 2030 respectively with the current growth rate.

This unprecedented population growth has severely impacted available land resources resulting in rapid land use changes, land degradation, land fragmentation, poor environmental quality, poor access to infrastructures and services, poor WATSAN condition s, increase of informal settlements and thereof an overall depletion of quality of life, thus creating a scenario of urban poverty. New residents and the urban poor living in peri-urban areas and informal settlements are particularly vulnerable to natural hazards due to their tendency of residing in high-risk areas and faulty shelters, having limited access to basic and emergency services, and a general lack of economic resilience (Dickson et al. 2012).

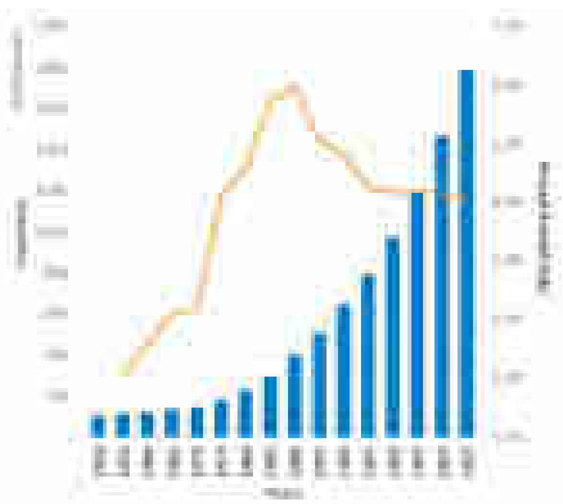


Figure 1 Population trend of KMC (1950-2025) [Source: UNDESA]

Climate change brings additional challenges with an increasing frequency, severity and variety of impacts on cities, their critical ecosystems, and citizens' livelihoods (Dickson et al. 2012). This has greatly increased the vulnerability of population to disasters and hazards, both natural and man-made as our cities and authorities are not adequately prepared to mitigate and reduce the exposures to such natural and human induces hazards.

> *IPCC defines exposure as exposure is defined as "the nature and degree to which a system is exposed to significant climatic variations"; sensitivity is defined as "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli1"; and adaptive capacity is defined as "the ability of a system to adjust to climate change (including climate variability and extremes), to moderate the potential damage from it, to take advantage of its opportunities, or to cope with its consequences".*

The exposure rate has significantly increased as a result to Climate Change (CC) factors; however, due to lack of preparedness and proper plan, the sensitivity has increased adversely; as well as the adaptive capacity of the population has decreased considerably due to the poor living conditions in the cities. The frequency, duration and intensity of extreme events such as floods, droughts, heavy rains, hurricanes and typhoons are expected to increase due to global warming. Emission of large quantities of greenhouse gases into the Earth's atmosphere as results of rising fossil fuel burning, land use change and deforestation are the main causes of global warming. Increase of heat in the atmosphere over time has led to the greenhouse effect, resulting in climate change. Rise in average global temperature; changes in cloud cover and rainfall particularly over land; melting of ice caps and glaciers and reduced snow cover; and increase in ocean temperatures and ocean acidity – due to seawater absorbing heat and carbon dioxide from the atmosphere - are the main characteristics of climate change (UNFCCC, 2007).

The Himalayan catchments of Nepal including watersheds in mountain regions are considered more vulnerable to risk of flooding, erosion, mudslides and GLOFs because the melting snow concedes with the summer monsoon season and any intensification of the monsoon and/or increase in melting is likely to contribute to flood disasters in Himalayan catchments. Continued rising temperature could lead to a rise in the snowline and disappearance of many glaciers causing serious impacts on the populations relying on the main rivers catchments (UNFCCC, 2007) and climate change may hit the major livelihoods of common people in all parts of the country.

Kathmandu Valley lies in this Himalayan catchment system in the Middle Mountain region, which is considered to be highly vulnerable to the Climate Change stimuli, and consequently the exposure to hydro-meteorological hazards have increased albeit the adaptive capacity to cope with such hazards have been in decrease attributed due to the poor planning of land and inadequate CC and hazard coping mechanisms in place.

1.4.2. Urban Issues-National Context

The municipalities and emerging towns of Nepal have developed haphazardly in the absence of stringent policy on regulating and managing the growth. The unplanned growth has created a number of problems like deficiencies in the basic urban services, lack of sanitation and solid waste management system, environmental degradation, encroachment of public land, forest and river, sprawl settlement development. The National Urban Policy 2064[1] identifies the following urbanization related key issues

1 राष्ट्रिय शहरी निती, २०६४, *Ministry of Physical Planning and Works, Dept. of Urban Development and Building Construction*

Issues	Elaboration
Unbalanced Urban Structure	Economic activities primarily concentrated in Kathmandu and periphery and large urban centres, large number of municipalities still exhibit rural characteristics
Weak Rural-Urban Linkage	Small towns suffer from the minimal investment from public and private sectors resulting into inadequate development of physical infrastructure
Environmental Degradation	With the encroachment to the public land and natural resources, inefficient or inadequate road networks, shortage of drinking water, unscientific dumping of solid wastes, loss of agriculture land, squatters problems
Ambiguous National Policy	No horizontal linkage with the Ministry of Local Development, Ministry of Physical Planning and Works and National Planning Commission resulting ambiguity in the policy formulation and implementation
Urban Poverty	Resulted by the inadequate employment opportunities, high land prices, lack of accessibility of basic urban services, pressure of migration due to even less employment opportunities in the rural areas
Weak Municipal Capacity	The capacity of the municipalities, with respect to administrative, technical and financial capabilities, have not developed to cope with the increasing demand for additional or improvement of services. Moreover, there has been total absence of elected body for several years.

The National Urban Policy (NUP) has put for Ward three main objectives to provide a framework to guide the urbanization process by giving due attention to the urban environment conservation through the involvement of central and local bodies. These are related to

a. Balanced national urban structure
b. Healthy and economically vibrant urban environment
c. Effective urban management

The first policy objective necessitates to the macro level of planning whereas the other policies could be promoted partially by accentuating local potentials and opportunities.

1.4.3. Urban Issues- Local Context

The primary cause of haphazard development relates to the non-existence of local level land use, zoning and land sub-division policy. Most of the inner roads are developed by widening the traditional foot trail by the proportionate contribution of land by the landowners of adjoining plots. Houses are built without any plan attributing difficulty in providing basic urban services. Keeping aside some exceptional cases, the municipality or the town development committee completely lacks control over the specific use of land. Some efforts on developing land use plan in some municipalities appear to have failed due to weak regulatory provisions. The building bye laws and the building codes are either not followed or not monitored adequately, resulting encroachment of public land, violation of construction permits or inferior construction practices. Moreover, the unprecedented rise of urban land price has encouraged land speculation that has led to the indiscriminate sub-division of agricultural land. The Town Development Committees, being political appointed body, are either not constituted or have become redundant due to current political turmoil. The local bodies are being administered by the government employees as the local elections could not be held for several years with this predicament. The construction of buildings have been taking place more rapidly on the periphery of municipality owing to reasonable low price of land and feeble bye laws.

All urban centres of Nepal more or less depict similar characteristics and the municipalities in the valley are not exception. Kathmandu has witnessed tremendous growth in built up areas in the past two decades. Construction of large buildings for apartments, hotels, hospitals and other commercial use is relatively new phenomena, presumably started coming up after relaxation on multi storey building permits and end of a decade long insurgency. These new developments are not only confined to the municipalities but have gone much beyond their delineated limit giving rise to the number of consequences such as

- generation of large traffic volumes causing congestions
- depletion of ground water due to indiscriminate extraction for the household and commercial uses
- increased vulnerability to fire, earthquake, landslide and flood hazards
- depletion of agricultural land and open spaces

1.4.4. Hazard Issues – National and Local Context

Nepal is ravaged by multiple natural hazards annually resulting in significant loss of lives and properties. Epidemics, floods and landslides are among the most frequent natural hazards with high magnitudes and intensities occurring throughout the country. Earthquake, cyclonic wind, thunderstorm, drought, famine, cloudburst, fire and avalanche are often recurring natural disasters in the country. In terms of vulnerability to natural disasters, UNDP/BCPR has ranked Nepal as the eleventh in terms of risk from earthquakes and thirtieth in terms of risk from flood (UNDP/BCPR 2004).

Nepal's location in a highly active tectonic region of the Himalayan belt has increased the risk of earthquake disaster in the region. The subduction of Indian plate under the Tibetan plate is considered as the major source of seismicity in the region. Over the last century, great earthquakes have occurred in the Himalayan region in 1803, 1833, 1897, 1905, 1934 and 1950 (Bilham, Gaur, and Molnar 2001). The 1934 Bihar-Nepal earthquake with magnitude of 8.4 took a toll of 4,300 people, destroying about 20 percent of all structures and damaging another 40 percent of buildings in KV. In recent decade, Nepal experienced two major earthquakes: A 6.5 magnitude quake in Bajhang district that killed 178 people and destroyed about 40,000 buildings and a 6.6 magnitude quake in Udayapur district that killed 721 people and destroyed 64,467 buildings (Earthquake and Megacities Initiative 2005).

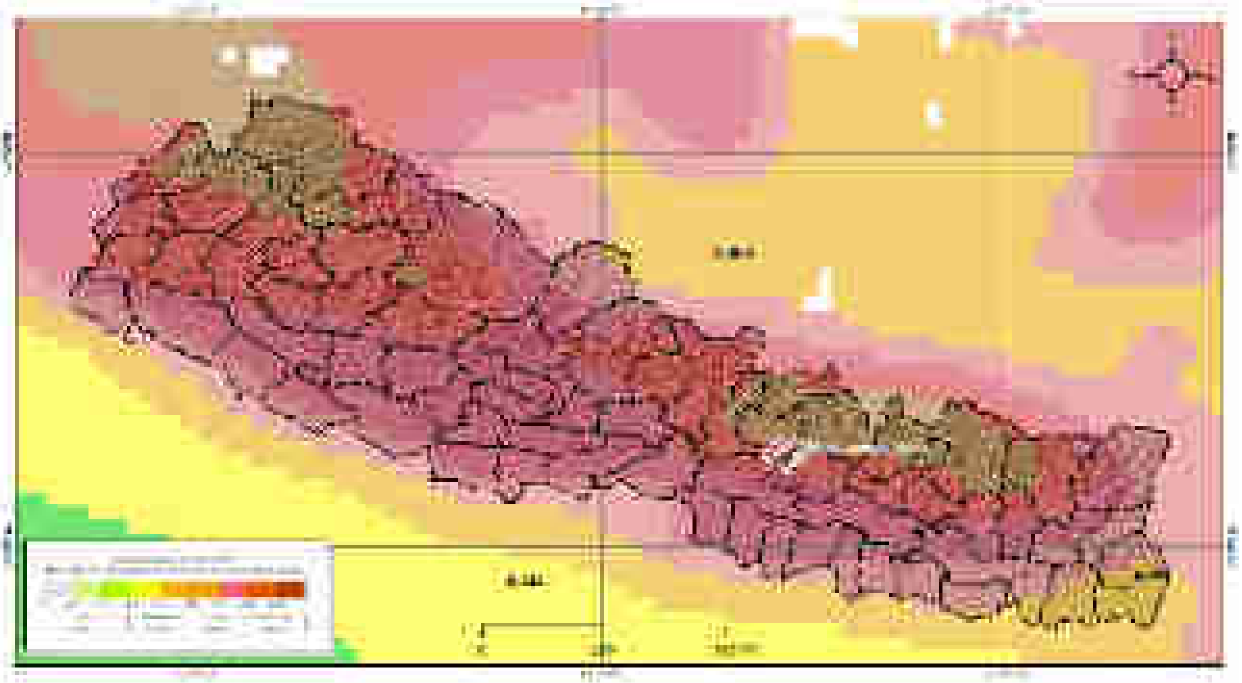


Figure 2 GSHAP seismic hazard map of Nepal [Adopted from (Giardini, Grünthal et al. 1999)]

The Himalayan catchments of Nepal including watersheds in mountain regions are considered more vulnerable to risk of flooding, erosion, mudslides and glacial lake outburst flows (GLOFs) because the melting snow coincides with the summer monsoon season and any intensification of the monsoon and/or increase in melting is likely to contribute to flood disasters in Himalayan catchments. Continued rising temperature could lead to a rise in the snowline and disappearance of many glaciers causing serious impacts on the populations relying on the main rivers catchments (UNFCCC, 2007) and climate change may hit the major livelihoods of common people in all parts of the country.

Kathmandu Valley lies in this Himalayan catchment system in the Middle Mountain region, which is considered to be highly vulnerable to the Climate Change stimuli, and consequently the exposure to hydro-meteorological hazards have increased albeit the adaptive capacity to cope with such hazards have been in decrease, attributed to the poor planning of land and inadequate CC and hazard coping mechanisms in place.

The location of KV in the active seismo-tectonic region and in the vicinity of active faults *(Refer Figure 59)* have further increased the exposure factor of population to the seismic hazard. The level of risk has been increased further in KV due to high urban growth rates and consequent high physical exposure and lack of preparedness. Further, the frequencies, variability and affects have aggravated due to the CC and its contributing factors. There are number of factors that contribute to the configuration of risk in cities. Firstly the location of the city in terms of geology , seismological hazard, flood plain, industrial areas, environmentally sensitive areas; secondly the urbanization process which leads to the concentration of populations in risk-prone cities, and risk–prone locations within cities; thirdly, in the cities with transient or migrant populations where social and economic networks tend to be loose. This is the case in the Nepalese context, where urban cities are located in hazardous zones, prone to multiple hazards with large number of exposed populations, augmented by population growth rate that exceeds 7 percent annually resulting in haphazard urban growth consequently resulting in the growth of urban divide in terms of economic, social and preparedness to disasters. It is often the poor, especially minority groups, who are socially excluded and politically marginalized, leading to the lack of access to resources and increased vulnerability.

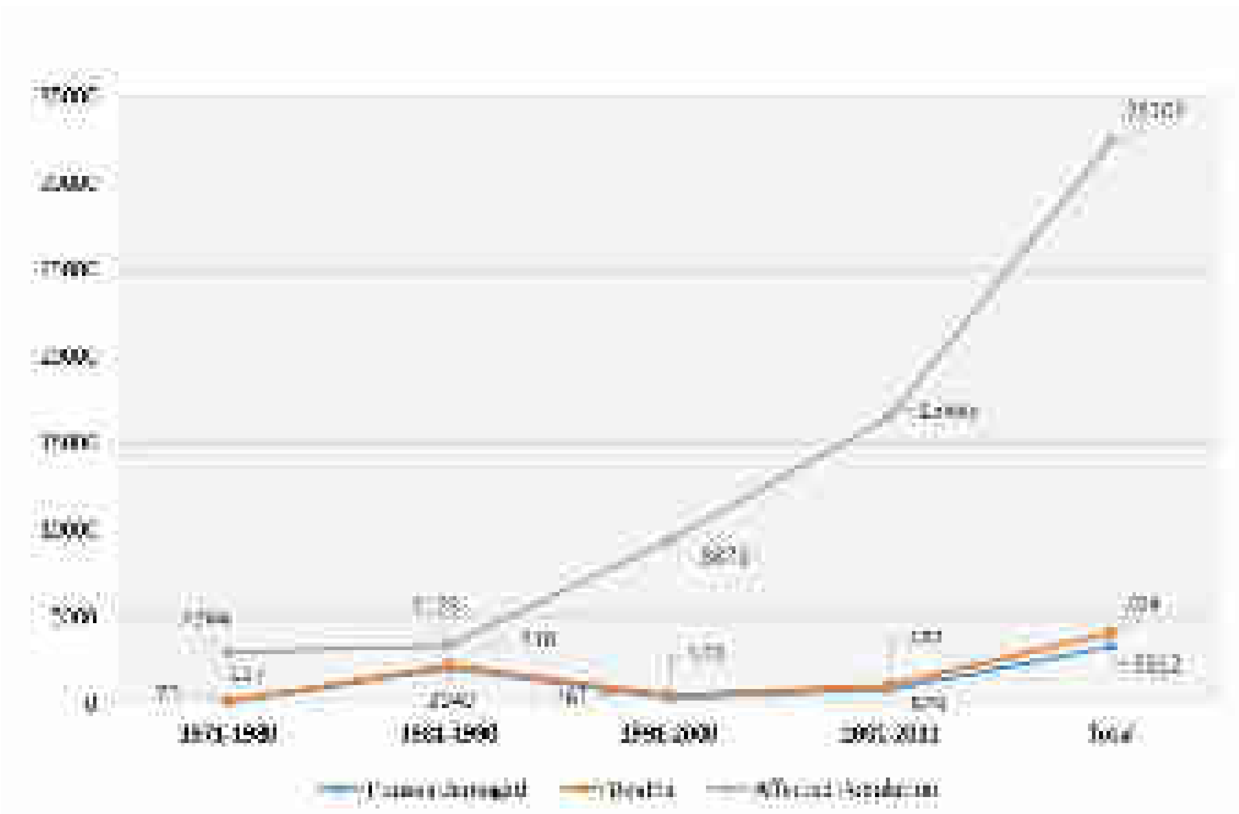
A recent report on Disaster Risk Management Programs for Priority Countries by GFDRR, Kathmandu has been reported as having the highest risk in terms of impact on people out of the 21 similar cities around the world that lie in the similar seismic hazard zone. Kathmandu Valley has a long history of enduring disasters and has lived through many such disasters which are still fresh in the memories of a generation of residents of the KV due to the catastrophic impact that resulted in loss of many lives and properties. The major disasters that have noticeably hit the KV have been earthquake, landslide and flood as presented in *Table 1*. Chronology of disasters that hit KV is presented in *Box 1*.

Table 1 Disasters and losses in KV (19-71-2011)

District	Events	Deaths	Injured	Missing	Houses Destroyed	Houses Damaged
Bhaktapur	Earthquake	7	43		289	1501
	Flood	2			75	228
	Landslide	3	7		106	
Kathmandu	Earthquake	3	107		7	17
	Flood	26	11	1	17	221
	Landslide	62	21	6	60	36
Lalitpur	Earthquake	1	25		430	137
	Flood	47	17	14	206	121
	Landslide	12	4		23	

Source Desinventar: http://www.desinventar.net/DesInventar/results.jsp, accessed Oct., 2013]

Figure 3 Temporal records of disaster losses in KV [Source: Desinventar]



Box 1 Historic disaster events in Kathmandu Valley

Event	Year/Date	Impact	Loss
Earthquake	1310 BS/1255 AD	About 7.7 Richter scale earthquake hit Kathmandu valley	One third of total population of Kathmandu were killed Numerous buildings and temples of the valley were entirely destroyed
	1316BS/ 1260 AD	Earthquake and subsequent epidemic and famine resulting from disaster	Heavy loss of live Many buildings and temples collapsed and many more were severely damaged
	1463BS/ 1408AD	Major earthquake hit the valley of Kathmandu and the surrounding areas Cracks on land appeared in many places.	Heavy loss of lives and livestock. Temples and buildings collapsed and were damaged - Completely destroyed Temple of Rato Matchindranath
	1737BS/ 1681 AD	Major earthquake said to hit Nepal and the Kathmandu valley	Heavy loss lives as well as many buildings including temples were either damaged or destroyed.
	1767 AD	21 shocks and aftershocks occurred in a span of 24 hours.	No written or verbal records of human loss or damages caused.
	1866 BS/ 1810 AD	No written or verbal records survive to indicate any human loss or the magnitude of sufferings and damages caused.	Loss in human lives and cattle were limited, Many houses, building and some temples either destroyed or damaged.
	1880 BS / 1823AD	17 earthquake tremors of various magnitudes were felt in Katmandu valley	No report of loss of human lives or livestock.
	1890 BS/ 1833 AD	Two major strikes were experienced in the Kathmandu valley	4214 houses were said to have collapsed within Kathmandu Valley
	1891 BS/ 1834 AD	Four major earthquakes were felt in the months of June and July	Destruction or damage of many buildings and temples No records of human or livestock casualties.
	1990 BS/ 1934 AD	8.4 Richter scale Great Nepal Bihar earthquake hit Kathmandu Valley	8519 people lost their lives 126355 houses were severely damaged 80893 buildings were completely destroyed.
	2050 BS/ 1993 AD	Central region and Mid-Western region affected	1 person dead, 11 injured, 72 houses destroyed, 451 buildings damaged loss of 48.39 million rupees
	2054 BS /1997 AD	Central region and Far Western region mostly affected	1 person injured, 1489 affected, 196 houses destroyed, 60 buildings damaged Loss of 51.29 million rupees
	2058 BS/ 2001 AD	Far Western region and some parts of Western and Central regions affected	2 dead, 3 houses destroyed Loss of 1.32 million rupees
	September18,2011	6.9 richte scale earthquake	3 killed due to collapse of wall
	June 9, 2012	4.8 richter scale earthquake	
	November 5,2012	5.7 earthquake with epicenter in Tibet hit Kathmandu	
	August 30, 2013	6 richter scale hit Kathmandu Valley	At least 1 person injured

Event	Year/Date	Impact	Loss
Flood	1954 AD	Flooding in Bagmati river especially in Balkhu	Two people died Cowsheds damaged, and farmland lost
	1993 AD	Heavy rainfall caused flooding and landslide	1,170 killed including 4 Chinese engineers working on the Bagmati Irrigation Project About 32,765 homes damaged Major bridges and highways connecting Kathmandu to rest of country damaged
	2002 AD	Heavy rainfall triggered flooding	Garment factory in the Balkhu corridor was washed away
	May 23, 2013	Flash flooding in Kathmandu	2 houses swept away in Baneshwor
Landslide	September30,1981	Debris flows, floods, and landslides in Lele-Bhardeo Area	70 lives and destroyed many houses, agricultural land, irrigation infrastructure
	1993 AD	Landslide triggered by the heavy rainfall	Heavy loss of lives, infrastructure and property
	July 2002 AD	Torrential rainfall triggered landslide in Matatirtha, Gairigaun	16 people killed Roads and houses damaged
	Undated	Landslide initiated due to stone quarrying in Dhungakhani	
	July 2002 AD	Quarry initiated landslide in Dhaksi village	
	August 2002 AD	Debris flow on the south east of Dudhpokhari reservoir, Kharibhanjyang	Destroyed a foot-trail and cultivation land of about 2150 sq. m
	August 2002 AD	Small debris flow triggered by rainfall in Samdugau	No record
	2002 AD	Quarry initiated landslide in Khahare (Bosan)	Destroyed dry cultivated land Affected natural flow of adjacent streams.
	Undated	Small landslide in Chitlang Bhanjyang with debris flow	Destructed surrounding sparse forestland, and the road
	2004 AD	Quarry initiated rockslide in Panighat	destructed the surrounding grassland and road corridor
	2012 AD	Landslide in Matatirtha	A house was damaged

In Nepalese context, good governance and political will to initiate and drive disaster preparedness has to be the top most priority. Appropriate governance is fundamental if risk considerations are to be factored into development planning and if existing risks are to be successfully mitigated (UNDP/BCPR 2004). However, there is a severe deficiency in mainstreaming disaster risks and preparedness in the development plans at central and local levels, both politically and technically. This is the primary reason that besets our municipal organizations rendering them unprepared and in many cases incapable to cope with major natural disasters and their immediate and long term impacts on different facets of urban fabric.

1.4.5. Hazard, Land Use and Risk Sensitive Land Use Plans

The impacts of hazard events are escalating not only due to the increased incidence and intensity of events, but also because of changes in the underlying factors that influence exposure and vulnerability. Exposure is driven by a number of socioeconomic dynamics, including population growth and density in hazard prone areas, economic expansion and concentration of economic assets in expanding cities and rapidly growing secondary cities. The vulnerability of exposed assets has increased due to mismanaged development that undermines the capacity of the population to withstand the impact of hazard events and environmental factors including climate change (The World Bank 2012).

Urban vulnerability is largely a consequence of improper urban management, inadequate land use planning, ill-regulated population density, poor construction practices, ecological imbalance, infrastructure dependency, and inadequate provision for open spaces. The accumulation of risks because of all of the pervasive situation and inappropriate decisions made in the past aggravate the vulnerability.

The worsening vulnerability of urban areas is one of the primary reasons for increase in disaster losses. The concept of vulnerability recognizes that a natural hazard alone by itself does not cause a disaster, but a disaster happens as an outcome of the interaction of biophysical condition or the presence of a natural hazard, and vulnerable conditions of people exposed to such hazards.

The significance of land use planning in *Disaster Risk Reduction (DRR)* is still not widely recognized by the policy makers and local planners. Reducing the risk of urban areas towards disaster is a systematic development and application of policies, strategies, and practices to minimize vulnerabilities and risks throughout society to avoid or to limit adverse impacts of hazards, within the broad context of sustainable development.

- Land use planning offer many opportunities and options to reduce human, economic, and physical losses due to natural disasters.
- Land use planning can identify and mitigate the root causes of disaster risk that are entrenched in the current land and settlements development practices.
- It can modify and reduce existing vulnerable conditions of people and places that have accumulated through years.
- It can reduce disaster damage before they happen instead of cleaning it up in the aftermath of a disaster.
- Land use planning may also modify the source of hazard, when possible, as in cases of floods and droughts.
- By reducing vulnerability and potential losses, people and places increase their resilience to disasters, enhance their ability to recover, and hasten the process of reconstruction and rehabilitation.
- Mainstreaming risk and vulnerability reduction in land use planning helps achieve urban growth and development without generating new risks.

Integrated vulnerability assessment and land use planning procedure combines the assessment of hazards, vulnerability and risk with the standard planning process. It is only possible when vulnerability assessment procedure that seeks to reduce risks have a factual and scientific basis. In order to use planning tools and techniques for risk reduction, it is necessary to evaluate the factors contributing to those risks. Integrated land use planning incorporates hazard identification and evaluation (e.g. analysis of frequency, severity/magnitude, return period or probability of a hazard and its severity), vulnerability analysis (e.g. loss of life, injury, building damage, economic impacts), and potential damage assessment (e.g. loss estimation), or collectively termed as vulnerability assessment.

Risk Sensitive Land Use Planning (RSLUP) seeks to adopt the best land-use options and translate the assessment of risks into appropriate location of land uses, functions, facilities and into land use regulations and policies. Applying land use planning techniques in DRR includes a comprehensive analysis of the land use behaviour and translation of those risk assessment into location of land uses, functions and facilities, into land use regulations and policies. Land use planning offers a wide range of techniques and tools that can help mitigate and prevent adverse impacts of seismicity and other disasters and enhance the resilience of urban areas to disasters. Some regulatory and non-regulatory planning tools involves location and structural approaches, e.g. land subdivision regulations, design of critical facilities and lifelines, zoning, building code implementation, and taxation.

The commonly use planning tools and techniques used for risk reduction include:

- Zoning and zoning ordinances
- On-plot regulations that limit height, floor pace, setback and plot coverage
- Building codes and subdivision regulations
- Infrastructural improvement plans
- Project development reviews such as EIA
- Parks and open space planning and development

1.5. Kathmandu Valley

Kathmandu Valley (KV) covers an area of 654.7 km^2 covering parts of Kathmandu (approx. 85%), Lalitpur (approx. 50%) and Bhaktpur districts. Geographically, the KV extents from $27^{o}49'4''$ latitude, $85^{o}11'19''$ longitude to $27^{o}34'33''$ latitude, $85^{o}34'57''$ longitude in the Middle Moun-

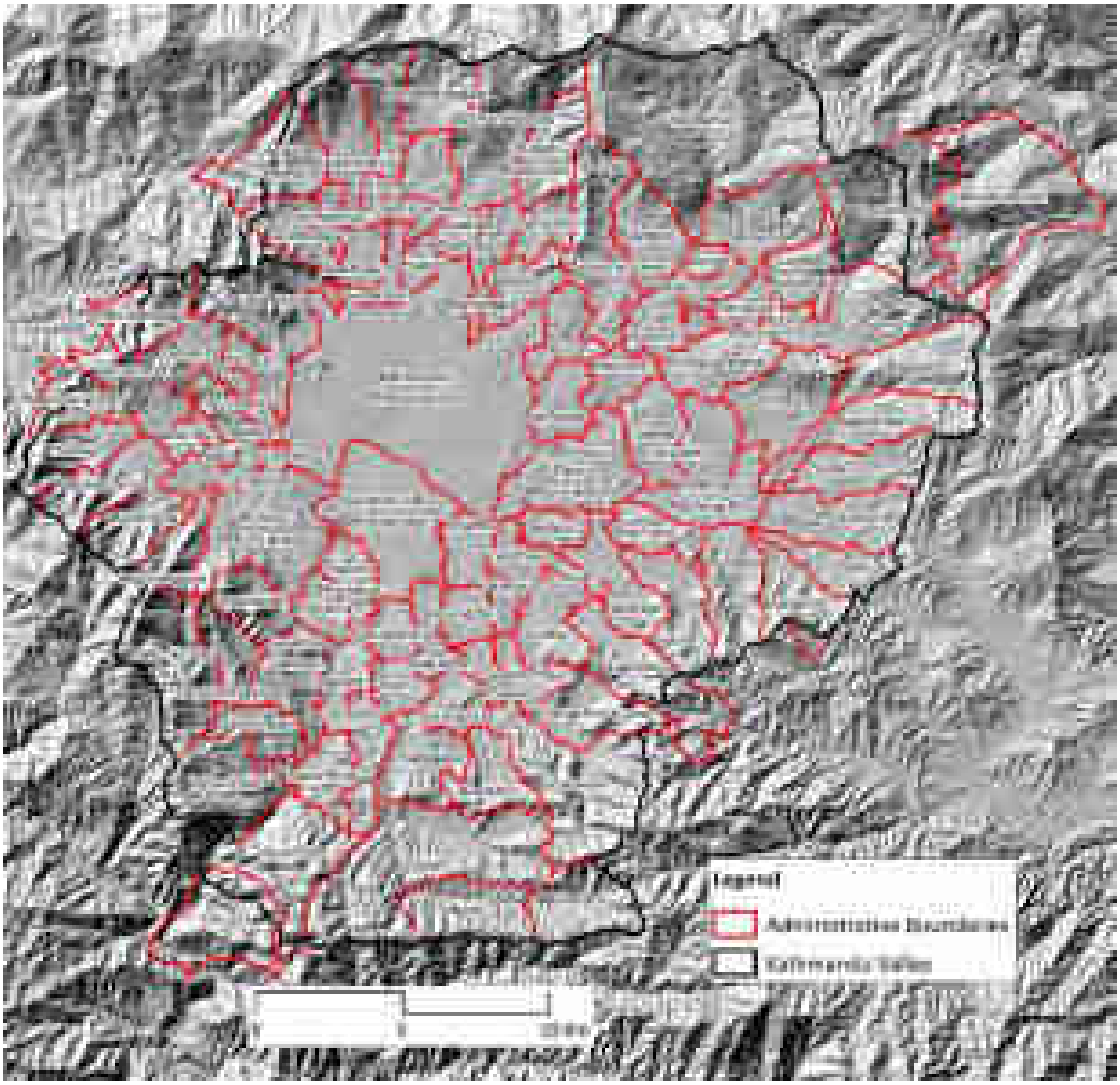


Figure 4 Kathmandu Valley and administrative units

tain physiographic region of Nepal. KV comprises five municipalities viz. Kathmandu Metropolitan City (KMC), Lalitpur Sub-Metropolitan City (LSMC), Bhaktapur Municipality, Kirtipur Municipality and Madhyapur Thimi Municipality; and 99 surrounding urbanizing and rural VDCs in three districts.

KV, a part of Middle Mountain Physiographic region and lies in Bagmati River Watershed. The watershed is nearly circular in shape consist of 227 km stream length with a density of 335.33 m/km^2 and is surrounded by Rosi Khola, Jhikhu Khola, and Indrawati Nadi Watersheds in the east; Tadi Khola, Kolpu Khola, Mahesh Khola, Palun Khola Watersheds in the west.

The major river networks that pass through Kathmandu valley are Nakhu Rver, Manohara River, Kodkhu River, Hanumante River, Godavari River, Dhobi River, Bishnumati River, Balkhu River and Bagmati River.

Administratively Kathmandu Valley lies in Bagmati zone of Central Development Region. KV boundary covers whole of Kathmandu and Bhaktapur district and parts of Lalitpur district. Until December 2014, KV was administratively divided into five municipalities (Kathmandu Metropolitan City, Lalitpur Sub-Metropolitan City, Bhaktapur Municipality, Kirtipur Municipality and Madhyapur Thimi Municipality) and 99 VDCs. In December 2014, the existing VDCs were merged to form 16 new municipalities and later in September 2015 one more municipality was added. Kathmandu Valley now has only 4 VDCs remaining in Lalitpur District along with 5 Municipalities, 11 Municipalities including Kathmandu Metropolitan city within Kathmandu District and 6 Municipalities in Bhaktapur district.

Figure 5 Sub-watersheds in KV

2. URBAN GROWTH IN KATHMANDU VALLEY

Urban growth is recognized as physical and functional changes due to the transition of rural landscape to urban forms. It occurs when the population distribution changes from being village to town and city (Thapa and Murayama 2010). Socio-economic and bio-physical factors/drivers are often the contributions of the urban growth. Bio-physical drivers include characteristics and processes of the natural environment such as weather and climate variations, landforms, topography, geomorphic processes, volcanic eruptions, soil types and processes, drainage patterns and availability of natural resources the such as migration, urban sprawl, agriculture and forest patterns (Verburg et al. 2004, Thapa and Murayama 2010). The socio-economic driver comprise demographic, social, economic, political, institutional factors and often is the result of processes such as population and its change, industrial structure and its development, and technology and technological changes, including infrastructure developments those which have local and regional impacts.

Changes of land, primarily agriculture and vegetation to built-up are the most apparent sign of urban growth. These changes are attributed to the aforementioned drivers or factors. To assess the drivers and the processes influencing the changes in land use morphology and resulting in urban growth in KV, a macro level study of land use changes has been done at this initial stage. A detailed micro level study will be done based on the pattern and trend shown by the micro level study. This chapter presents the preliminary results of the land use change modelling and analysis over the last four decades (years 1970-2010).

2.1. Urban Growth Trend Analysis 1970-2010

The changes in urban growth and its trend over the past decades was analysed using temporal series of LANDSAT TM/MSS imageries at decadal intervals over the period of last 40 years (1970-2010). The urban growth analysis showed the built-up has grown from 31 percent during 1970-1980, 89 percent during 1980-1990 to 125 percent and 191 percent during the decades of 1990-2000 and 2000-2010 respectively. This 191 percent explosion during the last decade coincides with the 10 years insurgency period attributing to mass internal displacement and in migration to the urban centres, especially the KV.

During the earlier decades 1970-1990, the growth is seen extending spatially outwards from the core municipal regions to the peri-urban regions. During 1990-2000, the growth is seen as spatially outwards

Box 2 Method for urban growth analysis

LANDSAT TM/MSS temporal series satellite imageries (1970-2010) with normalized year interval of 10 years (±2 years) were freely downloaded from the USGS web-site. These images were processed for ortho-rectification and atmospheric corrections. Images were analysed using Object based image analysis (OBIA) for land use classification using rule sets based on image spectral and contextual properties. The same object based classification rule sets were used for the classification of images from 1970, 1980,1990, 2000 and 2010 such that the biasness in classification is reduced. Five land cover/land use classes have been defined for the classification and assessment of land use transitions in macro level. These classes are cultivation, forest, built-up, water body and barren land (bare soil). The classified land use maps (from LANDSAT) of temporal series were then compared with high resolution aerial photographs and satellite images (aerial photographs for 1968, 1978, 1992; IKONOS image for 2000/2001, GeoEye image for 2011/2012 validation of general land cover/land use classifications.

Figure 8 show the land use patterns and the statistics of the KV of the years 1970, 1980, 1990, 2000 and 2010.

as well as development of scattered low density built-up in the surrounding VDCs of the municipalities. The growth trend is seen dramatically increased during 2000-2010 decade, where the spatial pattern is the combination of outward trend, developments along the major roads and significant increase in scattered development in the northern and western regions of the KV.

The spatial pattern of land use and changes from the above figures evidently shows that the urban areas of the KV were segregated in the confines of the old parts of the five municipalities and the outlying

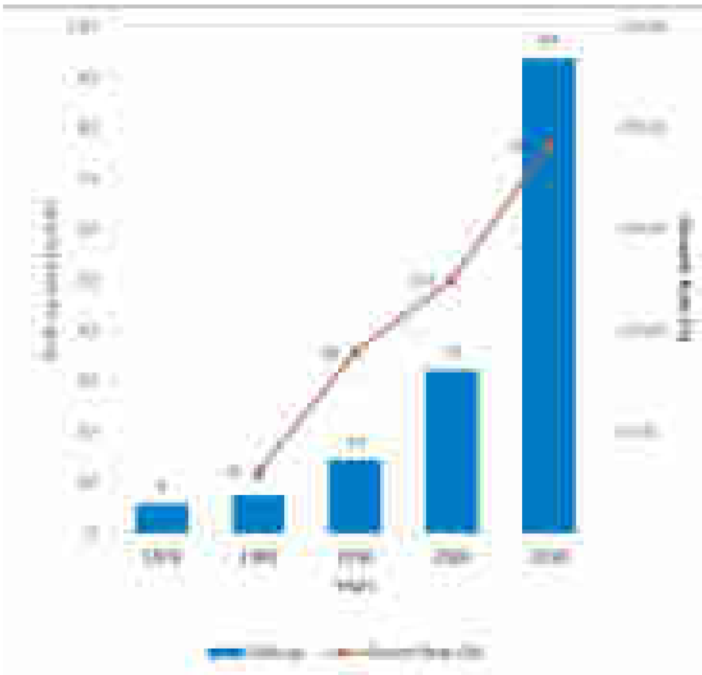


Figure 7 Built-up growth (1970-2010)

Figure 6 Built-up pattern of the year 2010

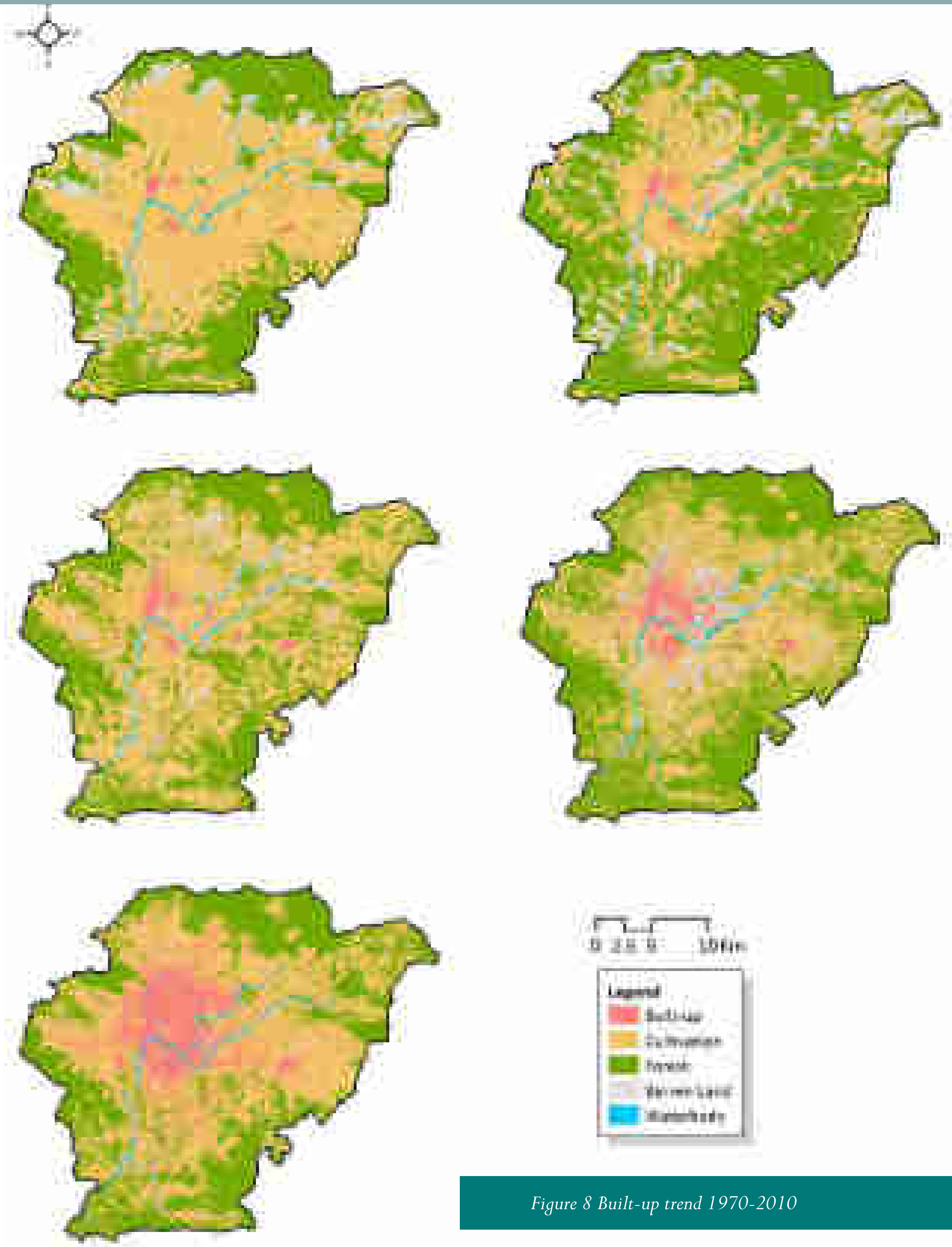


Figure 8 Built-up trend 1970-2010

old townships in the southern regions of Lalitpur during the 70's and 80's. Outward expansion of the urban area began in the 90's and during 2000, the core areas of KMC and LSMC are observed as a one spatial entity with several smaller urban units in the periphery of these two municipalities. During the last decade (2000-2010), drastic changes in urban pattern have been observed as the built-ups have expanded along the Arniko Highway, Kalanki-Thankot Road and other major roads that link the outlying towns/settlements with the five municipalities. Apparently, the outgrowth has increased more drastically in the period of 2000-2010, in the expense of prime agriculture land of the valley.

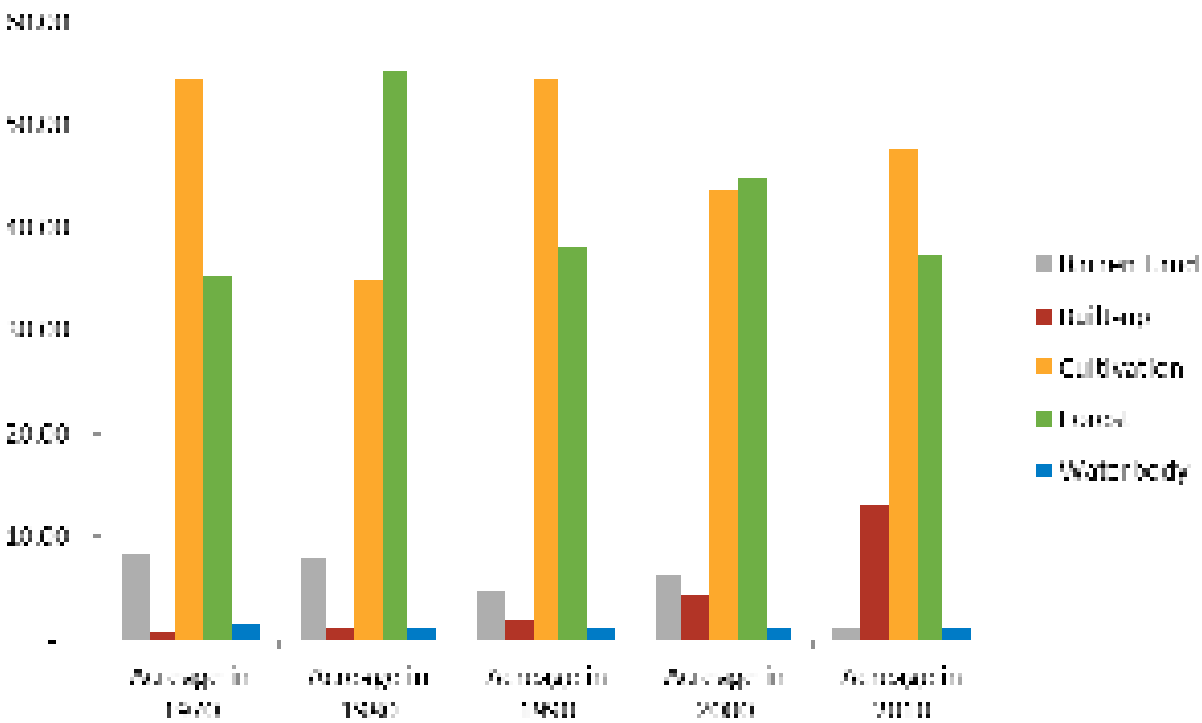


Figure 9 Land cover acreages from 1970-2010

The built-up area increased from about 1 percent to 13 percent of the total valley area from 1970s to 2010. Consequently cultivated areas decreased from 54 percent in 1970 to 47 percent in 2010. Bare land or open spaces also decreased from 8 percent to 1 percent between 1970 to 2010. Evidently, the built-up area increased in expense of loss of cultivated areas and open spaces during the last 4 decades.

2.2. Urban Growth Trend Scenarios

The trend of change in built-up over the past four decades was analysed to assess the transitions, gain/losses and the persistence of the land use over the last four decades. The results show that the conversion of land to urban development was accelerated in later decades of 1990s and 2000. Increase in built-up area was found to have occurred mainly at the expense of agricultural lands.

Box 3 Method for urban growth trend analysis

Land use change analysis was performed in the 'Land Change Modeller for Ecological Sustainability (LCM)' model. Consecutive land cover maps having identical legends (same code for each class) were used for analysing change in land use. The change analysis provides a quantitative assessment of change by graphing gains and losses by land cover categories. The net change shows the result of taking the earlier land cover areas, adding the gains and then subtracting the losses. The contributions to changes experienced by single land cover over the period of four decades were calculated. The change analysis was performed between pairs of images of 1970, 1980, 1990, 2000 and 2010 for working out change in land use over respective decades in KV. Accordingly, the transitions and exchanges that took place between the various classes during the years were obtained both in a map and graphical form. All the units were changed into hectares (ha). Cross tabulation matrix was obtained using the crosstab tool, which shows the distribution of image cells between the classes. The categories of date 1 are displayed on the X-axis while the same categories of date 2 are displayed on the Y-axis. Cross tabulation shows the frequencies with which classes have remained in the same (along the diagonal), or have changed in different classes.

- Gains and Losses maps depict where the addition or subtraction to a selected class (built-up in our study) have taken place.
- Persistence maps portray the locations where the land use classes have remained the same over the study period.
- Transition maps show the classes contributing to the development of a selected category of land cover (built-up in our case) over the period. These are effective tools in focusing the land use changes to a particular class relevant to the study.

Spatial trend (cubic trend) us used as the best fit polynomial trend surface to the pattern of change. It provides a very effective means of generalizing the trend. While interpreting the trend it is important to know that the absolute values do not bear any significant meaning. What can be inferred is that the lower the value, the less the change, the higher the value, the greater the change that has taken place.
In this study, the trend of change to built-up appears to have primarily concentrated towards the north-west part of KV throughout all four decades under study.
Figures 16-26 show the land use patterns and the statistics of the KV of the years 1970, 1980, 1990, 2000 and 2010.

2.2.1. Built-up Change Scenario of KV during 1970 and 1980

Over the decade of 1970-1980, only 179.64 hectares of land was added to the already existing built-up of 579.06 hectares, summing up to 758.7 hectares.

Cultivated land was the major contributor to the development; supplying 175.86 hectares of land, followed by nominal contribution of forest land i.e. 3.06 hectares. However, forest cover appeared to have increased significantly. The overall spatial trend of growth in built-up appears to be oriented towards north-west direction.

Table 2 Built-up transition matrix (1970-1980)

		Land Cover - 1970 (Ha.)					Total
		Built-up	Cultivated	Forest	Barren land	Water body	
Land Cover 1980 (Ha.)	Built-up	579.06	175.86	3.06	0.18	0.54	758.7
	Cultivated	-	19,516.23	3,660.75	1,752.93	113.04	25,042.95
	Forest	-	17,534.43	21,004.92	1,349.10	23.13	39,911.58
	Barren land	-	1,931.22	910.89	2,793.15	10.08	5,645.34
	Water body	-	0.18	-	-	829.17	829.35
Total		**579.06**	**39,157.92**	**25,579.62**	**5,895.36**	**975.96**	**7,2187.92**

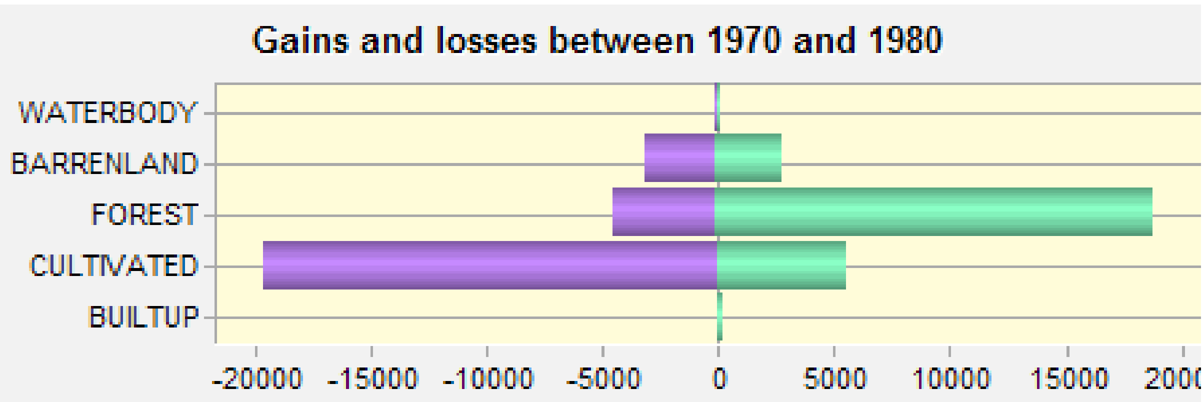


Figure 10 Gain and losses in land cover during 1970-1980

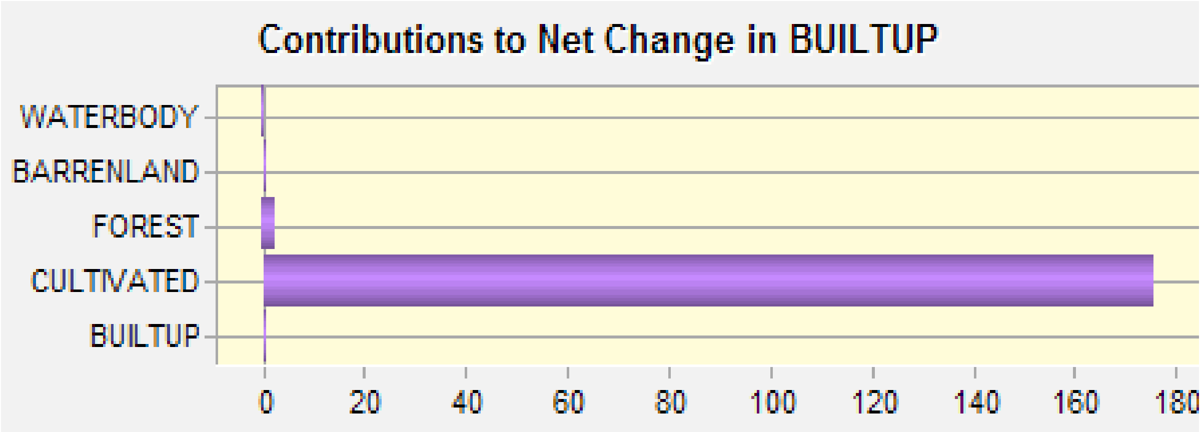


Figure 11 Land cover contributing to the net change in built-up (1970-1980)

Figure 12 Built-up transitions (1970-1980)

2.2.2. Built-up Change Scenario of KV during 1980 and 1990

During 1980s, built-up area increased by 680.76 hectares, adding up to 1439.46 hectares in total. Cultivated area contributed 552.96 hectares, maintaining itself as the highest contributor. Loss of forest to cultivation was also noticeable in this period. Similar to the previous decade, the overall spatial trend of growth in built-up appeared to be oriented towards north-west direction of KV.

Table 3 Built-up transition matrix (1980-1990)

		Land Cover - 1980 (Ha.)					Total
		Built-up	Cultivated	Forest	Barren land	Water body	
Land Cover 1990 (Ha.)	Built-up	758.70	552.96	87.57	40.23	-	1,439.46
	Cultivated	-	18,018.18	17,105.40	3,993.21	0.18	39,116.97
	Forest	-	5,288.40	20,693.79	1,392.21	-	27,374.40
	Barren land	-	1,183.41	2,024.82	219.69	-	3,427.92
	Water body	-	-	-	-	829.17	829.17
Total		**758.70**	**25,042.95**	**39,911.58**	**5,645.34**	**829.35**	**72,187.92**

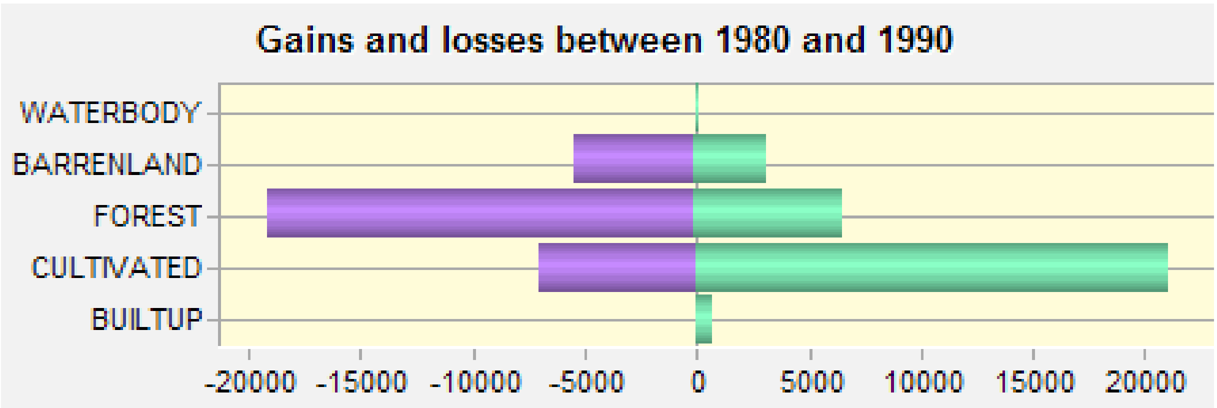


Figure 13 Gain and losses in land cover during 1980-1990

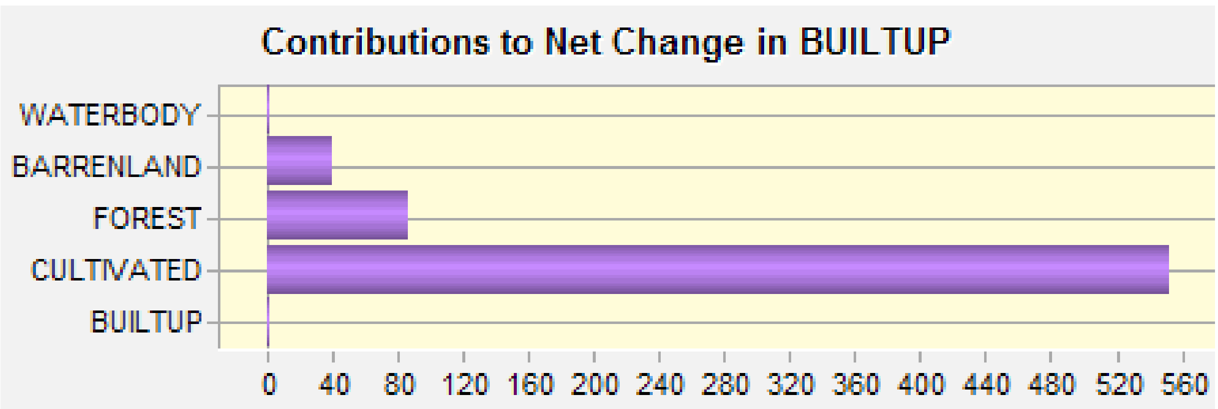


Figure 14 Land cover contributing to the net change in built-up (1980-1990)

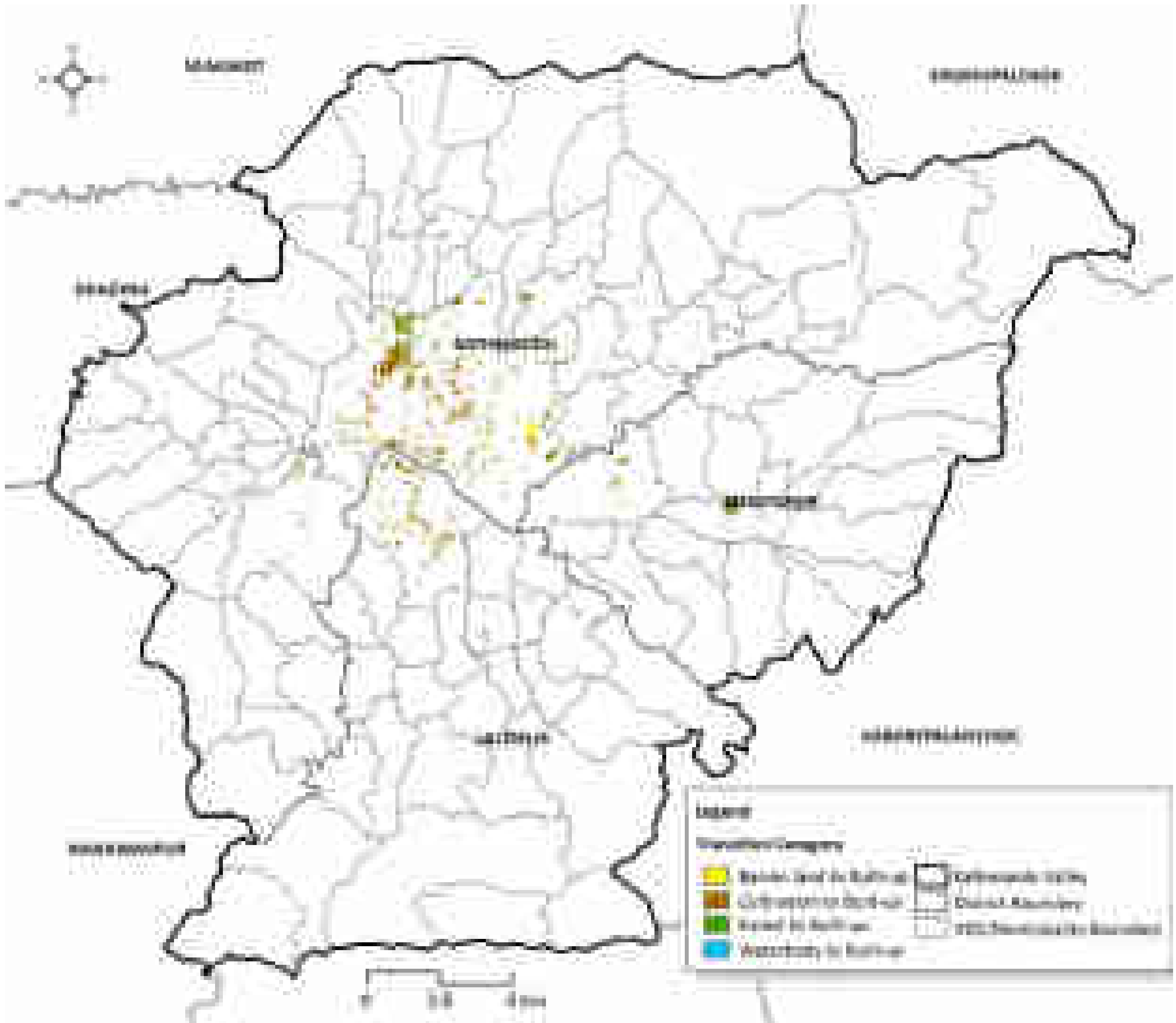


Figure 15 Built-up transitions (1980-1990)

2.2.3. Built-up Change Scenario of KV during 1990 and 2000

During the decade of 1990-2000, 1,796.31 hectares of land was further developed to urban built-up adding up to 3,235.77 hectares. Thus, the built up area doubled up during this decade. Cultivated area contributed significantly (1,527.03 hectares) towards built-up. Following the pattern of previous decades, the overall spatial trend of growth in built-up appeared to be oriented towards north-west direction of the KV.

Table 4 Built-up transition matrix (1990-2000)

		Land Cover - 1990 (Ha.)					Total
		Built-up	Cultivated	Forest	Barren land	Water body	
Land Cover 2000 (Ha.)	Built-up	1,439.46	1,527.03	56.07	213.21	-	3,235.77
	Cultivated	-	23,237.46	6,068.34	2,051.64	-	31,357.44
	Forest	-	11,209.23	20,478.42	603.27	-	32,290.92
	Barren land	-	3,096.18	767.52	552.87	-	4,416.57
	Water body	-	47.07	4.05	6.93	829.17	887.22
Total		**1,439.46**	**39,116.97**	**27,374.40**	**3,427.92**	**829.17**	**72,187.92**

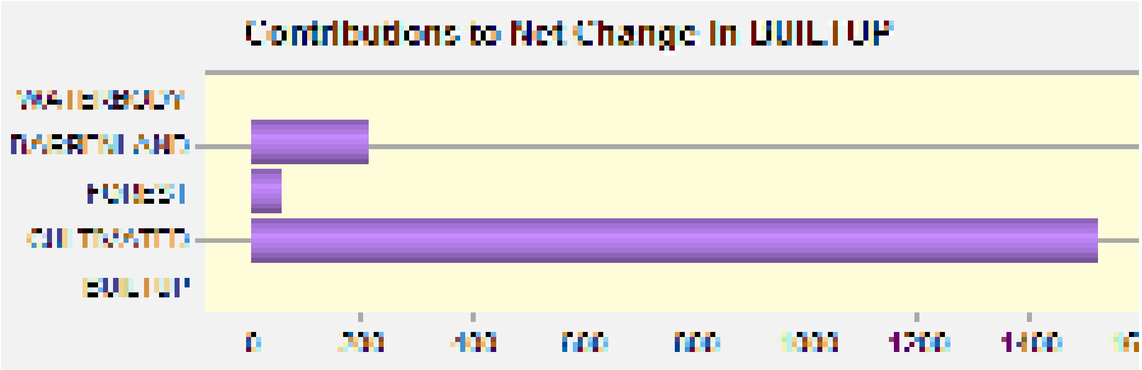


Figure 16 Land cover contributing to the net change in built-up (1990-2000)

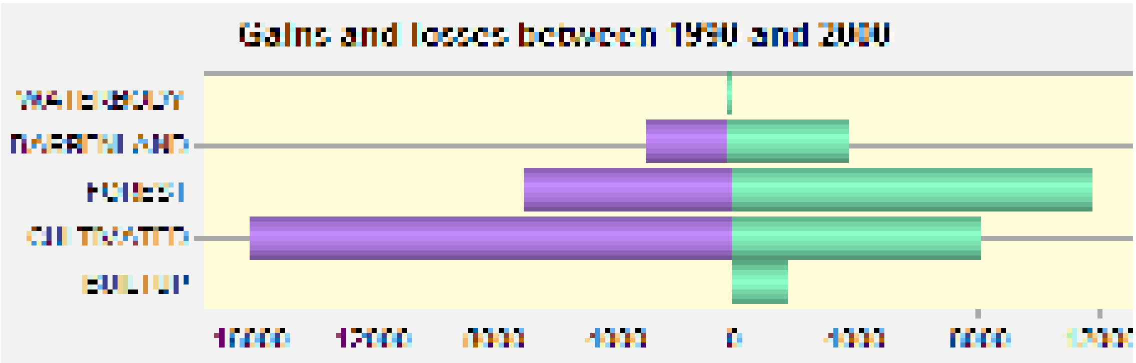


Figure 17 Gain and losses in land cover during 1990-2000

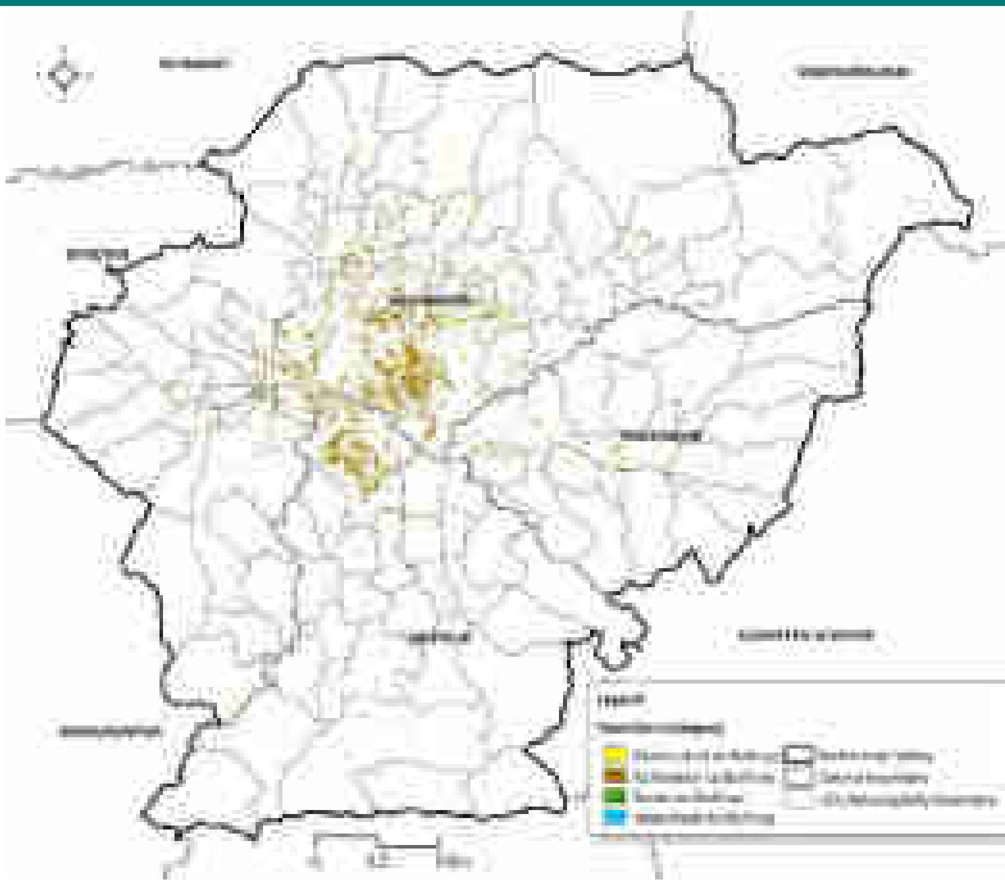


Figure 18 Built-up transitions (1990-2000)

2.2.4. Built-up Change Scenario of KV during 2000 and 2010

The trend of growth in built-up area culminated in 9378.45 hectares, over the decade of 2000s. As much as 6142.68 hectares of land was further built up, which is two times that of existing at the beginning of the decade. The overall spatial trend of growth in built-up, in line with the pattern of previous decades, appears to be oriented towards north-west direction of KV.

Table 5 Built-up transition matrix (2000-2010)

		Land Cover – 2000 (Ha.)					Total
		Built-up	Cultivated	Forest	Barren land	Water body	
Land Cover 2010 (Ha.)	Built-up	3,235.77	4,229.91	549.09	1,357.92	5.76	9,378.45
	Cultivated	-	22,620.06	9,080.10	2,538.27	34.11	34,272.54
	Forest	-	4,068.45	22,580.91	282.96	3.15	26,935.47
	Barren land	-	420.12	76.59	234.36	0.99	732.06
	Water body	-	18.90	4.23	3.06	843.21	869.40
Total		**3,235.77**	**31,357.44**	**32,290.92**	**4,416.57**	**887.22**	**72,187.92**

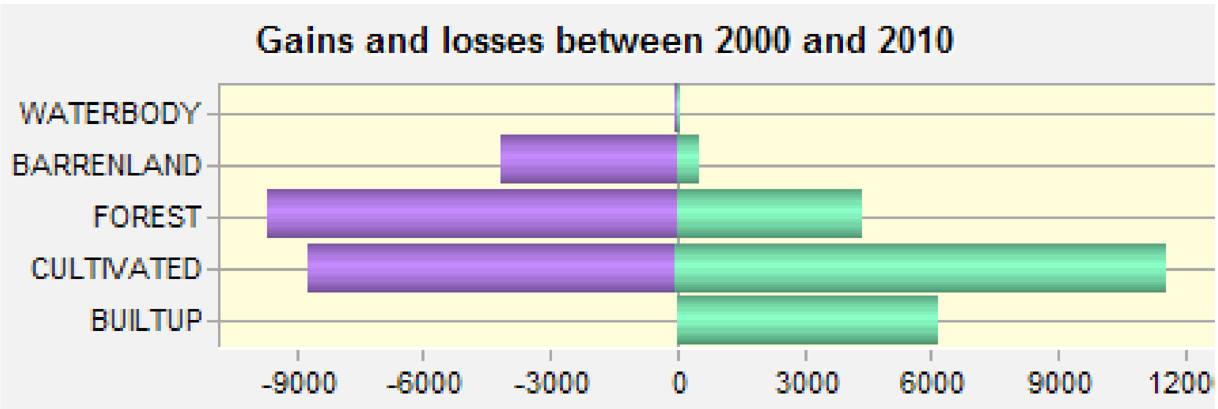


Figure 19Gain and losses in land use during 2000-2010

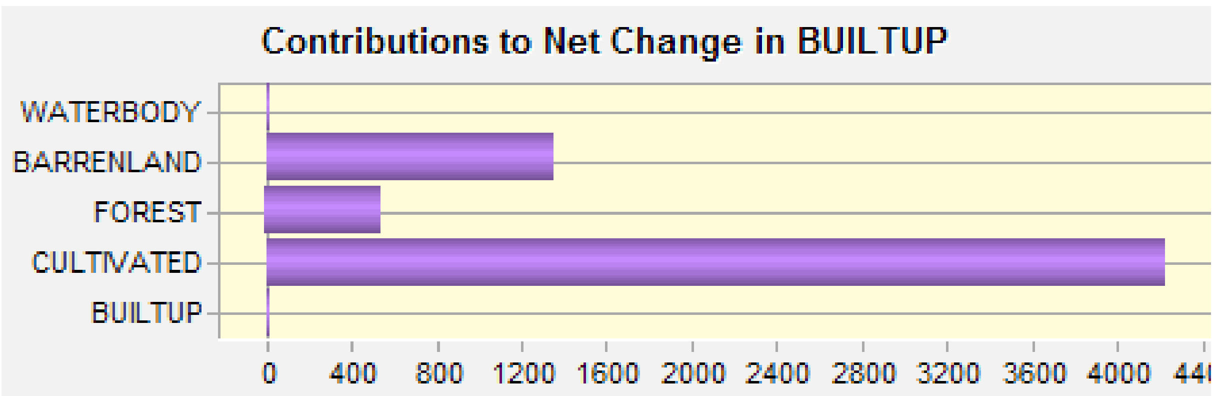


Figure 20Land cover contributing to the net change in built-up (2000-2000)

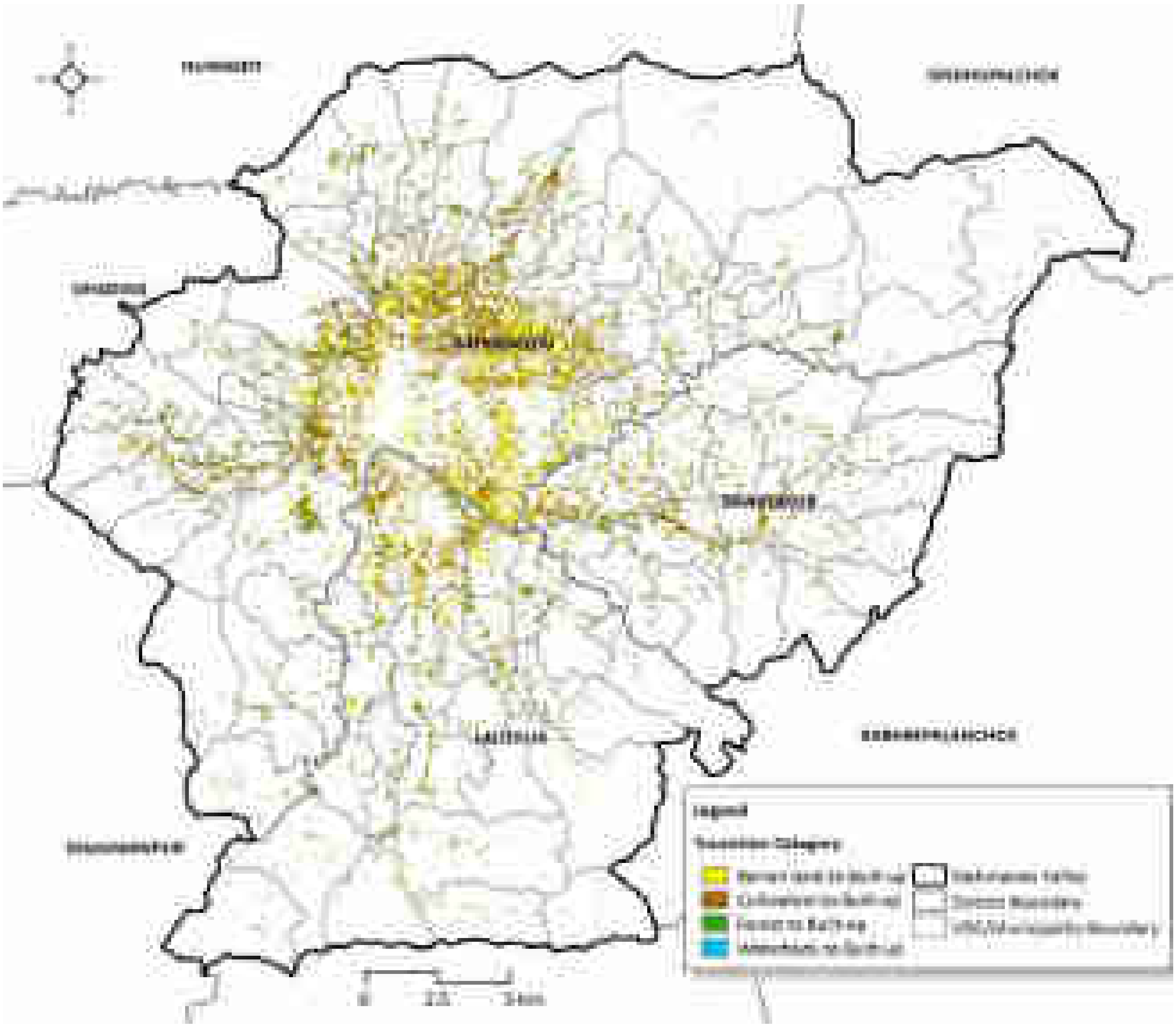


Figure 21 Built-up transitions (2000-2010)

2.2.5. Urban Growth Direction and Persistence

The current trend of urban expansion and land use conversion has most intensely been directed towards the northwest part of the valley, where the urbanizing VDCs like Dhapasi, Manamaiju, Gongabu, Ichangu-Narayan and non- urbanizing VDCs Tokha Saraswati has undergone major change during last decade. The land use change model also predicted the major change in the north-west direction of the valley for further years in the future if the current trend is permitted.

The third order polynomial equation models the trend and direction of change undergoing towards NW direction where the VDCs are urbanizing at an alarming rate

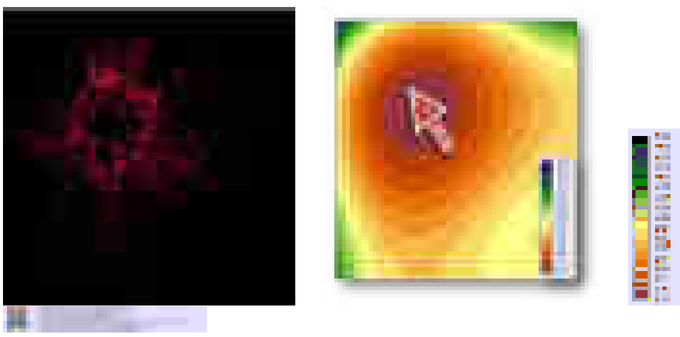


Figure 22Transition from residential to agriculture and direction of change

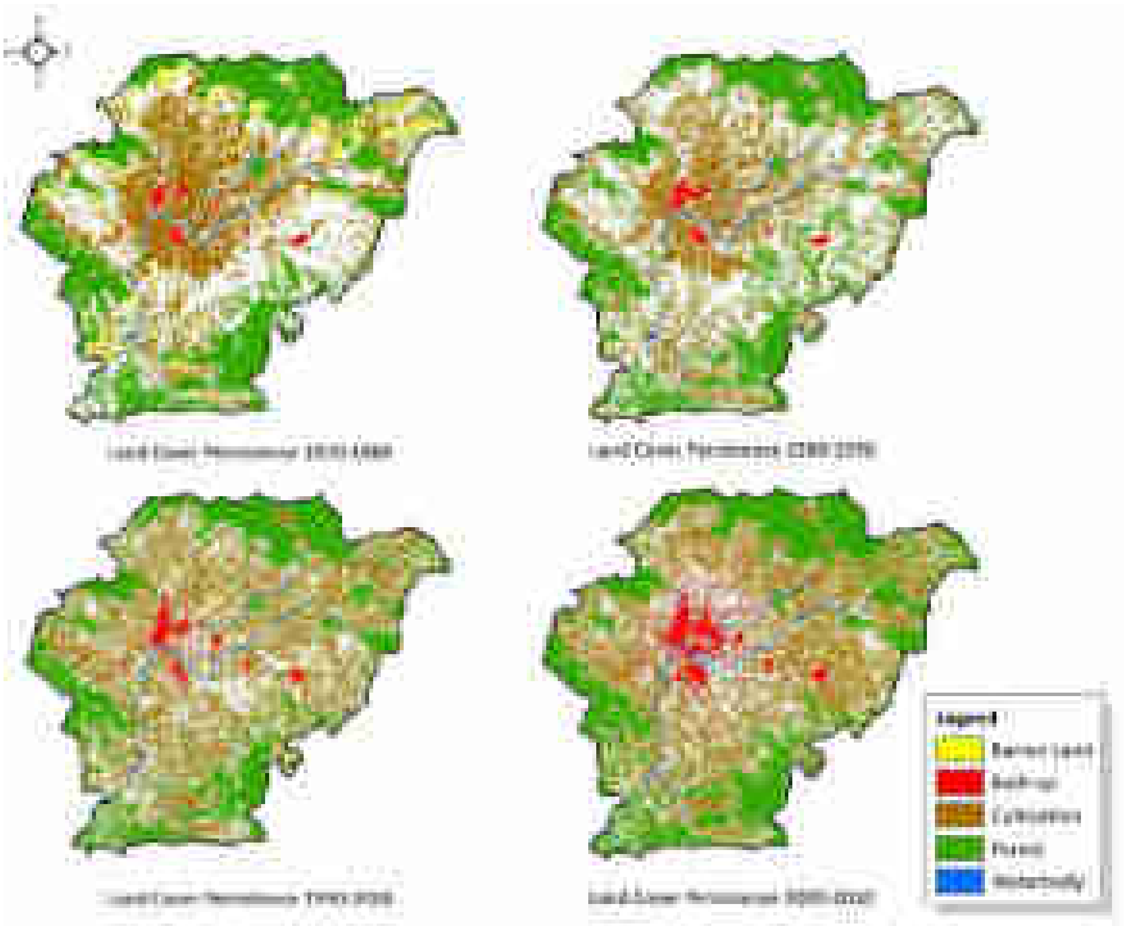


Figure 23 Land cover persistence maps (1970-2010)

The above land cover persistence maps (1970-2010) shows the locations where the land cover has not changed (i.e. remained the same) for the last decade. The areas where land cover have changed is mapped in white.

2.2.6. Land Use Change and Urbanization Trends 1990-2010

Over the period of 20 years (1990-2010), urban morphology has drastically changed in KV. This change can attributed to various socio-political and economic factors. Influenced by these factors and accelerated by haphazard and unplanned development, the built-up has increased from 38 sq. km in 1990 to 119 sq. km in 2012 over the period of 22 years, a staggering 211 percent increase. Consequently, cultivated land has decreased from 421 sq.km to 342 sq.km, a decrease of 19 percent over the period of 22 years. Within the built-up category, the proportion of mixed residential/commercial has increased by 524 percent and that of residential has increased by 331 percent over the last two decades. This unprecedented growth in the mixed residential/commercial and commercial

Land Cover	Area (in sq.km)			
	1980	1990	2000	2010/12
Agricultural	421.63	421.60	394.12	342.08
Built-up	38.03	38.09	66.54	118.65
Forest	253.50	253.34	253.56	251.08
Others	2.93	2.96	3.48	6.07
Open Space	2.29	2.39	2.03	2.01
Waterbody	3.48	3.50	2.14	1.98
Grand Total	**721.87**	**721.87**	**721.87**	**721.87**

Table 6 Land cover in KV (1980-2010/12)

land indicating drastic increase in constructions of new building for residential and small scale commercial purposes, generally an extended business for consumer goods supplies.

Currently in 2012, the built-up area covers 16 percent of the total area of the KV, agriculture area covers 47 percent and forests/vegetation covers 35 percent based on very high resolution satellite image[2] analysis of the year 2012. The following table shows the land use acreages from 1990, 2000 and 2012 based on aerial photographs (1992), IKONOS image (2001) and GeoEye image (2012). These land use categories have been used from the LTDP land use classification and definitions.

Table 7 Land Use of KV (1990, 2000 & 2012)

Land Use Classes	Area (sq.km)			Acreage (%)		
	1990	2000	2012	1990	2000	2012
Agricultural	421.60	394.12	342.08	58.40	54.60	47.39
Built-up	**38.09**	**66.54**	**118.65**	**5.28**	**9.22**	**16.44**
Commercial	0.20	0.37	0.37	0.03	0.05	0.05
Industrial	0.79	1.01	1.00	0.11	0.14	0.14
Institutional	3.70	4.29	4.45	0.51	0.59	0.62
Military	1.21	1.21	1.20	0.17	0.17	0.17
Mixed Residential/ Commercial	0.91	2.76	5.69	0.13	0.38	0.79
Public Utilities	0.26	0.30	0.30	0.04	0.04	0.04
Residential	21.83	46.18	94.19	3.02	6.40	13.05
Rural Settlement	1.17	1.13	1.86	0.16	0.16	0.26
Special Area	0.87	0.87	0.87	0.12	0.12	0.12
Transportation	7.15	8.41	8.71	0.99	1.17	1.21
Forest	253.34	253.56	251.08	35.10	35.12	34.78
Others	2.96	3.48	6.07	0.41	0.48	0.84
Recreational / Open Space	2.39	2.03	2.01	0.33	0.28	0.28
Water body	3.50	2.14	1.98	0.48	0.30	0.27
Total	**721.87**	**721.87**	**721.87**			

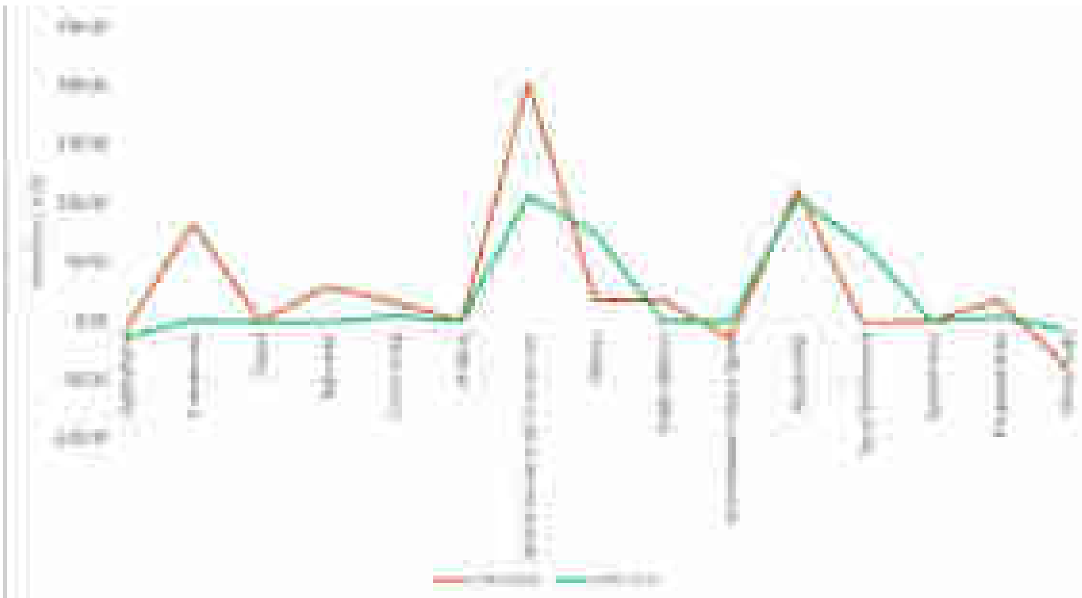


Figure 24 Land Use Gain-Loss in KV (1990-2000 & 2000-2012)

2 *GeoEye 0.5m MSS satellite image cover entire KV of the date 2012 was used*

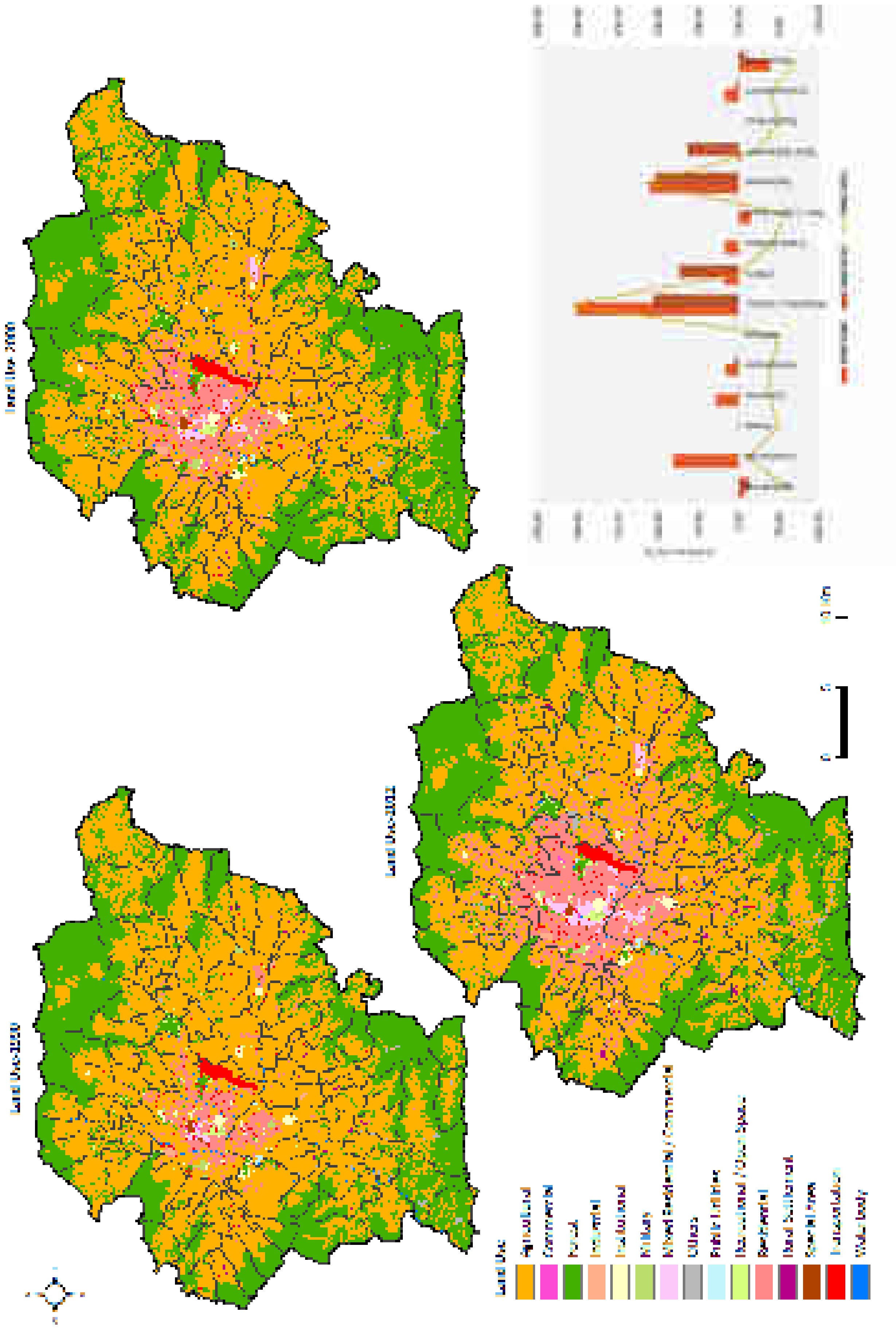


Figure 25 Land Use of KV (1990, 2000, 2010/2012)

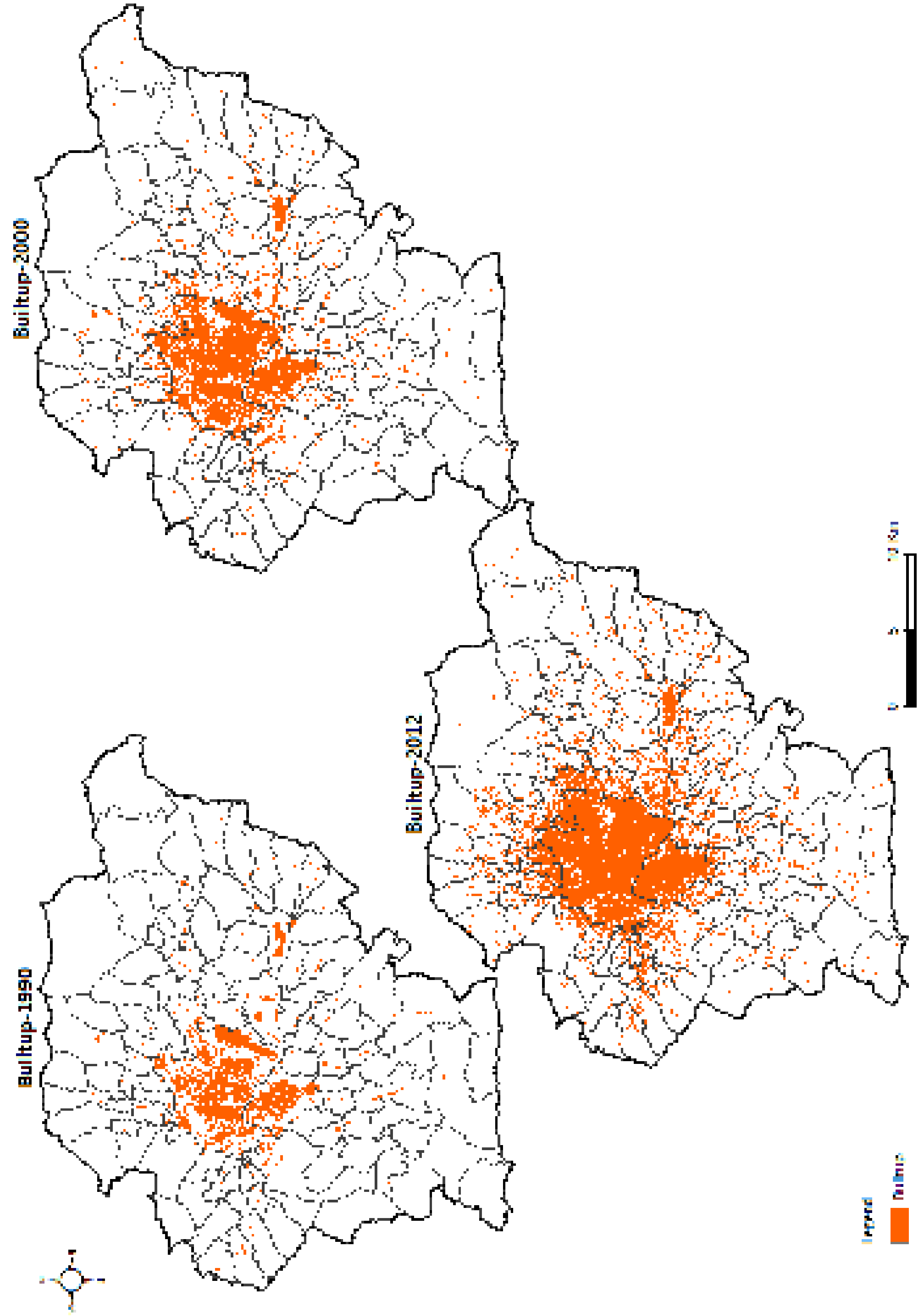


Figure 26 Built-up Area in KV (1990, 2000 &2012)

2.2.7. Areas of Rapid Urban Growth

Looking at the trend of change in built-up area of KV, it is apparent that the rate was higher in the central parts of the urban areas during the earlier decades. In the later decades the rate of urban growth is found to have increased in peripheral regions, protruding to VDCs.

The decade of 1990s showed a significant increase in built-up (51%) in ward number 20 of Lalitpur Sub Metropolitan city, which was closely followed by ward numbers 12 and 5 of LSMC and 2 and 10 of KMC, which were within the range of 40 to 50%. Among the VDC's, Gongabu showed highest built-up rate (12%), closely followed by Jorpati, Dhapasi, Sitapaila and Manamaiju.

Between 2000 and 2010, growth rate of built-up was high for many parts of valley, especially in urban fringes. Ward number 4 of Kathmandu and 9 of Kirtipur hit the highest growth rate of 62%, In addition to the ward numbers 3, 5, 6 and 7 of Kathmandu metropolitan city, Dhapasi and Gongabu VDCs also showed an increase in built-up above 50%. Ward numbers 10 of Kirtipur, 3, 7 and 8 of Lalitpur, 5 and 7 of Madhyapur Thimi also showed remarkable built-up growth, well above 30%. Built-up growth of Jorpati, Mahankal and Manamaiju VDCs were also above 30%. Other VDC showing remarkable change in built-up areas were Satungal, Sitapaila, Kapan, Gothatar, Tinthana and Imadol, which were in the range of 20 to 30%.

It is lucidly noticeable that the growth in the urban built-up tends to be spilling over towards the sub-urban areas and surrounding VDCs in the later decades. The aerial photos and satellite imageries presented below reflects the urban growth in some of the areas with significant growth in last decades.

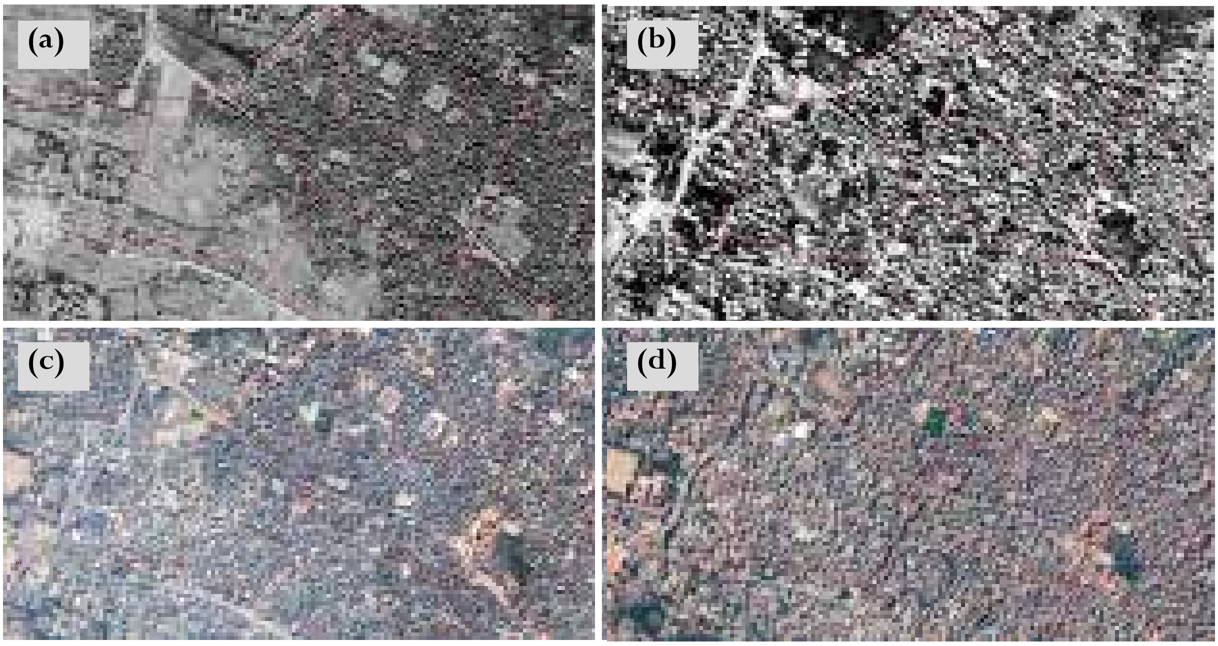


Figure 27 Illustration of urban growth in wards 3, 5, 20 and 21 of LSMC
(a) 1980 (b) 1990 (c) 2000 and (d) 2010

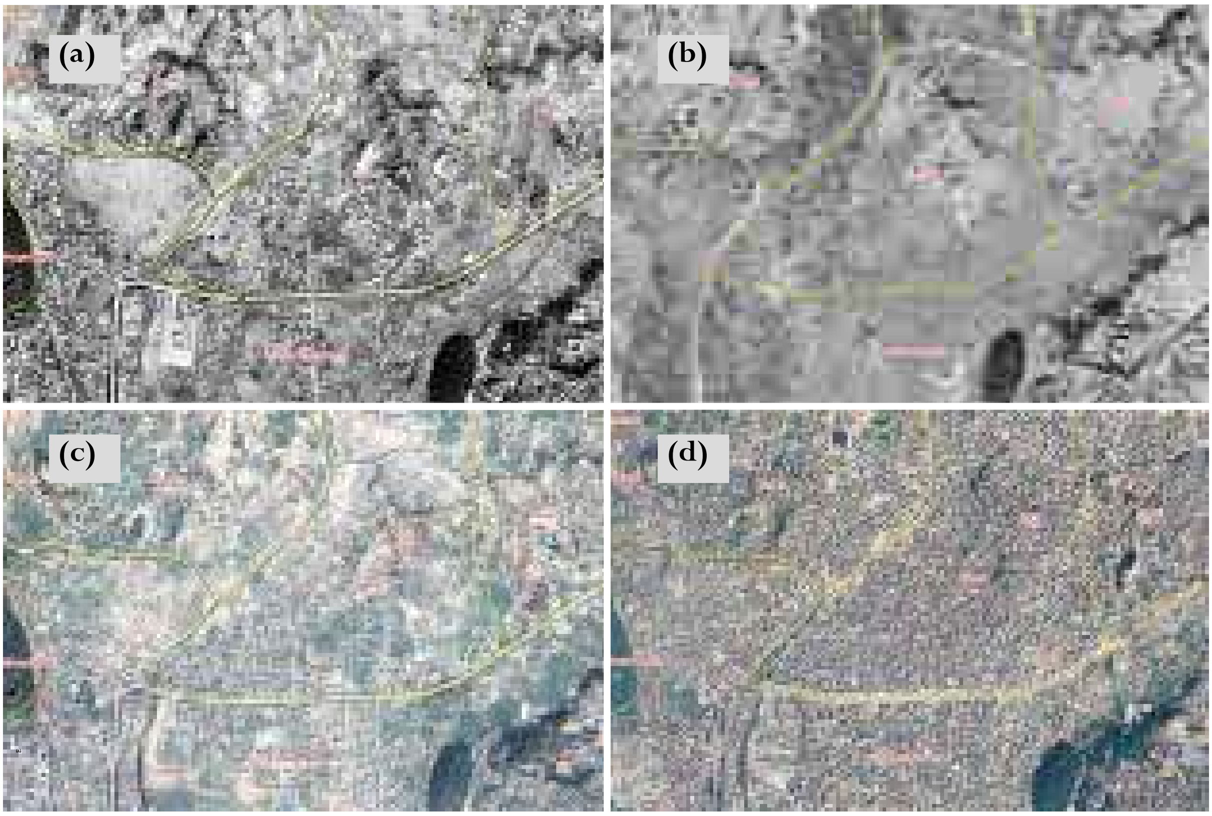


Figure 28Illustration of urban growth in Gongabu and surrounding areas of KMC (a) 1980 (b) 1990 (c) 2000 and (d) 2010

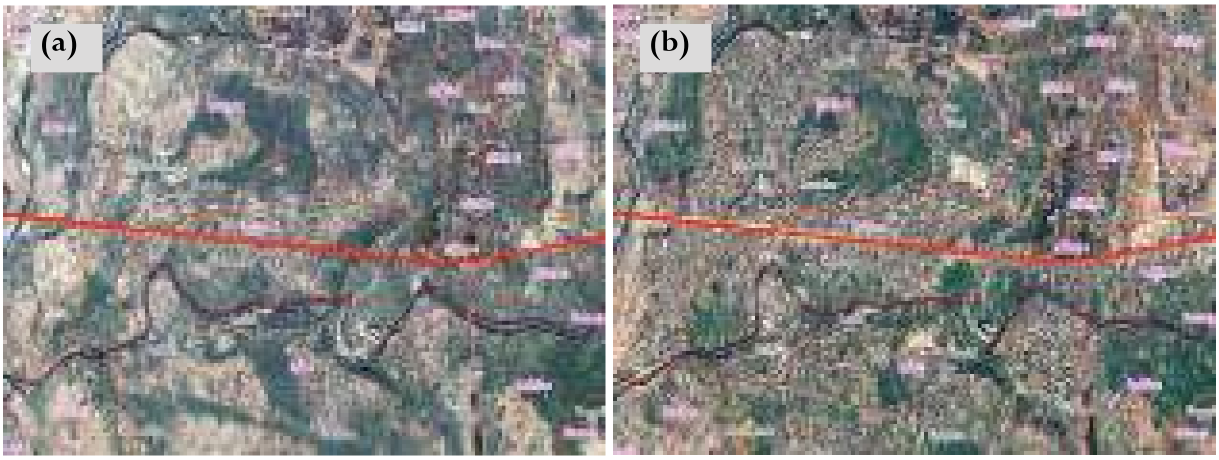
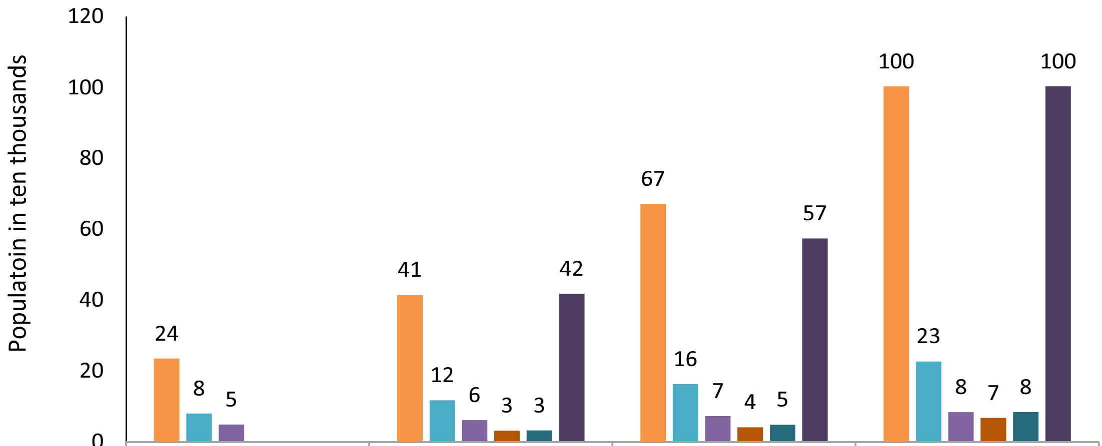


Figure 29 Illustration of urban growth in wards 15 and 17of Madhyapur ThimiMunicipality (a) 2000 (b) 2010

2.3. Population Growth Pattern and Trends

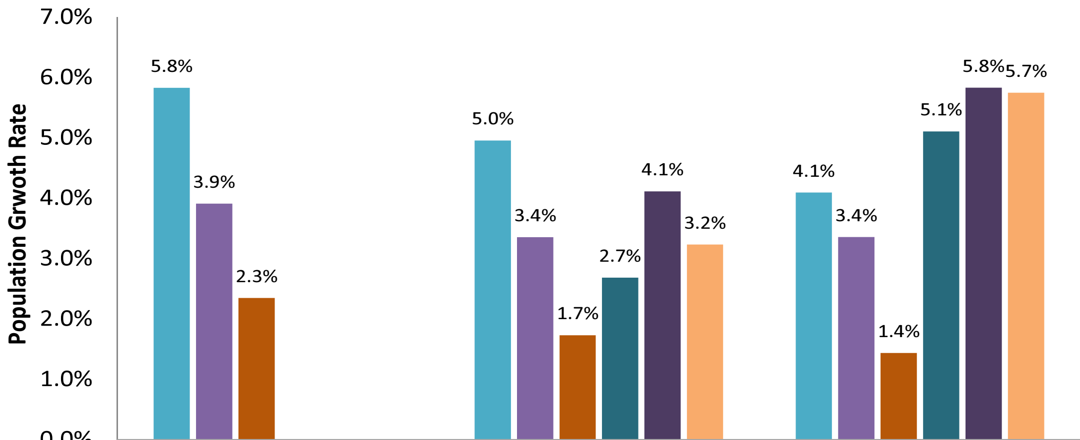
The population trend of KV was analysed using the population census of different chronological years i.e. (census years 1981, 1991, 2001 and 2011). The ward wise population trend analysis was done for the five municipal regions inside valley and VDC level analysis done for remaining 99 VDCs. The total population of Kathmandu Valley in the census year 2011 was 2,468,316 with the annual growth rate of 4.63%. The distribution of population in municipal regions and VDCs are presented in *Figure* 31.

The maximum annual growth rate of 5.7% with the increasing trend was observed in the urbanizing VDCs inside the valley. The decreasing trend of annual population growth was observed in the Kathmandu Metropolitan City, Lalitpur Sub-metropolitan City and Bhaktapur Municipality while comparing the consecutive year census data from 1981 to 2011. Increasing growth trend was observed for Kirtipur Municipality with annual growth from 2.7 to 5.1%; and Madhyapur Thimi Municipality with annual growth from 4.1% to 5.8%. The status of growth rate for different municipalities and VDCs inside KV is presented in *Figure* 30.



	Census 1981	Census 1991	Census 2001	Census 2011
KMC	235160	414264	671846	1003285
LSMC	79875	117203	162991	226728
BM	48472	61122	72543	83658
KM		31338	40835	67171
MTM		31919	47751	84142
VDCs		417576	573957	1003332

Figure 30 Annual Growth Rate



	Census 1981-91	Census1991-01	Census 2001-11
KMC	5.8%	5.0%	4.1%
LSMC	3.9%	3.4%	3.4%
BM	2.3%	1.7%	1.4%
KM		2.7%	5.1%
MTM		4.1%	5.8%
VDCS		3.2%	5.7%

Figure 31 Population trend of Kathmandu Valley

The population for 2020 and 2030 for Kathmandu valley, projected using geometric growth method[3] indicates 3,794,866 and 6,249,958 respectively. The distribution and projection of KMC shows that Ward 35 has the maximum growth rate of 8.1% in the year 2001-2011 with the density of 176 per unit hectare, followed by Wards 16, 29 and 3 respectively with the average annual growth rate of approximately 6%, similarly 5% growth rate was observed in the Wards 14, 10, 4 and 1. The negative growth trend was observed in the Wards 2, 27, 23, 30 and 24, with Ward no 24 having maximum negative growth rate of -4.1%. Ward 24 has the population density of 442 persons per unit hectare. The Ward 28 was found to have the highest population density of 1195 and Ward 8 was found to have the least densely populated ward with population density of 75 per unit hectare. The highest population was observed in Ward 16 with total population of 86,993 which was projected as 156,041 and 298,669 for years 2020 and 2030 respectively

Figure 32 Population distribution of KMC

Lalitpur Sub-metropolitan City comprises of 22 Wards with the total area of 1,515.4 hectares. In LSMC the maximum annual growth rate of 8.3% was observed for Ward 13, with the density of 194 persons per unit hectare. This was followed by Wards 2 and 14 with average growth rate of 6.5% and Ward 9 with the growth rate of 5%. Wards 16 and 18 of LSMC were found to have the negative annual growth rates with -2.3% and -1.9% respectively. The most densely populated Ward was Ward 21 with 704 persons per unit hectare and least populated Ward was Ward 15 with 65 persons per unit hectare. Ward 14 of LSMC has the highest population of 21,145 which was projected to years 2020 and 2030 as 36,496 and 66,931 respectively. The population distribution of LSMC is presented here.

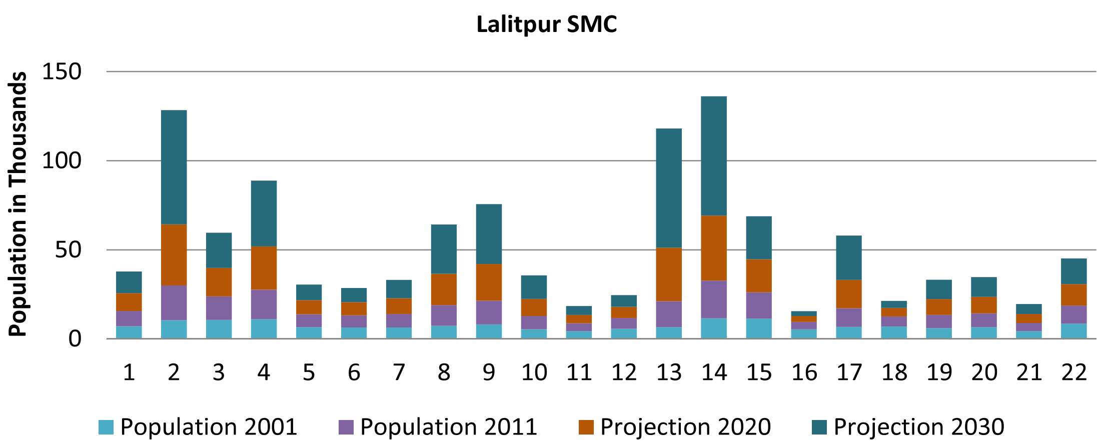


Figure 33 Population distribution in LSMC

3 *[Pt= P0 (1+r) t], where Pt is latter year population, P0 is Earlier year population , r is the rate of annual increase of population and t is the time interval.*

Bhaktapur Municipality consists of 12 Wards with total area of 655.7 hectares. In BM, the average of 5% growth was observed in Wards 2, 4 and 17.with Ward 2 being Ward with highest annual growth rate of 5.9%. In BM, eight Wards was found to have the negative growth rate, Wards 13,1,9,14,8,7,11 and 12 are the Wards with growth rates ranging from -1.6% to -0.6%. Other remaining Wards in BM were found to have mild growth rates of about 1% annual growth. The highest population was found in Ward 17 with 11,471 populations which were projected as 17,913 and 29,391 for the year 2020 and 2030. The most densely populated Ward was found to be Ward 9 with density of 1039 persons per unit hectare and least densely populated area was found in Ward 17 with population density of 72. The population distribution of BM was presented in *Figure 34*.

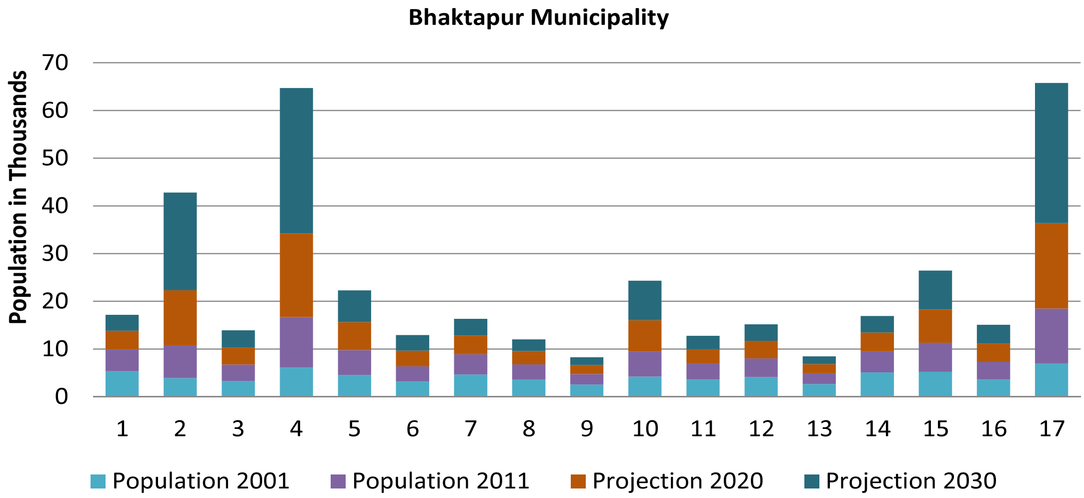


Figure 34 Population distribution of Bhaktapur Municipality

Madhyapur Thimi Municipality is divided into 17 Wards with total area of 1111.2 hectares of area. The consecutive census years of 1991, 2001 and 2011 reveals the total population of municipality as 31,919, 47,751 and 84,142 respectively. The municipality has the average density of 76 persons per unit hectare and maximum density was found in Wards 8 and 14. The largest annual growth rate of 12% was found for Ward 16 followed by growth rate of 9% for Wards 15 and 17. Similarly Wards 3 and 5 have the growth rates of 8.6% and 5.9% respectively. Negative annual growth rates are observed for Wards 2, 12 and 10 ranging from -0.3% to -1.4%. The population distribution of Madhyapur Thimi Municipality is presented in *Figure* 35.

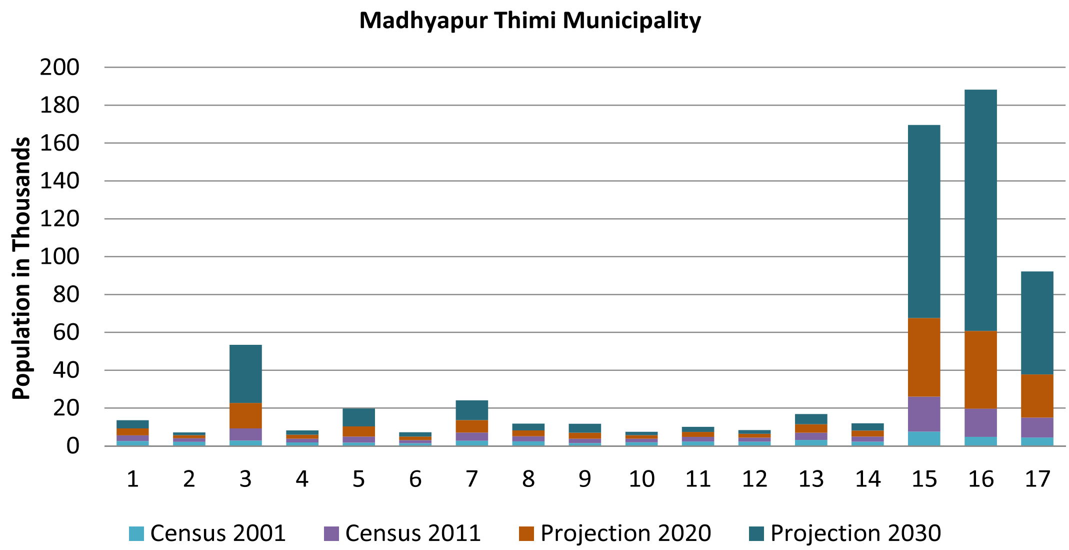


Figure 35 Population distribution of Madhypur Thimi municipality

Kirtipur Municipality is divided into 19 Wards and has a total area of 1476 hectares. The consecutive census years of 1991, 2001 and 2011 reveals the total population of municipality as 31,338, 40,835 and 67,171 respectively. The average annual growth rate of Kirtipur municipality in the census year 1991-2001 was 2.7%, which was increased to 4.9% in the year 2001-2011. The municipality has the average density of 45 persons per unit hectare with most densely populated Ward being Ward 10 with 919 persons per unit hectare and least dense Ward being 19 with only 12 persons per unit hectare. The highest annual growth rate of 11.3 was found for Ward 2, followed by Wards 1, 18 and 10 with respective growth rates of 9.3%, 7.4% and 6.4%. The only Ward with the negative growth rate was Ward 13 with annual growth rate of -0.4 % annual growth. The population distribution of Kirtipur is presented in *Figure 36*.

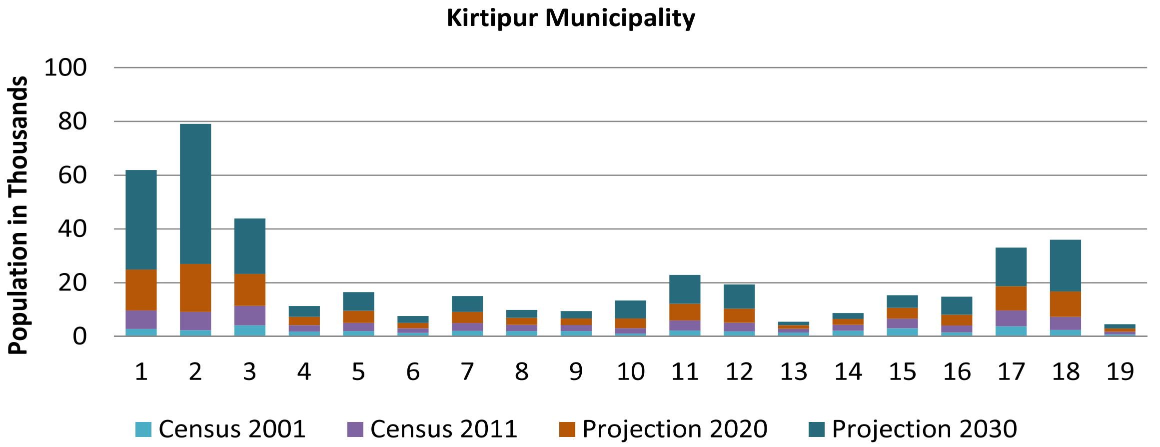


Figure 36 Population distribution of Kirtipur Municipality

Similarly, 57 VDCs in Kathmandu District covers the total area of 34,939.5 hectares. The census 1991, 2001 and 2011 reveals the total population of these VDC as 220,025, 351,140 and 658,928 respectively. The VDCs Manmaiju, Ichangu Narayan, Gothatar, Kapan, Dhapasi, Mahankal and Gonggabu have the staggering annual growth rates of 13.94%, 12.25%, 12.21%, 12.19%, 10.46%, 10.21% and 10.07% respectively. The VDCs Satikhel, Pukhulachhi, and Naglebhare were found to have the negative population growth rates ranging from -0.19 to -0.30%. The population distribution of VDCs inside Kathmandu District is presented in *Figure 37*.

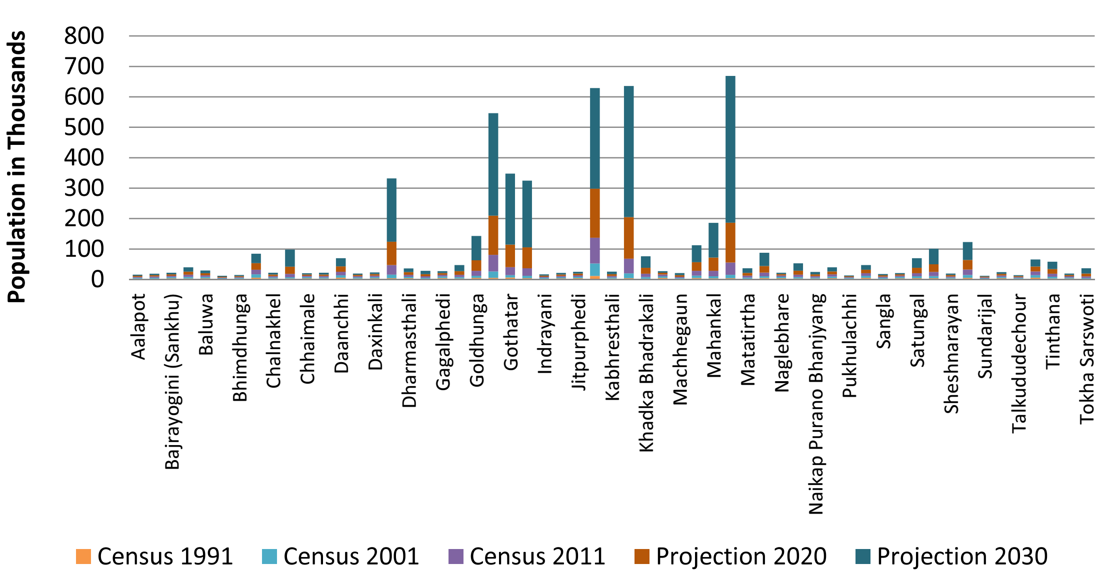


Figure 37 Population distribution of VDCs in Kathmandu District

Similarly, 26 VDCs in Lalitpur District, cover the total area of 17,028.6 hectares. The census of 1991, 2001 and 2011 reveal the population of these VDCs as 117,540, 144,893, and 210,484. Among these VDCs Imadol, Sainbu and Dhapakhel have the largest growth rates of 11.01%, 8.99% and 7.17%. The negative annual growth rates are observed for VDCs Bisankhunarayan and Ghusel with growth rates ranging from -0.5% to -0.09%. The population distribution of VDCs inside Lalitpur District is presented below.

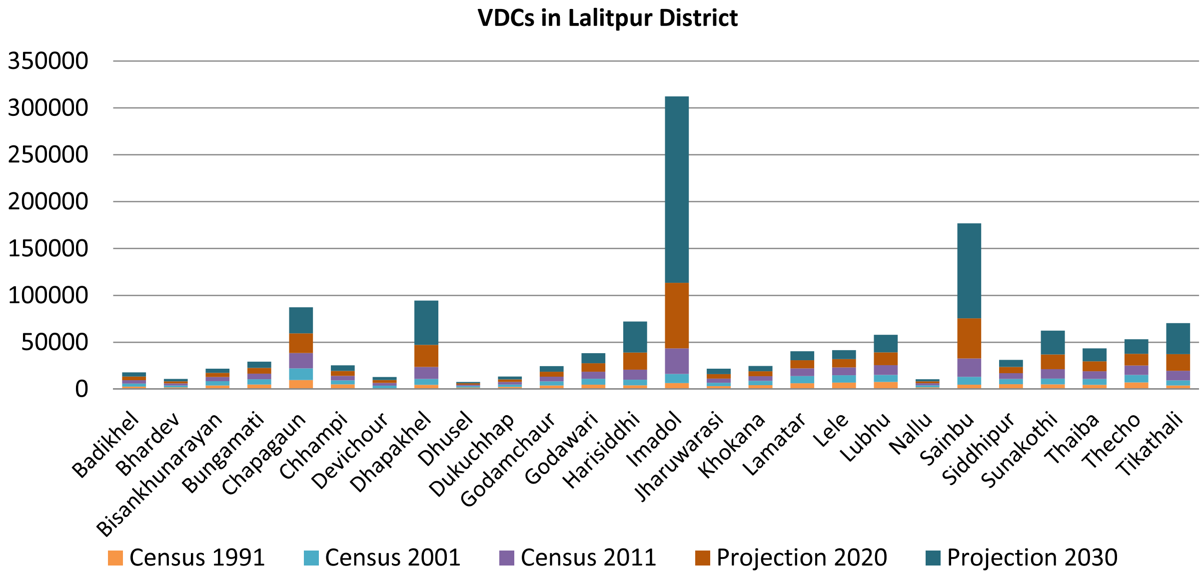


Figure 38 Distribution of population for VDCs in Lalitpur District

There are 16 VDCs are in Bhaktapur District, with the total area of 10,543.85 hectares. The census years 1991, 2001 and 2011 revealed the total population of these municipalities as 8,0011, 77,924 and 133,920 respectively. The VDCs Balkot, Sirutar and Kautunje were found to have the highest population densities of 56, 35, 45 per ha. Respectively. Among these VDCs only Gundu VDC has the negative growth rate of -0.12%. The VDCs with high growth rates are Kautunje, Sipadol and Jhaukhel with growth rates of 11.00%, 10.71% and 8.74%. The population distribution of VDCs inside Bhaktapur District is presented *Figure 39*.

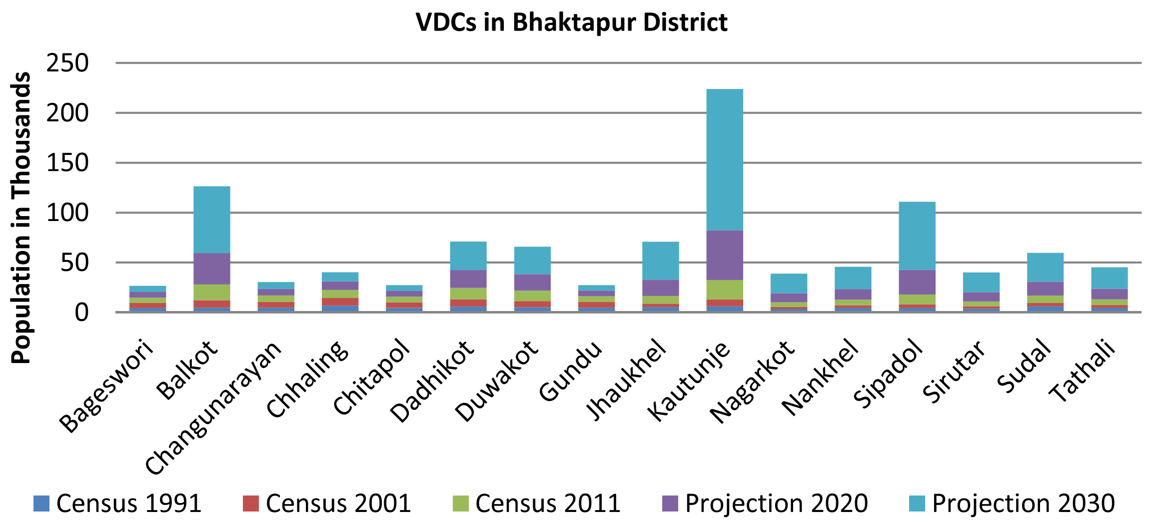


Figure 39 Population distribution of VDCs inside Bhaktapur District

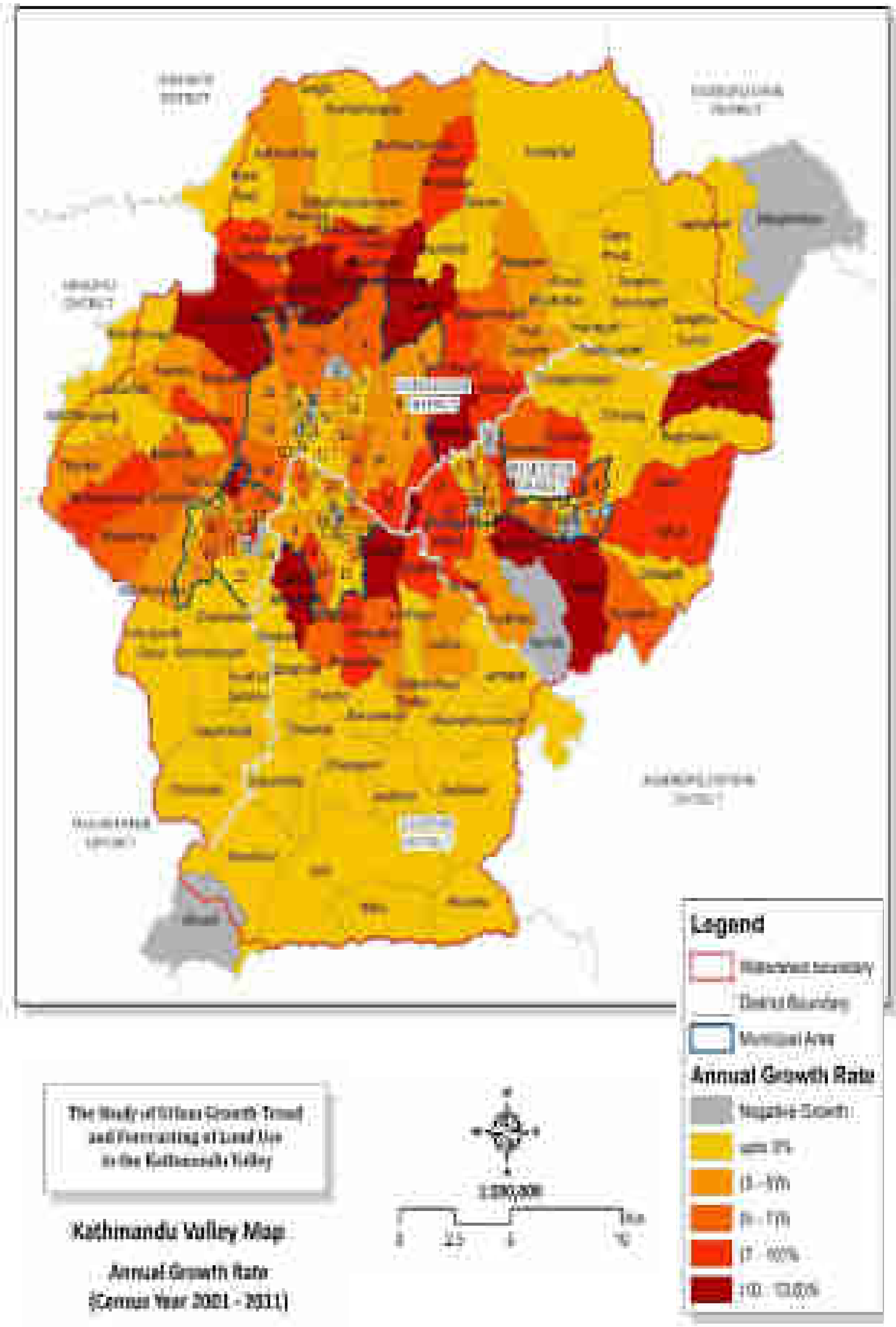


Figure 40 Population Growth in Kathmandu Valley (2001-2011)

3. DRIVERS OF URBAN GROWTH

The rapid urban growth discussed in the previous sections is attributed to various socio-political, economical and development factors, so called "the drivers" of changes. In the context of KV, these drivers have had significant influences since 1970, as being the capital city and the economical hub of the country. The in-migration of the population from surrounding and remote districts seeking economic opportunities, the political and conflict situation during the decade of 1996-2006, the ensuing political turmoil after 2006 has somehow directly or indirectly influenced the socio-economic and development trends of the KV. As a result, the urbanizing trend has also changed significantly characterized by haphazard and unplanned development due to lack of effective planning and its implementation.

Various factors pertaining to socio-economy, demography and development have influenced this growth trend. These factors are multi-dimensional in nature and are catalysts to the other factors as well as influence the impacts of other factors. For instances, economic opportunities give rise to the population growth, which in-turn influence increase in building constructions; infrastructure development, specifically road construction leads to increase in built-up densities along the road. There are positive factors or drivers, which influences the urban growth and there are negative drivers which inhibit the growth.

The following sub-sections presents the possible driving factors and their definitions, specific to KV. These drivers were derived based on the decadal land use change study of the KV from 1990-2012 and Key Informant Interviews. Analysis of the influence of these driving factors has been done using *Spatial Logistic Regression Model* as well as through KII with the experts in urban planning and development sector.

3.1.1. Economic Opportunities and Population Growth

Economic opportunities include wide varieties of economic activities like- job and business opportunities, industries, land value etc.(Priyanto 2010, Thapa and Murayama 2011). Spatially representing economical factor may be ambiguous in the absence of economic aspects of the activities going in the certain spatial context. In this study, the economic activities are assumed to occur primarily in the Central Business District (CBD) and due to the pull factor of the CBD, urban development is considered to be concentrated around and spreading outwards from the CBD. In this study proximity to Central Business District (CBD) and other market places are taken as major economic factor which drives growth of the valley. As such, the CBD is where commercial and financial activities occur, providing jobs in formal financial and banking sectors, providing opportunities for extended businesses and trade, as well as providing opportunities in informal sectors to support and sustain the formal sector activities. Further, the central administrative services are also located within the CBD in the context of KV. The CBD, therefore attracts the major workforce, therefore the built-up densities around the CBD is higher. This factor, however seems to inhibit the urban growth around the CBD as there may not be available growth space due to already present dense built-ups.

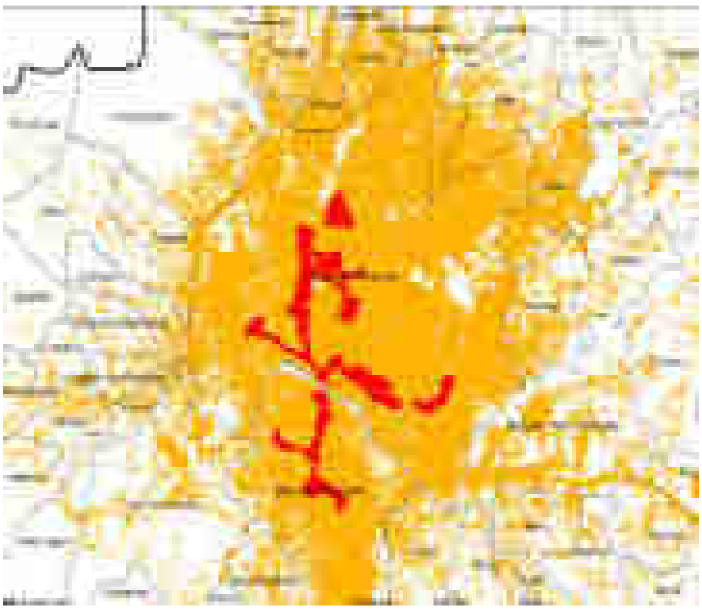


Figure 41 CBD in KV

Kathmandu Valley, located in the central region of Nepal has about 10% of total population in less than 1% of the country's area (CBS, 2011). High concentration of population in the valley is mainly due to centralization of economic activities, infrastructure facilities and concentration of government services. Recently, one of the survey conducted by (Nepal Rastra Bank 2012) estimates that the total value of the economic activities taking in the valley is NRs. 418 billion which accounts 31 percent of total GDP. This suggests that about one-third of the country's economic activities are concentrated in Kathmandu valley alone. The information is supplement by Nepal Labour Force Survey (NLFS), which estimates that Kathmandu valley accounts for 25 percent of nonfarm employment (Services and Manufacturing) which is equivalent to as many as 631,000 employees (Central Bureau of Statistics 2008). This figure exceeds over cluster around Eastern Terai and Central Terai surrounding Biratnagar and Birgunj which accounts for 18% and 19% of non-farm employment (i.e. 446,000 and 478,000 employees respectively). This shows that Kathmandu valley is the centre of economic opportunities which has been pulling huge proportion of migrants from different parts of the country. Compared with other urban areas, the Valley exhibits a larger share of migrants who are pulled by economic reasons. NLFS estimates that more than 25 percent of lifetime migration to the Kathmandu Valley is for job-related reasons (Muzzini and Aparicio 2013).

In this study, the economic activities are assumed to occur primarily in the Central Business District (CBD) and due to the pull factor of the CBD, urban development is considered to be concentrated around and spreading outwards from the CBD.   In this study proximity to Central Business District (CBD) and other market places are taken as major economic factor which drives growth of the valley. As such, the CBD is where commercial and financial activities occur, providing jobs in formal financial and banking sectors, providing opportunities for extended businesses and trade, as well as providing opportunities in informal sectors to support and sustain the formal sector activities. Further, the central administrative services are also located within the CBD in the context of KV. The CBD, therefore attracts the major workforce, therefore the built-up densities around the CBD is higher. This factor, however seems to inhibit the urban growth around the CBD as there may not be available growth space due to already present dense built-ups. Similarly, population growth is taken as one of the major driving forces that lead to urban expansion in many urban growth studies (Fang et al. 2005, Priyanto 2010)(Fang et al. 2005, Priyanto 2010). Population growth, is a direct indicator of economic opportunities and other factors such as political and security issues, which has led to migration of population into KV. Due to the population growth, the built-up and population densities within the existing urban area has significantly increased. As such, to accommodate the increasing population, horizontal outward growth is apparently being undergoing. This has led to a formation of urban agglomeration within the KV, spatially joining the designated development/growth nodes with the urban municipalities and the urbanizing VDCs. In this case of spatial agglomeration, the concept of growth nodes and development focussing around such growth nodes may not be relevant in 2020 and 2030 as these nodes is likely to be agglomerated into one urban footprint. Therefore, concept of "metro city", one continuous urban agglomeration within KV may be relevant.

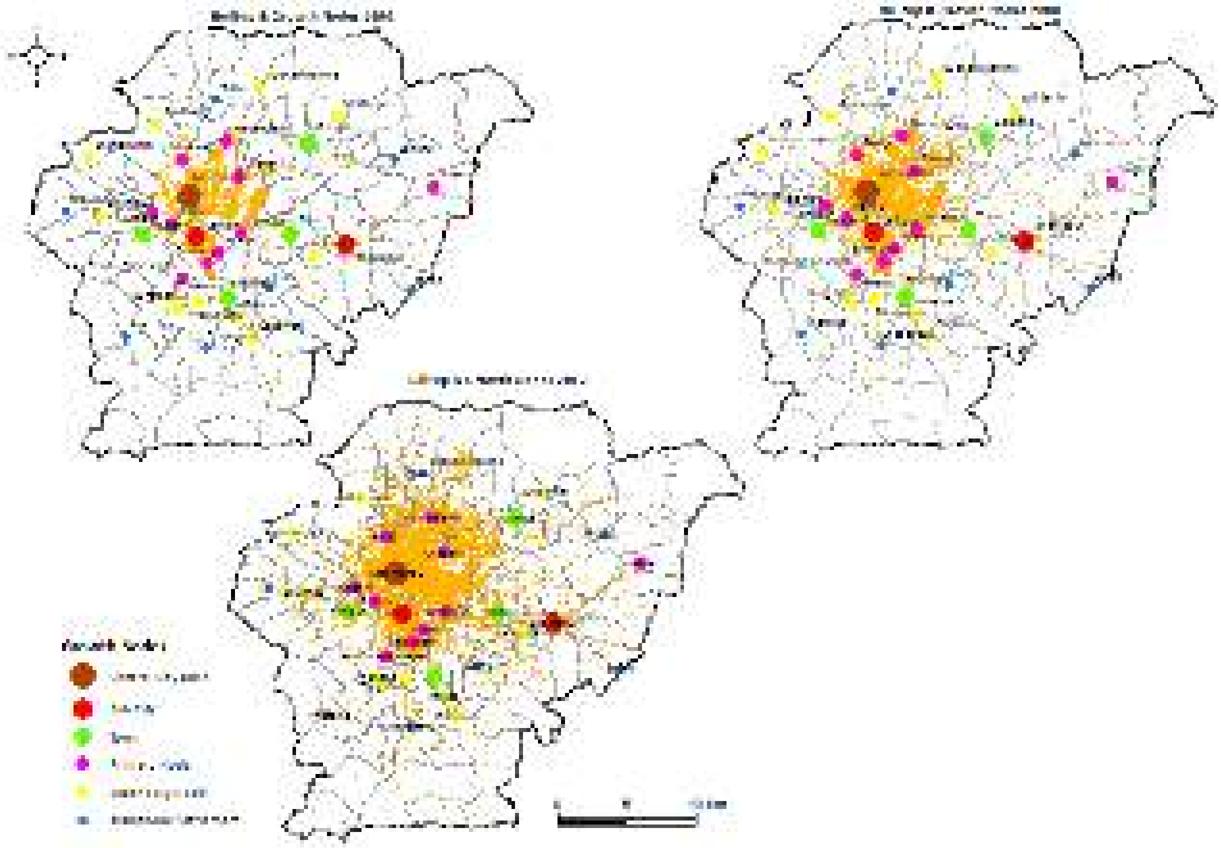


Figure 42 Urban growth nodes and built-up (1990, 2000, 2012)

3.1.2. Bio-physical Conditions

Bio-physical characteristics refer to characteristics and process of the natural environment such as landforms, topography, soil type, natural resources and drainage pattern. These characteristics usually affect urban growth pattern based on the suitability of land for specific purpose. Parameters such as slope, reserved forest and water bodies are taken as site specific characteristics which can either restrict or accelerate the growth of valley. Built-ups are generally discouraged in the slope, however, development of housing, hotels and resorts etc. are encouraged in the hillocks and on top of the hills as evident from ongoing developments around the hills of KV.

Figure 43 Development on hillocks surrounding KV

Unregulated developments have been ongoing along the Bagmati, Bishnumati, Dhobi Khola and other rivers in KV. The corridors of these rivers should be preserved as restricted zones considering potential flooding events and conservation of these drainage systems. Other areas susceptible to liquefaction, landslides and other natural hazards also restrict the development, and hence should be considered as inhibiting factors for the growth.

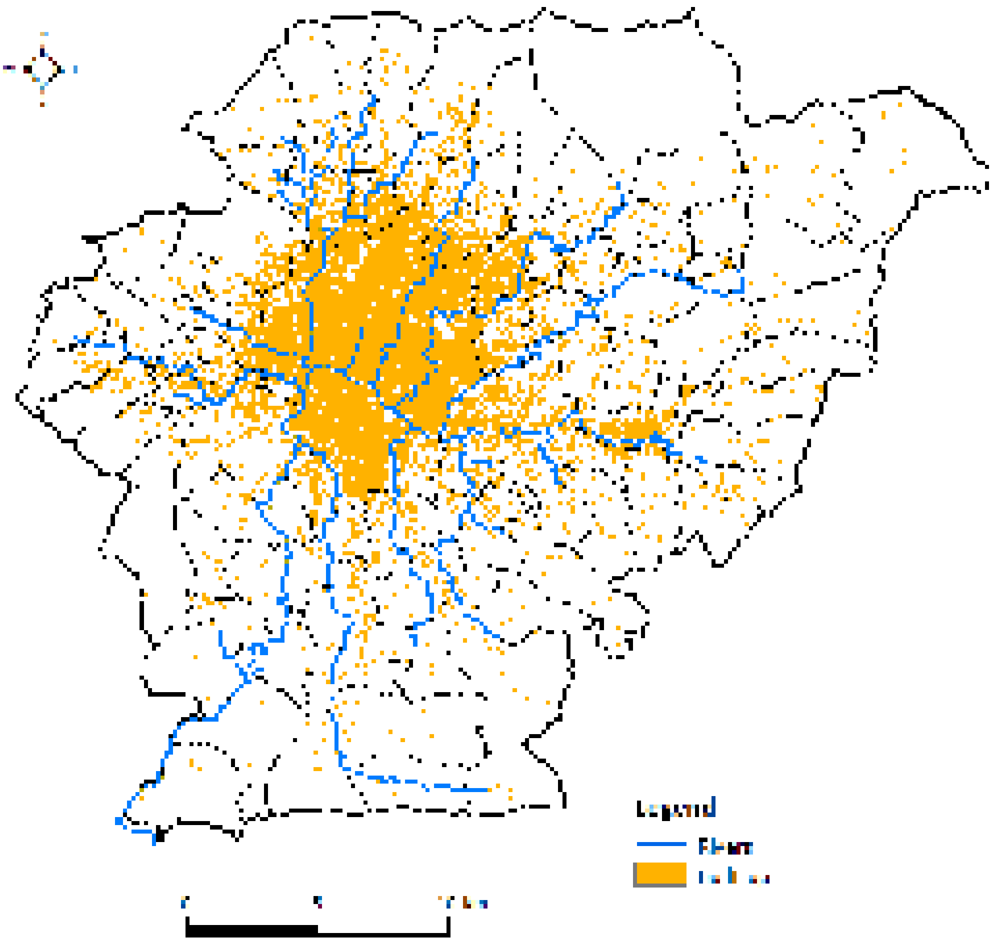


Figure 44 Rivers and built-up in KV

3.1.3. Road Networks and Planned Major Developments

It is assumed that whether a place is urban or not is highly correlated to accessibility of that place (Huang et al., 2009). Therefore transport related variables such as Major Road, Minor Road, Ring Road, Major Nodes are included as predictors of urban growth. These variables are widely mentioned in most of the literatures because of the fact that the area which is at closer proximity to transport related variables have greater tendency to grow in future due to potential benefits such as ease of access, economic opportunities, social services etc.

The growth of the road network in valley in 70s and 80s was 62 percentage and 50 percentage. The growth phenomenally picked up in 90s with a record of 154 percentage and it slowed down in between 2001 to 2012 with a decade average of 31 percentage. On the analysis of the road pattern and its development, the following conclusions are pertinent to the growth.

- The growth of road network inside ring road is much less compare to the one outside ring road.
- In terms of the road density, outside ring road records a density one third of that of inside ring road. Between 1990 and 2001, road extension inside ring road was at the higher level with a growth of 7.8 km/sq.km to 16.8 km/sq.km (almost double). This is owed mainly due to defying of the legal restriction on opening access through ring road green belt.

- If the growth of road length is calculated in terms of road density, the growth generally matches for all the three districts: Kathmandu, Lalitpur and Bhaktapur with particularly Lalitpur on lower side. Bhaktapur and Lalitpur although seems to have been discriminated in overall road length development but road density wise, the status is comparable.
- Looking at the motorable accessibility, in 1970, out of 99 VDCs (excluding municipalities: existing and proposed), 23 VDCs (Kathmandu: Alapot, Sankhu Bajrayogini, Baluwa, Bhadrabas, Chapali Bhadrakali, Chhaimala, Chhunikhel, Gagal Phedi, Indrayani, Jhor Mahankal, Lapsi Phedi, Matatirtha, Nanglebhare, Pukhulachi, Sankhu Suntol, and Naikap Puranobhanjyang, Lalitpur: Devichour, Ghusal, Dukuchhap and Godamchaur, Bhaktapur: Chitapol, Nagarkot, Nanghel and Sudal) were unconnected with motorable road network. In 1980, the unconnected VDCs dropped to 10 VDCs (not were connected were same 4 VDCs of Lalitpur and six other VDCs of Kathmandu (Alapot, Bhadrabas, Chhaimale, Chunikhel, Matatirtha and Nanglebhare). By 1990, one VDC of Lalitpur: Dukuchhap) was not connected to the road network.

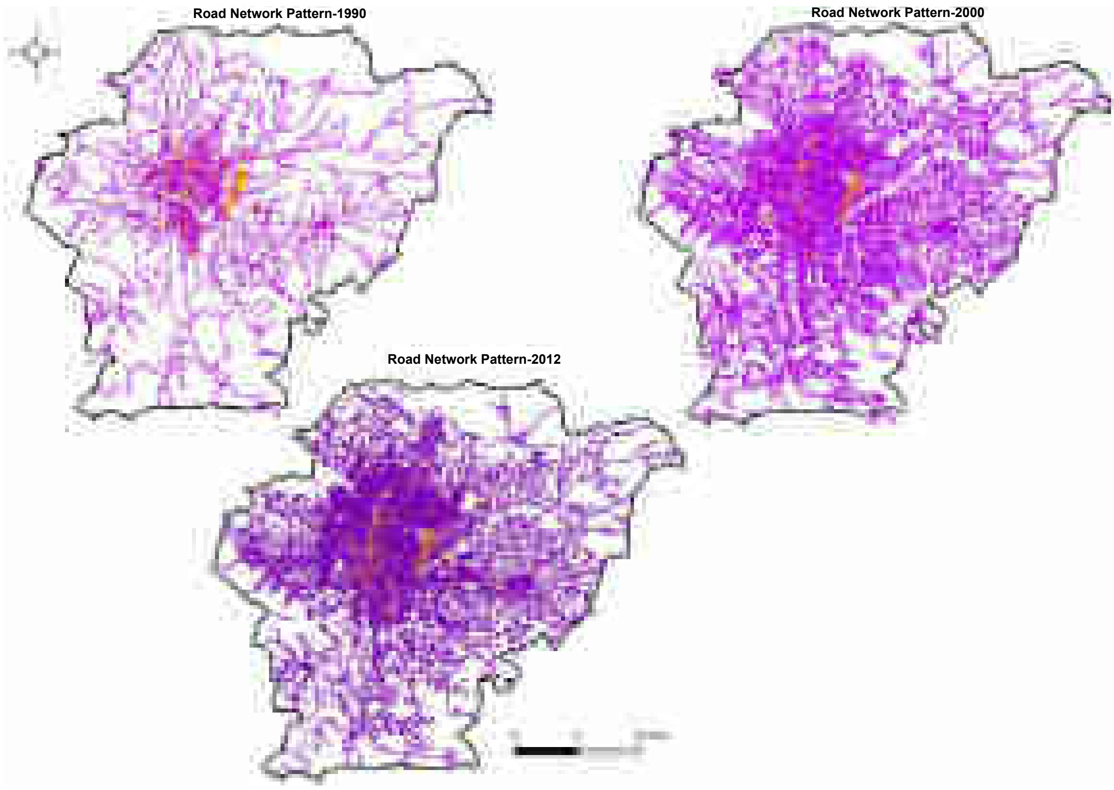


Figure 45 Road network pattern of KV (1990, 2000 & 2012)

In this study proximity to road network was determined by calculating Euclidian distance to major road, minor road and ring road. The classification of Major and minor road was based on SSRN 2010 where road was categorized as National Highway, Feeder Road Major, Feeder Road Minor and District Road. National Highway and Feeder Road Major are categorized as Major Road. It also includes planned major development such as Outer Ring Road and Fast Track. Remaining roads are categorized as Minor Road.

Besides the existing road network and its influence in the urban growth, the planned extensions and new development also tend to influence the growth pattern. The planned Outer Ring Road and the proposed Fast Track, will likely influence the growth trend within their corridors.

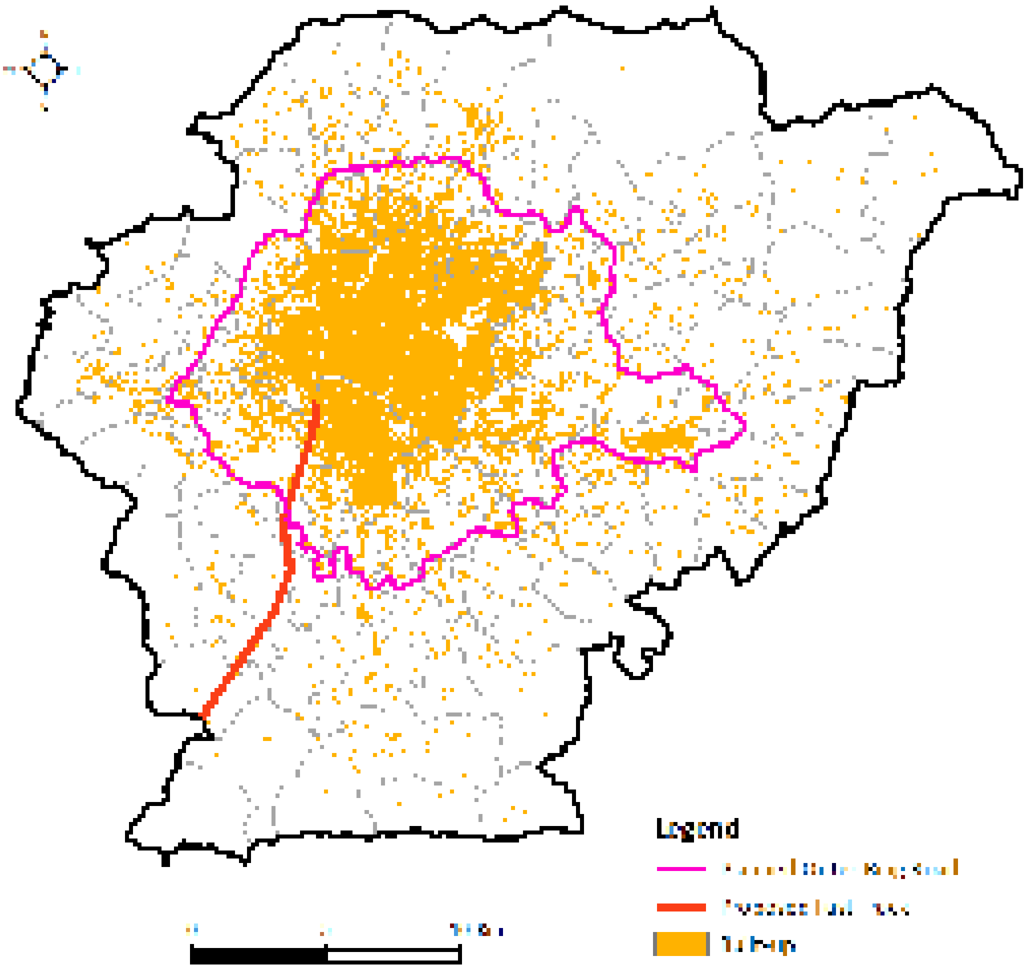


Figure 46 Planned Outer Ring Road and Proposed Fast Track

3.1.4 Access to Infrastructures and Services

The level of urbanization and level of development is closely related with accessibility to infrastructure and services such as- clean drinking water, electricity, education, health facilities and sanitation (Andres & Tae-hwan, Unknown). Besides it is also likely to affect the future growth pattern of the city because it enhances the thrust towards urbanization of rural-urban fringes which eventually increase the built-up areas at their proximity. Therefore this study has considered educational and health facilities as a driving factors of urban growth in Kathmandu Valley. Other facilities such as drinking water provision and electricity are not considered, considering the piped drinking water connectivity is not available throughout the KV, and as this urban amenity is provisioned only after the development occurs, in case of unregulated development. Based on the logistic regression of the relationship between urban growth and accessibility to the institutions, it was found that an area tends to have higher probability of urban growth if there are no institutions which seems logical as urban growth around institutional area is very low or almost nil as these institutional areas are within the CBD or in already saturated built-up areas.

3.1.5. Land Market

The value of land is one of the major parameters to induce land use change. Most often, the increase in land value is directly proportional to the increase in density. The land gets converted into more profitable use as its value increases. The value of agriculture land is determined by its productivity. However, the determinants of the value of urban land are the width and status of the frontal road, availability of utilities, proximity to the city center or business opportunities, shape of the land, direction, width depth ratio etc.

The factors deterrent to the land value are the land having steep slope, drainage constraints, adjacent to the river, high tension line or electric sub-stations and solid waste dumping site etc. The valuators of Nepal appear to have implicitly considered these factors while valuating the land. However, there's a complete absence of officially approved scientific approach of valuating the land. Most popular method in practice is to consider the type of front road and the location. This method is adopted by the government while assessing the value of land for tax purpose. The land with no public access gets the lowest value.

However, it is the situation of demand and supply that governs the most for transaction of the land which are influenced by the factors like the lending policy, economic situation, political stability and peace. The market value of land is generally higher than the rate fixed by the government. The extent of difference however varies from place to place. The banks normally arrive at the value of land by aggregating market rate and government rate with the weightage of 70:30.

In the absence of official land index, the government rates for different areas in the past several years have been compiled to analyse the growth pattern. Such rates are fixed by the land revenue office based on the type of roads i.e. metalled, gravel or earthen and the location of such roads. The valuation is basically used for the taxation during land transfer. The government rates though do not reflect the market value, provide a fair approximation on the trend of increase of land value. In the past one decade, the land value has increased as high as 25 times. Such high increment has been observed in the VDCs rather than the municipalities owing to the fact that the land price of the municipality has already attained to a threshold limit and the geometric growth could no longer be continued. The urban growth in terms of price was therefore limited to less than 5 times. Table 8 provides the list of the areas that came across different growth in land prices over the past decade.

The land prices remained high within the ring road and the periphery. The adjoining areas or the urbanizing VDCs also had high land prices. The most expensive land, as valued by the government, is the parcels adjoining to Kopundol, Jawalakhel and Lagankhel which is about Rs. 3.8 million. Similarly, most of the land parcels adjoined to the central Kathmandu (Tripureswor, Jamal, Lazimpat, Putalisadak, Kamaladi, Thapathali) are equally expensive.

Table 8 gives the summary of land value changed over the period of last decade (2002-2010), based on the valuation by Land Revenue Offices in the Kathmandu Valley.

Table 8 Land market price growth (2002-2010)

Kathmandu	Lalitpur	Bhaktapur
5 to less than 10 times		
Balambu VDC	Badegaun VDC	Bageswori VDC
Bandbhangyanj VDC	Badikhel VDC	Balkot VDC
Chhaimale VDC	Bistachhap VDC	Bhaktapur Municipality
Dharmasthali VDC	Bungmati VDC	Changunarayan VDC
Goldhunga VDC	Chapagaun VDC	Chitapol VDC
Jhormahankal VDC	Chhampi VDC	Dadhikot VDC
Jitpurphedi VDC	Dhapakhel VDC	Duwakot VDC
Kirtipur Municipality (1 to 19)	Godamchaur VDC	Gundu VDC

Kathmandu	Lalitpur	Bhaktapur
Matathirtha VDC	Harisiddhi VDC	Jhaukhel VDC
New Naikaap VDC	Imadol VDC	Katunje VDC
Old Naikaap VDC	Jharuwarasi VDC	MTM (all wards)
Pharping Bhimsensthan VDC	Khokana VDC	Nagarkot VDC
Phutung VDC	Kitini VDC	Nakhel VDC
Sangla VDC	Lamatar VDC : Inside Valley	Sipadol VDC
Satungaal VDC	Lele VDC	Sirutar VDC
Shesnarayan VDC	Lubhu VDC	Sudal VDC
Sinamangal Land Pooling	Saibu (Bhaisepati) VDC	
Sitapahila-Munc	Sanagaun VDC	
Sokhel VDC	Sunakothi VDC	
Suychatar VDC	Thaiba VDC	
Talku Dudechaur VDC	Thecho VDC	
Thankot Mahadev VDC	Tikathali VDC	
Thankot VDC	LSMC (Ward No 1 to 9, 12, 13, 15, 20)	
Tinthana VDC		
Tokha Chandeshwori VDC		
KMC (Ward -13)		
KMC (Ward -14)		
10 to less than 15 times		
Bandbhangyanj VDC	Bistachhap VDC	Bageswori VDC
Dadapauwa VDC	Dhapakhel VDC	Balkot VDC
Dahachowk VDC	Godamchaur VDC	MTM (4, 5, 6)
Goldhunga VDC	Imadol VDC	Nakhel VDC
KMC (Ward -14)	Jharuwarasi VDC	
Suychatar VDC	Lamatar VDC : Inside Valley	
	Thaiba VDC	
	Thecho VDC	
	Tikathali VDC	
	Ward No 19	
	LSMC (Ward No 2, 3, 4, 5)	
15 to less than 20 times		
Chalnakhel VDC		Bageswori VDC
		Sipadol
20 to less than 25 times		
Chalnakhel VDC	LSMC (Ward - 4)	Bageswori VDC
Badbhanjyang VDC		Sipadol

3.1.6. *Building Construction Patterns*

The average permits issued in the last five year (2007-2011) for the construction of buildings in the municipalities is about 6,141. The trend of building permit shows negative trends in KMC and LSMC (17 percent and 7 percent decrease respectively over the last five years). However, in BM, MTM and KM the trend is in increase with average of five year as 16 percent, 4 percent and 6 percent respectively. The five years' average of the building permits in KMC was 4,059 which constituted about 66 percent of the total permits issued in five municipalities.

There could be a number of reasons for the retardation of the building construction in Kathmandu and Lalitpur. One of which could be the changes on lending policy as imposed by Nepal Rastra Bank. The other reason could be the expansion of the building constructions outside the five municipal. The data of the building permits issued by the VDCs could not be obtained, therefore, definitive conclusion could not be drawn whether the construction has actually gone down or shifted from urban area to the fringes. However, on comparisons of temporal satellite images and built-up trend from the land use maps, it is apparent that the building construction pattern has significantly shifted along the fringes of the municipalities beyond their boarders as well as in the internals of the VDCs where there are easy access roads. Table 9 presents the statistics of building permits issued by five municipalities during the period of 2007 to 2011.

Table 9 Building permits issued in last 5 years in municipalities[4]

Municipalities	2007	2008	2009	2010	2011	Total	Average
KMC	6,086	4,439	3,703	3,174	2,891	20,293	4,059
LSMC	1,026	1,050	1,108	747	712	4,643	929
BM	249	352	352	248	287	1,488	298
MTM	366	549	500	433	378	2,226	445
KM	338	406	478	474	407	2,103	421
Total	**8,065**	**6,796**	**6,141**	**5,076**	**4,675**	**30,753**	**6,151**

[Source: from KMC, LSMC, BM, MTM and KM]

3.1.7. *Implementation of Plan and Policies*

Implementation of plan and policies such as land use zoning, transportation policy, development control and investment plans have high capabilities to direct future urban growth. Due to absence of master plan and land use plan of the valley, policies related to land use restrictions and environmental constraints have been considered as the driver of urban change.

3.1.8. *Political Situations*

Political situation of the country in the past two decades has played a vital role for rapid urbanization of the KV. During the decade long conflict, internal migration to KV drastically increased for safety and security reasons, which attributed to the increase of rental and housing units in the valley, especially in the municipal regions. The valley felt a tremendous urban growth at the expense of prime agriculture land around ring road during the period of 1995-2005. Therefore, the loss of agriculture land to the built-up is considered as a proxy of the political influence, since spatially modelling of socio-political factors is rather complex.

3.2. Quantifying Driving Factors and their influences in Urban Growth

Driving factors influence the urban growth at different spatio-temporal scales and their roles as contributors to explaining change dynamics of urban land changes with time (Ahmed, Bramley, and Verburg 2014). Quantifying and representing these drivers of changes requires spatio-temporal modelling of the variables related to the drivers or the proxy variables of the drivers. Spatio-temporal modelling of the direct vari-

4 *Building permit data from VDCs were inconsistent and not available throughout, therefore not presented*

ables of the aforementioned drivers and the proxy variables in case the direct spatial variables were not available.

The driving factors and their influences are categorically assessed using the Analytic Hierarchy Process (AHP), quantified and spatially modelled using Logistic Regression (LR) model.

3.2.1. Analysis of driving factors using AHP method

The Analytic Hierarchy Process (AHP) developed by (Saaty 1988) is one of the most commonly used approaches for multi-criteria decision making processes (Bagheri, Sulaiman, and Vaghefi 2012, Thapa and Murayama 2010, Triantaphyllou and Mann 1995). It allows the users to assess the relative weight of multiple options against given criteria. The relevant data for the analysis are derived by using pairwise comparison which is then used to obtain the relative weights of different criteria. (Saaty 1988) established a consistent way of converting such pairwise comparisons into a set of numbers representing the relative priority of each of the criteria.

One of the strength of the AHP is that it measures the degree of consistency present in subjective judgement made by the decision maker (Thapa and Murayama 2010). The consistency ratio (CR) is a mathematical indicator of the consistency of pairwise comparison. The standard tolerance of CR is less or equal to 0.10. Lower the CR more accurate is the ranking process. In decision making process if CR of the individual matrix or entire matrix is higher than the threshold value, then decision makers should re-check their judgement.

In this study, there were total 32 key informants participated in a workshop and contributed for the assessment and ranking of eight driving factors of urban growth in the valley. However, only 16 interviewee were able to complete the questionnaire or pairwise comparison. Therefore 16 matrices were developed for three different study areas- Municipalities, Urbanizing VDCs and rural VDCs. According to the rule of AHP, reciprocal computation, value normalization, principal vector weights computation and consistency test were performed for each matrices of each zone. All inconsistent matrices were reviewed and adjust the value in such a way that the CR value is below 0.1. Final matrices for each areas received CR within the range of 0.01-0.03 which is far below the threshold value. Then according to final scores the drivers of urban growth are ranked as shown in Table 10.

Table 10 Driving factors from AHP method

Drivers	Core		Urbanizing VDC		Rural VDC	
	Weight	Rank	Weight	Rank	Weight	Rank
Economic opportunities	14.9%	1	11.9%	6	13.0%	3
Population Growth	14.4%	2	13.1%	3	17.3%	1
Access to infrastructure and services	12.5%	4	13.8%	1	15.5%	2
Physical Condition(terrain ,river, environment)	11.2%	5	11.7%	7	11.7%	4
Land market	10.8%	6	12.8%	4	10.6%	7
Plans and policies and their implementations	12.5%	4	12.7%	5	11.6%	5
Political situations	13.1%	3	13.1%	2	11.0%	6
Other social(remittance & traditional values)	10.5%	7	10.9%	8	9.2%	8

Figures 47, 48 and 49 respectively shows the weights of driving factors on urban growth in different thematic zones of the valley according to Key Informant knowlegde. The AHP analysis showed, economic opportunities was the major determinants of urban growth in the core city area which is obvious from the current trend. The centralized economy and concerntration of administrative services has been pulling huge proportion of population from differnt parts of the country which is also shown by differnt studies such as(Central Bureau of Statistics 2008, Nepal Rastra Bank 2012). Consequently, large amount of land has been transformed into built-up area to cater the increasing population and their demand. Therefore, population growth is the second major factor of urban growth in the core area. Similarly, political situation has a weight of 13.10% which shows that the city area has been a shelter for large number of people who have migrated for safety and security. Accessibility to infrastructure/services and plans and policy have equal contribution with 12.5 percent influence. Many facilities such as school, hospital, roads, parks etc. are well established in this zone(Thapa and Murayama 2010). Similarly, there has been lots of infrastructure development projects and redevelopment projects in the core area of the city. The physical condition, land market and others social factors played a weak role compared to others. This may be because of the relatively flat terrain of the city core area and very less area available for the development.

Figure 48 presents the impact of driving factors in Urbanizing VDCs of the valley. Urban growth in urbanizing VDCs are mainly influenced by access to infrastructure and services (13.8 percent). There has been lots of road network extensions and development in this zone. Similarly, large number of educational institutions and hospital building has been emerged in this zone making most part of the area accessible to services. Population growth and political situation have an equal influences of 13.10 percent. Less economic opportunities, extreme poverty and more recently the security situation due to internal conflict in the rural areas has pushed lots of people to migrate to the fringe areas of the valley in search of opportunities and security (Unknown 2010). Therefore these two factors plays a major role for the development of this area. Land market (12.8 percent) and plan and policies (12.7 percent) are another influencing factor of urban growth in this zone. This is because local people, land brokers, and real estate developers are quite active in this zone.

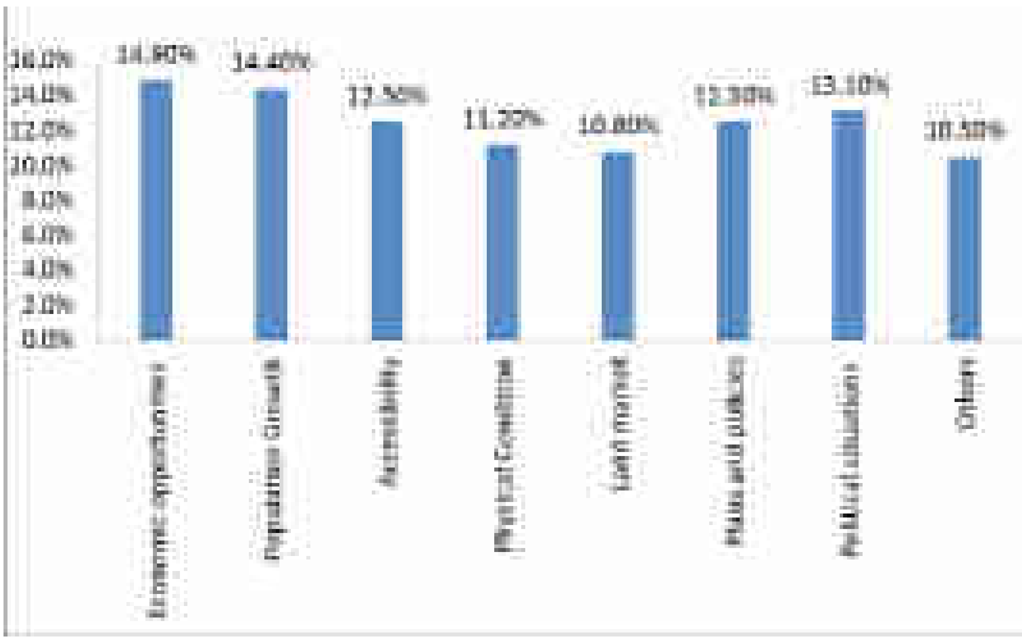


Figure 47 Impact of driving factors for Core area

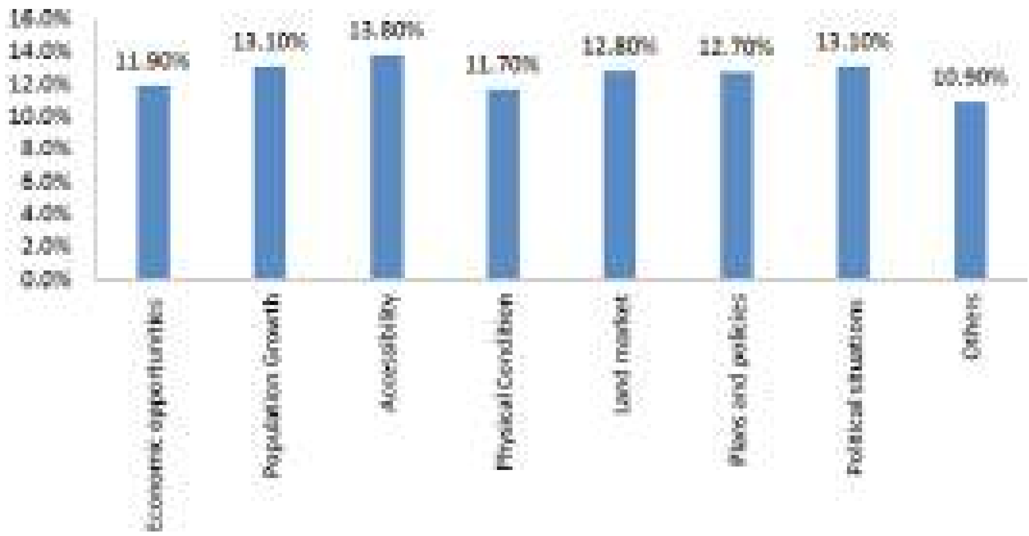


Figure 48 Impact of driving factors for Urbanizing VDCs

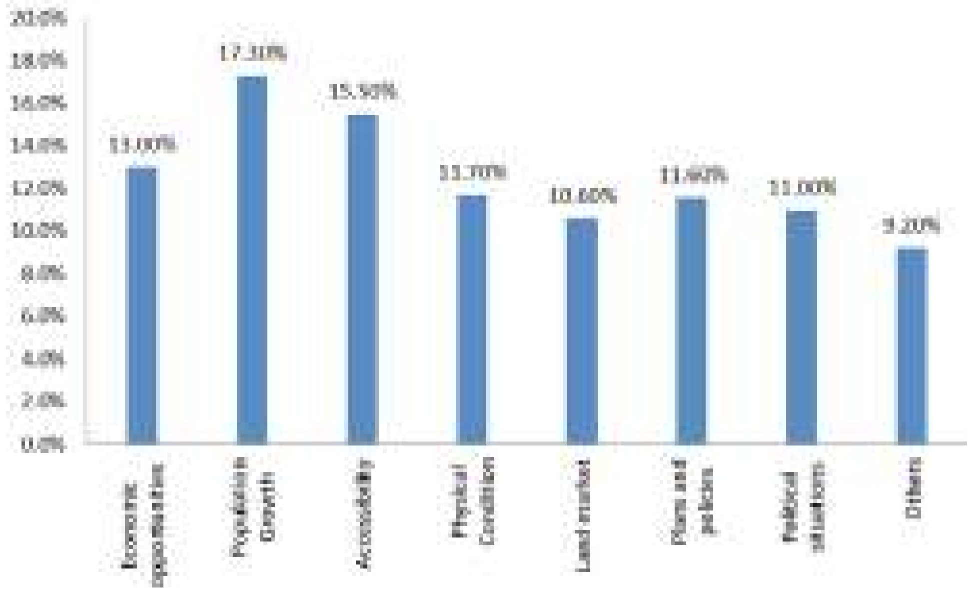


Figure 49 Impact of driving factors for Rural VDCs

3.2.2. Analysis of driving factors using Logistic Regression Model

Different indicators representing the drivers are derived and spatially modelled. These spatially modelled variables (presented in Table 11) are checked for multi-collinearity and spatial auto-correlation to further analyse the variables using Logistic Regression (LR). To quantify the indicators of the drivers following spatial variables were used in LR model.

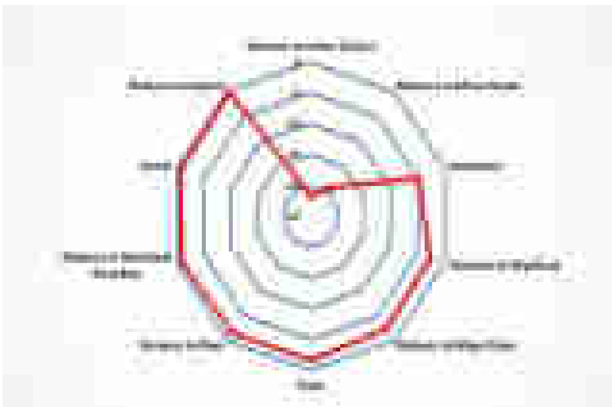


Figure 50 Influence of driving factor with negative correlation with urban growth

The major determinants with negative correlation with urban growth are distance to existing urban cluster and distance to minor roads with the coefficient value -21.6 and -19.2. This indicates that probability of urban growth is higher in the areas closer to these variables. The strong negative relation between urban growth and these factors seems logical in Kathmandu Valley because most of the new settlements are growing at the proximity to the existing urban cluster which is due to human nature to live in cluster rather than in isolated region for the sake of safety or communication. Similarly, most of the growths are observed along the minor roads which are serving as local or service roads rather than along the major road which is one of the interesting findings from this study. It means to construct a house; the household would select the area with road facilities which may serve them for commuting from one place to other. Therefore the model shows that urban growth of the valley has been controlled by road accessibility which is contributing to the spatial pattern of linear urban development along the road networks.

Another interesting finding from the study is the negative relationship between presence of institutions and urban growth. An area tends to have higher probability of urban growth if there no institution which seems logical as urban growth in institutional area is very low or almost nil. Degree of slope has also a negative influence on the growth of settlement which is because of the fact that most of the urban growth is occurring in relatively flat area than in surrounding elevated lands. Similarly other distance related factors such as- distance to ring road, distance to major road, distance to river, distance to municipal boundary, forest and distance to airport have also negative association with urban growth.

Among the factors which have positive influence in urban growth, population density seems to be major determinant with an odds rate (OR) of 43.9 and coefficient 3.78. This indicates that the probability of urban growth is 43.9 times larger when the population density is increased by one unit. In other word, probability of urban growth is higher in areas with higher population density. There is also a significant positive relation between proportion of urban area in a neighbourhood and probability of urban growth. This can be easily observed from the land cover map of 2010 where built-up area in the urban fringe of the valley is mostly clustered around the existing urban areas which indicates that areas with higher proportion of urban areas and higher tendency to develop than areas which have less urban proportion in the surrounding. Similarly, the positive spatial interaction between road density and urban growth reflects that urbanization trend in Kathmandu valley is highly dependent on road accessibility. The probability of urban development is increased by 3.8 times for every unit increase in road density in a particular area. Thus accessibility to road networks is an important determinant of urban growth. Both formally developed housing units and unregulated residential developments are occurring along the road network which is an evident for the significant positive relationship between these components. Other factors like- proportion of agricultural land in a neighbourhood, distance to rural settlement and distance to school are also positively associated with urban growth.

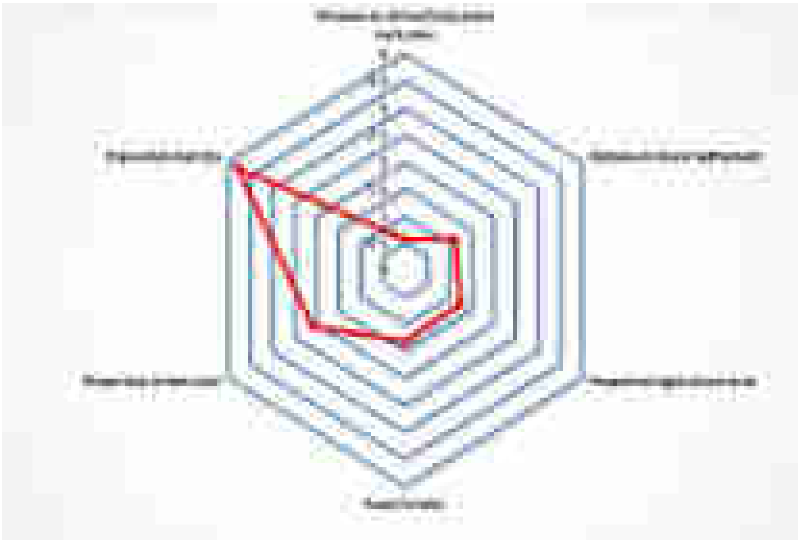


Figure 51 Influence of driving factors with positive correlation with urban growth

Table 11 Spatial variables for the drivers of urban growth in KV

Factors	Variables	Description	Variable Type
Dependent	*y*		
		1-Urban	Binary
		0-Non-urban	
Independent	*x*		
1. Site specific characteristics			
	Slope	Degree of Slope	Continuous
	PopDen	Population density (persons/ sq.km)	Continuous
	Institution	Institutional areas	Categorical
	Forest	Forest	Categorical
2. Proximate factors			
	Dist_RingRd	Distance to Ring road (m)	Continuous
	Dist_Hosp	Distance to Major hospitals (m)	Continuous
	Dist_School	Distance to educational facilities(m)	Continuous
	Dist_MjRd	Distance to major road(m)	Continuous
	Dist_MnRd	Distance to minor road(m)	Continuous
	Dist_MjNodes	Distance to major Nodes(m)	Continuous
	Dist_Urban	Distance to existing urban cluster(m)	Continuous
	Dist_RuralSett	Distance to rural settlements(m)	Continuous
	Dist_River	Distance to rivers(m)	Continuous
	Dist_MunicBo	Distance to municipal boundary(m)	Continuous
	Dist_Airport	Distance to Airport(m)	Continuous
	Dist_CBD	Distance to Central business district(m)	Continuous
3. Neighbourhood factors			
	RoadDen	Density of road (km/sq.km)	Continuous
	Prop_Urban	Proportion of urban area in 42x42 rectangular window	Continuous
	Prop_Agri	Proportion of agricultural area in 42x42 rectangular window	Continuous

4. POLICY REVIEW ON LAND USE PLANNING OF KV- CONTEXT AND CURRENT SITUATION

Various plans have been formulated at different times for sustainable development of Kathmandu Valley with the resources from Government of Nepal or with grants and assistance from donor agencies. Only few of the plans were ever implemented and others were not effective on implementation aspect and some plans still overlaps with the jurisdiction of the other plans and policies. Excerpts of the reviewed plans and policies, which are relevant to land use and planning are briefly presented hereunder.

4.1. Kathmandu Valley Physical Development Plan 2028 (1972)

The Plan prepared by a team of native and expatriate planners with initiation of the United Nations urban planning expert was published by the Department of Housing and Physical Planning in 2028 BS (1972). In preparing the Plan, the previous as well as the current situation of the Valley was studied and strategies and programs were proposed for the future. It recommended the development of settlement in the plain land area (*tar* - तार) and maintenance of greenery in wetland (*dol*- डोल) area according to the geographical structure of the KV.

4.2. Physical Development Plan of Kathmandu Valley 1969

This plan incorporated several aspects of planning such as regional development plan, urban design, settlement development plans and others. The plan envisaged the future development up to twenty and thirty years for balanced development of Kathmandu Valley and formulated short term and long term plans. The plan raised the critical issues related to continuing population pressure in Kathmandu Valley, unplanned urban development, loss of agricultural land and forest and disturbance to the ecology as well as encroachment of historical and cultural sites of the valley.

The plan recommended the interventions such as promoting development in west and south west of the existed urban area in Kathmandu Valley to ease the population pressure in urban areas; promoting development in south and south east direction of Bhaktapur Municipality; construction of road to link the southern part of Lalitpur with the south-western part of Bhaktapur and promoting the development in southern part of the valley.

4.3. Land Use Plan of Kathmandu Valley 2033 (1976)

The Department of Housing and Physical Planning formed a team to prepare a land use plan based on the Physical Development Plan prepared in 2028 BS (1972). The team prepared not only an extensive land use plan but also building construction standards. The Kathmandu Valley Town Development Committee was established in order to enforce the plan; and the offices of the Committee were also set up in Kathmandu, Lalitpur and Bhaktapur districts. In addition, a planning team was formed to render regular technical assistance to the Committee. Development of inner and outer ring road, various residential and protection zones were proposed in the plan. The plan recommended the land use zoning and regulations for coordinated development of Kathmandu Valley. For physical development planning it divided the area of Kathmandu Valley into broadly three different categories in which inner core settlement of Kathmandu and Lalitpur belonged to category "Ka", the settlements adjacent to the existing core settlements of Kathmandu and Lalitpur was termed as category "Kha" and the spread and sparse settlements of Kathmandu Valley which has to be compacted were termed as category "Ga". However, this was not updated regularly and made it rather rigid later due to rapidly transforming development scenario.

4.4. Kathmandu Valley Physical Development Concept 2041 (1984)

The Kathmandu Valley Physical Development Concept 2041 BS (1984), prepared by the Kathmandu Valley Town Planning team, the plan included the updating of land use plan and revised building construction standards. The plan attempted to revise the land use plan of 1976. However the plan could not be approved by the Government of Nepal.

4.5. Kathmandu Valley Urban Land Policy Study 2043 (1986)

The study was carried out with technical assistance of USAID. This Study provided detailed information on matters such as geographical situation, landscape, land use and ownership in the Kathmandu Valley and also prepared policies on the use of available land for urban development. The designs prepared in the course of study were used for various purposes but this policy also could not be implemented.

4.6. Urban Development and Conservation Scheme 2045 (1988)

Under the leadership of Ministry of Housing and Physical planning, the plan launched programs such as conservation of wetlands and river banks in Kathmandu Valley. Similarly land pooling and the guided land development programs were launched under this scheme.

4.7. Kathmandu Valley Urban Development Plan and Program 2048 (1991)

Kathmandu Valley Urban Development Plan and Program was prepared by Department of Housing and Urban Development, with the technical assistance of the Asian Development Bank. The plan analysed causes and effects of the urbanization of the Kathmandu Valley and recommended some of the actions, only few of which were implemented.

The plan recommended that Kathmandu Valley should be regarded as the primary administrative, cultural, tourism, ancient monuments conservation centre and developed likewise. Similarly it stressed on the fact that Kathmandu Valley must be regarded as extended form of Kathmandu City and it should not be the centre of industrial activities. The plan aimed at densification of Kathmandu and Lalitpur settlements and thereby reducing the urban sprawl in the valley, conservation of ecology and agricultural lands in rural part of the valley by developing agricultural economy. Similarly the plan suggested the development of inner ring road area of Kathmandu Valley and restricting development in wetland and adjacent to the rivers and conservation of Phulchoki and Chandagiri watersheds as wildlife reserve.

4.8. Bagmati Basin Water Management Strategy and Investment Program 2051(1994)

Strategies and programs were formulated for the protection and development of the Bagmati watershed area, Program was prepared by the then Ministry of Housing and Physical Planning, with technical grant assistance of the World Bank. A number of matters contained in the study report are incorporated in some projects relating to river training. However, the project could not be implemented.

4.9. Study on Regularization of Urbanization of Kathmandu Valley 2052 (1995)

This Study was carried out with joint effort of the National Planning Commission and International Union for conservation of Nature (IUCN). The study dealt with causes of environmental degradation in Kathmandu Valley and recommended measures for mitigation. However the document was not approved by the government for implementation.

4.10. Environmental Plan and Management of Kathmandu Valley 1999

The study dealt with the environmental and ecological issues in Kathmandu Valley and sustainable ways for development of the valley. The plan identified population growth, loss of agricultural land, location of industries and existing institutional setup as well as weak implementation of plans and policies as the main reason for the degradation of ecology in the valley. The plan suggested that the valley wide programs should be developed with the development slogan as "well managed, healthy and convenient valley". Similarly the plan recommended valley wise land use plan should be developed, restricting the development in high agricultural potential areas, river bank, slope area, environmentally sensitive areas. The plan recommended the establishment of Eco-town in the Kathmandu valley, merging urbanizing VDCs in the existing municipal areas and re-defining the urban boundaries. Improving the road access and developing the master plan for sewerage network. And conserving the entity of traditional settlements in Kathmandu valley.

4.11. Local Self Governance Act (LSGA)

Local Self-Governance Act and regulations provide legal basis for land use planning by local bodies i.e. DDCs VDCs and Municipalities. It stated different functional roles for local bodies in preparation of annual and periodic plans. The functions and duties of VDCs include reference to physical development in order to prepare criteria for houses, buildings, roads and other physical infrastructures etc. to be constructed within the village development area, and to grant approval as prescribed for the construction of them. Formulate land-utilization plans of the village and to implement or cause to be implemented the same. For which purpose VDCs are empowered to prepare by-laws as required. The role of municipality relating to physical development plan include to frame land-use map of the Municipality area and specify and implement or cause to be implemented, the industrial, residential, agricultural, recreational areas etc. Develop green zones, parks and recreational areas in various places in the Municipality area and approve or cause to be approved designs of houses, buildings etc. to be constructed in the areas of the Municipality. In addition to the functions, the Municipality may also perform the optional functions in the Municipality area such as to control unplanned settlement within the Municipality area and to make the structure and development of the town well-planned through the functions such as GLD and land pooling schemes. With respect to land use planning the three DDCs within the Valley have no specific functions other than to prepare district level subject-wise programmes to be operated in the VDCs. DDCs also have to prepare annual and periodic programmes as well as a resource map. In addition DDCs are required to prepare a master plan of district-level roads, paths and bridges as well as construct and maintain them.

4.12. Town Development Act

The Act provides the legal basis for town planning to occur in any area designated as a "Town planning area". Town planning is seen as an activity focussed on a particular area, to achieve an end result, such as land pooling or guided land development. As such the Act is the means for a Town Development Committee to carry out the function of "town planning" within a designated area. The Act is not designed to support town planning as a process, applicable to a wider area, such as Kathmandu Valley. Act is effective and many municipalities elsewhere established Town Development Committees to tackle urban issues, and third amendment to the Act (paragraph 3A) enabled municipalities to use the Act providing that activities were approved by the concerned Town Development Committee (or the then Department of Housing and Urban Development in the event that there was no committee). Despite the provisions contained in paragraph 3, "the committee may formulate town planning to carry physical development of a town in an integrated manner, in any part of Nepal, and to determine land uses in a (designated) area", the Act is not sufficiently robust to enable comprehensive land use planning within an entire town or valley.

4.13. Kathmandu Development Authority Act

This Act was approved in 1988 and was not utilised until recently in 2012 when KVTDC is dissolved to form Kathmandu Valley development authority. This Act concerns the establishment of the Kathmandu Valley Development Authority, whose functions shall pertain to land use planning, the development in land-use areas and the prescription of methods of construction works, the formulation and implementation for the development and maintenance of cultural heritage, the protection and conservation of the environment and natural resources. Subsequent sections establish all the powers given to the Authority in connection with its functions. The Kathmandu Valley Development Authority has the power to: (a) impose by public notice a ban on any type of physical change in any property within the area prescribed for a period not exceeding three years; (b) stop any action taken without prior approval or in violation of the given terms and conditions; (c) undertake land development programs for the purpose of arranging residential plots and other urban activities; (d) mobilize financial resources, upon approval of the Government in order to meet necessary expenses. Organs of the Kathmandu Valley Development Authority are: the Kathmandu Valley Development Board whose functions pertain to the policy making and the evaluation of the progress achieved in the implementation of the plan, and the Board of Directors for the direction, supervision and management of the operations of the Kathmandu Valley Development Authority. Furthermore, the Act states the composition and rules of procedures of said organs. Final provisions concern the settlement of disputes, the powers of the Government and the penalties to be enforced in case of contravention.

4.14. National Urban Policy 2064 (2007)

National urban policy of Nepal has the objectives to promote a balanced urban structure, sustainable urban environment and effective urban management. The national urban policy views urban centres as catalysts for economic development and places the role of local governments at the core of urban development agenda, while recognizing that investments have not kept in pace with the urban growth.

National Urban policy unlike other plans and policies have significantly given concern over disaster risk reduction and mitigation planning in Nepal. National Urban Policy 2064 in its Clause 4.2.9 related to the strategy 3.2.9 deals with the mitigation of loss due to natural disasters by adopting the trend of developing disaster management plan at local level and states the responsibility of local bodies to prepare the disaster management plan to mitigate the loss during the natural hazards. Similarly article "Ka" under the same clause deals with the role of the local body to develop the methodology for construction of safe, affordable and environmentally viable buildings. Article "kha" states the role of local body to foster the locally available traditional knowledge and skills in relation to alternative building construction materials and alternative technologies. Article "Ga" deals with updating the existing building codes in periodic manner and implementing it for the construction of governmental, private and public service buildings. Article "Gha" states the role of local body to restrict development in environmentally sensitive areas and article "Na" states the role of municipality to encourage and direct all the local bodies for developing their own action plan and implementation of the plan against vulnerability due to disasters such as earthquake, landslide and fire. Finally article "Cha" states about community mobilization and rising awareness in local level in relation to mitigation of natural hazards in local level through the initiation of local bodies.

4.15. National Land Use Policy 2069 (2012)

The need for national land use policy was envisaged for the optimum use of land, land classification and development of country in social, environment and economic aspects through land use planning. Similarly for identification of safe areas for residential, agricultural and industrial activities with infrastructural facilities with proper consideration to sustainability of the environment. For Conservation of water recharge areas, forest areas, water sources and eco-diversity and wildlife habitat areas and for Identification of potential environmentally sensitive areas for landslide, flood prone areas and act towards mitigating the adverse impacts. The national land use policy has a vision for optimum use of the land resource for sustainable development of country through development in social, economic and environmental development. The National land use policy of Nepal has set the goal for ten years to classify all the land units in Nepal according to topography, capacity, utility and need, and five years goal for completing the same for municipal area, district headquarters, urbanizing VDCs and land adjacent to major roads. Similarly the policy has a goal for establishing new institutional setup for monitoring, management and regularization of land units according to the aforementioned classification within two years of time.

The national land use policy has put forward seven policies such as classification of land according to agricultural areas, residential areas, commercial areas, industrial areas, forest area, public utility area and others. The use of land should strictly follow the land classification system and to restore 40 percent of the total land as forest, the governmental land will be conserved. Government has the power to acquire any land for expansion of infrastructure. In order to limit the fragmentation of land and to promote the coordinated urban development, the land development schemes like land pooling will be implemented. To maintain the balance between development and environment, land in urban areas will be declared as open space and green areas. The environmental sensitive areas will be identified and conserved. The projects will be launched with due consideration to sustainable development approaches as well as implications to climate change and development of settlement areas in hazard prone areas will be demotivated. The sites related to culturally, historically and religiously important areas and tourism destination will be conserved and maintained. Land use planning will be implemented in coordination with the land use policy and hierarchy based land use planning will be launched. The land use classification will correspond to the land taxation system and minimum land valuation. The land use will be considered for its optimum use and return and vacant land and barren land will be converted to other uses.

4.16. Long Term Development Concept Plan of Kathmandu Valley 2000

The Long Term Development Concept Plan (LTDP) of Kathmandu Valley was prepared by Kathmandu Valley Town Development Committee (now Kathmandu Valley Development Authority-KVDA) in July 2000 and was approved by Government of Nepal in 2002. This plan envisaged the strategies for development of Kathmandu Valley in 2020 and also analysed the drawbacks of the other plans and policies of the past. The study recommended several strategies for planning Kathmandu with the vision of 2020 such as development initiatives in regional context, development nodes, interrelation of land-use and transportation, efficient land use planning and conservation of agricultural areas, easy transportation based planning, accessibility to public open space, settlement expansion with infrastructural facility and improving the carrying capacity of the valley. The details of the strategy review are presented in Chapter 5 of this report. The plan attempts to deal the scenarios of valley in holistic approach but due to haphazard urban sprawl and political instability of recent past, the 2020 vision seems unattainable and requires major review and updating.

4.16.1. LTDP Strategy

The LTDP had proposed following policy for development in KV:

a) To convert KVTDC into the Regional Planning Institution for Kathmandu Valley with the proportionate representation of local authorities and the plans need to be approved from there.
b) To decentralize the employment and investment opportunities to the urban fringe areas according to the carrying capacity of each municipality or VDC.
c) To specifically delineate the boundary of Urban and Rural areas in order to protect the agricultural land. Urban infrastructure to be limited in the urban areas only.
d) To concentrate the large investments in the designated areas only, scattered development will be discouraged.
e) Environmental Impact Assessment will be made mandatory for large projects.
f) Tourism service industries to be promoted for the economic development of the valley.
g) Environmentally vulnerable industries like carpet (dying/ washing) and brick kilns will be displaced from the valley.
h) To develop Bhaktapur as the heritage city of ethnic Nepalese arts and culture.
i) To develop the entire valley as a singular administrative entity and district level development committees will be merged to the Valley Administrative Unit.
j) To develop public parks and open spaces by protecting the public land
k) To displace the Army and Police Barracks to the periphery of the valley.

4.16.2. Land Use Pattern

According to long term development plan of Kathmandu Valley for 2020, analysing the land use trend of Kathmandu Valley for three decades, it was observed that there is a rapid decrease in agricultural areas inside the valley on the contrary to which, the non-agricultural land use was observed to have risen throughout that period. The long term development concept plan categorized land use of Kathmandu Valley under following classes as presented in Table 12.

Table 12 Land Use categories proposed by LTDCP 2020

SN	Land Use Classes
1	Agriculture
2	Forest
3	Non agriculture
3.1	Urban area
3.1.1	Residential
3.1.2	Mixed residential and commercial
3.1.3	Commercial
3.1.4	Industrial
3.1.5	Institutional
3.1.6	Army
3.1.7	Public utility
3.1.8	Transportation
3.1.9	Special Area
3.1.10	Recreational/ Open spaces
3.2	Rural Area
3.2.1	Residential
3.2.2	Old Settlement
3.3	Water body
3.4	Others / Barren land / Airport

Buildings and other structures are built in either side of the major roads in the valley. The current land use trend reveals that rural settlements are scattered and building works are being done around such settlements in an unplanned manner. Consequently, agricultural land is gradually being decreased.

The agriculture land in the valley has a great importance. Its multitude aspects are as follows:

- The agricultural sector is the life support of the Valley habitants because it contributes to maintain bio-diversity including human life. It has also helped to protect underground water in order to mitigate air and water pollution and manage solid wastes.
- The agricultural sector is the main stay of the economy of the Valley, which yields an ample amount of grains, vegetables and other cash crops.
- The agricultural sector is related with the cultural heritage of the Valley inhabitants. Various festivals and social rites and rituals are related with agriculture.

The LTDCP 2020 forecasted that if the trend of urbanization continued, it is forecasted that there will be no agricultural land by 2082 B.S. (2025). Consequently, it will have serious impact on the cultural and economic activities of the Valley inhabitants. Preventive measures include agriculture zoning; non-investment in construction works in the agricultural area; and provision of relief and facility to the farmer. The precautionary measures include development of infrastructures in the barren land to increase population density in the existing urban area and shifting elsewhere the military camps and brick factories located in the urban area.

4.16.3. Residential Density

The residential density was considered as an important element for urban development. Criminal activities, unhealthy environment and social distortions appear in a highly dense city. But the streets in the place with high density appear to be safer than those in the place with low density. The constraint of land in the Valley is one reason for encouraging the higher density. Various kinds of analysis revealed that density of the 500 persons per hectare is economically optimum. Building a 3-storey house in a housing plot, with an area of 4 Anna, for two households could help maintain that density. A substantially big effort has to be made in order to raise the current low density to the optimum level.

4.16.4. Transportation

According to LTDCP, the substantial investment has already been made on roads even though they are insufficient in terms of standards. In order to improve transportation, it is required to reduce congestion level on the street immediately, to mitigate air pollution, to encourage pedestrian walking, to improve the neighbourhood access and to increase public transport facilities. Priority should be given to improvement of internal roads and improvement of the surface of important urban roads so as to improve the situation of transport in the future. In doing so, undeveloped areas and open spaces and the places where there is no wider road and there is difficulty with movement should be chosen. Moreover, service tracks should be improved in either side of the ring road and widened to facilitate movement. Equally important is to build the proposed inner ring road and prohibit motor vehicles on the inner roads. It is necessary to develop parking facilities in proper places in order to have pedestrian walking on inner roads and to have proper management of vehicles in other areas. In building new roads in the future, goals should be to concentrate development and works in proper places and provide employment and services and facilities in those areas. This could lessen movement of people from the rural area to the city core. Establishment of such service centers will not only reduce the pressure of traffic on the ring road and main urban roads but also facilitate expansion of city, which becomes contrary to the principle to control urban expansion. It is imperative to pay attention to these matters in determining alignment of by-pass roads or connect roads to be built in the future. In this context, electric light rail transit could be a reliable alternative of public transport.

4.16.5. Land Requirements

LTDCP estimates that 3600 hectares of land will be required for the next 20 years at the rate of 300 persons per hectare. If the current trend of urbanization continues, one fourth thereof will be required; it is, therefore, necessary that agriculture land be conserved by pursuing a number of policy measures. It is essential to increase density of population in the ring road and neighbourhood areas and utilize the land effectively by building multi- storied residential buildings. For this, the trend of one-person-one-plot and the owner-built system should be gradually discouraged in residential uses. In addition, equally important is to develop urban areas outside the Valley to reduce the pressure of migration.

4.16.6. Review of LTDCP Implementation Plan

LTDCP has identified and proposed these priority programs for integrated development of KV:

Harisiddhi Town Development Program

To develop 713 ha (14,000 ropani) of land for residential lot to accommodate 150,000 people, with the density of 210 ppha, by taking Harisiddhi, Imadol, Siddhipur and Thaiba VDC.

Current Status: Feasibility study was carried out by Institute of Engineering

Conservation of Rivers

The right of way of the rivers flowing through Kathmandu will be delineated on the basis of 100 years' return flows. The sand extractions, solid waste dumping, sewer connections, squatter settlements along river will be strictly prohibited. The rivers will be environmentally protected.

Current Status: A High Powered Steering Committee for the Protection of Bagmati River has been constituted. Detail design regarding conservation is being carried out by the consultants in the support of ADB. The squatter settlements have been evacuated at various places; most recently in Thapathali area, behind Maternity Hospital. The physical improvement works to start soon.

Conservation of Forest and Watersheds

The forest and natural water sources within 20 km. range from Kathmandu will be conserved for the protection of water sources, landslides and develop the areas for tourism attractions.

Melamchi Water Supply Project
The project aims to supply 170 ml/day of water in the Kathmandu Valley from Melamchi River through 27 km tunnel and transmission system.

Current Status: Construction works underway. The project is not expected before 2017.

Conservation of Cultural Heritage and Historic Settlements
Programs will be developed to conserve the cultural, religious and tourist sites.

Improvement and Extension of Ring Road and Highways
Service roads beside the ring road will be developed. Several parking lots and pedestrianization in the core city area will be developed. The arterial roads will be widened and improved.

Current Status: Kathmandu Sustainable Urban Transport Project (KSUTP) is already on floor and the detail plans to improve the traffic, public transport and the vehicular emissions are being carried out by the consultants. Similarly, the improvement of the footpath, drainage, courtyards in the inner city core has also started under KSUTP as separate package. Kathmandu Valley Town Development Committee (now Kathmandu Valley Urban Development Authority) has been widening the internal roads in a massive scale.

Chapagaon-Budhanilkantha Link Road
In order to provide additional access from the south of the city to the north, the Chapagaon-Budhnilkantha road via Harisiddhi, Lubhu, Dadhikot, Thimi and Gokarna, will be developed. This will help relieve traffic in the Satdobato - Koteshwor-Chabahil-Maharajgunj section of the ring road. This road will benefit to the people living in the urban fringes in the south east of Kathmandu. The road may be extended further east to connect to proposed fast track to Terai.

Current Status: An Outer Ring Road (ORR) has later been proposed to compliment the program. The ORR, 72 km in length, has been proposed to pass through the old settlements near foothills around the valley. The area for the ring road (50m wide) is proposed to get through land pooling, and 250m strip on the both sides of the road is proposed for residential/ commercial lots development. The detailed design of most of ORR is complete. Process to obtain Landowners' consensus to implement the project is being carried out currently.

Wastewater Management
The domestic wastewater will be collected and conveyed through the trunk sewers and taken to the treatment plant before discharging to the river. Direct discharge to the rivers will be strictly prohibited.

Current Status: No progress, except Bagmati Conservation Program, has been observed so far. In the contrary, more sewers are being taken to the rivers to discharge without treatment

4.17. Proposed LTDCP 2020 Land Use Plan Vs Present Land Use

4.17.1. Land-use and Transport Inter-Relationship

According to LTDP 2020, a good co-ordination between transportation and its surrounding land use can help to guide better urban development in the future. Along with the change in land use pattern, development of new road or extension/widening of existing road can also increase the number of vehicle in the road. Therefore allocation of different institutes, school, health facilities, airport etc. and their interconnection by the transport networks should be well planned.

However the land use map of 2000 and 2012 reveals that the settlement is mainly clustered in the areas where there is presence of minor roads such as- local roads, service roads and access roads without following any organized pattern and planned development. As distance increases away from these roads the urban growth tends to decline. Many roads which might have been started as footpaths were converted into motorable tracts. This is because of the opportunities related to closer proximity to road-networks which force the residents to locate their house near the transport facilities. Therefore locating closer to transport facilities is one of the important priorities to decide where to locate settlements in many urbanizing VDCs in Kathmandu valley. In other words, households select the locations that reduce their travel time and hence concentration of settlement along the road networks.

4.17.2. Efficient Land Use Plan and Conservation of Agricultural Areas

Efficient land use plan not only guide the future shape of the city but also helps in sustainable development and management of urban development. In order to prevent the uncontrolled growth of the city and to protect the fertile agricultural land LTDP has proposed the densification of existing city area by proper development of the vacant lands. However it can be observed that due to absent of land use plan, the city is expanding further and further out by consuming the prime agricultural land especially in the fringe area (refer Figure 53). Within the decade of 2000-2012, around 13.2 percent of agricultural has been lost due to horizontal expansion of the city. If this trend continues, it can be imagine that within 2020 and 2030 huge amount of productive land will be developed into built-up area.

4.17.3. Formulation of Plan based on Easy Transport Linkage

Rapid urban expansion coupled with unmanaged settlement development has led to various problems such as-pollution, congestion, loss of natural and cultural heritage, haphazard solid waste disposal, etc. In addition to growing urban population it has also led to increasing demand for infrastructure and services. In this regard, transport linkage between different settlements can play a major role to reduce the size of services to be distributed for the increasing demand of population. LTDP has proposed the densification of settlements in different parts of the valley by enhancing interaction and easy accessibility between the settlements. This will be achieved by encouraging mix land use or generating employment opportunities at closer proximity to the residential zone which ultimately helps to reduce the traffic volume in the road. In addition, it will encourage people to commute to their workplace by walking or cycling and protect the environment from getting polluted.

4.17.4. Accessibility to Open Space

Excessive unplanned urban growth can lead to loss of natural open spaces causing vulnerabilities and impacts on urban environments. Therefore the preservation of open spaces has become an important topic in many regions around the world (Geoghegan 2002)(Geoghegan 2002)(Geoghegan 2002)(Geoghegan 2002)(Geoghegan 2002). It has associated with its many potential public goods, such as aesthetic, recreational, aid on emergency situations etc. In this respect, LTDP 2020 proposed to preserve river banks and other unsuitable areas for urban development such as- steep lands as open spaces for ecological balance of the nature.

However, it can be observed that built-up areas have tremendously increased along the river bank within the decade of 2000-2010. Moreover, both private and public open spaces such as- residential or local open spaces, open areas in agricultural areas have been in-filled with new constructions. This has resulted into lack of green spaces and poor accessibility to open spaces for the people in that neighbourhood. Nevertheless, to protect the remaining open spaces for humanitarian purposes, recently International Organization for Migration (IOM) in co-ordination with Government of Nepal has identified open spaces in 83 sites over the entire valley which can be seen in Figure 52.

Figure 52 Open spaces and their connectivity

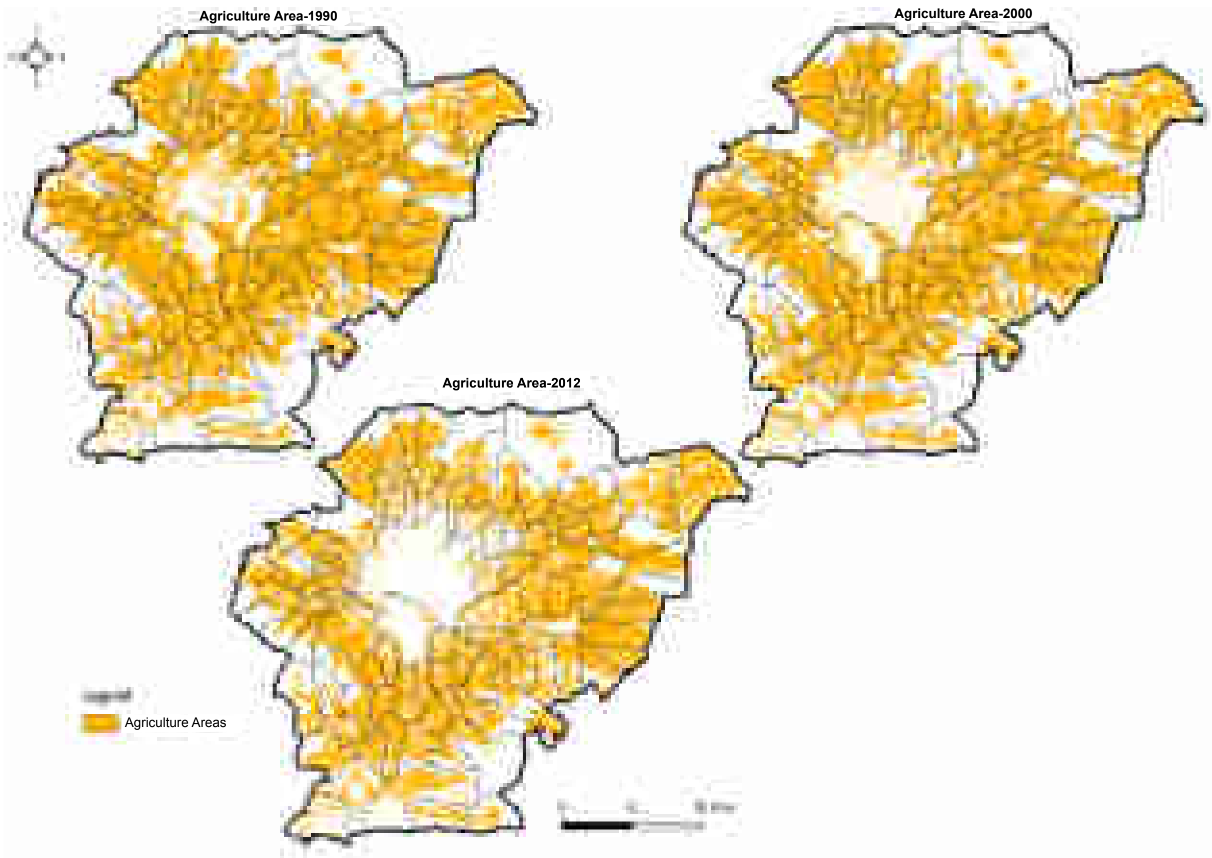


Figure 53 Agriculture land in KV (1990, 2000 & 2012)

4.17.5. Settlement with Physical Facilities

For the proper development of urban area it is mandatory to plan the physical environment of the area beforehand. In this regards, LTDP 2020 proposed to preserve the natural environments with minimum facilities such as- road, drinking water, drainage and sewerage facilities including social facilities such as- school, hospitals, police station, economic centres etc. for the proper urban development.

Conversely, it can be observed that during 2000-2012, urban expansion is not limited in area with such facilities but further expanded in those areas where there are no such facilities at all. For example Saibu VDC which is one of the fast urbanizing VDC in Kathmandu valley has still lots of people who do not have access to sewerage and drainage system. Therefore most of the household still depends upon conventional system (septic tank) for the sewage disposal. Likewise, many other VDCs have similar picture.

4.17.6. Carrying Capacity

In order to meet the growing demand of infrastructure and services, and to improve the haphazard urbanization of the valley, Kathmandu valley Development Authority (KVDA) has recently proposed the new concept of Integrated Urban Service Centre (IUSC) in different location of the city. It is an approach which facilitates the urban services in proper location to consume fewer resources, emit less pollution and is more sustainable in general (KVDA 2070)(KVDA 2070)(KVDA 2070)(KVDA 2070)(KVDA 2070). The feasibility study for this approach has been carried out in different locations- such as- Bagmati area, Chakrapath area, Sanepa area, Pulchowk area, Balkhu-Kuleshwor area, Kalanki-Kalimati area, Koteshwor-baneshwor area etc. One of the intent of this approach is to restrain the population pressure within the carrying capacity of the urban areas.

Similarly, LTDP 2020 also proposed similar concept in its development strategy to increase the carrying capacity of the valley by construction of high rise buildings for institutional and commercial activities, high rise apartments for residential purpose and encourage mix land use.

5. MULTI-HAZARD AND VULNERABILITY IN KV

5.1. Geology and Regional Tectonics

5.1.1. Geology

The entire range of Himalayas extends for about 2,400 km from Nanga Parbat (8,125m) in the west to Namcha Barwa (7,755m) in the east with 200 – 250 km width. The Himalayan range shows a convex southward bend and terminates on both east and west ends with two remarkable syntaxes (Sharma 1990). Gansser (1964) divided the Himalayas into five divisions from west to east following geographical as well as political boundaries (Gansser 1964), namely, Punjab Himalaya (550 km), Kumaon Himalaya (320 km), Nepal Himalaya (800 km), Sikkim-Bhutan Himalaya (400 km), and NEFA (North-East Frontier Assembly) Himalaya (400 km). Among these, the Nepal Himalayas covers about one-third of the total length of entire Himalayan range extending from Mahakali River in the west to Mechi River in the east.

The Nepal Himalayas *(Figure 54)* is divided into following five major geological zones from south to north, respectively (Amatya and Jnawali 1994, Hagen 1968):

- Terai Zone
- Sub Himalayan (Siwaliks) Zone
- Lesser Himalayan Zone
- Higher Himalayan Zone, and
- Tibetan-Tethys Zone

Terai Zone

It is the southernmost geological unit of Nepal Himalaya. It is characterized by the fluvial sediments that are derived from the northern mountainous region. It is also defined as the northern extension of the Indo-Gangetic Plain.

Sub Himalayan (Siwaliks) Zone

It extends throughout the country from east to west, and demarcated by the Main Frontal Thrust (MFT) to the south and by the Main Boundary Thrust (MBT) to the north, respectively. The Siwaliks split in Dang and Chitwan area forming dun valleys. The Siwaliks consists of fine to very coarse sized molasses-like fluvial sedimentary deposits demonstrating the uplifting history of the Himalaya (Gansser, 1964).

Lesser Himalayan Zone

This zone lies between the Siwaliks and Higher Himalaya and forms the hanging wall of the MBT and the footwall of the Main Central Thrust (MCT). It comprises Precambrian low-grade metamorphic rocks, also called as metasedimentary rocks. This zone also comprises many complex structures such as folds, faults, nappes, and klippes showing a complicated tectonism.

Higher Himalayan Zone

It is separated from the Lesser Himalayan Zone by the MCT in the south and extends to the Tibetan-Tethys Zone in the north running throughout the country. This zone comprises medium to high-grade metamorphic rocks such as banded and augen gneiss, marble, and migmatites. The South Tibetan Detachment System (STDS) separates it from the Tibetan-Tethys Zone in the north.

Tibetan-Tethys Zone

It begins from the top of the Higher Himalayan Zone and reaches to the north in Tibet. This zone comprises highly fossiliferous calcareous sedimentary rocks of Palaeozoic to Miocene age. In Nepal, the Tibetan Tethys rocks are well exposed in the Thak Khola (Mustang), Manang, and Dolpa area. Due to thrust, some rocks belonging to the Tibetan Tethys Zone are also exposed on the top of southern hills of the Kathmandu Valley.

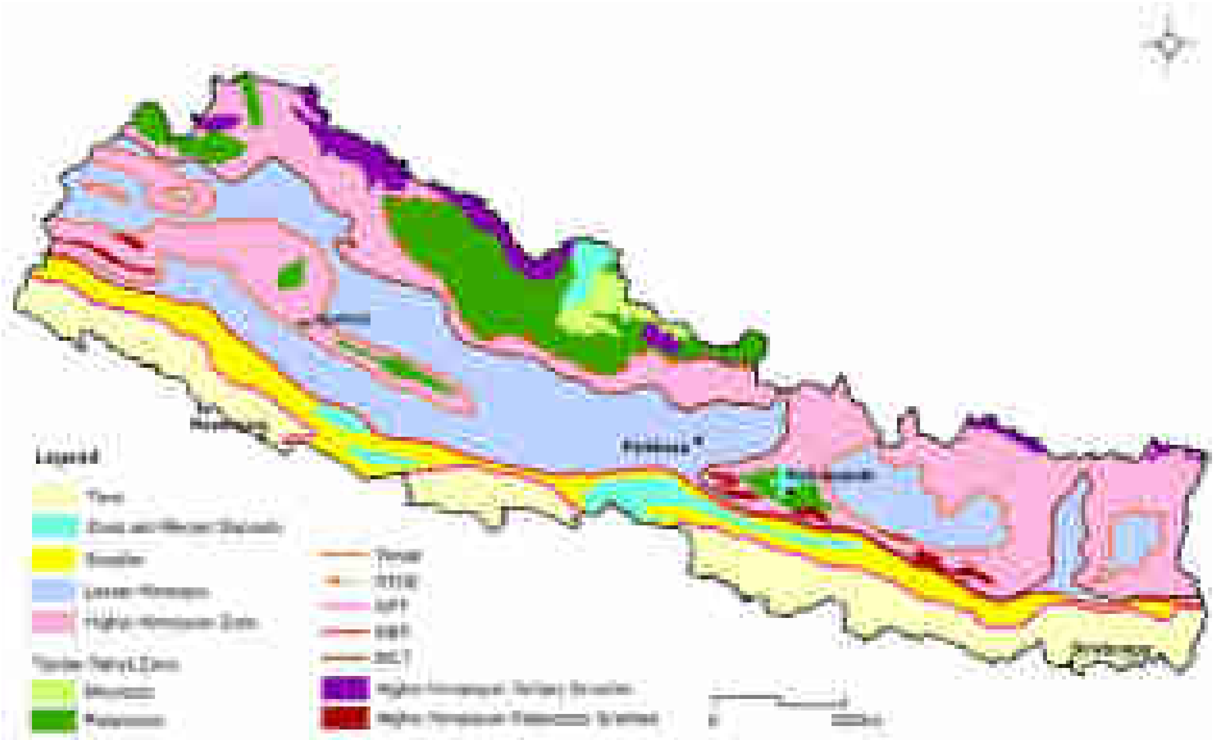


Figure 54 Geological Map of Nepal (Amatya & Jnawali, 1994)

5.1.2. Regional Tectonics and Structural Setting

Nepal Himalaya, being a dynamic mountain, there are numbers of geological structures present. Different types of folds, faults, and thrusts can be observed in regional scale and extending throughout the country. There are four principal thrusts/faults that separate different geological zones regionally in the Nepal Himalaya *(Figure 54)*.

Main Frontal Thrust (MFT) – It is also called as Himalayan Frontal Thrust (HFT). It separates the unconsolidated loose sedimentary deposits of Terai Zone in the south with young and immature sedimentary rock sequence of Siwaliks in the north. It is the youngest tectonic unit existed in the Himalayan range.

Main Boundary Thrust (MBT) – It separates the Siwaliks in the south with comparatively matured sedimentary and meta-sedimentary rocks of the Lesser Himalaya in the north.

Main Central Thrust (MCT) – It separates the Lesser Himalayan rocks with highly metamorphosed Higher Himalayan rocks. The MCT does not look to be extended from west to east in a linear trend like MBT and HFT. Instead, windows, nappes, and klippes have been developed by the MCT.

South Tibetan Detachment System (STDS) – It is not a single thrust /fault like other three thrusts, but it comprises several normal faults that are developed from west to east of Nepal. It separates the sedimentary rocks formed in the Tethys basin during the formation of Himalayas from the high-grade metamorphic rocks of Higher Himalayas.

Among these major thrusts/faults, MBT and MFT are most active and have potential to produce large earthquakes in the future. Besides these major faults, there are several local active faults that extend locally in any directions with different slip amount.

5.1.3. Local Geology and Structural Settings

The geology of Kathmandu valley is classified into two categories: hard basement rocks and soft sediments. The Kathmandu Valley has formed a basin where the peripheral hilly area comprises low to medium grade metamorphic rocks and intrusive rocks belonging to Lesser Himalayas as well as sedimentary rocks equivalent to Tibetan Tethys Zone (Stöcklin and Bhattarai 1977). The stratigraphy of the Kathmandu Valley can be divided into two groups namely, the Bhimphedi Group and Phulchowki Group of the Kathmandu Complex (Stöcklin 1980, Stöcklin and Bhattarai 1977) Precambrian metamorphic rocks are transitionally changed to middle Palaeozoic sedimentary rocks that are equivalent to the Tibetan-Tethys Zone on the upper part (Stöcklin 1980). Except in the periphery, bedrocks are presented in the form of small isolated hillocks within the soft sediment of basin such as in Balkhu, Swayambhu, and Pasupatinath. The stratigraphy basement rocks with main constituents is presented in table *Table 13*.

Table 13 Stratigraphic subdivisions of the hard rock (Stöcklin 1980, Stöcklin and Bhattarai 1977)

<table>
<tr><th>Rock unit</th><th>Group</th><th>Formation</th><th>Thickness (m)</th><th>Main Lithology</th><th>Age</th></tr>
<tr><td rowspan="8">Kathmandu Complex</td><td rowspan="5">PHULCHOWKI GROUP</td><td>Godavari Limestone</td><td>300</td><td>Limestone, dolomite</td><td>Devonian</td></tr>
<tr><td>Chitlang Formation</td><td>1000</td><td>Slate</td><td>Silurian</td></tr>
<tr><td>Chandragiri Limestone</td><td>2000</td><td>Limestone</td><td>Ordovician</td></tr>
<tr><td>Sopyang Formation</td><td>200</td><td>Slate, Calc-phyllite</td><td rowspan="2">Cambrian</td></tr>
<tr><td>Tistung Formation</td><td>3000</td><td>Metasandstone</td></tr>
<tr><td colspan="5">T R A N S I T I O N</td></tr>
<tr><td rowspan="2">BHIMPHEDI GROUP</td><td>Markhu Formation</td><td>1000</td><td>Marble, Schist</td><td rowspan="2">Precambrian</td></tr>
<tr><td>Kulikhani Formation</td><td>2000</td><td>Quartzite, Schist</td></tr>
</table>

The central part of the valley comprises semi-consolidated fluvio-lacustrine sediments. The depth of valley sediments is more than 650 m. at the central part of the valley, under Baneshwor, which gradually decreases towards the marginal ends (Moribayashi & Maruo, 1980). The oldest sediments found in the basin are reported of Plio-Pleistocene age (~5 to 2.5 million years ago), while the youngest sequence deposited in about 11000 years ago. The soft sediments are distributed on the central part of the valley covering about half (~49.4 percent) of the entire Kathmandu Valley. The soft sediments can be categorized into three units: Alluvial fan and talus deposits, Fluvio-lacustrine deposits, and recent floodplain deposits. The details of geological divisions found in the Kathmandu Valley are presented in *Table 14*.

Table 14 Lithological succession of the soft sediments in Kathmandu Valley (DMG 1998)

Formation	Thickness (m)	Main Lithology	Age
Alluvial Fan Deposit	Varies	Gravel, sandy gravel, sand, and silt	
Tokha Formation	200	Well-graded sandy gravel, peaty clay and lignite	
Gokarna Formation	300	Fine laminated poorly graded silty sand, gravel	
Chapagaun Formation	110	Silty sandy gravel with occasionally boulder beds	
Kalimati Formation	450	Organic clay, fine sand beds and peat	
Kobgaun Formation	50	Fine sand, silty sand and poorly graded gravel	
Lukundol Formation	80	Sandy, clayey silt with gravel and clayey sand	
Basal Boulder Bed	100	Boulder conglomerate with sand and silt	Pleistocene

The Mahabharat Synclinorium is a well-known fold system, which is the main generator of the Kathmandu basin. The axis of synclinorium trends WNW–ESE and runs parallel to the ridgeline of the Chandragiri Range, but observed on about 500 m south from the ridgeline. This synclinal fold is also named as Chandragiri Syncline ((Stöcklin and Bhattarai 1977). There is a local anticline fold observed between Tinthana and Kirtipur trending WNW–ESE, but its western continuation is covered with valley sediments. Besides the folds, there are local faults occurred in the Kathmandu Valley. A large fault named Kalphu Khola Fault runs almost east-west direction through the northern part of valley. It has produced a faulted topography with horst and graben structure (Sakai 2001). This Kalphu Khola Fault seems equivalent to the MCT reported by (Rai 2001). Sakai (Sakai 2001) has recognized two active local faults in the southwest of the valley, namely the Chandragiri Fault and the Chobhar Fault (Sakai 2001). The Chandragiri Fault passes through the Bosan Khola on the northern foothill of the Chandragiri Range, while the Chobhar Faultch passes through the north of the hillocks of Chobhar and Kirtipur. Similarly, Sakai (2001) presented some more longitudinal faults extending west-east, such as through Pasupatinath, Swayabhu, and Balkhu, and one transform fault near to Danuwargaun (Arita et al. 1973, Saijo et al. 1995, Yagi et al. 2000) The faults reported in the Kathmandu Valley are shown in *Figure 56*.

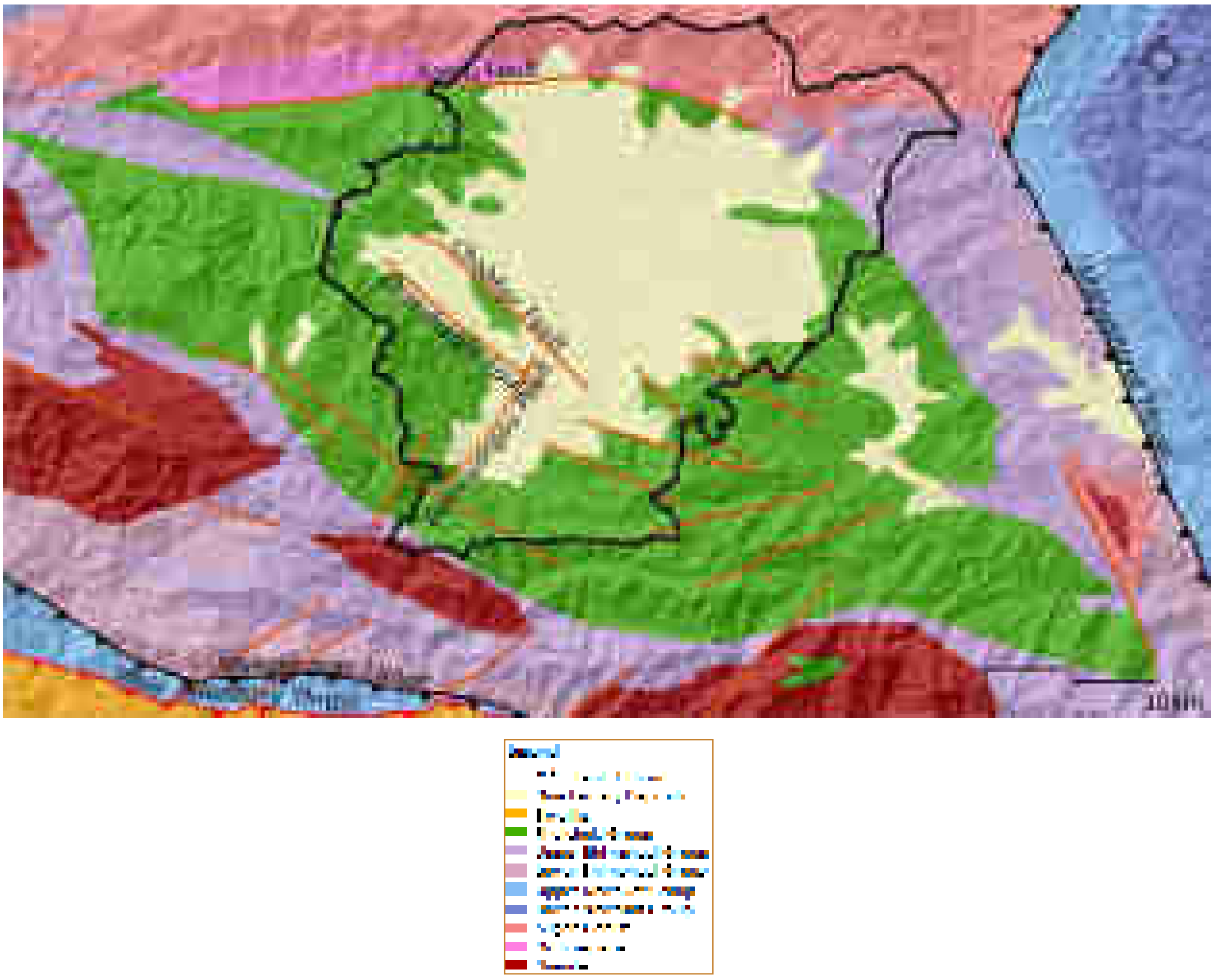


Figure 56 Regional geology and active faults in KV (based on Stocklin and Bhatrrai, 1977 and Sakai 2001)

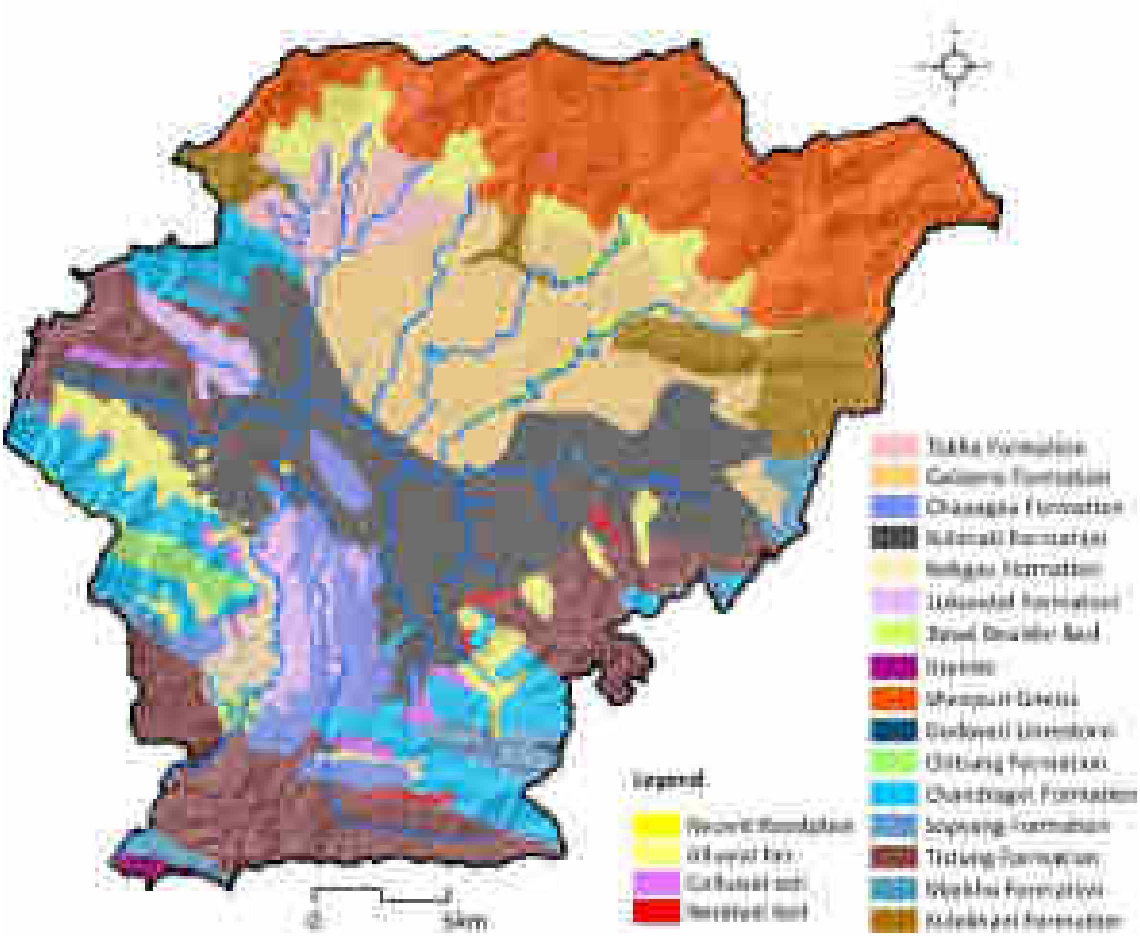


Figure 55 Engineering Geological Map of Kathmandu Valley (modified after (DMG, 1998))

5.1.4. Seismotectonics of Nepal

The entire Himalayan range is dynamic zone of active deformation due to continuous moving of the Indian plate beneath the Eurasian plate. The collision of those two plates has started about 50 Ma (million years) ago and produced a giant mountain range with thickened crust and lateral tectonic setting (Molnar and Tapponnier 1975). Powell and Conaghan (Powell and Conaghan 1973) proposed an evolutionary model presenting two phases of orogeny in the formation of Himalaya (Powell and Conaghan 1973). At first, an active subduction zone presented along the present-day Indus-Tsangpo suture zone in Mesozoic - early Tertiary time. That phase ended in Eocene by collapsing the suture zone after collision of two plates occurred. The second phase is characterized by the formation of the intracontinental thrusts from Miocene to the present in the Indian plate where the Indian plate is underthursting the Eurasian plate since middle Tertiary to the present. At present, the Indian plate is converging to the Eurasian plate at the rate of 5 mm/yr (Patriat and Achache 1984). GPS measurements show that a part of this convergence (about 2 mm/yr) is still being absorbed by a horizontal shear and crustal shortening in the Himalaya (Bilham et al. 1997, Jouanne et al. 2004). The crustal shortening processes are still active in the Himalayan range that are exhibited by large earthquakes (Mw>8.0), e.g., the Nepal-Bihar Earthquake (1934), the Kangara Earthquake (1905), or the Pakistan Earthquake (2005). Apart from the convergence of Indian plate, the shortening of the Himalayan crust is being occurred due to southward propagation of the thrusts. To the north of the Himalaya, entire Tibetan Plateau comprises extensional tectonics characterized by movement along E–W trending strike-slip faults and N–S trending normal faults associated with several grabens.

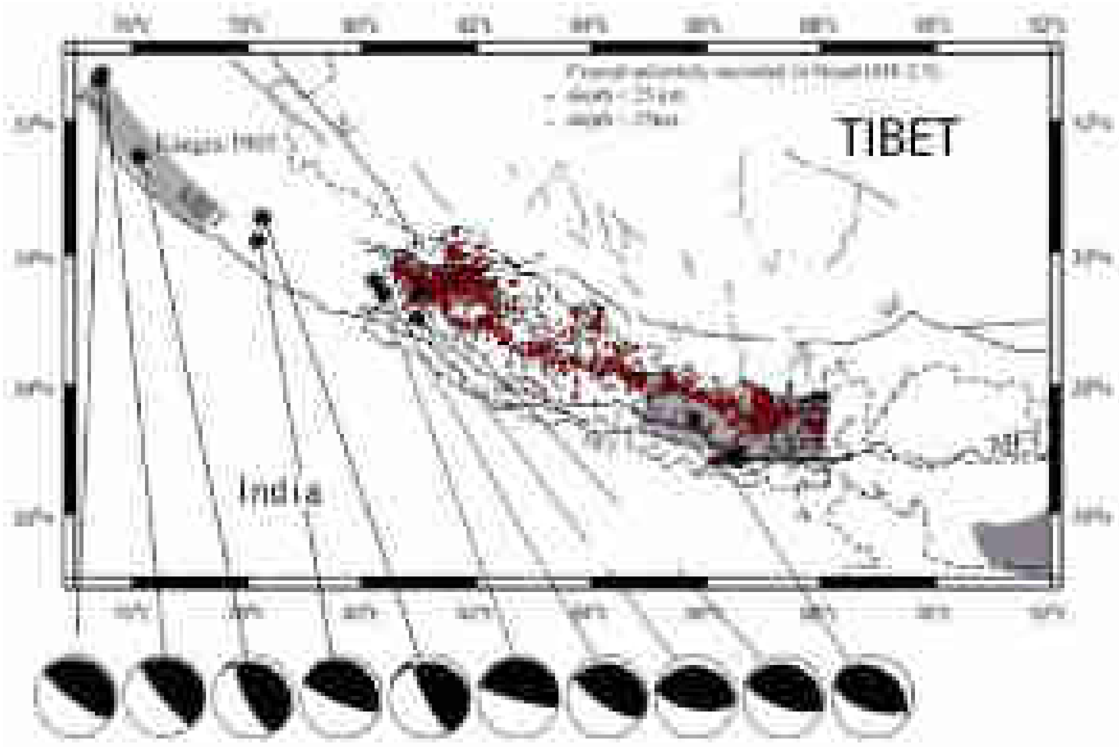


Figure 57 Focal mechanism and microseismicity for the Nepal Himalaya and adjacent region (Jouanne et al. 2004)

5.1.5. Seismicity

During the past few decades, the entire Himalayan range has been recognized as an active seismic zone that is supported by historical and recent earthquakes (e.g., Pakistan earthquake, 2005; Sikkim earthquake, 2011). The overall characterization of Himalayan range is solely based on the measured magnitudes of the earthquakes experienced in this belt. Historical catalogue of earthquake shows that most of the seismic events are located on the front part of the Higher Himalaya trending east to west. Likewise other region, the Nepal Himalaya is characterized by a very intense microseismic activity to keep it seismically active. *Figure 57* shows that the microseismic activity is particularly intensified in the Eastern and Far-Western Nepal, while some patches of seismicity are also detected in the southern part of Tibet. In Nepal, a narrow belt of seismicity follows approximately the topographic front of the Higher Himalaya as a main feature of microseismicity in Nepal Himalaya, which was recognized in Central Nepal from the analysis of the 1985-1995 earthquake data recorded around the Kathmandu (Pandey et al. 1995).

In case of Siwalik, there are very few earthquakes recorded throughout the Himalaya. The Udayapur earthquake in 1988 (Magnitude 6.5) is the most noticeable earthquake observed in this range that occurred in the depth of 50 km beneath the Siwalik. It has no equivalent earthquake along the entire arc.

5.2. Seismic Hazard and Vulnerability

Historical records show that Nepal has experienced numbers of large earthquakes in the past centuries. The most devastating earthquakes had been recorded in 1255, 1408, 1681, 1803, 1810, 1833, 1866, and 1934 (Chitrakar and Pandey 1986, Pandey et al. 2002, Pandey and Molnar 1988). Due to lack of seismic instruments, the magnitude and intensity of each previous earthquake are unknown. *Table 15* summarizes the major historical earthquake events recorded within Nepal.

Table 15 Distribution of historical earthquake near Kathmandu and the damages in Kathmandu

Date	Magnitude	Intensity in KTM	Epicenter dist. from KV	Damage/Casualty in KV Valley
Jun 7, 1255	7.7 (assumed)	X	Near KTM	One third population of KTM valley were killed including the then King Abhaya Malla. Many buildings and temples were collapsed.
1408	NA	X	Near KTM	Many houses and temples including Rato Matchendranath were completely destroyed
1681	7.0 (assumed)	IX	Near KTM	Heavy loss of lives and many buildings and temples either damaged or destroyed
1810	NA	IX	NA	Many houses and temples were collapsed
Aug 26, 1833	7.8	X	~40 km NNE to KTM	About 500 people were killed. More than 4000 houses were destroyed
May 23, 1866	7.0	X	Near Kath-mandu	Many houses and temples were damaged or destroyed.
Jan 15, 1934	8.4	IX-X	~175 km SEE to KTM	4296 people were killed. 12,397 houses were collapsed and more 40 thousands buildings and temples were damaged.
Aug 21, 1988	6.5	NA	~170 km East to KTM	8 people kill and 71 were injured. 650 houses were collapsed; more than 1800 houses and temples were damaged.

The 1934 Nepal-Bihar earthquake (Mw = 8.3) is thought to be a repetition of 1833 Rasuwa-Sindhupal-chok earthquake, which had a magnitude of 7.8 (Bilham 1995). National Seismological Center (NSC) has been continuously monitoring the earthquake events since 1978; however the seismic data are available only after 1994. There are several small to medium earthquakes by magnitudes that have been occurred making epicenter near to Kathmandu valley that have caused relatively less to no damage in the valley. A complete description of historic earthquakes is included in annex of this report. The locations of past earthquakes is presented in *Figure 58*.

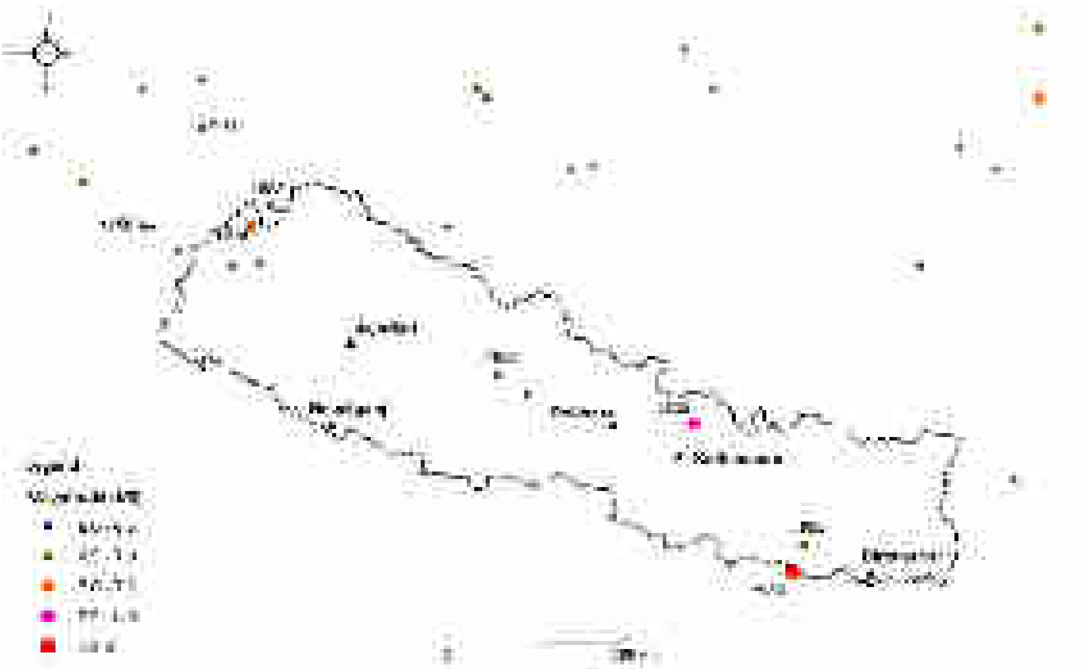


Figure 58 Historical Earthquakes (1752-1999 AD) occurred in the territory of Nepal and surrounding (Source: NSC)

The instrumental records of the seismic events in Nepal show a non-uniform distribution of seismicity throughout the Nepal Himalaya although a general trend can be recognized. The trend consists of a narrow belt of predominantly medium sized earthquakes beneath the Lesser Himalaya, which extends from east to west just south to the Higher Himalayan front. All the available fault-planes indicate that the cause of seismic origin is solely thrusting. The focal depths for the Himalayan earthquake vary from 10 – 20 km. *Figure 59* presents the earthquake catalogue from 1994-2013 recorded by the National Seismological Center (NSC)[5]

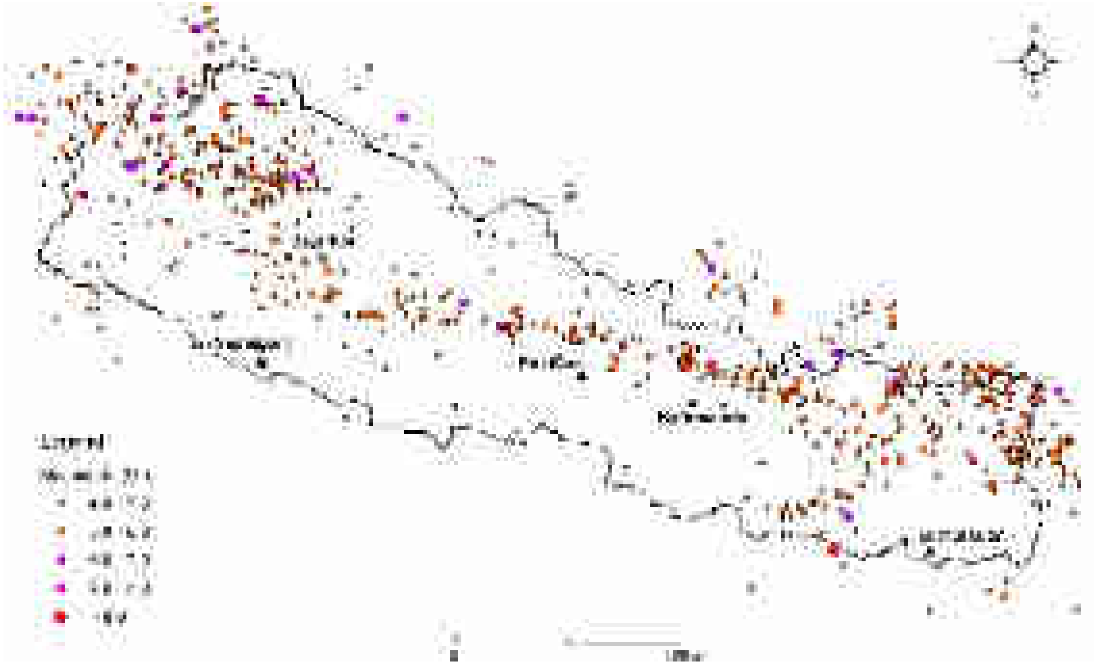


Figure 59 Seismic catalogue map of Nepal (earthquakes (> 4.0 ML) recorded between 1994 and August 2013 by NSC)

5.2.1. Seismic Hazard Assessment

Seismic hazard is usually expressed in terms of probabilities of occurrences of certain earthquake induced ground shaking in a given spatial as well as temporal frame (Giardini et al. 1999). Earthquake hazard is commonly described in terms of the level of ground shaking that has a 10% chance of being exceeded in 50 years corresponding to a return period of 475 years (Sinadinovski et al. 2005).

Seismic hazard can be accessed through different models such as earthquake source models, occurrence models, ground motion models, and seismic hazard calculation approaches (Balassanian 2002). The ground motion models are generally attenuation relationship that expresses the ground motion as a

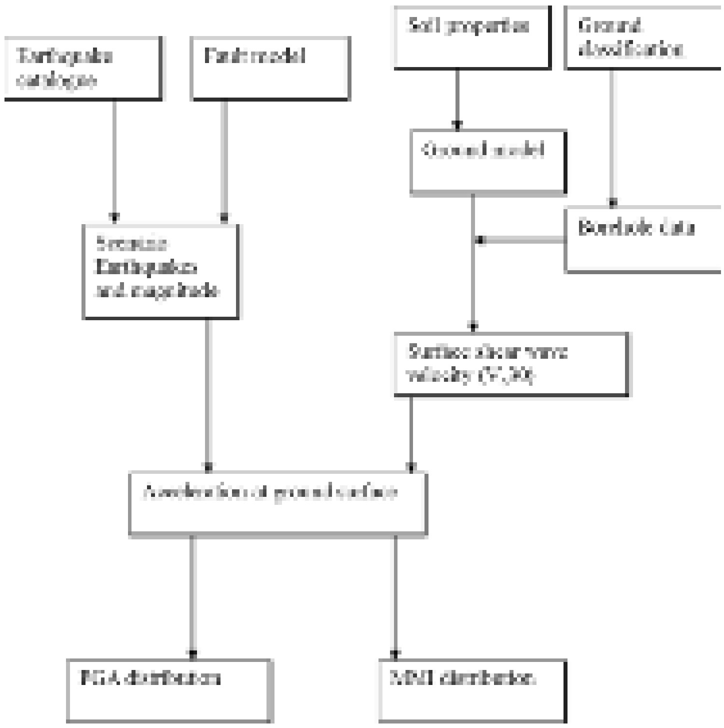


Figure 60 Flow chart of seismic hazard assessment

5 *http://www.seismonepal.gov.np/*

function of magnitude and distance from the epicenter of an earthquake. The ground motion attenuation relationship has been determined through two different approaches: empirical and theoretical. The empirical approach is based on previously recorded ground motion, while the theoretical approach is based on seismological models to generate synthetic ground motions that account for source, site and path effects (Balassanian 2002).

In this study, the ground motion at a particular place is generated based on the regional seismicity model, an attenuation model, and a site response model. The ground motion is represented by the *Peak Ground Acceleration* (PGA), which defines the maximum acceleration experienced by the soil during the scenario earthquake. Seismic intensity in modified Mercalli scale (MMI) is computed from the obtained PGA values at corresponding site to show the earthquake hazard for a particular scenario earthquake. *Figure 60* shows a flowchart of overall methodology adopted in the present study.

5.2.2 . Scenario Earthquake Model

In the Kathmandu Valley, the last devastating earthquake was in the year 1934, which epicentered in the east Nepal. That earthquake severely affected eastern and central Nepal including many parts of north-east India. Almost 100 years prior to the 1934 EQ, there was another huge earthquake that hit central Nepal in 1833 with its epicenter at Sindhupalchok, very close to Kathmandu Valley. Those two earthquakes show that one of the area was silent since about 200 years and another since 100 years. Long seismic gap indicates that there is a possibility of occurring earthquake in near future. In the present study, the seismicity of the Kathmandu valley is modeled by taking the epicenters of those two earthquakes assuming the re-occurrence of earthquakes of similar magnitudes. Besides those sources, two active thrust/faults were also considered to model the seismicity of valley. In which, one was Main Boundary Thrust (MBT), a regional thrust, that passes through the south of Kathmandu Valley; and the second was a local normal fault that passes through northern foothill of Chobhar within the valley.

Table 16 Scenario Earthquakes in KV

Scenarios	Earthquake	Description
Scenario I	1833 Sindhupalchok Earthquake	The magnitude of this historical earthquake was 7.8. Reoccurrence of 1833 Sindhupalchok earthquake is taken as first scenario earthquake, whose epicenter was about 40 km far from the Kathmandu valley.
Scenario II	1934 Nepal-Bihar Earthquake	– It is one of the largest earthquake occurred in the Himalayan region. The epicenter of this earthquake was near to Nepal-India boarder, eastern Terai. The recorded magnitude of this earthquake was 8.4. In this study, the re-occurrence of the 1934 Bihar-Nepal earthquake is modeled. The epicenter of the 1934 NB earthquake is 175 km from the Kathmandu valley.
Scenario III	Main Boundary Thrust (MBT)	It is an active thrust in the Nepal Himalaya. It is assumed that an earthquake would be possible from the thrust zone of MBT. In this study, a regional earthquake with magnitude 8.0 is considered, whose epicenter will be hypothetically located at about 20 to 35 km south from the Kathmandu valley.
Scenario IV	Chobhar Local Earthquake	Locally, the Chobhar Fault, located on the foothill of Chobhar and Kirtipur hillocks, is taken as a possible seismic source of local earthquake within the Kathmandu valley. Since it is an active fault (Sakai, 2001), occurrence of an earthquake with magnitude of 6.5 is considered with an epicentric distance of 1 to 15 km. Since the Kathmandu valley is large, the distance to the epicenter is varied for different location points.

5.2.3. Ground Model

The ground model was prepared on the basis of borehole logs distributed in the Kathmandu Valley. There were 104 (shown in *Figure 63*) boreholes of depth up to 20-30 m used to prepare layers and sub-layers beneath the surface. The lithological and geotechnical properties of soil materials are used to calculate the response of the scenario earthquakes. Detailed description of the selected borehole logs are presented in *Technical Report Volume 2 Multi-Hazard and Risk Assessment in Kathmandu Valley,* under this study.

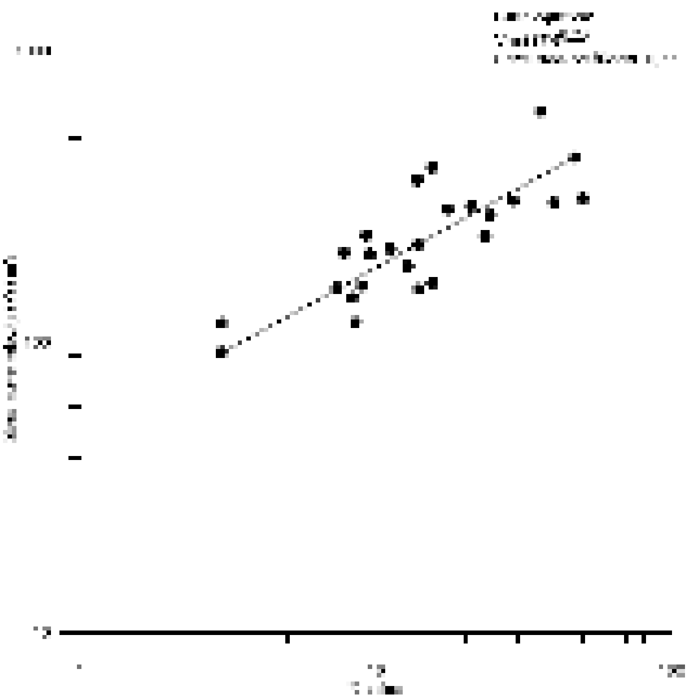


Figure 61 Relationship between N-value and Vs

The borehole logs give information on thickness of soil layers, groundwater level, and geotechnical properties of soil such as the standard penetration test (SPT)-N values and soil densities. The N-values were further used to compute the site amplification. Shear wave velocities (V_s) were computed for each borehole location site. An empirical relationship between N-value and shear wave velocity is adopted from (Pokhrel 2006), which was based on field and lab experiments *Figure 61*.

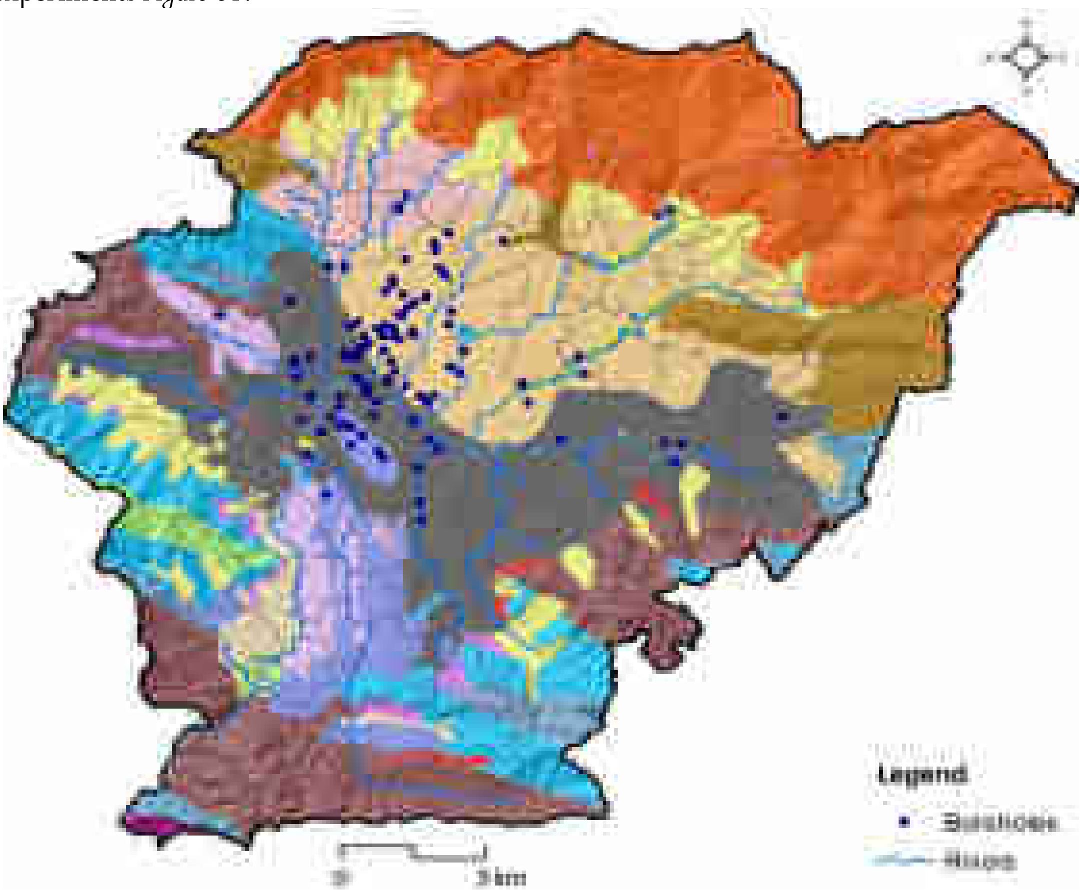


Figure 63 Locations of borehole logs in KV

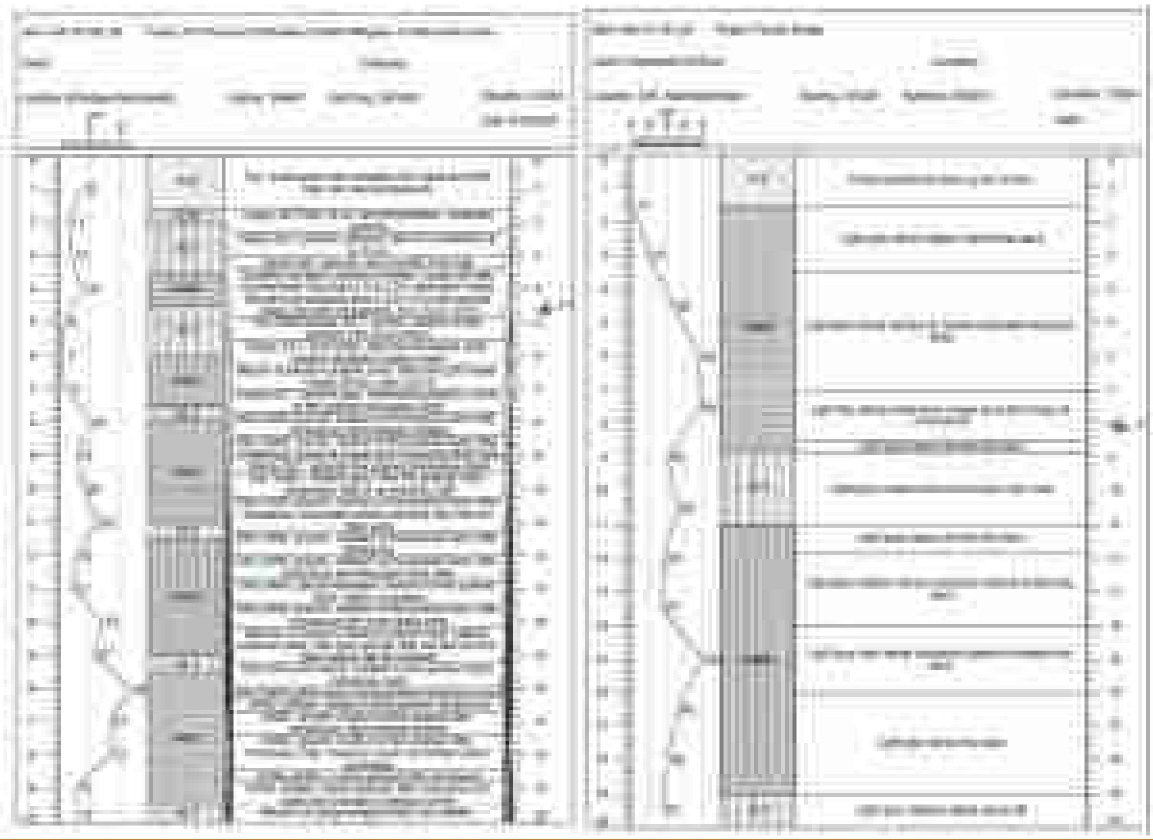


Figure 62 Sample illustrations of borehole logs used in the study

5.2.4. Acceleration in Ground Surface

The ground motion is computed as a function of magnitude and distance of an earthquake from the particular place, and properties of earth materials at that place, which is expressed as an attenuation relation. In the present study, peak ground acceleration (PGA) values were calculated at each borehole location for each different scenario earthquakes, where SPT and/or shear wave velocity (V_s) values are available.

$$T = 4 \times \sum_{i=1}^{n} \frac{H_i}{V_{si}}$$

where, T is longest predominant period (in *second*), H_i is thickness of individual (i^{th}) layer of soil, and V_s is shear wave velocity of i^{th} layer of soil.

5.2.5. Ground Response and Predominant Period (TG)

The ground motion differs from place to place due to variation in the engineering properties and thickness of soil layers. The ground response can be used to report the interaction between ground acceleration and structural systems. The response spectrum (RS) reflects the frequency content, amplitude of ground motion, and the effect of subsequent filtering the structure. The predominant period (TG) of earthquake ground motion is so calculated to see the effect of ground motion in the structural designs in the study area. The predominant period of an earthquake is used by structural engineer to design the structures so that the natural period of the structure does not coincide with the predominant period of earthquake ground motion, thereby mitigating the possible damage to the structure due to earthquakes (Fukazawa et al. 2003).

In the KV, the real ground subsurface layers are not homogeneous. Instead, there is a distinct heterogeneity in the composition and geotechnical properties. Thus, in the present study, an empirical equation is adopted from Okamoto (1984) to calculate the longest predominant period at a location using soil thickness and shear wave velocity (Okamoto 1984).

5.2.6. Peak Ground Acceleration (PGA)

The peak ground acceleration (PGA) at a given location is the maximum acceleration experienced by the soil materials at ground surface during an earthquake. For each earthquake scenario with the known moment magnitude and epicenter distance, the maximum ground acceleration was determined at particular location by using the relation of (Boore, Joyner, and Fumai 1997)

$$\ln Y = b_1 + b_2(M_w - 6) + b_3(M - 6)^2 + b_5 \ln r + b_V(\ln \frac{V_s}{V_A}) \quad (Eq. 3)$$

where, $r = \sqrt{(r_{jb})^2 + h^2}$ *(Eq. 4)*

$$\text{and } b1 = \begin{cases} b_{1SS} & \text{for strike-slip earthquakes (b1 = -0.313);} \\ b_{1RS} & \text{for reverse-slip earthquakes (b1 = -0.117);} \\ b_{1ALL} & \text{if mechanism is not specified (b1 = -0.242).} \end{cases}$$

In this equation,

Y is the ground motion parameter (i.e., peak horizontal acceleration, *PGA*) in g unit;

M_w is the moment magnitude,

r_{jb} is horizontal distance from the station to the epicenter (in *Km*),

V_s is the shear wave velocity (in *m/sec*), and

$b_2, b_3, b_5, b_V, h,$ and V_A are the coefficients.

The values of coefficients in the above equation are to estimate PGA for the random horizontal component at 5 percent damping. In the present study, b_1=b_{1ALL} (=-0.242) is taken since the mechanism of earthquake scenario is not specified. Similarly, b_2=0.527, b_3=0.0, b_5=-0.778, b_V=-0.371, h=5.57, and V_A=1396 are used in the present analysis (Boore, Joyner, and Fumai 1997).

5.2.7. Stochastic Modelling of the Distribution of PGA, Vs, and TG

Stochastic modelling is the process of drawing probable scenario of the distribution of the attribute in a temporal or spatial framework. The stochastic simulation is a process of generating alternative, equally probable joint realizations of an attribute from the stochastic model. In the present study, stochastic simulation is done finally to get the spatial distribution of desired attributes: PGA, Vs, and TG. The values of average shear wave velocity (Vs) and the values of the longest predominant period of earthquake (TG) are computed at each borehole as explained in the previous sections. Similarly, the PGA values are also calculated at each borehole for all four different scenario earthquakes.

Since, the variation in the data values is not uniformly distributed within the entire valley, the spatial distribution of the PGA, Vs, and TG are modelled by using well-known geostatistical tools. Variogram model was applied to get the trend of variability of data values in the valley. The domain (study area) was divided into grids of 100 m by 100 m cell size, and the information at each borehole locations is assigned to the respective grid. The prediction at locations, where information is unknown, and the simulation of predicted results were achieved by conditioning on the information computed at these 104 borehole locations. In that process, geostatistical tools, particularly, Ordinary Kriging was used in prediction and Sequential Gaussian Simulation (SGSIM) was used in simulation of predicted results following the respective algorithms explained in GSLIB user's guide (Deutsch and Journel 1998). An ensemble probability map is produced after simulation from 100 realizations, where each realization map shows a probable spatial distribution of data values in the study area. The process of modelling is same for PGA, Vs, and TG, however the input data information are different for each. Finally, the simulated result is combined with the adjacent areas with bedrocks, alluvial fans, and recent flood plains; and presented in the GIS environment.

5.2.8. Distribution of PGA, Vs, and TG in the Kathmandu Valley

The spatial distribution of shear wave velocity *(Figure 67)* predominant period of earthquake (*Figure 68)* and the peak ground acceleration for four scenario earthquakes *(Figure 69*) are generated. The shear wave velocity and predominant period of earthquake were calculated only in soft sedimentary deposits of the valley because there was no borehole data information in the bedrocks and alluvial fan deposits. The variation of shear wave velocity in the valley sediments ranges from 154 m/s to 300 m/s, while it increases in alluvial soil and bedrocks *(Figure 64)*. The longest predominant period of earthquake in the valley sediments ranges from 0.4 to 0.8 second (*Figure 65)*. It implies that the buildings from 4 to 8 storeys, are more likely to be affected during the earthquake.

The PGA distribution map for the 1833 Sindhupalchok earthquake scenario shows the KV sediments would experience PGA range of 342–497 gal (i.e., 0.35g–0.51g). The Kalimati, Balkhu and Suryabinayak areas would experience maximum horizontal acceleration *Figure 66 (a)*. The reoccurrence of 1934 Nepal-Bihar earthquake would create the PGA ranging from 142 gal to 206 gal in the Kathmandu Valley. Likewise the 1833 Sindhupalchok earthquake, Kalimati, Kuleshwor, and Suryabinayak area would experience the maximum ground acceleration *Figure 66 (b)*. The PGA distribution map for the MBT scenario earthquake shows the PGA values ranges from 380 gal to 703 gal in the valley sediments. The maximum ground acceleration would be experienced in Kalimati, Balkhu, Bungmati, Suryabinayak, and neighbouring regions *Figure 66 (c)*. The local earthquake scenario would experience PGA of 354–929 gal. The maximum ground acceleration would be experienced in Kalimati, Balkhu, and Sanepa area *Figure 66 (d*). From all four scenario earthquakes, the regions in the vicinity of Kalimati and Suryabinayak are highly hazardous in terms of seismicity.

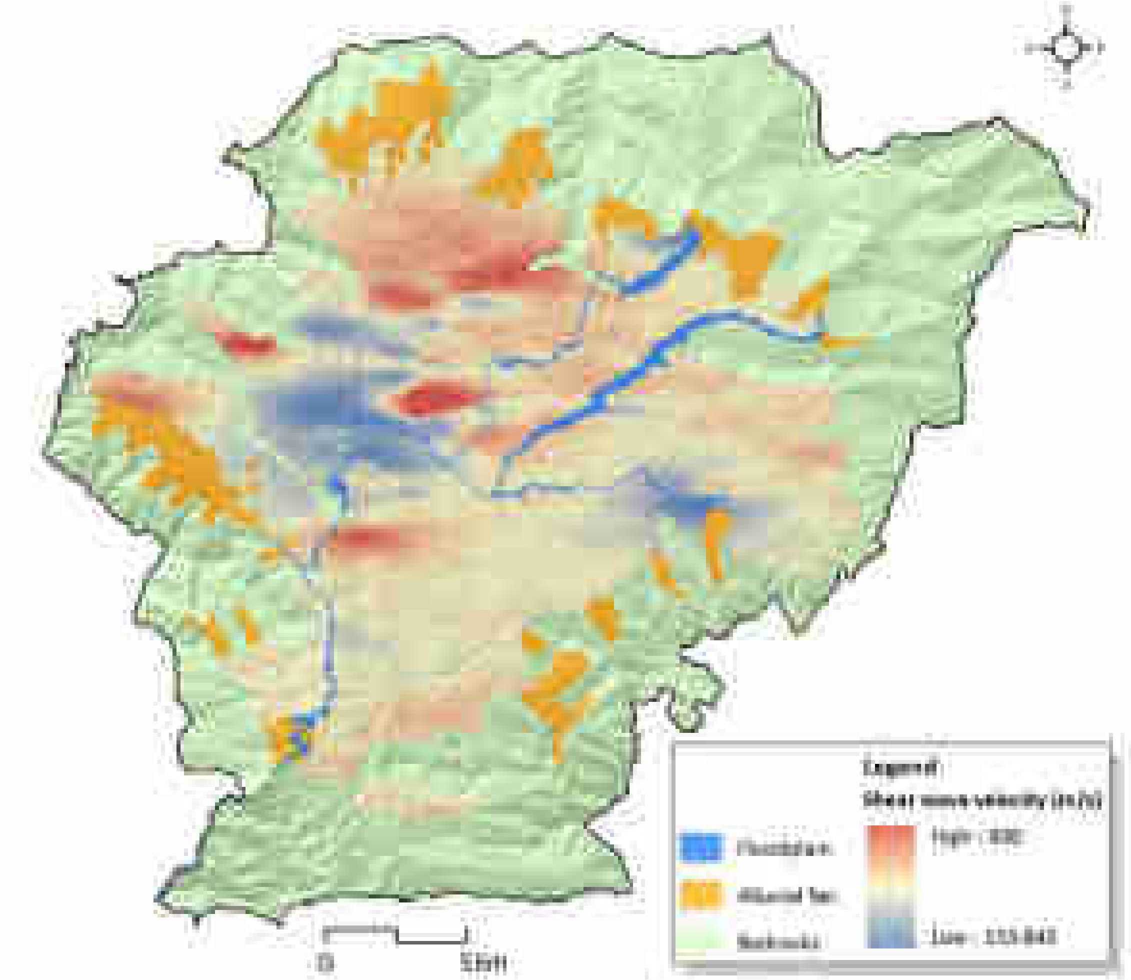


Figure 64 Shear wave velocity (Vs) in KV

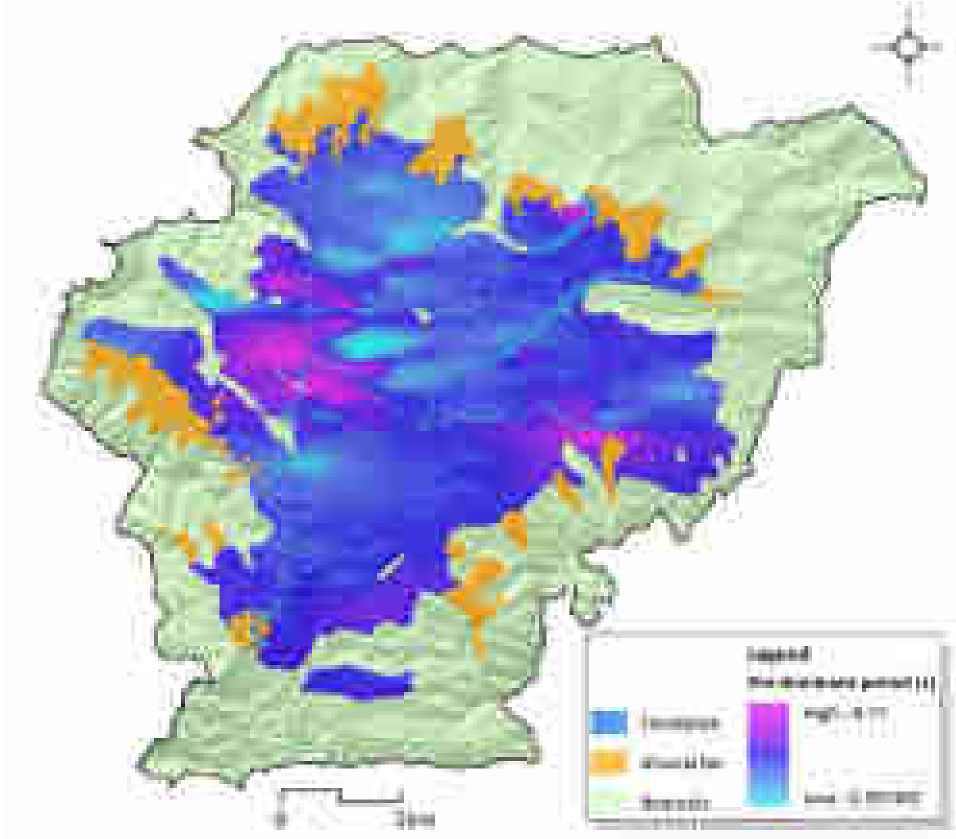


Figure 65 Predominant period of earthquake (TG) in the KV

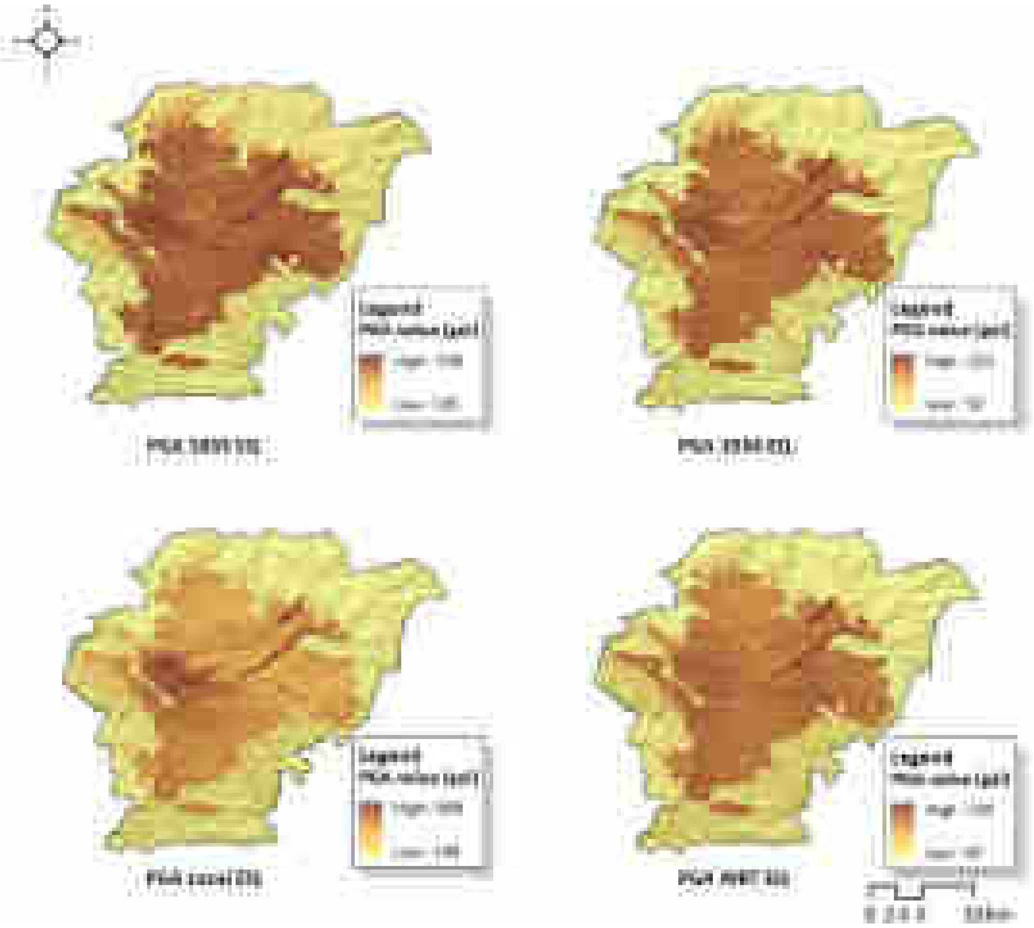


Figure 66 PGA in different EQ scenarios in KV

5.2.9. Seismic Intensity

The seismic intensity distribution for the probable intensity of the scenario earthquakes in terms of Modified Mercalli Intensity (MMI) scale is computed at each grid cell from the PGA distribution map using PGA-MMI relationship (Trifunac and Brady 1975)

$Log_{10}(PGA) = 0.3\ MMI — 0.014$ (Eq. 5)

where, PGA is the peak ground acceleration, and MMI is the modified Mercalli intensity.
The spatial distributions of MMI for four different earthquake scenarios are shown in *Figure 67*.

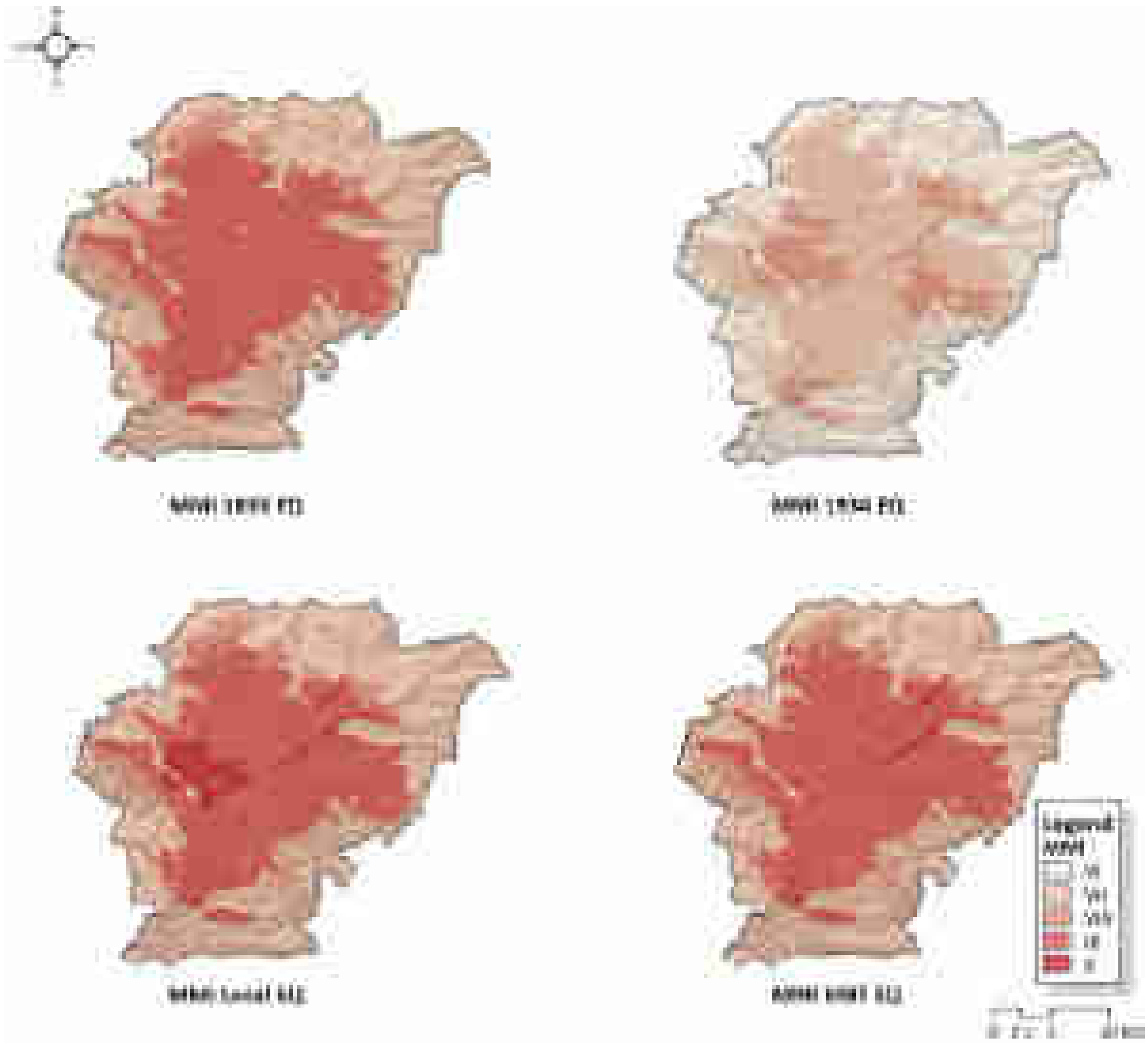


Figure 67 MMI in different EQ scenario in the KV

5.3. Liquefaction Susceptibility

Liquefaction is always associated with an earthquake if the earthquake is occurred in non-consolidated sediments dominant with sand and silt. The term 'Liquefaction' was originally used by Mogami and Kubo in 1953 (Kramer 1996). The generation of excess pore pressure under undrained loading condition is principal criteria for all liquefaction. When cohesionless soils are saturated with water and rapid loading occurs under undrained condition, the pore pressure increase and the effective stress decreases to result the liquefaction. Liquefaction is caused by earthquake shaking in the loose sediments. Since, the KV is filled up with unconsolidated to semi-consolidated sediments, liquefaction hazard assessment is very crucial. A liquefaction susceptibility map demonstrates the spatial distribution of different liquefaction potential zones. The liquefaction potentiality depends basically on the engineering properties of soil, water table, and strength of ground motion during an earthquake.

5.3.1. Factors Affecting the Liquefaction Susceptibility

Liquefaction susceptibility is a function of the geotechnical properties of soil and topographic position of the unit. There are several factors that affect the liquefaction susceptibility, such as sedimentation process, age of deposit, water table depth, engineering properties of sediment grains, depth of burial, density state, proximity to a free face and ground slope (Youd and Perkins 1978). In the present study, a liquefaction susceptibility map is prepared for the Kathmandu valley based on the following processes and parameters:

- Sediment grain size, inter-granular relationship, and type of origin (manually filled-up or naturally deposited),
- Elevation of groundwater table,
- Age of sedimentary deposits and the depositional environment,
- Historical records about liquefaction occurred in the area,
- Surface and subsurface geological condition, thickness of individual soil layers,
- Spatial distribution of Standard Penetration Test (SPT) *N*-values obtained from the boreholes in the area, and
- The estimated 'Ground motion threshold' required to initiate liquefaction.

5.3.2. Liquefaction Hazard Analysis

Various methods are in practices for the liquefaction hazard analysis under two approaches: qualitative and quantitative. The analysis of liquefaction susceptibility following qualitative approaches was performed by (Iwasaki et al. 1982), and (Youd and Perkins 1978), while the analysis of liquefaction susceptibility based on quantitative approach can be found in the works of several researchers such as (Iwasaki, Tokida, and Arakawa 1984, Seed 1979, Seed and Idriss 1971) and others. In the present study, a quantitative approach presented by (Iwasaki, Tokida, and Arakawa 1984) has been used to analyse the liquefaction susceptibility. Based on this method, the liquefaction potential can be estimated simply by using the fundamental properties of soils, viz. N-value, unit weight, mean particle diameter (D_{50}), and maximum acceleration at the ground surface (PGA).]

The liquefaction potential for an individual layer stands by comparing the resistance against liquefaction of this layer (R) with the driving dynamic force that could cause liquefaction (L). With these values, factor of safety with respect to liquefaction (F_L) is determined using the relation at an arbitrary depth (Iwasaki, Tokida, and Arakawa 1984)

$$F_L = \frac{R}{L} \qquad \textit{(Eq. 6)}$$

where, F_L for specific soil at certain location is less than 1.0, it can be said that the soil liquefies during an earthquake.

In the above relation, L is the earthquake-induced dynamic load in soil element, which can be simply estimated by (Iwasaki, Tokida, and Arakawa 1984).

$$L = \frac{\tau_{\max}}{\sigma_v'} = \frac{\alpha_{s\max}}{g} * \frac{\sigma_v}{\sigma_v'} * r_d \qquad (Eq.\ 7)$$

where, τ_{max} is the maximum shear stress (in kgf/cm), α_{smax} is the PGA at the ground surface (in gals), g is the acceleration of the gravity (= 980 gals), σ_v is the total overburden pressure (in kgf/cm^2), σ_v' is effective stress (in kgf/cm^2) and r_d is the reduction factor expressed as

$$r_d = 1 - 0.015z \qquad (Eq.\ 8)$$

where, *z* is depth in meters from the ground surface.
Similarly, *in-situ* resistance of the soil element to dynamic load in terms of *R* is (Iwasaki, Tokida, and Arakawa 1984)

$$R = 0.882\sqrt{\frac{N}{\sigma_v' + 0.7}} + 0.225\log_{10}\frac{0.5}{D_{50}} \qquad (Eq.\ 9)$$

for 0.04mm≤ D_{50}≤0.6mm,
and

$$R = 0.882\sqrt{\frac{N}{\sigma_v' + 0.7}} - 0.0 \qquad (Eq.\ 10)$$

for 0.6≤ D_{50} ≤1.5mm.
where, *N* is the number of blows, σ_v' is effective stress (in kgf/cm^2) and D_{50} is the mean particle diameter (in mm).
The liquefaction potential in terms of potential index (P_L) is defined as (Iwasaki, Tokida, and Arakawa 1984)

$$P_L = \int_0^{20} F(z)W(z)d \qquad (Eq.\ 11)$$

where, *z* is the depth in meters;
W(z) is a depth-weighting factor, W(z) = 10 - 0.5z,
$F(z) = 1 - F_L(z)$ for $F_L(z) \leq 1$ and $F(z) = 0$ for $F_L(z) > 1$

This equation considers just the profile in the top 20m; P_L values calculated from this equation ranges from 0 to 100. In this study the soil layer above water table were considered as non-liquefiable layer. The cumulative liquefaction potential for a location at the surface (P_L) is classified according to following

Table 17 Classification of liquefaction susceptibility

Value	Susceptibility class	Remarks
PL = 0	No / Very Low Liquefaction	Liquefaction susceptibility is very low or not at all. In the Kathmandu Valley, bedrocks are categorized under 'No' and alluvial fans are under 'very low'. Detailed investigation on soil liquefaction are not needed in general
0< PL <5	Low	Liquefaction susceptibility is low. Detailed investigations on soil liquefaction are necessary for important structures
5<PL<15	Moderate	Liquefaction susceptibility is moderately high. Detailed investigations for soil liquefaction are usually necessary
15<PL<25	High	Liquefaction susceptibility is high. Detailed soil investigations are mandatory
PL >25	Very High	Liquefaction susceptibility is very high. Area should be avoided for developing structures

5.3.3. Spatial Distribution of Liquefaction Susceptibility in the Kathmandu Valley

The value of liquefaction potential at a location is different for different earthquake scenarios. Stochastic simulation was performed to generate the spatial distribution of liquefaction potential values in the soft sedimentary deposits of the KV for four different liquefaction susceptibility scenarios for each scenario of earthquake as shown in maps in *Figure 68*.

The liquefaction susceptibility map generated for the 1833 Sindhupalchok earthquake shows that the areas in the vicinity of Kalimati, Nakhu, Suryabinayak, Thimi, Lazimpat, and Tokha would experience high to liquefaction if the similar earthquake reoccurred *Figure 68a*. Most of the valley sediments would be moderately liquefied due to such earthquake.

The liquefaction susceptibility map for 1934 Nepal-Bihar earthquake *Figure 68b* shows that Rabibhavan, Kalimati, and Teku area including Thamel and Gyaneshwor area would experience moderate to high liquefaction. Most of valley sediments lie under low susceptibility zone showing that the valley might face mild liquefaction if the 1934 earthquake reoccurred.

Most of the valley sediments would be affected by high liquefaction if an earthquake (ML=8.0) occurred in the MBT *(Figure 68c)*. Some areas in the vicinity of Solteemode, Kalimati, Teku, Lainchaur, Tokha in

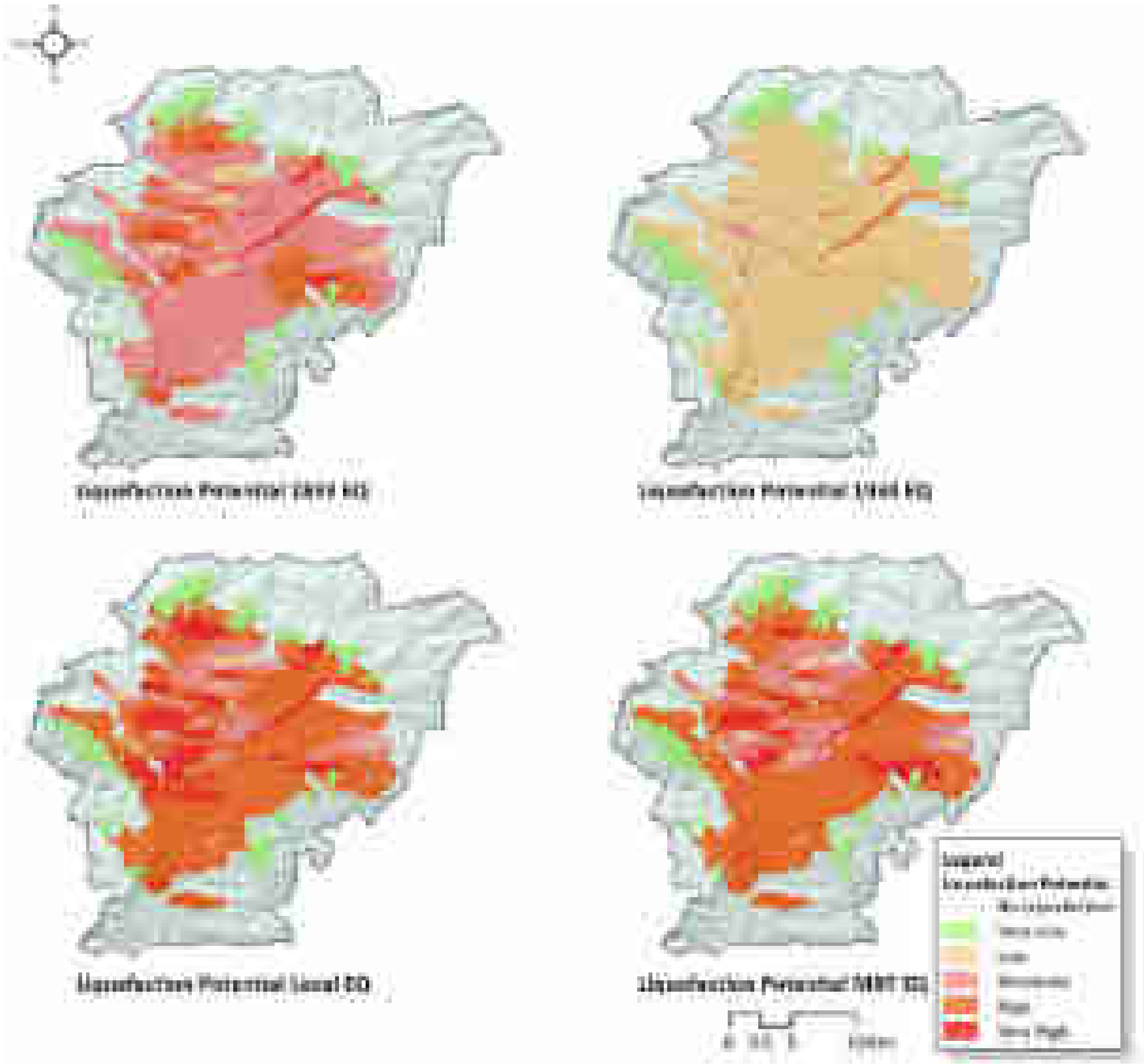


Figure 68 Liquefaction susceptibility (a) Scenario I (b) Scenario II, (c) Scenario III & (d) Scenario IV

Kathmandu, Dhobighat, and Nakhhu in Lalitpur, and Thimi, and Suryabinayak area of Bhaktapur would face very high degree of liquefaction. Tribhuvan International Airport (TIA) lies under moderate susceptible zone.

For the local earthquake scenario, high and very high liquefaction susceptible zones are dominant in the soft sediments of the Kathmandu Valley (Figure 68*d)*. The areas having bedrocks and alluvial fan deposits on the basement could only be safe if such earthquake occurred in the valley.

5.3.4. Liquefaction Vulnerability Assessment

Based on the above prepared liquefaction susceptibility/potential maps and mapped buildings, assessment of buildings susceptible to various liquefactions zones are assessed. Following are the assessment observations for buildings susceptible to liquefaction hazard for different scenario earthquakes:

- For the liquefaction susceptibility of scenario earthquake of 1833 Sindhupalchowk EQ, total of 10,051 buildings are in very high liquefaction potential zones. This is 3 percent of the total mapped buildings in the KV. Similarly, 61,312 buildings are in high liquefaction zone (17 percent); 193,302 (54 percent) in moderate liquefaction zone; 26,123 (7 percent) in low and 23,524 buildings (6.5 percent) are in very low liquefaction zones. Of the total buildings in very high liquefaction zone, 75 percent are in municipalities, 9 percent in rural VDCs and 16 percent buildings in urbanizing VDCs.
- For the scenario 1934 Nepal-Bihar earthquake, which has lesser effect (in terms of PGA and resulting MMI), total of 969 buildings are in high liquefaction zone (0.3 percent of the total). However, in this earthquake scenario, about 79 percent buildings in KV are exposed to low liquefaction potential.
- For the local scenario earthquake, total of 60,183 (17 percent) buildings are vulnerable to very high liquefaction susceptibility; 168,428 buildings (47 percent) are vulnerable to high liquefaction; 55,383 (15 percent) to moderate; 6,794 (2 percent) to low and 23,524 (12 percent) to very low liquefaction hazard.
- For the scenario earthquake at MBT, 38,202 buildings (11 percent) are in very high liquefaction zone; 165,320 (46 percent) are in high; 77,296 (22 percent) in moderate; 9,970 (3 percent) in low and 23,524 (12 percent) in very low liquefaction potential zones.

5.4. Flood Scenario in KV

Flooding is a natural and recurring event for a river or stream. Flooding is a result of heavy or continuous rainfall exceeding the absorptive capacity of soil and the flow capacity of rivers, streams, and coastal areas. This causes a watercourse to overflow its banks onto adjacent lands. Floodplains are, in general, those lands most subject to recurring floods, situated adjacent to rivers and streams. Floodplains are therefore "flood-prone" and are hazardous to development activities of the vulnerability of those activities exceeds an acceptable level.

Although floods are natural phenomena, human activities and human interventions into the processes of nature, such as alterations in the drainage patterns from urbanization, agricultural practices and deforestation, have considerably changed the situation in whole river basins. In the same time, exposition to risk and vulnerability in flood-prone area has been growing constantly. The probability of flooding is expected to increase: the earth's climate is changing rapidly. Development activity, particularly deforestation and intensive crop production, may drastically change runoff conditions, thereby increasing stream flow during normal rainfall cycles and thus increasing the risk of flooding. More intensive use of the floodplain, even under strict management, almost always results in increased runoff rates.

Kathmandu Valley - an intermountain valley surrounded by hills from all around where River Bagmati originating from "Bagh Dwar" in northern hills of Shivapuri passes the valley crossing through three gorge at Gokarneswar, Gaurighat, and Chobar plays a vital role in draining out the volume of water of watershed covering an area of 630.38 sq.km. During monsoon the situation becomes more sensitive when the water from other major rivers in the valley pours into the mainstream of Bagmati. These major rivers in the KV are Manohara, Hanumante, Kodku, Dhobi, Bishnumati, Mahadev Nakkhu, Balkhu and Godavari rivers that flows through KV and confluences into the Bagmati River. Sub-watersheds[6] of Bagmati River in KV is listed in Table 18 and the map presented in Figure 5.

Table 18 Sub-watersheds in KV

Name of Watershed	Area in sq.km
Bagmati Khola Watershed	195.9
Balkhu Khola Watershed	44.48
Bisnumati Khola Watershed	81.84
Dhobi Khola Watershed	27.22
Godavari Khola Watershed	45.85
Hanumante Khola Watershed	95.49
Kodku Khola Watershed	34.04
Mahadev Khola Watershed	24.37
Manahara Khola Watershed	75.2
Nakhhu Khola Watershed	55.94
Total	**680.33**

Due to rapid urbanization and exponential population growth, the pressure on land for settlement is growing day by day. As a result of which most of the floodplain are either filled with concrete cultural landscape or is encroached for developmental activities. More over in due to excessive concretization of the surface, infiltration capacity of soil has plunged resulting direct flow of rainwater to river leaving no other option rather than carrying voluminous water flowing through urban area. Furthermore as a result of natural climate change, intense rainfall pattern further intensify the flow of water in River and streams generating flood situation. Thus it has become necessary to predict the flood situation and the level of flood situation in extreme flood situation at different return period. Therefore the present study is made to generate the flood inundation map to get to know about the flood hazard risk on different elements on flood plain as well as for better and sustainable developmental plan.

5.4.1. Rainfall Analysis of KV

The collected daily rainfall data from the DHM meteorological stations were analysed and summarized for determining rainfall distribution pattern *Table 19*. From the obtained rainfall data, the annual average maximum rainfall (Thankot) was found 1905 mm and minimum rainfall (Khumaltar) was 1208 mm found. The isohytal map of 42 years annual average precipitation showed highest precipitation occurred in (Thankot and Godavari area) around the hills surrounding the valley as shown in Table 19.

Table 19 Annual average rainfall, rainfall trend and rainy days of KV

Station	Station ID	Annual Avg. Rainfall (mm)	Rainfall Trend	Rainy Days
Godavari	1022	1872	Decreasing	Decreasing
Maharajgunj	1039	1508	No Change	Decreasing
Bhaktapur	1052	1492	Decreasing	Increasing
Chapagaun	1060	1392	Decreasing	Decreasing
Khokana	1073	1352	Decreasing	Increasing
Thankot	1015	1905	Decreasing	Increasing
Khumaltar	1029	1208	Decreasing	Increasing
KTM Airport	1030	1437	Increasing	Decreasing
Nagarkot	1043	1526	Increasing	Decreasing

[Source: DHM]

The high hilly (north-western) part surrounding the valley receive more precipitation and it gradually decrease towards the center. The rainfall trend and rainy days of Kathmandu Valley has decreased from place to place. The hyetograph analysis of annual average precipitation and rainy days show gradual decreasing

6 The sub-watersheds have been delineated using 20m DEM extracted from contours and spot levels from the National Topographical Map, Survey Dept. 2001. GIS based Soil and Water Assessment Tool (SWAT) (Srinivasan, Arnold, and Jones 1998)was used to analyze and delineate the sub-watershed boundaries.

trend of precipitation and rainy days *(Figure 70)*. Number of rainy days in Kathmandu was maximum in 1987 and minimum in 2007. These numbers were generated by analysing the data of 5 years interval. On comparing number of rainy days with average rainfall *(Figure 70)* decreasing trend was found, but it varied from place to place shown in *Table 19*, where the majority of KV rainfall stations has decreasing rainfall and increasing rainy days.

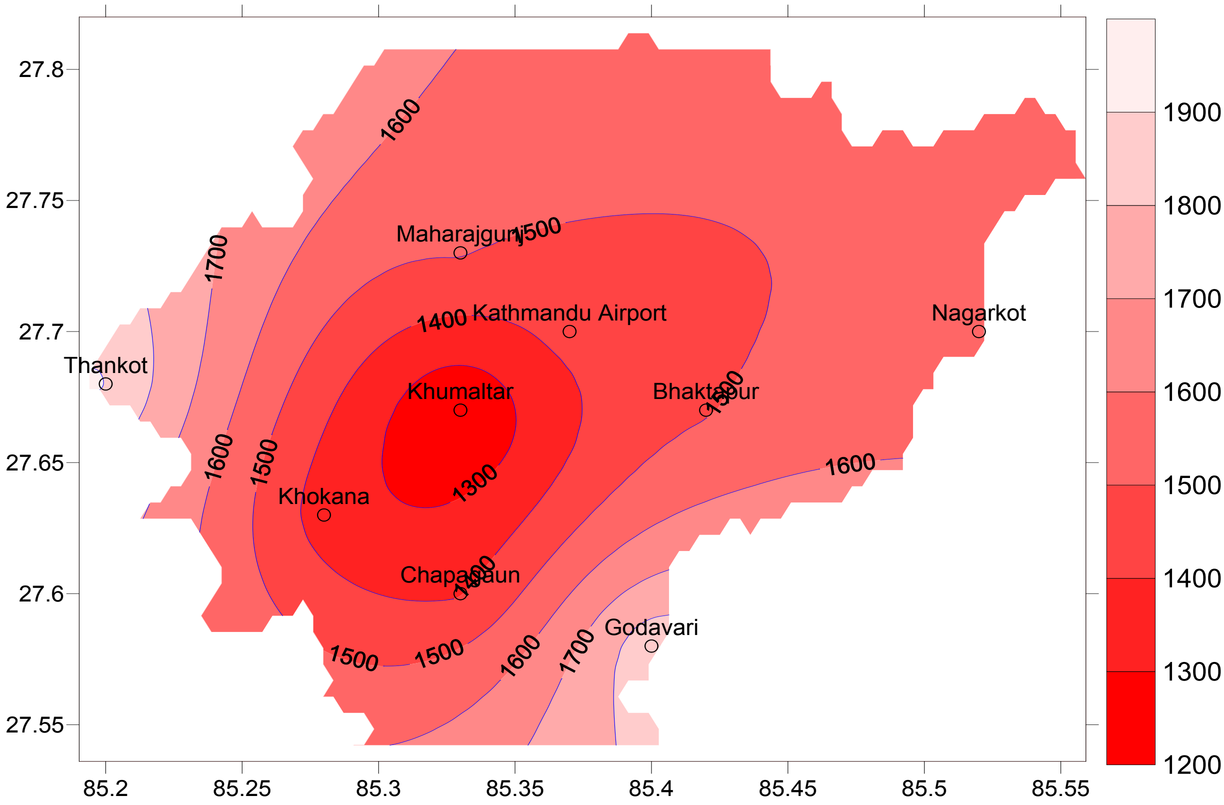


Figure 69 Isohytal map of 42 years annual average precipitation in KV

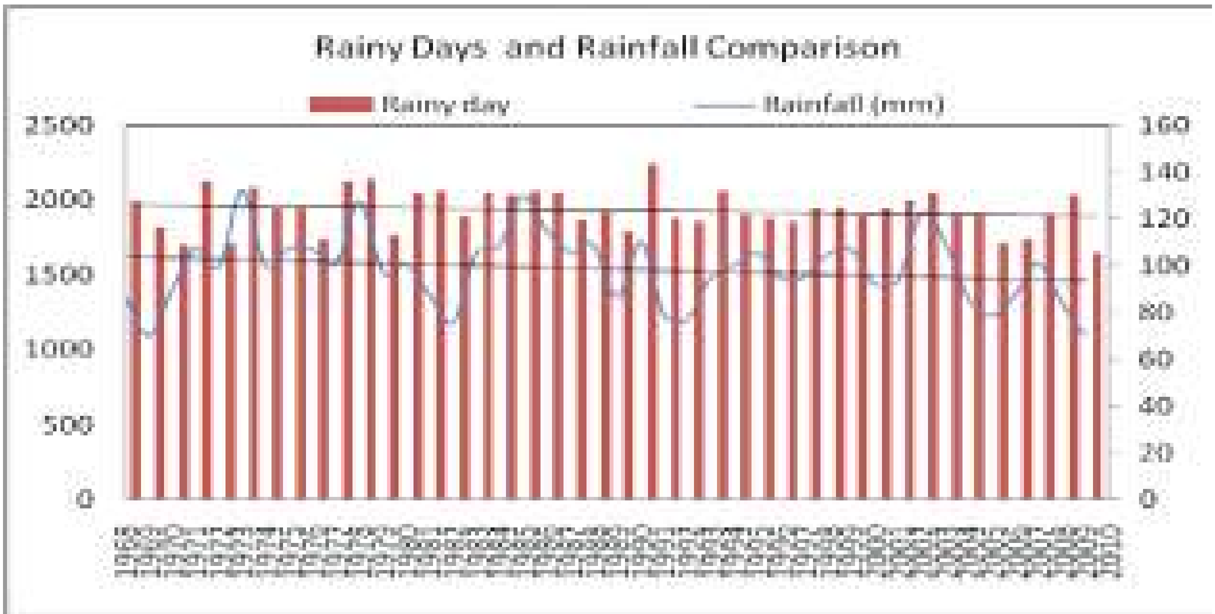


Figure 70 Comparison of Hyetograph and Rainy Days in KV (1968-2010)

5.4.2. Projected Rainfall Scenario

Rainfall scenario of KV, represented by the measurement at the Tribhuvan International Airport for 2030s to 2060s were predicted by statistical down scale model in 30 year intervals as shown in *Figure 72*. The monthly rainfall trend follow exact pattern of observed value with slight bias in estimated values of A1B and A2 scenario *Figure 71*.

Projected rainfall from both the scenarios (A1B and A2) from the year 2000 to 2030s and 2030s to 2060s shows different relationship for rainfall scenarios. Negative rainfall trends of (-) 4.4531mm per year decrease is seen from 2000 to 2030 and positive trends of (+) 2.5249 mm per year increase is seen from 2030s to 2060s by A1B scenario. Contrarily, the A2 scenario shows increase rainfall trend (+) 7.6222 mm and (+) 12.854 mm per year from 2000 to2030s and 2030s to 2060s. It means after 2030, rainfall will be increased in KV.

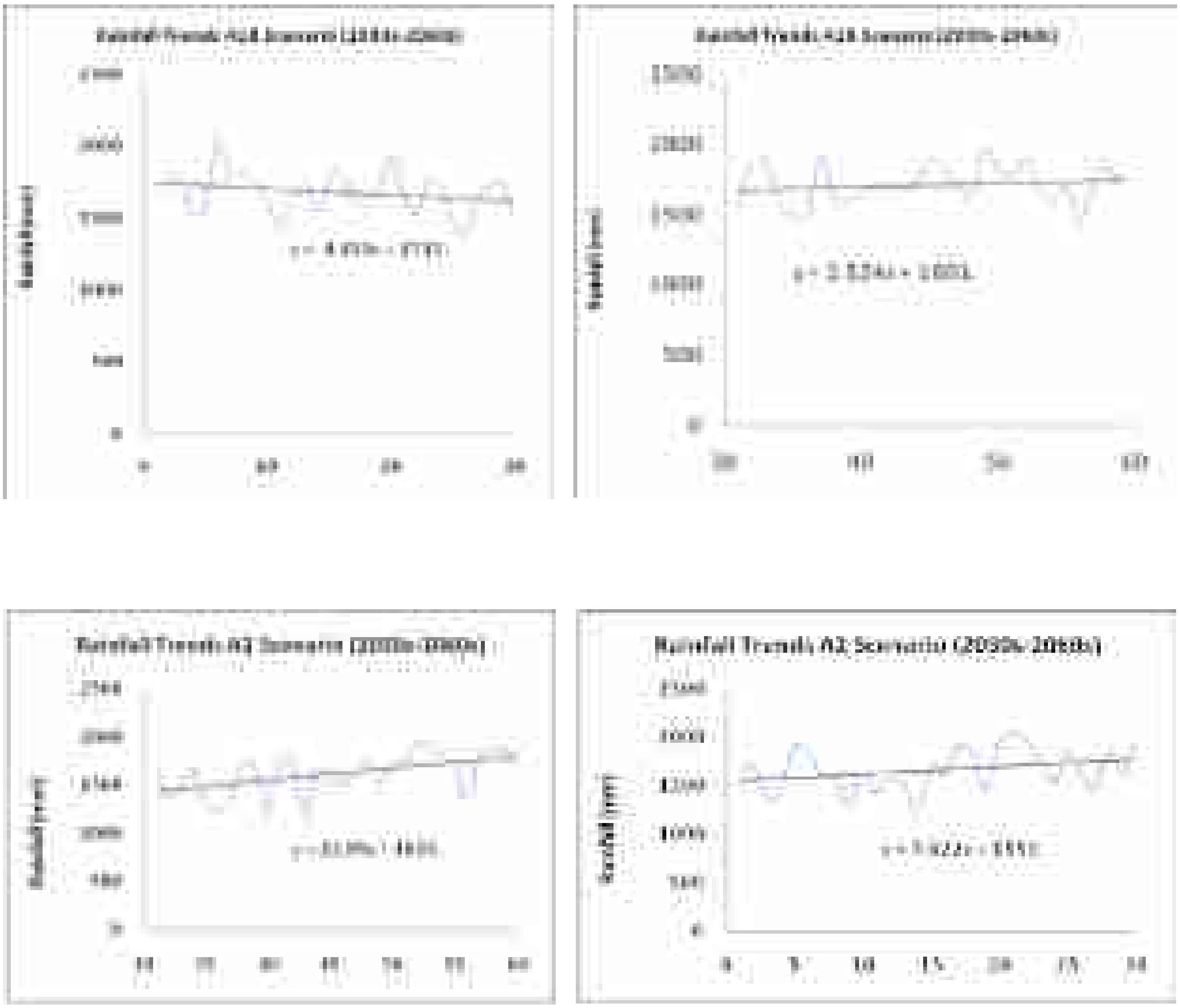


Figure 72 Rainfall trend (a) A1B (2030-2060), (b) A1B (2030-2060), (c) A2 (2030-2060) and (d) A2 (2030-2060)

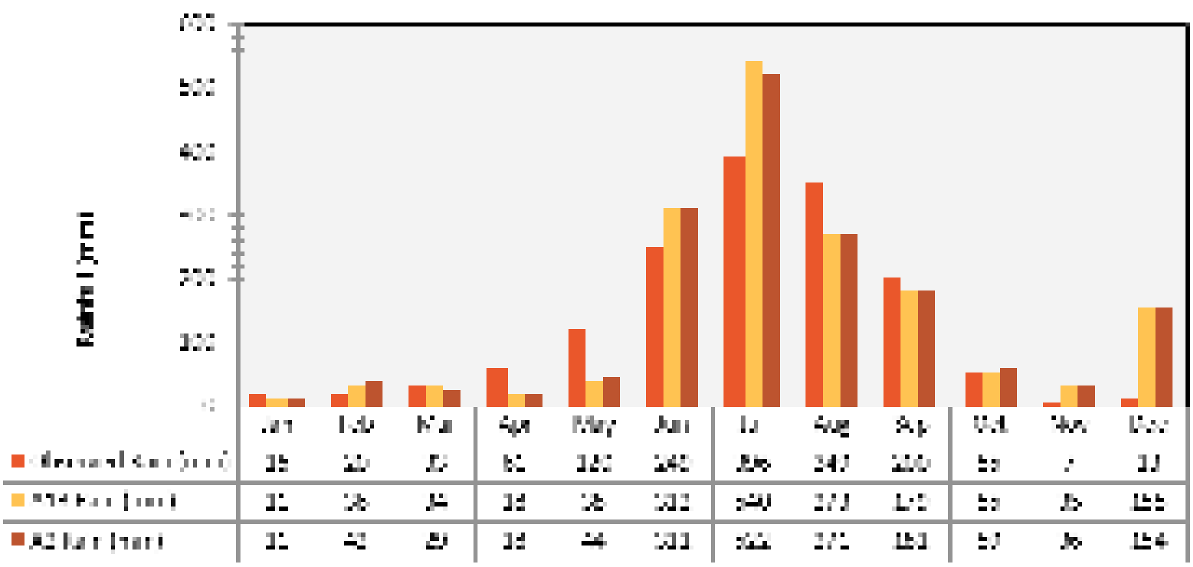


Figure 71 Monthly average rainfall scenario of KV (2001-2060)

5.4.3. Hydrological measurements of flow in major rivers of KV

Hydrological measurement were carried out at different locations in KV using different methods viz. as current meter method, tracer dilution method, float method and slope area methods. The detail summary of the result is present in *Table 20*. This discharge measured data were used for model calibration, validation and application for flood frequency analysis in Gumbel's methods.

Figure 73 Flow measurement using Tracer Dilution method
(b) River Cross Sectional Survey using electronic level for Bagmati River in Khokana

Table 20 Validated Discharge of Bagmati River at KV

No	Place	Drainage Area (Km2)	Date	Discharge Measurement Method	Peak Discharge (m^3/s)				Remark
					High Flood Recorded	High Flood Measured	Average Discharge	Observed	
1	Mahadev Khola	8.371	16/01/2013	Slope Area		34.00			Un Gauge
2	Mahadev Khola	8.371	16/01/2013	Float				0.137	Un Gauge
3	Bishanumati	5.373	16/01/2013	Slope Area	7.30	8.00			Gauge but Remove
4	Bishanumati	5.373	16/01/2013	Float			0.050	0.206	Gauge but Remove
5	Tika Vairab	42.059	16/01/2013	Slope Area	181.0	193.00			Gauge but Remove
6	Tika Vairab	42.059	16/01/2013	Current Meter			0.190	0.036	Gauge but Remove
7	Bagmati Gokarna	55.620	17/01/2013	Current Meter				0.207	Un Gauge
8	Bagmati Sundarijal	15.457	17/01/2013	Slope Area	74.80	75.00			Gauge
9	Bagmati Sundarijal	15.457	17/01/2013	Current Meter			0.229	0.200	Gauge
10	Bagmati Gaurighat	68.000	23/07/2002	Publication	108.0				Gauge
10	Monahara	62.880	18/01/2013	Current Meter				0.191	Un Gauge
11	Monahara	62.880	18/01/2013	Slope Area		49.00			Un Gauge
12	Mohan Pokhari	6.472	18/01/2013	Float				0.053	Un Gauge
13	Mohan Pokhari	6.472	18/01/2013	Slope Area		55.00			Un Gauge
14	Bagmati Chovar	585.858	28/07/1972	Publication	856.0				Gauge but Remove
14	Bagmati Khokana	606.250	31/12/2013	Tracer				4.620	Gauge
15	Bagmati Khokana	606.250	31/12/2013	Current Meter			4.220	4.350	Gauge
16	Bagmati Khokana	606.250	31/12/2013	Slope Area	942.0	943.42			Gauge

[Source: field measurement and DHM publications]

5.4.4. Hydrological analysis of KV Watershed

The Bagmati River is a perennial river fed by storm and spring flow. The river flow is generally governed by the surface runoff flow during rainy sessions and depends upon groundwater flow when the river does not receive rainfall. Hyetograph of average annual precipitation and average annual runoff of the Kathmandu valley shows that there is a negative correlation between rainfall and runoff trend *(Figure 74)*. The stream flow gauging stations within the catchment area of the Bagmati River basin were analysed for determining average river discharge from 1992 to 2009. The stations included for this analysis are at Sundarijal, Gaurighat Tika Bhairab and Khokana. Analysis of available discharge data of these gauge stations shows that the river discharge in these stations have decreasing trend from 1992 to 2009.

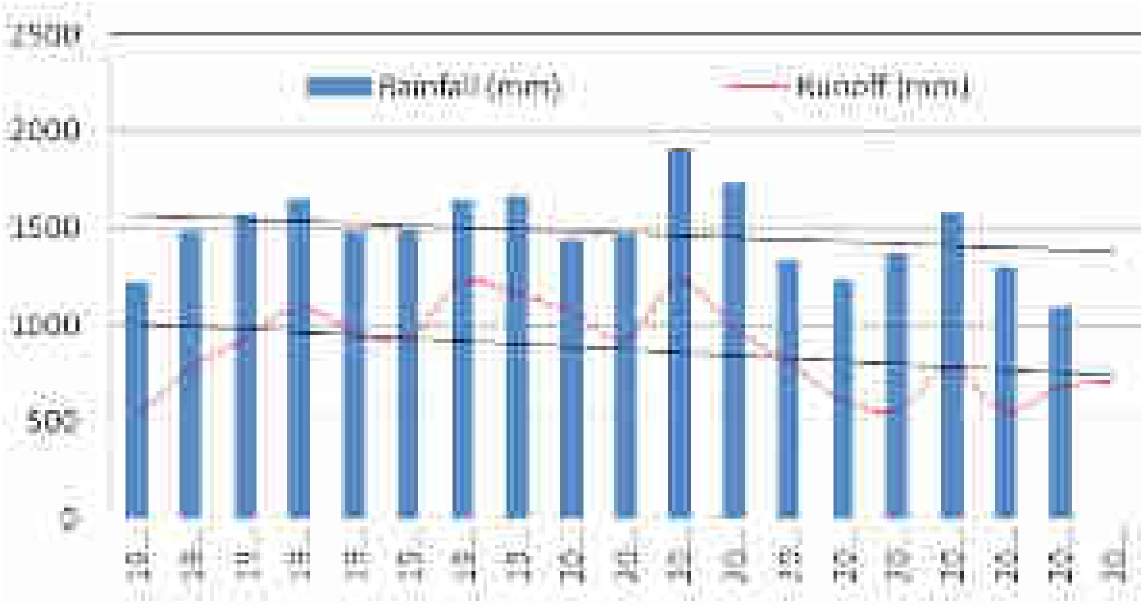


Figure 74 Hyetograph and Hydrograph Trend of Bagmati River in KV

5.4.5. Rainfall-Runoff Relationship

The rainfall trend is observed increasing in KTM airport and Nagarkot station readings but in majority of Kathmandu valley stations decreasing rainfall and increasing rainy days are seen as discussed above. Discharge in rivers are generally governed by the amount of precipitation received from catchment annual rainfall, the monthly rainfall is maximum in July 396 mm but the maximum runoff is 242 mm obtained in August due to the soil moisture *(Figure 75)*.

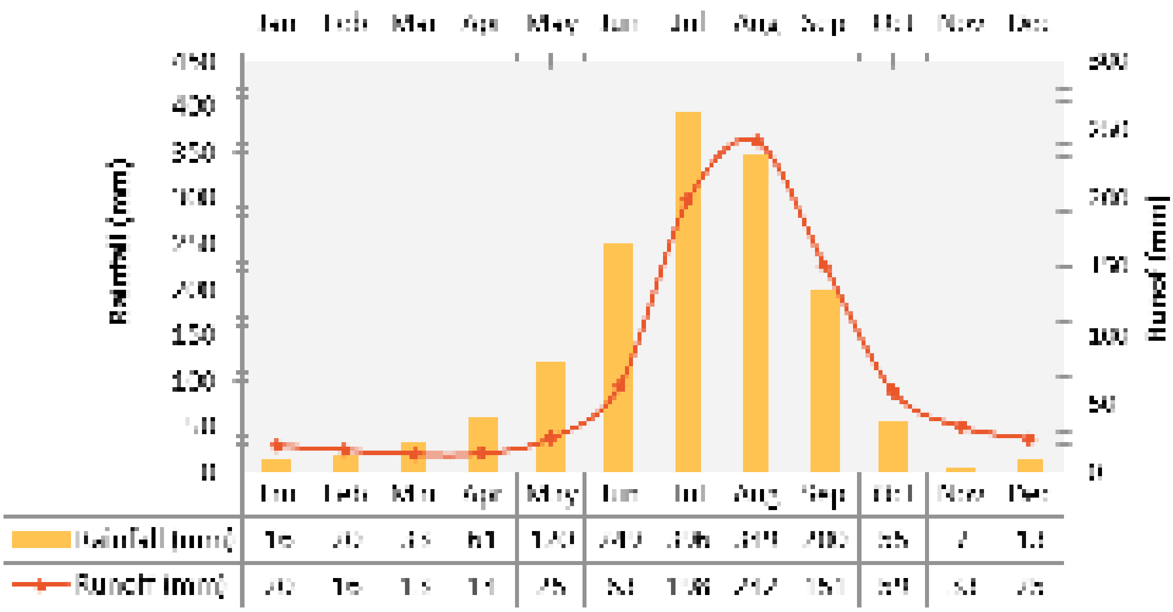


Figure 75 Monthly Rainfall Runoff Relationship of Bagmati River in KV

5.4.6. *Flood Frequency Analysis*

For flood prediction analysis HEC- HMS model and Tank model are used. Due to the lack of evaporation data pick flow cannot be captured from these hydrological models. In this situation measured extreme flood data from gauging station were used for flood frequency analysis which is more reliable than the modelled data. The flood frequency analysis Gumbel method is used for prediction of rainfall and flood peaks in different return period which is tabulated in Table 21 and Table 22.

Table 21 Return Period of Rainfall and Discharge Over KV

Return Period (yrs)	KV Average Rainfall (mm)	Bagmati at Khokana Discharge (m^3/s)	KV Outlet Discharge (m^3/s)
2	1505	412	461
5	1738	685	766
10	1893	866	968
20	2040	1040	1162
50	2232	1265	1413
100	2376	1433	1601
200	2518	1601	1789
500	2707	1822	2036
1000	2850	1989	2223

5.4.7. *Flood Inundation Mapping*

Flood hazard assessment and mapping was done for the estimation of flood inundation extent area and the depth of inundation for different return periods. This assessment was done based on flood flow modelling and simulation. The assessment was done using hydrological analysis for rainfall-runoff modelling and hydrodynamic modelling to analysis water surface profile.

5.4.8. *Hydrological Analysis*

Simulation of the precipitation-runoff processes of dendritic watershed systems physical representation of the watershed using a basin model. Simulation of infiltration losses, transforming excess precipitation into surface runoff, computation of base flow contributions to sub-basin out flow, flow routing. Computation of outflow from sub-basin from rainfall data by subtracting losses, transforming excess precipitation and adding base flow. Rainfall-runoff simulation was done using HEC-HMS and HEC-GeoHMS tools.

Table 22 Flood frequency in different return periods in different river catchments

River Name	Area (Km^2)	Return Period (years)								
		2	5	10	20	50	100	200	500	1000
Bagmati at Sundarijal	15.473	11.435	24.997	33.977	42.591	53.740	62.095	70.420	81.402	89.703
Bagmati at Gokarna	54.940	40.601	88.759	120.643	151.228	190.816	220.482	250.040	289.036	318.508
Bagmati at Gauri Ghat	67.940	50.947	111.376	151.386	189.764	239.441	276.666	313.756	362.689	399.671
Bagmati at Sankhamool	74.010	54.694	119.567	162.519	203.720	257.050	297.013	336.830	389.362	429.064
Bishanumati Khola Budhanilkantha	5.606	2.911	4.326	5.263	6.162	7.325	8.197	9.066	10.212	11.078
Bishanumati Confluence	81.830	42.487	63.146	76.824	89.944	106.927	119.653	132.333	149.061	161.704
Nakhu at Tika Bhairab	42.085	42.259	84.375	112.260	139.007	173.629	199.573	225.423	259.526	285.301
Nakhu at Confluence	55.944	56.176	112.161	149.228	184.784	230.807	265.295	299.657	344.991	379.253
Balkhu Khola Confluence	44.478	42.259	84.375	112.260	139.007	173.629	199.573	225.423	259.526	285.301
Dhobi Khola Confluence	27.210	14.128	20.997	25.545	29.908	35.555	39.787	44.003	49.566	53.770
Godhavari Confluence	45.849	23.805	35.380	43.044	50.395	59.911	67.041	74.145	83.518	90.602
Monan Pokhari Hanumante	6.487	3.368	5.006	6.090	7.130	8.477	9.485	10.491	11.817	12.819
Hanumante Monahara Confluence	95.485	49.577	73.683	89.644	104.953	124.770	139.619	154.415	173.935	188.688
Kodku Confluence	34.044	17.676	26.271	31.961	37.420	44.485	49.780	55.055	62.014	67.274
Mahadev Khola Upstream	15.270	7.928	11.783	14.336	16.784	19.953	22.328	24.694	27.816	30.175
Mahadev Khola Downstream	24.370	12.653	18.806	22.879	26.786	31.844	35.634	39.410	44.392	48.158
Monahara Upstream	63.108	46.637	101.954	138.579	173.711	219.185	253.262	287.214	332.007	365.861
Monahara Downstream	75.197	55.571	121.485	165.126	206.987	261.172	301.776	342.232	395.607	435.945
Bagmati Chovar	587.870	397.895	661.817	836.557	1004.171	1221.131	1383.711	1545.699	1759.411	1920.929
Bagmati at Khokana	608.790	412.054	685.369	866.327	1039.906	1264.586	1432.952	1600.704	1822.021	1989.287
Kathmandu Valley	**680.380**	**460.509**	**765.964**	**968.201**	**1162.192**	**1413.294**	**1601.459**	**1788.937**	**2036.280**	**2223.215**

5.4.9. Hydro-dynamic Modelling

Hydro-dynamic modelling was done by one-dimensional hydraulic calculations for a full network of natural and constructed channels calculation of water surface profiles for both steady and unsteady gradually varied flow, this was done using cross-sections for river and flood plain including left and right bank locations and flow paths, roughness coefficients (Manning's n), and contraction and expansion coefficients.

5.4.10. Flood Inundation Modelling

For flood prediction analysis, HEC-HMS model and Tank model were used. Besides, for better and reliable result, extreme flood data from gauging station were used for flood frequency analysis. Gumbel method is applied for prediction of rainfall and flood peaks in different return period.

Flood flow modelling was done by calibration of Manning's coefficient for various land cover classes, hydraulic analysis and modelling of river X-section, simulation of profile for given return period and discharge, simulation of the profile in steady state flow method (in HecRAS).

Figure 76 Hundred years return period inundation and depth in Sankhamol Dobhan, Lalitpur

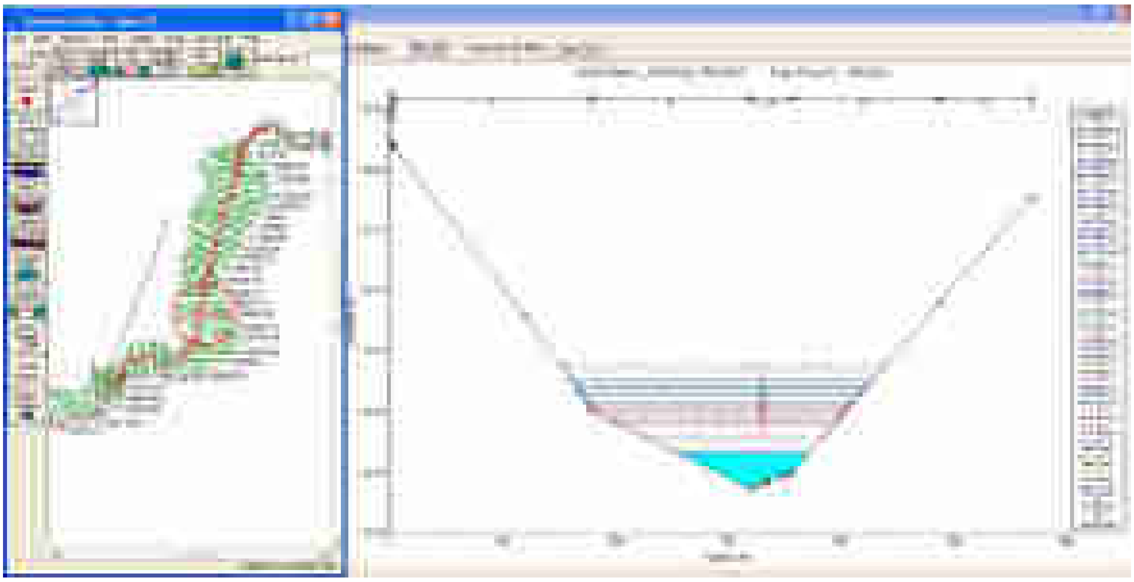


Figure 77 Illustration of HEC-RAS generated cross section at Sankhamol Dobhan

Analysis result presented in Table 23 shows maximum inundation depth in different return periods of the flood in KV at different rivers. Table 24 presents the locations in KV with maximum inundation depth for 10 years return period flood event (frequently occurring flood events). Table 25 presents the locations of the widest extent of the 10 years returning flood event. Figure 81 presents the flood inundation scenarios in different return periods in KV.

Table 23 Maximum depth in different years return period interval of flood event in KV

Name of River Section	Depth (in m)								
	2 yr	5yr	10 Yr	20yr	50 yr	100 yr	200 yr	500 yr	1000 yr
Bagmati (Sundarijal-Sankamul Doban)	2.30	2.97	3.46	3.86	4.32	4.63	4.90	5.25	5.50
Bagmati (Sankamul Doban-Chobar George)	4.75	6.38	7.31	8.12	9.08	9.74	10.36	11.12	11.66
Bagmati (Chobar-Lower Reach)	23.72	24.65	25.16	25.60	26.13	26.49	26.83	27.26	27.57
Manahara Khola	9.33	9.81	10.03	10.22	10.42	10.56	10.68	10.83	10.93
Kodku Khola	4.23	4.34	4.41	4.47	4.53	4.57	4.61	4.67	4.71
Dhobi Khola	3.01	3.16	3.25	3.32	3.41	3.47	3.52	3.59	3.64
Bishnumati Tributary	2.76	2.86	2.92	2.96	3.02	3.06	3.09	3.13	3.16
Hanumante Khola	1.13	1.20	1.29	1.38	1.47	1.54	1.60	1.68	1.73
Mahadev Khola	1.25	1.31	1.34	1.36	1.41	1.42	1.44	1.47	1.49
Nakkhu Khola	3.69	4.35	4.69	4.96	5.28	5.50	5.70	5.94	6.11
Balkhu Khola	2.04	2.79	3.27	3.70	4.19	4.54	4.87	5.27	5.56
Godavari Khola	1.52	1.63	1.70	1.76	1.83	1.88	1.92	1.98	2.03
Bishnumati Khola	1.57	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60

Table 24 Locations in KV comparatively under maximum depth at 10 years return period flood event

Name of River Section	Location Name
Bagmati (Sundarijal-Sankamul Doban)	Sankhamul Dovan, Aryaghat,Basuki chowk, Atarkhel, Shankhadol, Pathib-hara, Gokarna
Bagmati (Sankamul Doban- Chobar Gorge)	Chovar, Sainbu Bhanjyang, Thapathali
Bagmati (Chobar-Lower Reach)	Chalnakhel, Bansbari, Naikhandi, Hansdol, Bhandarkharka
Manahara Khola	Koteswor,Chhapro,Gothatar,Karkigaun,Thapagaun,Kapahiti,Balkumari
Kodku Khola	Imadol, Sitapakha, Dhapakhel, Ganglethok,Thangu,Tasinchok
Dhobi Khola	Ghattekulo, Dillibajar, Baudha Mahankal, Galphutar, Bhangaltar, Pandit Gaun
Bishnumati Tributary	Baluwapati, Phutung, Karkigaun
Hanumante Khola	Phaidol,Balkot,Basidol,Thimitar,GatahagharSallaghari,Bungal,Jagati,
Mahadev Khola	Shiddhitol, Dungrungpani, Nepaltar, Lamabazar Paiyatar, Ravitar
Nakkhu Khola	Baniyagaun,Chhayasikot,Karyabinayak,Dhaichhap,Thapagaun,Bistagaun,S alyantar
Balkhu Khola	Balkhu,Gangkhel,Kalanki,Nariwalphat,Duppa,Salyansthan,Tusal,Bayachap ,Akashtol
Godavari Khola	Balkot,Tikathali,Thaikot,Sanagaun,Borcha,Libhu,Charghare,Damaitar,Ban degaun,Taukhel
Bishnumati Khola	Kuleswor,Teku,Kharibot,Tamsipakha,Dhalko,Khusibu,NayaBajar,Siddhitol, Mahedevtar

Table 25 Locations of the widest extent of flood inundation at 10 years return period

Name of River Section	Location
Bagmati (Sundarijal-Sankamul Doban)	Guheswori
Bagmati (Sankamul Doban- Chobar Gorge)	Buddhanagar
Bagmati (Chobar-Lower Reach)	Hansdol
Manahara Khola	Gothatar
Kodku Khola	Gwarko
Dhobi Khola	Gattekul
Bishnumati Tributary	Hilledol
Hanumante Khola	Devdol, Thapatol
Mahadev Khola	Paiyatar
Nakkhu Khola	Nakkhu bajar
Balkhu Khola	Akashtol
Godavari Khola	Bishnudol
Bishnumati Khola	Shobhabhagwai, Mhaipi

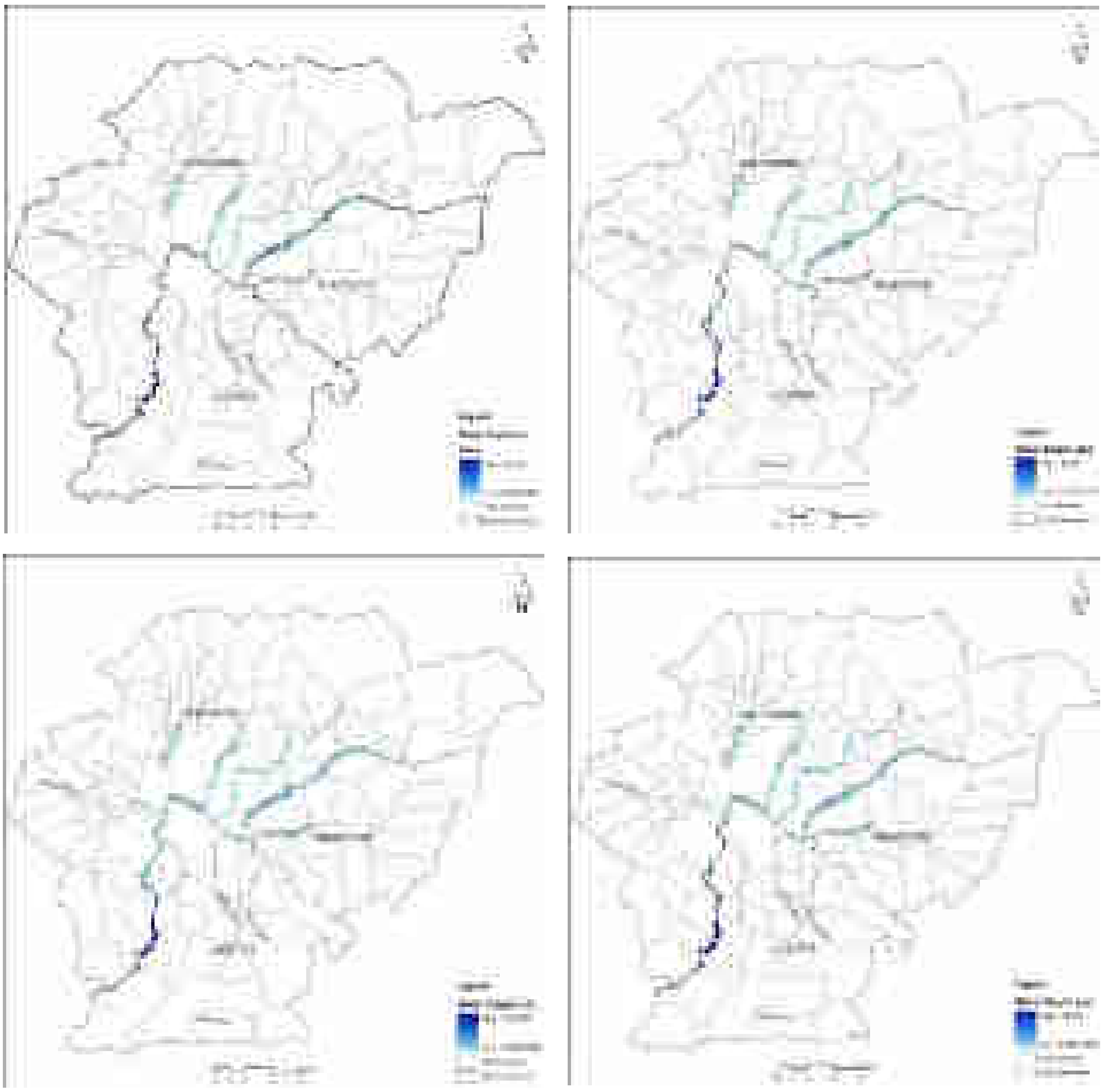


Figure 78 Flood Inundation Map at (a) 2 yrs., (b) 50 yrs., (c) 500 yrs. & (d) 1000 yrs. return period

5.4.11. Flood Hazard Vulnerability

Flood hazard vulnerability to the buildings and infrastructure (road network) is assessed for the modelled scenario flood events of 50, 100, 200 and 500 years return periods in the river systems of KV (Bagmati River, Balkhu Khola, Bishnumati River, Dhobi Khola, Godavari Khola, Hanumante Khola, Kodku Khola, Mahadeve Khola, Manohar Khola, Nakhu Khola and Sangle Khola).

Vulnerable Buildings

Mapped buildings *(n=353,630)* were assessed for possible inundation by different rivers for flood scenarios in different return periods. Following vulnerability scenario is observed based on flood simulation and inundation mapping:

- For 50 years return period, total of 14,329 buildings are likely to be inundated with 13,956 buildings in depths upto 2m, 340 buildings in depth 2-5m, and at least 33 building in depth 5-10m. Major flooding is foreseen in Dhobi Khola with estimated 5,312 buildings affected by inundation with at least 5 buildings up to 5 m depth. Bagmati and Bishnumati rivers are also likely to cause submergence of 3,806 and 2,2295 buildings respectively. *(Refer Table 26)*

- For 100 years return period, total of 14,593 buildings are likely to be inundated. Among these, 14,169 number of buildings will be submerged up 2m water, 399 buildings 2-5m and 25 buildings 5-10m of water. Flood in Dhobi Khola, is likely to affect 5,425 buildings, Bagmati River flood is likely to affect 4,153 buildings and the Bishnumati flooding is likely to affect 2,313 buildings. *(Refer* Table 27*)*

- The total number of buildings likely to be inundated in the event of 200 years return period flooding is 14,945 throughout the KV. Among these buildings 14,918 buildings will be submerged 2-5m, and 27 buildings are likely to get submerged in 5-10m water. Dhobi Khola, Bagmati and Bishnumati Khola are likely to affect more buildings than other smaller rivers in the KV. *(Refer* Table 28*)*

Table 26 Affected buildings in 50 years return period flood

Rivers	<=2m	2m - 5m	5m - 10m	Total
Bagmati	3,806	187	21	4,014
Balkhu	384	66	10	460
Bishnumati	2,295			2,295
Dhobi	5,312	77		5,389
Godavari	41			41
Hanumante	342			342
Kodku	263			263
Mahadev	482			482
Manohara	561			561
Nakhu	202	1	2	205
Sangle	268	9		277
Total	**13,956**	**340**	**33**	**14,329**

Table 27 Affected buildings in 100 years return period flood

Rivers	<=2m	2m - 5m	5m - 10m	Total
Bagmati	3,900	230	23	4,153
Balkhu	392	80		472
Bishnumati	2,313			2,313
Dhobi	5,346	79		5,425
Godavari	41			41
Hanumante	349			349
Kodku	266			266
Mahadev	488			488
Manohara	600			600
Nakhu	205	1	2	208
Sangle	269	9		278
Total	**14,169**	**399**	**25**	**14,593**

- In 500 years return period flooding event, total of 15,319 buildings in KV are likely to be affected. Among these, 15,286 buildings are likely to be submerged in waters 2-5m and 33 buildings are likely to be submerged in 5-10m waters. *(Refer* Table 29*)*

Table 28 Affected buildings in 200 years return period flood

Rivers	<=2m	2m - 5m	5m - 10m	Total
Bagmati		4,325	25	4,350
Balkhu		483		483
Bishnumati		2,341		2,341
Dhobi		5,461		5,461
Godavari		41		41
Hanumante		359		359
Kodku		268		268
Mahadev		495		495
Manohara		643		643
Nakhu		222	2	224
Sangle		280		280
Total		**14,918**	**27**	**14,945**

Analysis of flood simulations in different return periods and the extent of the inundation areas clearly shows that the buildings presented in the adjoining tables are located in the old flood plains of these rivers predominantly Dhobi Khola, Bagmati River and Bishnumati Khola, which traverses through the core densely built areas of the KMC. Buildings built in the flood plains of Dhobi Khola, in Kapan VDC and KMC are effected. Similarly, Bagmati River inundates the buildings in Jorpati and KMC, Bishnumati Khola floods effect the buildings in rivers in Khadka Bhadrakali, Tokha Saraswoti, Dhapasi, Gongabu, Manamiaju and KMC. Buildings in Imadol, Harisiddhi, LSMC and Dhapakhel are likely to be affected by the floods in Kodhku Khola. Certain areas along the Bagmati are also affected within LSMC. *(Refer Figure 80 & Figure 79)*

Table 29 Affected buildings in 500 years return period flood

Rivers	<=2m	2m - 5m	5m - 10m	Total
Bagmati		4,529	31	4,560
Balkhu		503		503
Bishnumati		2,360		2,360
Dhobi		5,510		5,510
Godavari		43		43
Hanumante		367		367
Kodku		272		272
Mahadev		505		505
Manohara		680		680
Nakhu		233	2	235
Sangle		284		284
Total		**15,286**	**33**	**15,319**

Figure 80 Inundated buildings by Dhobi Khola, Bagmati and Bishnumati Rivers for 100 years return period flood

Figure 79 Buildings constructed in the old flood plains of Dhobi Khola and Bagmati River in KMC.

Vulnerable Road Network

Road network affected by the flooding events have been assessed based on the mapped road networks (using high resolution satellite images and ground survey, 2012) and simulated flood models for 50, 100, 200 and 500 years return periods. In the report, the statistics of affected roads have been presented for strategic and other roads, and in details based on pavement types and road width class presented in Annex C. Analysis based on road surface types, width and other parameters can be done using the accompanying road GIS database. Following vulnerability scenario is assessed for the road networks in the KV:

- For the event of 50 year return period flood in the KV, total of 264 km of the stretch of road is likely to be inundated of which 20 km is strategic road and 244 km other roads in the KV. Of this road, 95 km is paved and 169 km unpaved. Categorizing the road based on width, this inundated length consists of 213 km of roads <5m and 51 km >=5m in width.
- For 100 years return period flood event, total 268 km of road networks is likely to be inundated. Of this length, 20 km is strategic road and 248 km other roads. Of the inundated roads, 97 km are paved and 172 km unpaved. Based on width, 217 km are <5m and 51 =>5m width.
- For 200 years return period flood scenario in KV, total 274 km road is likely to be inundated of which 21 km is strategic and 253 km other roads. Based on pavement types, the inundated length is 99 km paved and 175 unpaved. Similarly, based on width category, 222 km road is <5m and 52 km >=5m of the inundated road segments.
- Similarly, for 500 years return period flood event, 280 km road is likely to be inundated, of which 22 km is strategic road and 258 other roads. Of the inundated road, 101 km are paved and 179 km unpaved; 227 km <5m and 53 km>=5m in width.

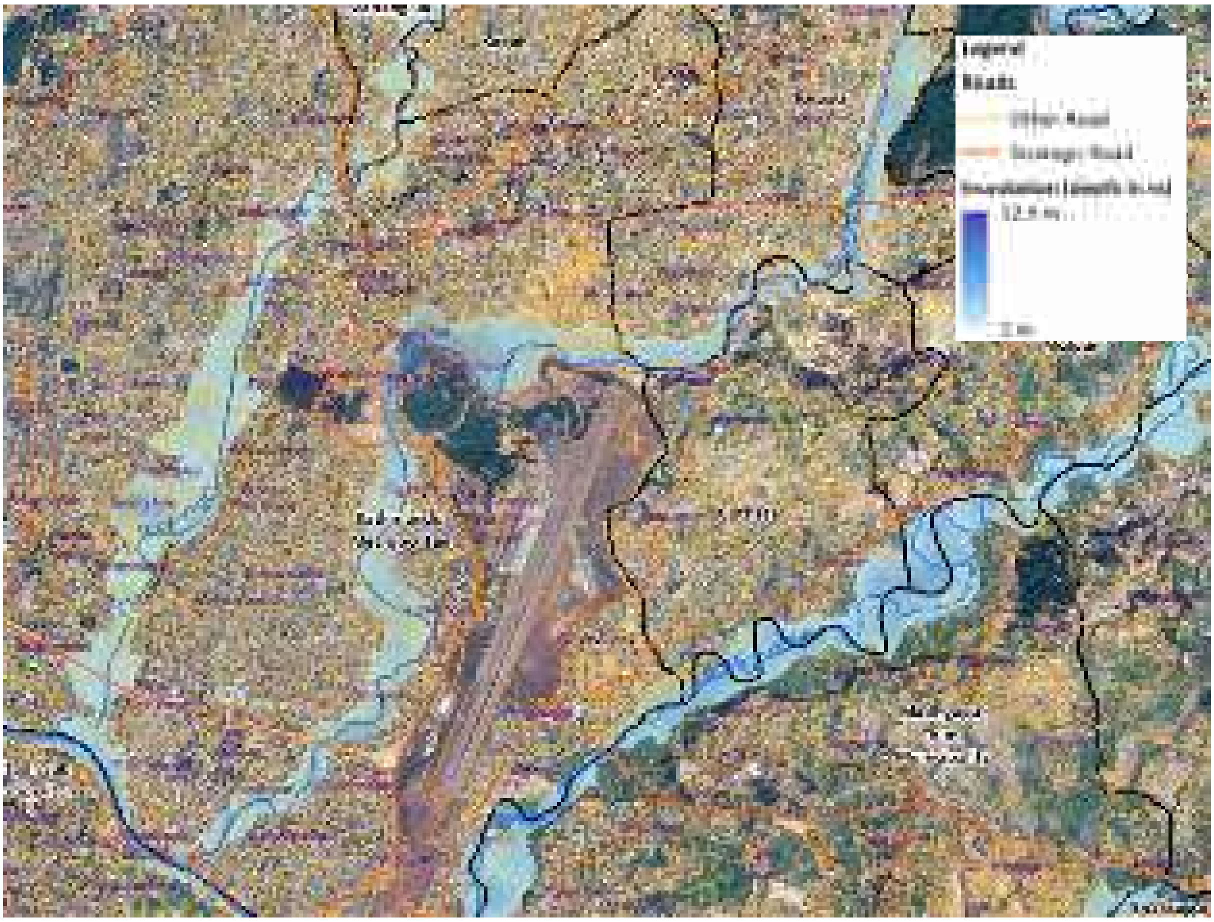


Figure 81 Flood for 100 years return period and road networks in city areas of KV

In all the flood events Bagmati, Dhobi, Bishnumati, Manohara and Hanumante Khola are the main rivers causing greater affects to the roads. Inundation of strategic roads is likely to cause disruption of major traffic in these roads, damage to the road surface, deposition of debris, scouring of the edges and may even wash away certain sections. The strategic and other major roads in the flood plains, therefore needs additional consideration in surface type, river training, drainage system to support unhindered traffic flow during and after any such flooding events.

The road system and the side drains themselves are not well designed or at most rudimentary during heavy rainfall, causing surface flow along the roads disrupting traffic in municipal areas. Therefore, the inner roads are also effected frequently flooded during heavy rainfall in the KV.

5.5. Landslide Hazard and Vulnerability

Among the natural Hazard, landslide is common and a serious problem in most mountainous areas, causing damage to critical infrastructure and daily activities of people along with tolls of injuries and death of human being. Rugged topography, unstable geological structures, soft and fragile rocks, common earthquakes, along with heavy and concentrated rainfalls during monsoon periods cause severe landslides and related phenomena in the Himalayan region. Landslides in the Himalaya are scale-dependent, from massive extent of whole mountain ranges (gravity tectonics) through failure of single peaks to very minor slope failures (Shroder and Bishop 1998).

Over geological time, widespread deposits of transported debris (colluvium) can accumulate on slopes, often to several metres in thickness. Reactivation of movements within this colluvium is common on many hill slopes, and it is often difficult to identify this movement unless there are obvious effects, such as progressive cracking to buildings (Scott Wilson 2003).

Urbanization and other physical developmental activities such as road construction, land cutting further add disturbance in the hill slopes leading to landslide due to internal imbalance of slope or for heavy rainfall. It is therefore necessary to know the landslide prone zones before any construction activity begins so that adequate control measures can be applied well in time. Landslide susceptibility mapping, which delineates the potential landslide zones, is therefore became necessary for Kathmandu Valley for this study.

Landslide hazard assessment and mapping was done by identifying and mapping the historic and existing landslides in the valley to model landslide susceptibility due to prevailing soil, terrain, and catchment area triggered[7] by rainfall.

5.5.1. Landslide Scenario in KV

With visual interpretation of high resolution aerial photographs and satellite image of the year 1990, 2000 and 2012, mapping with ground observations, the scenario of landslide in KV is found in an increasing trend. The table below shows the number of events that has occurred in three decades in KV.

Table 30 Past landslides

Years	Land slides
1990	37
2000	96
2012	219
Total	**352**

5.5.2. Landslide Hazard Mapping KV

Slope stability analysis and modelling was done using (Stability Index Mapping–SINMAP). SINMAP considers infinite slope stability approach to give stability of slope based on slope gradient, soil and geological characteristics along with hydrological parameter such as '*Topographic Wetness*'.

7 Landslides triggered by earthquake has not been assessed in this study.

$$[illegible]$$ (Eq. 12)

The stability index (SI) value ranges between 0 (most unstable) and 1 (least unstable).

SINMAP model classified the slope stability into six broad classes *viz.* Stable, Moderately Stable, Quasi Stable, Lower threshold, Upper Threshold and 'defended slope'. To generate the Stability Index and Topographic Wetness Index Map of Kathmandu Valley, A DEM of 20m is generated from Topographic contour and Spot Heights. The landslide inventory points were collected from Satellite Image of different time period.

To generate the Stability Index and Topographic Wetness Index Map of Kathmandu Valley, DEM of 20m was generated using contour and spot heights from the national topographical map data (Survey Department 2001). The landslide inventory points were collected from satellite image of different time period. Geological map and Land System Map and few soil profiles data of LRMP (Land Resource Mapping Project 1986)have been used as base data to set the soil parameter.

5.5.3. Stability Index Mapping (SINMAP)

Landslide hazard assessment has been done using SINMAP (Stability Index Mapping) (Pack, Tarboton, and Goodwin 1998) method based on the infinite slope stability model (Hammond et al., 1992; Montgomery and Dietrich, 1994). This method balances the destabilizing components of gravity and the restoring components of friction and cohesion on a failure plane parallel to the ground surface. It models the spatial distribution of shallow debris slides combining a mechanistic infinite slope stability model with a steady-state hydrology model. The method derives its terrain stability classification from inputs of topographic slope and specific catchment area and from parameters quantifying material properties (such as strength) and climate (primarily a hydrologic wetness parameter). SINMAP approach applies to shallow translational land sliding phenomena controlled by shallow groundwater flow convergence. It does not apply to deep-seated instability including deep earth flows.

With 352 number of landslide inventory points, DEM and assigned soil parameter, the SINMAP model derived the topographic Wetness Index map (*Figure 82)* that shows the saturation index in steady state hydrologic condition in the valley and Soil Stability Map shows the potential Susceptibility zone of landslides in six range of stability index.

Table 31 Area under different Saturation Zone

Saturation	Area (in sq.km)	Percentage
Low Moisture	275.08	38.11
Partially Wet	267.56	37.07
Threshold Saturation	23.95	3.32
Saturation Zone	155.25	21.51
Total	**721.85**	**100.00**

The *Table 32* shows that around 46 percentage of the total area of Kathmandu valley is not stable or in other word susceptible to landslide. This area mostly existed in the hill slopes surrounding the valley from all corner. Major part lies in southeast and south west hill slope and few are in North West and Northern part of

Table 32 Contribution of Area in different Stability Index

Stability Index	Area (in sq.Km.)	Percentage	Susceptibility
Defended	16.15	2.24	High
Upper Threshold	57.75	8.00	High
Lower Threshold	132.33	18.33	Moderate
Quasi Stable	71.04	9.84	Low
Moderately Stable	49.48	6.85	Low
Stable	395.08	54.73	None

Kathmandu Valley. Of total susceptible area nearly 28 percentage area falls not under Lower threshold to Defended Zone where according to model destabilizing factor or any other external factor are not required to induce instability. Nearly 55 percentage areas in KV are stable where developmental activities can be done considering the prevention to significant destabilizing factor such as high magnitude earthquake tumour or any other anthropogenic activities that may disturb the soil stability. The landslide potential is shown in *Figure 83*.

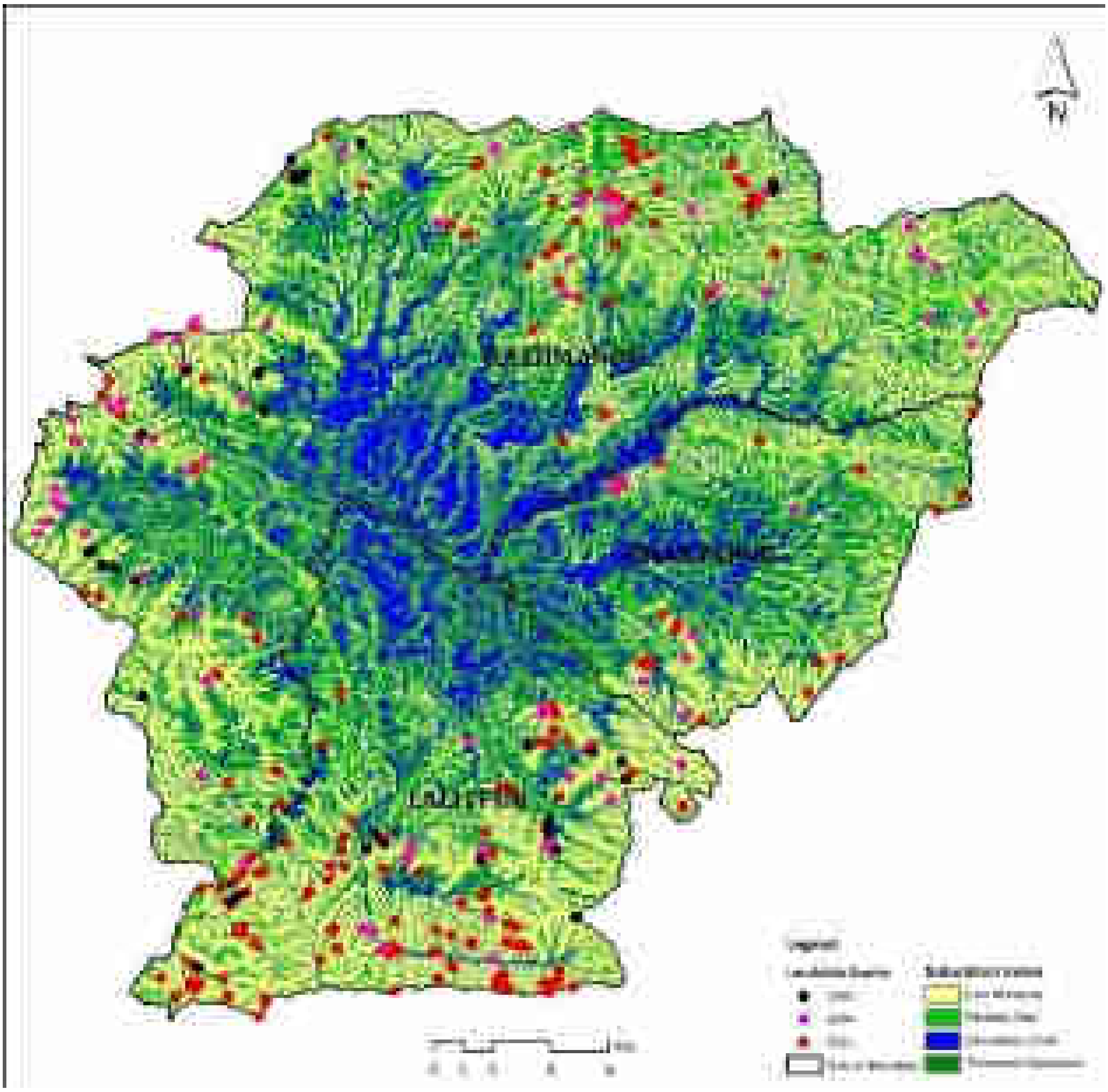


Figure 82 Topographic wetness index and existing landslides in KV

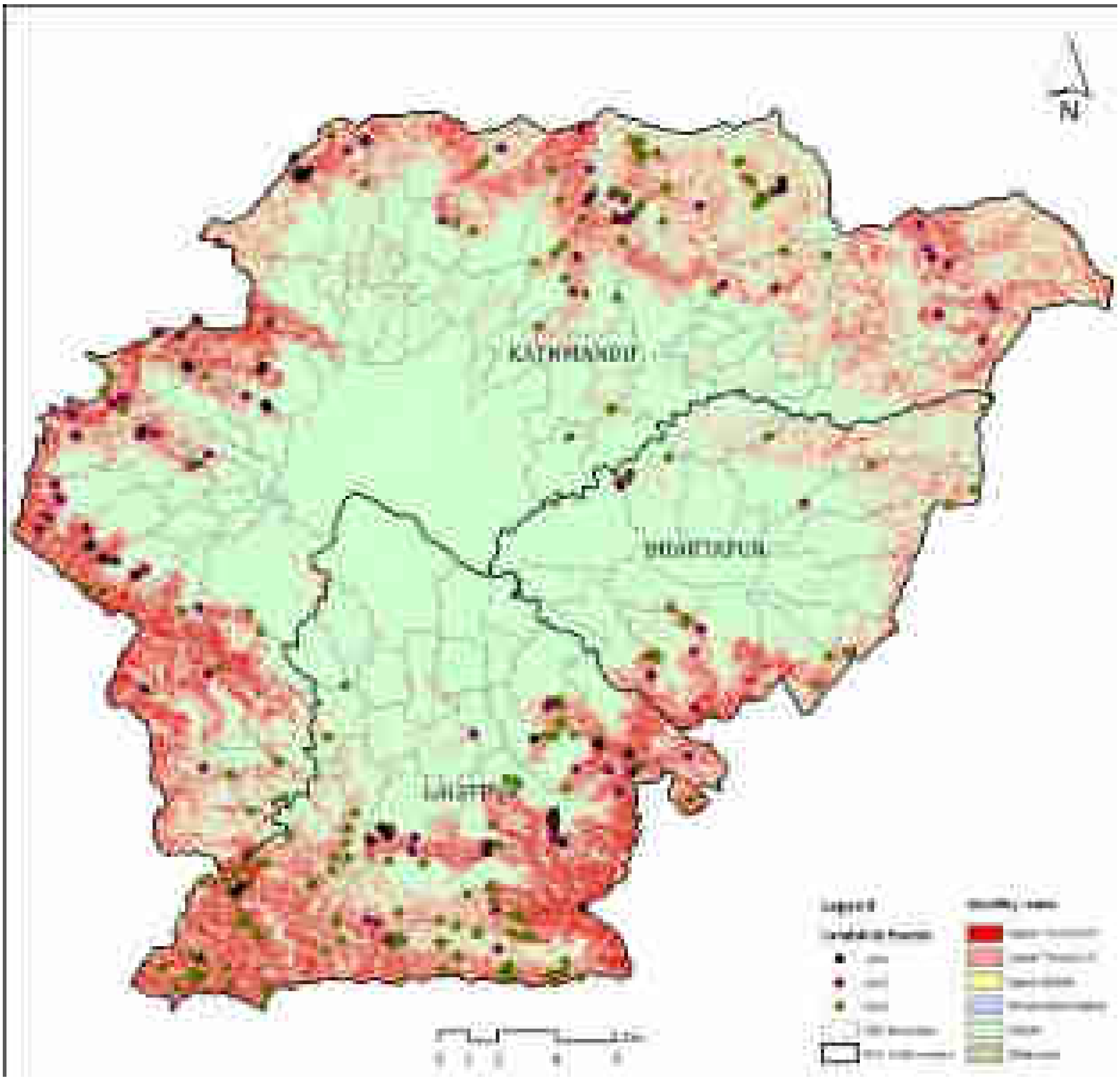


Figure 83 Existing landslides and landslide potential areas in KV

5.5.4. Validation of Landslide Susceptibility Mapping

From the study it was found that around 76 % areas (106.28 Ha) of occurred landslide were under unstable zone (Table 33). The remaining 23.30 percentage area of landslides occurred in stable region, which, according to the model was due to significant destabilizing factor.

5.5.5. Landslide Hazard Vulnerability

Vulnerability to the buildings are roads were assessed for existing landslide and land slide potential based on the mapping of existing landslides and potential landslide areas as described in the aforementioned sections.

Table 33 contribution of Storability index in existing landside Area

Stability Index	Area (In Ha.)	Percentage
Defended	10.84	7.82
Upper Threshold	24.24	17.49
Lower Threshold	39.68	28.64
Quasi Stable	20.72	14.95
Moderately Stable	10.80	7.79
Stable	32.28	23.30
Total	**138.56**	**100.00**

Vulnerable Buildings

Mapped buildings were assessed for landslide vulnerability based on their proximity to the existing active landslides and modelled landslide potential maps. The vulnerability scenario of buildings due to landslide is as briefed hereunder:

- There are altogether 352 existing active landslides in the slopes of KV (Refer *Figure 84*) with total of 326 individual buildings in its near vicinity (within 50 m), which are vulnerable to slope failure.
- The landslide susceptibility and vulnerability analysis showed total of 1,414 buildings in high susceptible zone, 8,667 buildings in moderate susceptibility zone and 22,544 buildings in low susceptible zones of landslide in the KV (Refer Table 34, detailed in Annex D, Table D1)
- Buildings in KMC, Nanglebhare, Jitpur Phedi, KM, Lele, Lapsiphedi, Chaling, Nagarkot and Bageshowri VDCs are at higher exposure levels to landslide. Buildings in Ghusel VDCs are at very high exposure levels to landslide susceptibility (279 buildings).

Figure 84 Buildings close to landslide area in Chunikhel VDC, Ward 7

Table 34 Buildings vulnerable to landslide susceptibility

VDCs/Municipalities	High	Moderate	Low
Municipality	12	288	2,568
Rural VDCs	1,205	6,584	13,565
Urbanizing VDCs	197	1,795	6,411
Total	1,414	8,667	22,544

Vulnerable Roads

On assessment of roads exposed to landslide (within the existing land slide zone or in the proximity within 50m distance), following observations are made:

- Total of 7.85 km of road is affected, of which 2.7 km stretch are strategic roads and remaining 5 km other roads. These roads are located in the urbanizing VDCs (0.95 km) and in rural VDCs (6.9 km).
- Of the potentially vulnerable roads, 0.83 km are black topped, 5.4 km are earthen, 0.74 km are gravel and 0.92 km are track. (Refer Annex D, Table D2)
- On analysis of roads in the vicinity of existing landslides, total of 42 km of roads are in landslide hazardous areas; of which 4 km is black topped, 22 km earthen, 7 km gravel and 9 km tracks.

5.6. Environmental Hazards and Vulnerability

Environmental hazard is a general term which refers to any event or situation that has the potential to harm or damage the surrounding natural environment and adversely affect the health of people. It incorporates areas from pollution to natural disasters. It can range from chemical, physical, mechanical, biological and psychosocial environmental hazards. Air pollution, water pollution and land pollution are some of the examples of impacts of environmental hazards attributed to brick kilns, quarry, forest fire and solid waste disposal. Environmental hazards can be natural or human induced. They can occur during different seasons and the level of impacts of each hazard depends upon the risk and vulnerability of that environment and its surroundings. Risk of negative impact on the environment is dependent on the hazard and the vulnerability of the components of the environments itself. Influence area, level of effect and duration of effect differs on the basis of the types of substances involved in the hazard. Additionally, substances also behaves differently based on surrounding environment such as land use, types of soil, weather condition etc. Owing to rapid industrialization, the management of solid waste has become increasingly difficult in Kathmandu Valley.

Under this study, assessment environmental hazards was limited to the impacts of brick kilns based on primary data collection and field observations. Assessment of environmental impacts due to solid wastes and sewerage system was done with limited scope using the secondary available data. This report only presents the assessment of impacts due to quarries and brick kilns. The assessment of solid waste and sewerage system can be found in details in the *Technical Report Volume 2 Multi-Hazard and Risk Assessment in Kathmandu Valley*.

5.6.1. Brick Kiln

Brick kilns are thermally insulated chambers or ovens in which controlled chamber temperature regimens are produced to bake the dried green bricks resulting in hard and durable bricks. Brick kilns fall into one or both, of the following categories of Intermittent Kilns in which bricks are fired in batches e.g., Clamp, Scove and Scotch; and/or Continuous Kilns in which firing occurs continuously, e.g., Hoffman, Bull's Trench, Habla, etc. The most common types of brick kilns found in the Kathmandu Valley are Bull's Trench Kiln, Hoffman Kiln and Vertical Shaft Brick Kiln (VSBK). These brick kilns produce black smoke consisting of harmful gases and small particles of ashes which are the one of the major contributors of air pollution in KV

Kathmandu Valley is the main center of all economic and development activities. Exploding population inflow, rapid urbanization and valley centric industrialization due to different available opportunities have caused increased demand for living spaces and construction materials such as bricks and concrete. This demand for living spaces is creating a trend of conversion of agricultural land into built up area especially near the Ring Road. The agricultural fields are also being threatened by emission of smoke from the brick kilns and extraction of fertile top soil.

Brick kilns were introduced in KV in around 2050 with the growing demand for building houses and it grew in numbers to more than 200 around the Kathmandu valley near the river banks and other sources of water. Traditional clamp kiln were slowly replaced following ban of moving chimney bull's trench kiln in 2059 due to growing pollution and improved brick kiln were introduced. There are currently about 112 fixed chimney brick kilns in Kathmandu valley; 108 bull's trench kiln (Natural draught and Forced Draught), 2 Vertical Shaft Brick Kiln (VSBK) and 2 Hoffman Kiln. These brick kilns are located at the outskirts of ring road and concentrated mainly in Bhaktapur and Madhyapur Municipality in the East, Lalitpur Municipality in the South and Thankot in the West.

5.6.2. Impacts of Brick Kiln

Smoke emissions affecting the health and soil extraction from agricultural land are the two hazardous environmental impacts of brick kilns in the KV. According to a study by URBAIR in 1997(Grønskei et al. 1997), brick kilns were found responsible for 31 percent of the total suspended particles and 28 percent of PM_{10} particles in the Kathmandu valley. Similarly a study conducted during brick kiln operating season at Tikathali VDC of Bhaktapur district shows that air pollution were three times higher during the brick kiln operating time than during off season. In Jhaukhel VDC of Bhaktapur district near the brick kilns, PM_{10} was recorded as 568.78μg/m^3 and 158.33 in Sipadol; south of Jhaukhel away from brick kilns pointing to the cause of PM_{10} emissions as brick kilns (Raut 2003).

The impact of smoke emissions from chimneys mainly depends upon these parameters:

- Type of fuel used
- Design of the brick kiln (height of chimney),
- Atmospheric conditions
- Proximity to urban settlement and
- Elevation of urban settlement.

Most of the brick kilns have been found to use Assam coal and some use steam coal with dust of wood. Assam coal contains higher amount of sulphur relative to anthracite coal and contains lesser carbon with possibility of higher PM_{10} particles, SO_2 and SO_3 emissions. More than 95 percent of the brick kilns are Bull's trench kiln having fixed chimney, height varying from 40 feet to 125 feet which determines the mixing height of the smoke and also the dispersion area of the smoke emitted. The production capacity of these brick kilns were in the range of 20-100 lakhs per season using 55- 1500 tons of coal. Due to growing urbanization and demand for settlement spaces, houses are being built closer and closer to the brick kilns; some at a distance of 25 to 30 m. The impact of smoke emitted has been observed more during the morning and evening than afternoon due to the unstable atmosphere which helps in dispersion of smoke to a larger area. The geographical condition of Kathmandu Valley forms the deep inversion layer during the dry season especially during winter which acts like a cover over the city and the concentration of pollutants may build up considerably due to poor atmospheric dilution (Pandey 1987).

It was also observed that the settlement areas at the elevation similar to the elevation of height of chimney and in the direction of wind suffered from direct impact of smoke emissions.

Box 4 Method for calculating pollution load

Following approach method was adopted for calculating pollution load for the burning of the coal in brick kilns by using the formula;

Pollution Load (X i) = Fuel Consumption (Fw) x Emission Factor (Xj)

where,
Xi is the pollution parameter
Fw is the quantity of fuel consumption
Xj is the emission factor
[Source: Environment Management Plan, Government of Orissa]

Type of fuel	Consumption T/Day	Emission factor(Kg/Day)				
		SPM	SO2	NO2	HC	CO
Lignite coal	Fw	3.5 (A)	15 (S)		0.5	1

(Emissions Factors from WHO Publication No.62 were used)
where,
A – It is the percentage ash content of combustible by weight.
S – It is the percentage sulphur content of combustible by weight.
Ash Content of Lignite Coal – 0.4,
Sulphur Content for Coal – 0.005

Table 35 Emissions from brick kiln

Type of fuel	Consumption (T/Day)	Emission factor(Kg/Day)		
		NO^2	HC	CO
Lignite coal	2.67	8.01	1.34	2.67

5.6.3. Impact area

Most of the brick kilns add coal every 15 to 20 minutes during charging phase which causes incomplete combustion of the coals and creates more pollution emitting dark smoke. For the remaining period, generally gray smoke is observed. The maximum concentration of the particle size is above 5 microns. Hence the dispersion of the dust particles varies from 200m to 1000m (Government of Orrisa 2012).

High concentrations of pollutants are observed before noon and then decreases during the afternoon. The decreasing trend from morning to late afternoon is the result of increasing wind speed through the same time period. The persistent westerly and south westerly winds flush urban pollutants from the valley (Dhaubadel 2000).

5.6.4. *Health Impacts*

The health concerns arise from the smoke emissions from brick kilns which consists of harmful gases such as CO, CO_2, NO_2, SO_2, SO_3 and particle emissions which are the causes of respiratory diseases, headaches and irritation of eyes. People living at close proximity to the brick kiln and at the same level of elevation as chimney height face higher level of emissions and for longer duration.

Traditionally, symptoms of daily exposure to unhealthy levels of pollution include reduction in lung function, chest pain, and cough (Gold et al. 1999). Prolonged exposure may lead to respiratory infection and lung inflammation, with the most drastic result being irreversible change in lung structure and chronic respiratory illness. Those most prone to pollution related affliction are children, because of their underdeveloped defence mechanism, and the elderly, due the enhancement of pre-existing respiratory diseases (Gold et al. 1999).

Figure 85 Brick kilns situated in Jharrasi, Chapagaon and BadikhelVDC

It has been observed that many of the people living in the 250m to 500m zone around the brick kilns in Bhaktapur district and Dakshinkali VDC of Kathmandu district show higher frequency of respiratory problems, black spot in the sputum and common cold with few cases of eye irritation and headache more frequent during morning and evening. However, only few cases were observed for respiratory problems around Imadole area in the same zone. Though more cases of impact on human health are still prevalent, it was reported to have decreased following the shutting down of brick kilns near settlement areas and introduction of fixed chimney brick kilns.

5.6.5. *Agricultural Impacts*

The removal of topsoil for urban uses mainly for construction brick is growing rapidly due to increased urbanization and industrialization. On average a brick kiln extracts soil from an area of 133 ropanies[8] of prime agriculture land and during the season produces on average 49 lakhs bricks. The volume of soil extracted by a single brick kiln is around 6,000 cu. m.

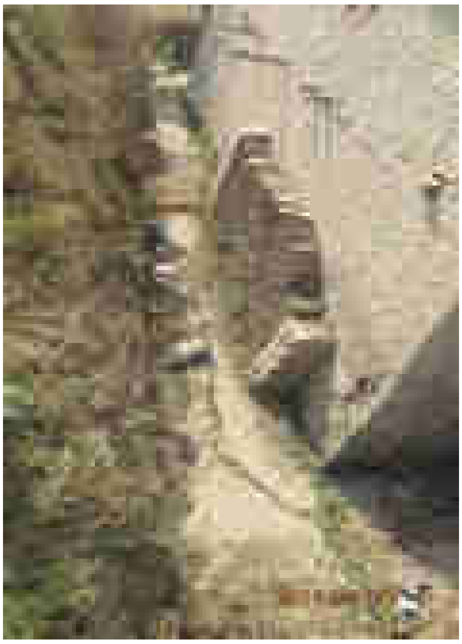


Figure 86 Crack observed due to soil over extraction below the building

The removal of top soil causes loss of fertility of soil. Studies have shown that concentrations of essential nutrients like nitrogen (N), phosphorus (P) and potassium (K) are very low in fields that have been used by the brick industry (Tuladhar and Raut 2002).

Soil extraction also causes loss of organic matter and the sand content increases in the soil near brick kilns. Soil organic matter is a reservoir for plant nutrients, enhances water holding capacity, protects soil structure against compaction and erosion, and thus determines soil productivity. All agriculture to some extend depends on the content of soil organic matter as well as the soil nutrients.

8 1 Ropani = 508.74 sq.m.

Maintenance of organic matter is critical for preventing land degradation. The impact on the agricultural is seen during both the operational season and off season of brick kilns. During the operational season the small particles from the smoke emissions cover the tiny pores in the leaves of plants causing lowered oxygen intake inhibiting the growth of plants. Especially production of vegetable and fruits like oranges have been observed to decrease in production or in some cases no production in the areas near the brick kilns during the operational seasons. In some cases, diseases have also been reported in plants like broad bean and wheat.

Figure 87 Occurrence of black spots in the flower of broad bean plant: Top and Bottom

During off season, the loss of nutrients and organic matter from fields causes lowered production averaging 20-25 percent. The economic burden on the farmers arise not only from the low production but also the cost of nutrient replacement of the soil. Farmers are using inorganic fertilizers to compensate for nutrient loss in once very fertile lands but yet receive lower agricultural yields. The extraction of soft top-soil required for brick production is causing an alarming loss of prime agriculture land in the KV.

Besides these impacts, there is also the loss of habitat of microorganisms living in the soil, destruction of ecosystem that are directly linked to the soil and the microorganisms inhabiting the soil. In some rare cases, the over extraction of soil has caused landslides along road and structural failures in houses near soil extraction sites. Though the reduced visibility is less observed during afternoon, it has still been reported in areas with higher concentration of brick kilns such as in and around Bhaktapur, especially in the mornings along with blackening of building exteriors. The water sources near the brick kilns have also been reported to have dried and become more polluted since introduction of brick kilns in these areas of KV. *Figure 88* shows the locations of brick kilns in the KV and region of their hazardous impacts.

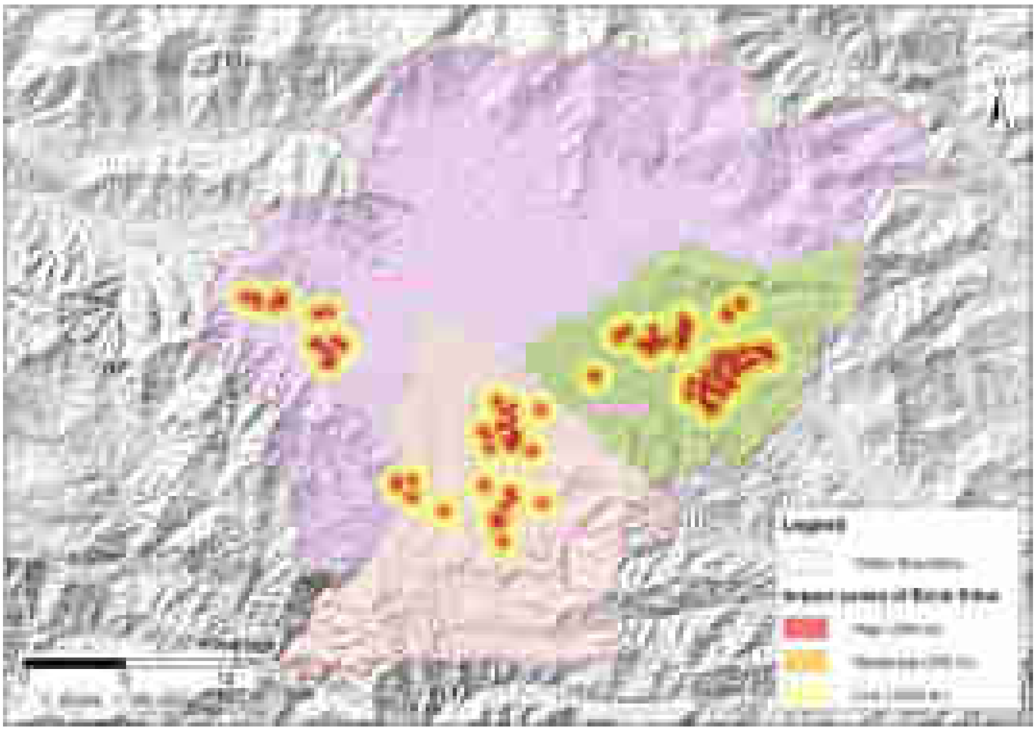


Figure 88 Map showing impact zones of Brick kilns within KV

5.7. Industrial Hazards

Industrial accidents are type of technological hazard attributed to the human activity and interaction with social, environmental, and technological systems. Technological hazard has been defined as "the storage or use of hazardous substances where in the event of a major accident and release of toxic, explosive or flammable materials local people and the nearby environment could be seriously affected (Walker, 2000). Nuclear technology, pollution, warfare and industrial accident are examples of technological hazards. Technological hazards can occur during transportation, production, storage or at time of disposal of inflammable, volatile or other hazardous substances. Influence area, level of effect and duration of effect differs on the basis of the types of substances involve in the hazard. Additionally, substances also behaves differently based on surrounding environment such as land use, types of soil, weather condition etc.

Compared to past, the range of industrial hazards has increased and could still diversify in the future owing to new developments in industries. The rapid urbanization and trend of compact settlement along with simultaneous increase in industries exposes the large population to the hazards associated with the industries often called as urban hazards. The hazards dealt with in this chapter are the industrial hazards with possible events of BLEVE and VCE like gas stations, gas distribution centers which has the possibility to cause huge loss of life and property.

Under this study and mapping, industrial hazards has been assessed for the following types.

5.7.1. Boiling Liquid Expanding Vapour Explosion (BLEVEs)

Boiling Liquid Expanding Vapour Explosion (BLEVEs) typically occur in closed storage tanks when liquefied gas store under the high pressure. Cooling below the boiling point or storage at the high pressure are two methods to store the gas in liquefied form. But the flammable and non-flammable liquefied gases have chances to react in form of BLEVE in case of container of liquefied gas comes in touch with fire ignited sources increase the pressure in the tank. In case of failure of tank chemical is released with the explosion (BLEVEs).

When the container fails, the chemical is released in an explosion. If the chemical is above its boiling point when the container fails, some or all of the liquid will flash-boil—that is, instantaneously become a gas. If the chemical is flammable, a burning gas cloud called a fireball may occur if a significant amount of the chemical flash-boils.

The main hazards from BLEVE are:

- Fire
- Blast
- Thermal radiation
- Projectiles

Fire

A fire is a complex chain reaction of fuel and oxygen which generate heat, smoke, and light. Sparks, static electricity, heat, or flames are major sources to ignite the fine more over if a chemical is above its auto ignition temperature it will spontaneously catch on fire without an external ignition source. The sources of fire are dry timbers, husk, saw mill products, chemical storages etc. Chemical properties like volatility, flash point, and flammability limits are help to derive the chances or causes of fire. Thermal radiations that follow the aftermath of fire accident is the most significant effect of fires.

Following are considerations for fire hazard assessment:

- Boiling point of fuels (petrol=950^{o}C, diesel=154-3050^{o}C, kerosene=150-3000^{o}C)
- Existence/effectiveness of fire fighting mechanisms
- In case of fire, the pattern of its spread in the surroundings

Thermal Radiation
The industrial fires and resulting thermal radiation originating from it cause damage or injury from a distance via transmission of thermal radiation. Such type of radiation is completely different from the nuclear radiation, will be strongest at the source of a flame and will become rapidly weaker as moving away from the source. The intensity of for causing damage is measured by the level of thermal radiation. Thermal radiation (also called thermal radiation fluxes) are measured and expressed as units of power per unit area of the item receiving the energy. Besides, damage or injury is also depending upon the exposure time.

The fire from BLEVE in the following scenario may results the following:

Table 36 Scenarios of BLEVE fire and effects

Heat Energy	Distance from source	Remarks
10KW/ sq. km	300m	Potentially lethal within 60s
5 kW/ sq. km	450m	2nd degree burn within 60s
2 KW/ sq. km	600m	Pain within 60s

Blast and Projectiles
An explosion is a release of energy that causes a blast wave. Explosions are very significant in terms of its damage to property (Khan and Abbasi 1999). The overpressure blast wave is generated as a result of the rapid expansion of the superheated liquid which can cause injury and damage such as structural collapse or projection of missiles.

The pressure felt at a distance from the center of explosion is measured by using Baker model to obtain scaled overpressure vs. scaled distance.

The parameters used by the model are defined by the following equations:
R= r (P0/2Eo) 1/3 (Eq. 13)
P'= Ps/P0 (Eq. 14)

Where,
R = scaled distance
r = distance from the center of explosion
P0 = Atmospheric pressure
Eo = Expansion energy or heat of combustion
P' = Scaled Overpressure
Ps = Side on overpressure

Maximum psi in case of BLEVE has been estimated from the gas stations to LPG tank distribution centres although both have high potential to cause loss of both life and property to the distance of 2000m for the gas stations and 500m for the LPG tank distribution centres.

Applying the guidelines from (Birk 1995a, b):
- 80-90 percent projectiles fall within 825m from tank side
- Severe rockets can go 3090m
- In very severe, very rare cases it may be possible to see rockets travel to 4550m.

5.7.2. Vapour Cloud Explosion (VCE)

According to CCPS, a vapour cloud explosion (VCE) is "an explosion resulting from the ignition of a cloud of flammable vapour, gas or mist in which flame speeds accelerate to sufficiently high velocities to produce significant overpressure."

These explosions occur by a sequence of steps:

- Sudden release of a large quantity of flammable vapour. Typically this occurs when a vessel, containing a superheated and pressurized liquid, ruptures.
- Dispersion of the vapour throughout the storage site while mixing with air.
- Ignition of the resulting vapour cloud.

Any process containing quantities of liquefied gases, volatile superheated liquid, or high pressure gases is a good candidate for a VCE. From a safety standpoint, the best approach is to prevent the release of material. A large cloud of combustible material is very dangerous and almost impossible to control, despite any safety systems installed to prevent ignition.

Maximum distance that may be engulfed in flames during the development of BLEVE fireball is given by the equation (Martinsen and Marx 1999):

$D_{max} = 5.8 M_{FB}^{1/4}$ *(Eq. 15)*

where, M_{FB} = mass of flammable material

Maximum fireball distance that may be engulfed during the development of BLEVE fireball has been estimated as approximately 206 m.

5.7.3. Vulnerability of the Surroundings to the BLEVE and VCE

The vulnerability of the surrounding based on the types of existing buildings, their functional use and their proximity to the gas stations and LPG tank distribution centres were assessed. Most of the structures built in the Kathmandu Valley are cement mortar and cement buildings with high probability of complete damage in scenario of BLEVE.

Being ranked as 11th most risk country to earthquake and learning from what occurred in Kobe, Japan; if similar events of earthquake induced fire occurred in Nepal, the combined impact of earthquake and consequent fire could trigger the BLEVE in gas stations and LPG tank distribution centres. Although an area far from the settlement would be highly recommended for these, these are established in the heart of Kathmandu valley close to the bustling city areas which has become the important part of the daily Kathmandu life without which it could not run.

The constant load shedding has made compulsion to the gas stations owners to run generators to efficiently operate them which are very close to the gas stations and increase the risk of triggering fire which could lead to BLEVE. The electrical transmission lines running just above the gas stations also pose higher risk of causing fire.

5.7.4. Impact scenario analysis

Total of 4 LPG tank distribution centres, gas stations and petroleum reserves were surveyed within the Kathmandu valley for the scenario of BLEVE and VCE analysis.

The modelling of the BLEVE scenario for the petroleum stations and gas depos showed that areas surrounding Sinamangal, Ghattaghar, Balaju and Thankot were more likely to suffer high damage and loss of life and property than other areas.

5.7.5. Safety measures

The number of fire extinguishers required by NOC was not met and were date expired in many cases with small percentage of trained personnel to operate it.33.33% of the total sampled industries did not have access to uninterrupted supply of water in case of fire which is a must in these kind of industries in case of fire.

The number of people working in most of industries was 2 to 3 during the day time and only 1 in most of the industries during the night. This number not only gives us the idea about the response capacity in case of any accident but also the number of people that will be immediately affected

The buildings close to gas stations were studied for their structural vulnerability to earthquake showing 18.18 percent of them structurally vulnerable with visible signs of cracks and improper construction.

The field study showed that there were few incidents of fire in gas stations.

Although these data present vulnerable status of industries, the possibility of BLEVE and VCE in these industries are very low but strict compliance to the safety rules have to be insured for developing capacity to handle any kind of emergency and new industries with possibility of BLEVE must be established at least a km away from settlement areas.

The maps below (*Figure 91 and Figure 92*) show different industries with potential of BLEVE and VCE within the KV and the impact scenario in case of BLEVE in terms of blast pressure in psi units. The map has been produced using the data collected from the field study and scientific calculations for blast pressure exerted during BLEVE of gas stations and LPG tank distribution centres, Blas pressure has been calculated in terms of PSI which gives the probability of serious injury or fatality of the occupant for different types of buildings.

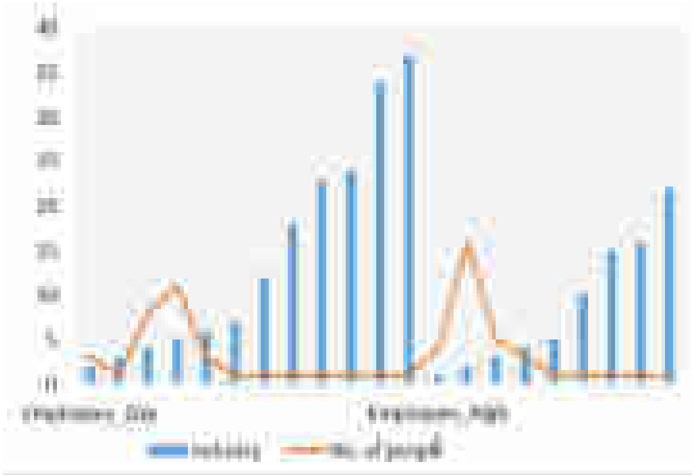


Figure 89 No. of employees in sampled industries

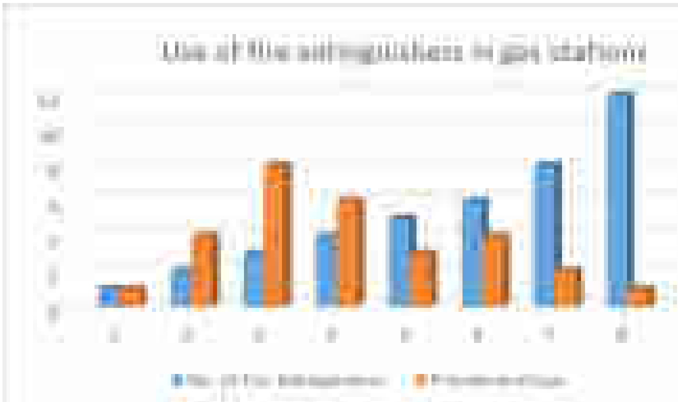


Figure 90 No. of fire extinguishers used in gas depot

Table 37 Fire accidents in the gas stations in recent years

Year	Reason	Loss (NRs.)	Deaths	Injured
2062	Electric short circuit	500,000	0	2
2068	Spark in Fuelling Machine	0	0	0
2069	Temp Difference	0	0	1

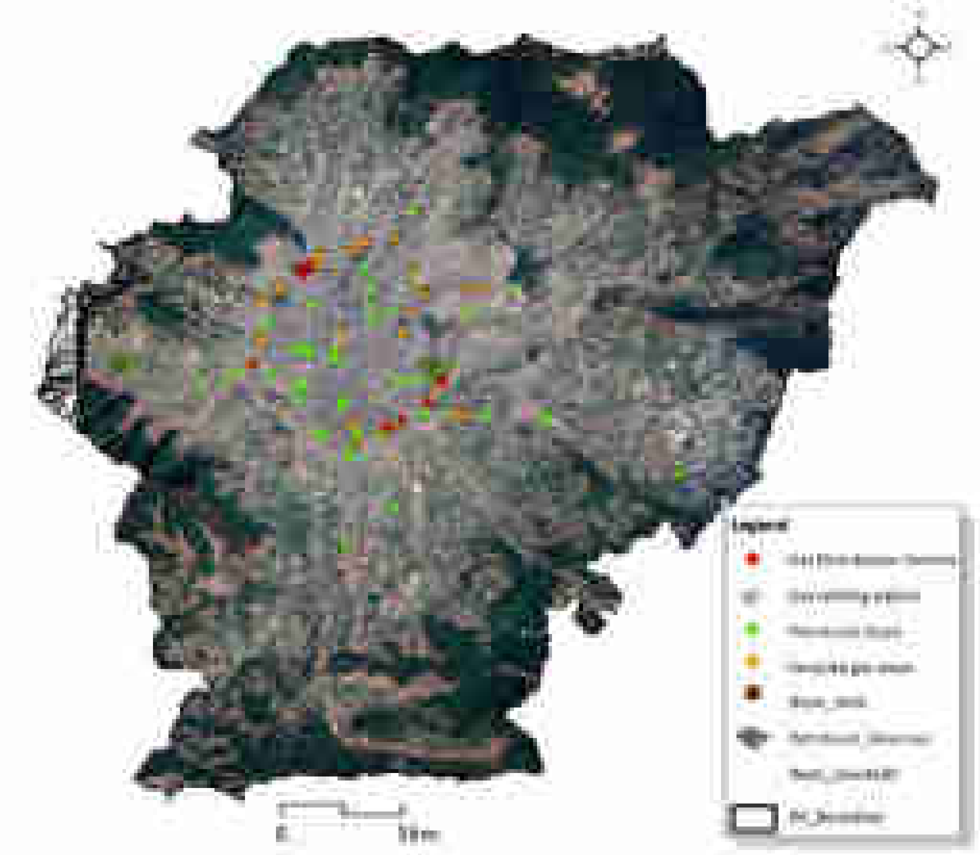


Figure 91 BLEVE potential industries in KV

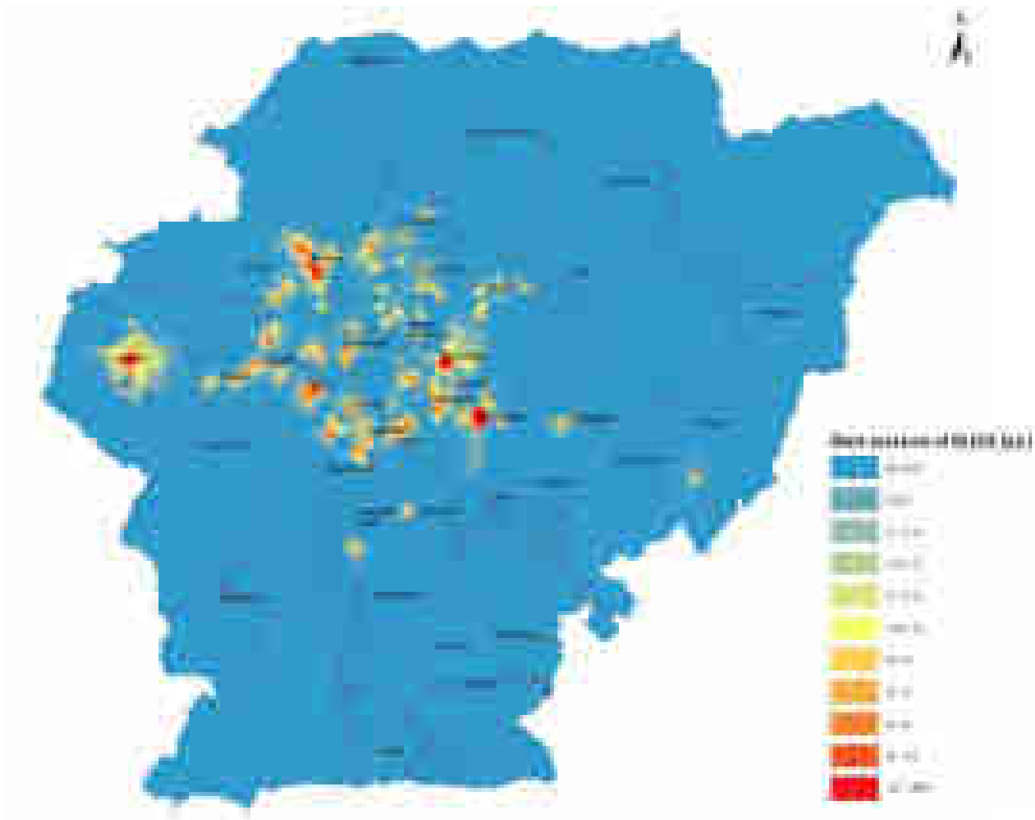


Figure 92 Impact Scenario Analysis for BLEVE in KV

6. URBAN GROWTH PROJECTION OF KV

Urban growth and land cover changes is the complex phenomenon. Monitoring these phenomenon may be challenging but one of the crucial matter in most of urban studies to understand and forecast the future urbanization trend and projection. Projection of urban growth under different scenarios is widely used in urban planning domains to support policy formulation and decision making. This study has attempted to understand the spatial and temporal dynamics of urban growth and land use change processes in Kathmandu Valley, identified and quantified the driving factors of urban growth and project the future urban growth pattern. Under this chapter, the scientific basis of future growth projections of KV under different scenarios are discussed.

6.1. Land Use Transition Potential Modelling

The probability of land use transitions under different scenarios was modelled using a raster based probabilistic land use change modeller method which uses artificial intelligence algorithm Multi-Layer Perceptron (MLP) based on Artificial Neural Network (ANN) for transition potential assessment and land use change projections. While assessing the transition potentials, the model launches MLP in an automated training mode that monitors and modifies the start and end learning rate of a dynamic learning procedure of the ANN. The dynamic learning procedure starts with an initial learning rate and reduces it progressively over the iterations until the end learning rate is reached when the maximum iterations is reached. The significant oscillations in the Root Mean Square (RMS) error are detected after the first 100 iterations, the learning rates at start and end are reduced by half and the progress is started again.

The MLP parameters used for the transition potential modelling were land use maps (years 1980-1990, 2000 and 2012), DEM and slope. Topographical parameters DEM and slope were used as opportunities and constraints for the model to predict the urban sprawl as more difficult the terrain, the less likely it is for urban sprawl.

The catalysts for land use change used in this model were cost distance from the CBD (Central Business District); that is agglomeration of major economic and financial centres inside Kathmandu Valley and the distance to road. Access to road, development and urban sprawl has significant positive correlation in urban growth in Kathmandu Valley and elsewhere in the country.

The constraints area fed in the model was open spaces, protected forest areas, institutional areas and monumental zones, as in this model the prime interest is to depict the sprawl of residential and mixed residential-commercial areas in KV. The land use transition potential model was then run with processed land use maps, DEM, slope, development inducer and development barrier spatial data as inputs. The transition potential modelling achieved reliable accuracy level of 76.04 percentage.

Table 38 MLP neural network parameters

Start learning rate	6.68121
End Learning rate	7.8125
Momentum factor	0.5
Sigmoid constant	1.0
Layer nodes	7
Stopping Criteria	
RMS	0.01
Iterations	10000
Accuracy rate	100%
Running Statistics	
Iterations	10000
Learning rate	0.0000
Training RMS	0.4044
Testing RMS	0.4046
Accuracy Rate	76.04%

Figure 97 shows the transition potential model which states the probability percentage of change for a land use from agricultural and other into residential and mixed residential and commercial areas. The transition potential value varies from 0 to 97 percentage potential for change. The high potential areas were found to be the infill areas inside the existing built-up areas of Kathmandu Valley and the immediate proximity to the existing built-up areas with better road access.

It was also observed from the model that the conversion of land use will mostly comprise between the agricultural to residential transition throughout the valley. The current trend of urban expansion and land use conversion has most intensely been directed towards the northwest part of the valley, where the urbanizing VDCs like Dhapasi, Manamaiju, Gongabu, Ichangu-Narayan and non- urbanizing VDCs Tokha Saraswati has undergone major change during last decade. The land use change model also predicted the major change in the north-west direction of the valley for further years in the future if the current trend is not controlled.

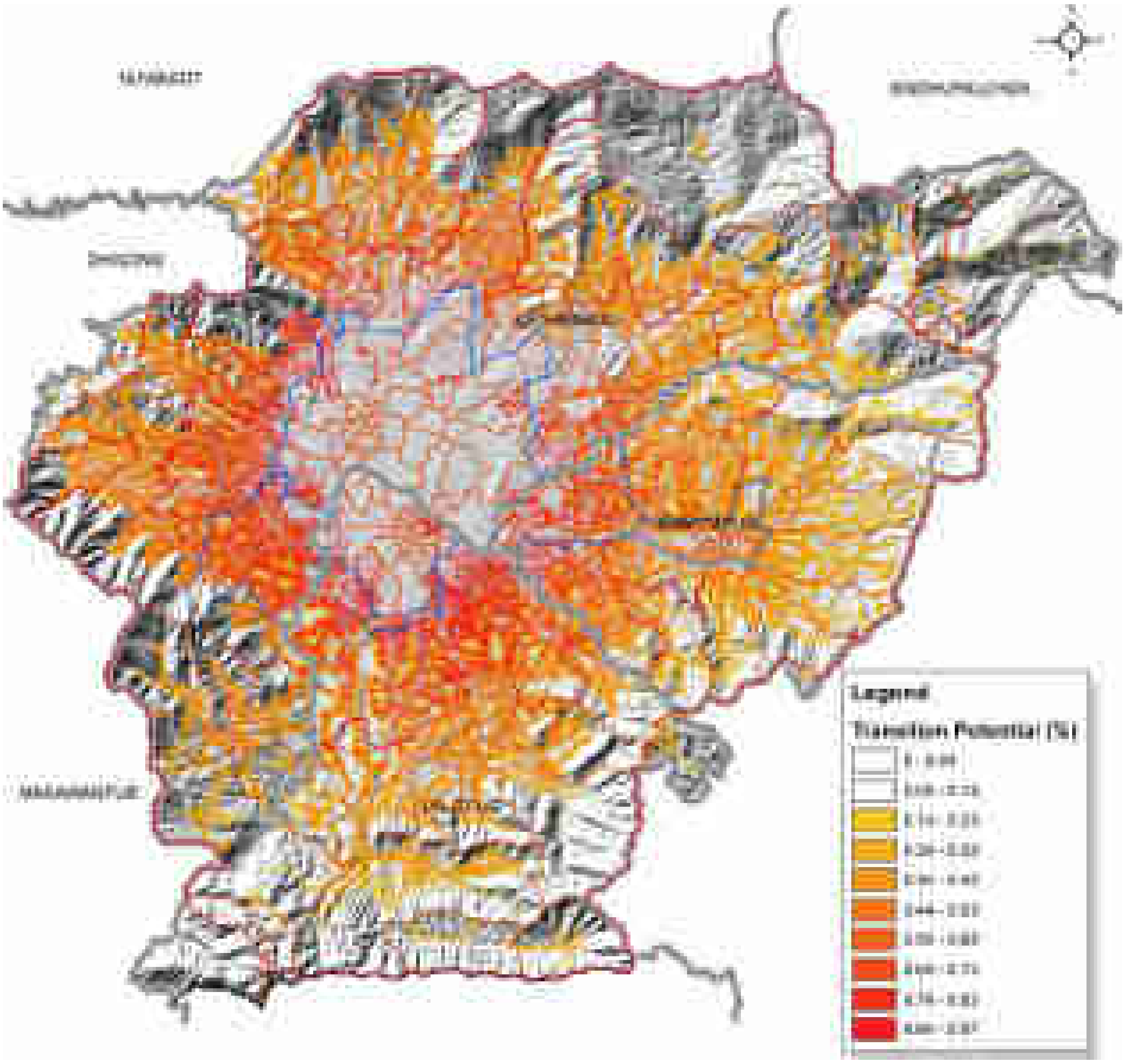


Figure 93 Transition potential model

6.1.1. Land Use Prediction Model

The land use change prediction is done over the intermediate order of decadal land use map. After the automated training mode in MLP Neural Network and RMSE correction, the land use change model runs MLP-Neural Network for land use change potential and land use change prediction based on sub-model parameters. The land use change prediction for certain year is based on the transition potential of the area and other constraints and dynamic road expansion over time. The predicted land use map for year 2020 and 2030 are presented in *Figure 94* and *Figure 95* respectively.

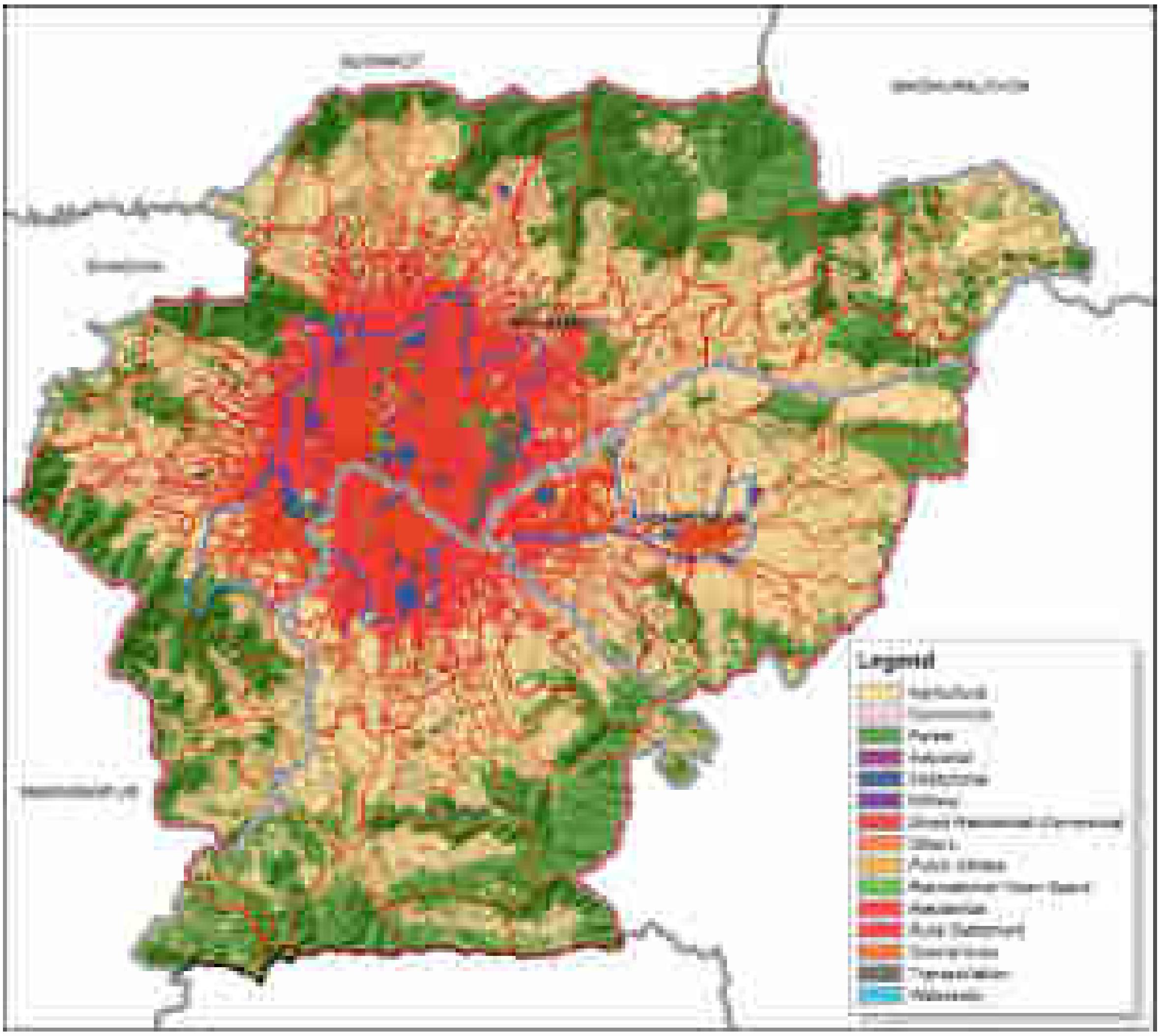


Figure 94 Predicted land use map for 2020

The predicted land use map of 2020 and 2030 displays the haphazard urban sprawl growing radially outwards along the major transportation routes and growing north-west direction of the Kathmandu valley, which has the major ground water recharge area in Kathmandu valley. The map shows the growth in urbanizing VDCs and further expansion into non-urbanizing ones. The 2030 map (*Figure 96*) shows further aggravation of the urban sprawl into the ecology and environment and haphazard growth along the transportation routes. The predicted map clearly displays the conversion of the prime agricultural areas inside Kathmandu valley into residential uses, triggering multiple adverse consequences and thereby resulting massive vulnerable community inside Kathmandu regarding composite risk.

The land use change modelling and prediction from MLP neural network reveals that agricultural area that is around 36,000 hectares in the year 2000 comprising 50.4 percent of the total area of the valley has diminished to 47.31 percent in the year 2012. If the current trend is left unabated, the agricultural areas will further decrease to 42 percent and 38 percent in the years 2020 and 2030 respectively. A positive corelation is observed between the decreasing trend of agricultural areas and increasing trend of residential areas in the valley. The residential areas occupied approximately 6,000 hectares in the year 2000, which was increased by 5 percent in 2012 resulting around 9,000 hectares. Furthermore it is predicted that residential areas in the valley will comprise about 19 percent of the total areas in the year 2020 and 22 percent in the year 2030 resulting 13,000 and 16,000 hectares of residential areas.

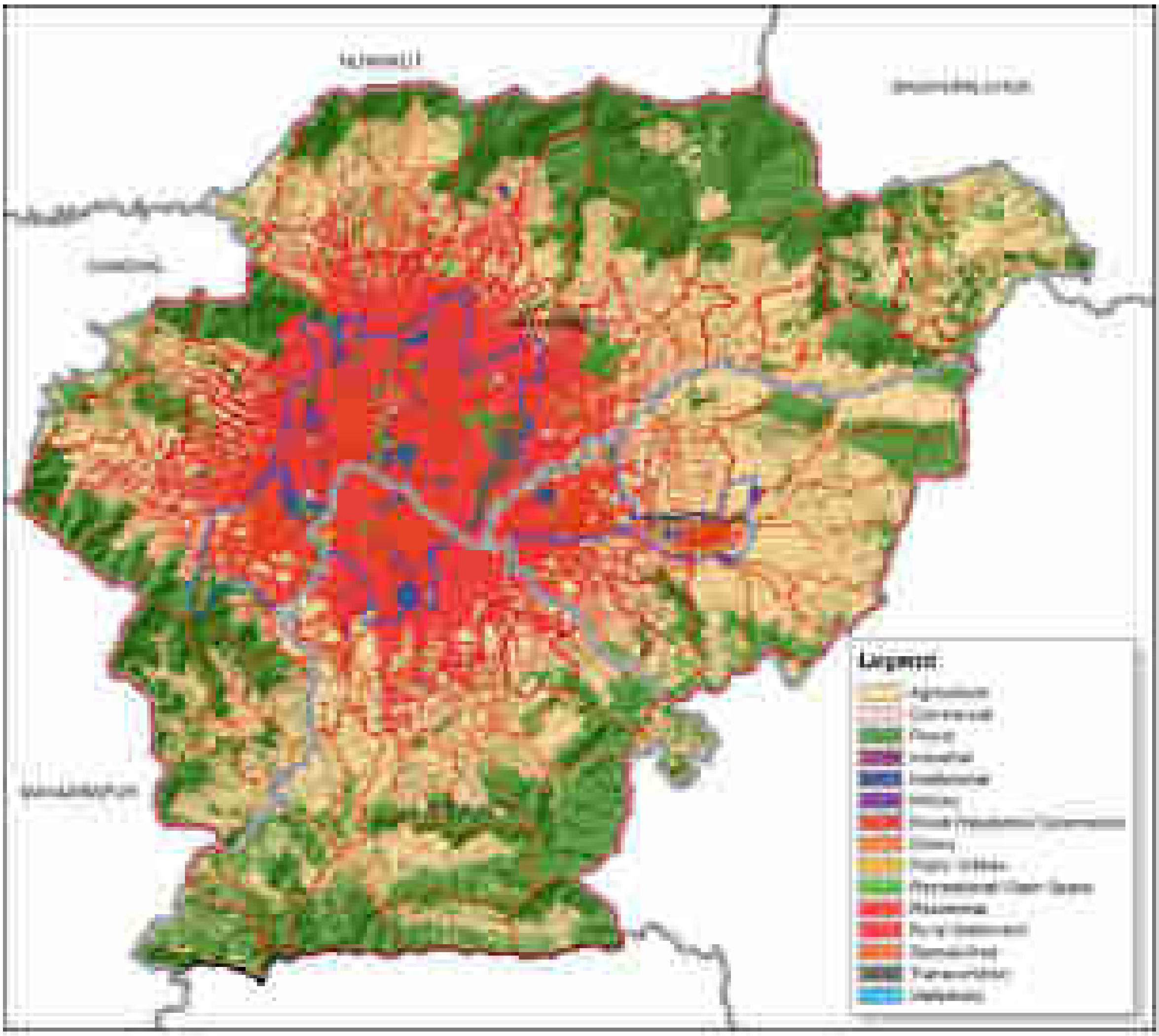


Figure 95 Predicted land use map for 2030

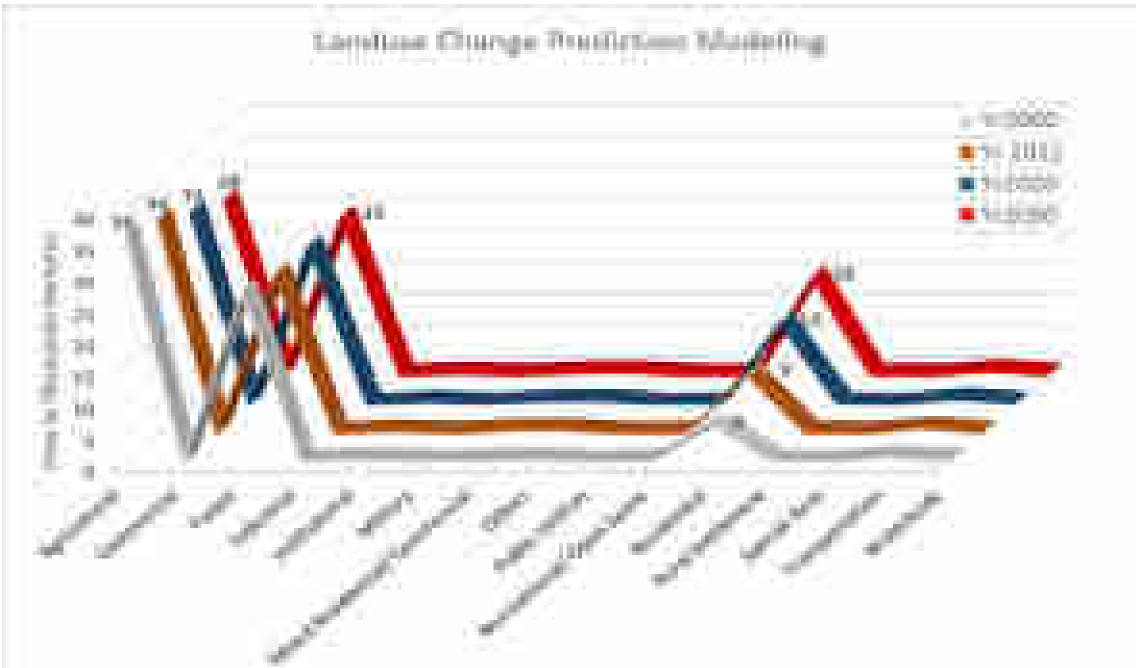


Figure 96 Land use change prediction modelling

6.2. Land Use Projection 2020 and 2030

6.2.1. Business as Usual (BAU) Model

The projection of growth in Kathmandu Valley is based on the probabilistic growth pattern which relies on dominant drivers or catalysts for urban expansion witnessed over time in the KV. The catalysts were discussed in Chapter 3 of this document. It can be observed that built-up areas in 2012 land use map was 10,537 hectares which is projected to increase to 16,219 hectares in 2020 and 21,378 hectares in 2030 (as per LR model), if the current trend of urban growth is left unabated. It is estimated that at each decade approximately 6,000 hectares of arable land in Kathmandu Valley will be converted into the built-up area. From the predicted maps of 2020 and 2030 for business as usual model (see *Figure 97*), it can be observed that urban growth is expected to occur as diffusion growth extending from already built up areas in an in-filling and expansion manner. The results suggest that an important part of city's future growth may occur in area adjacent to already consolidated urban areas, thereby mitigating sprawl development. The driving factor of this type of growth is good accessibility and connectivity, especially in relation to the services and amenities located in the central areas.

Figure 97 shows urban area of the valley expected to increase to 162.2 km^2 in 2020 which is almost 1.5 times of present built-up area. Moreover it is estimated that during 2030 the urban area of the valley will be 213.8 km^2 which is twice as much as present built-up area. This type of growth trend of Kathmandu Valley shows that the urban planning policies have largely been over ruled by private interest of people. As a result, the valley sprawl has occurred in a diffused manner. Although the local authorities are aware of the unsustainable nature of the growth, they have limited tools and resources to generate strategies that can control the current tendencies of growth. *Figure 98* presents the BAU scenario of urban growth in 2020 and 2030 uisng LR model.

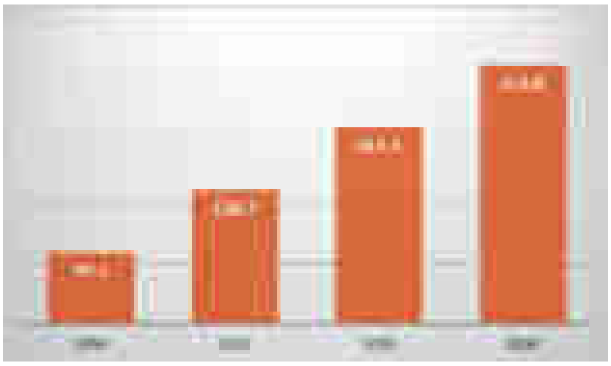


Figure 97 Urban growth trend according to BAU model

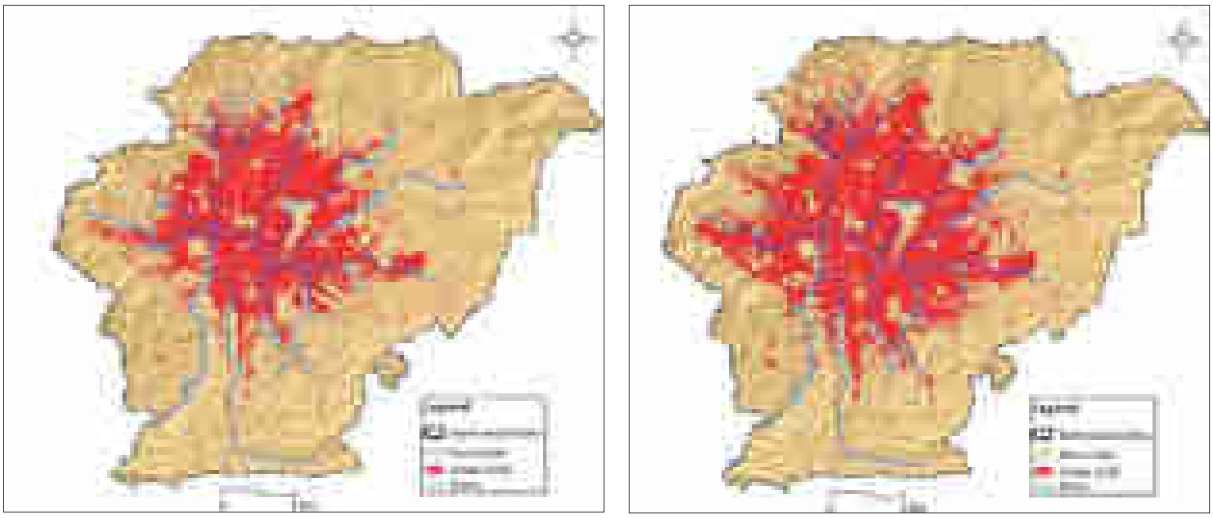


Figure 98 Probability of urban growth in 2020 and 2030 according to BAU model

6.2.2. Land use projection 2020 and 2030 LTDCP envisaged model

The LTDP 2020 plan mainly focuses in the growth control through the demarcation of the urban and rural boundary as well as the preservation of prime agricultural land in order to control the unmanaged and uncontrolled land development system of the valley by eating up the fertile agricultural lands. Taking certain factors into consideration like the environmental management, habitable community and a good living condition, various concept plans for urban growth management have been prepared. Therefore this study incorporated following constraints and restriction that are stated in LTDP 2020 plan for the sustainable growth of the valley.

(a) Land use restrictions
- Cultural and religious Heritage Zones,
- Airport

(b) Physical constraints
- Rivers and ponds
- Slope greater than 30 degrees

(c) Environmental constraints
- Reserved forest, Public Parks and Open spaces which could be used for humanitarian purposes during earthquake event (IOM),
- Risk and hazardous areas such as- Flood prone areas, industrial hazardous area, landslide areas,
- Ecologically sensitive areas such as- water recharge zones and prime agricultural areas.
- *Assumption:* Present built-up area in undevelopable areas will remain constant.

The results from LTDCP envisaged model suggests that the probability of urban growth in future will be driven by biophysical factors, proximity factors and neighbourhood factors which can have either positive or negative correlation with urban growth. The major determinant of the urban growth are distance to minor road, distance to urban cluster, institutional areas, distance to major road and distance to ring road. Other factors such as presence of forest, distance to school and distance to municipal boundary do not have dominant effect on driving growth of valley. The strong negative relationship between minor road and urban growth indicates that there is high probability of urban growth in areas which are at the closer proximity to minor roads that are serving as local road and service roads. Similarly, urban growth is mostly concentrated in area adjacent to existing built-up areas i.e. areas which are closer to existing urban cluster. The main reason behind this is good accessibility and connectivity to services and amenities located in the central city areas as in Business as usual model.

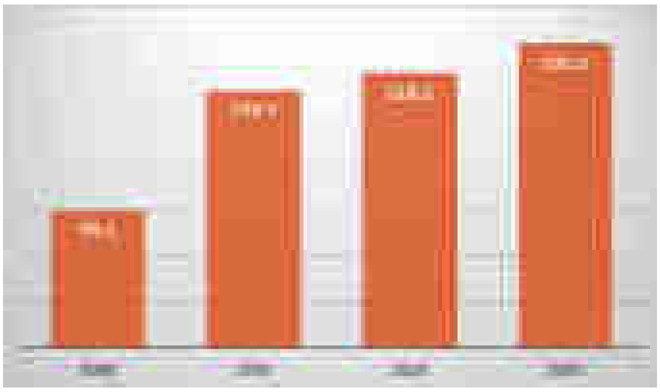
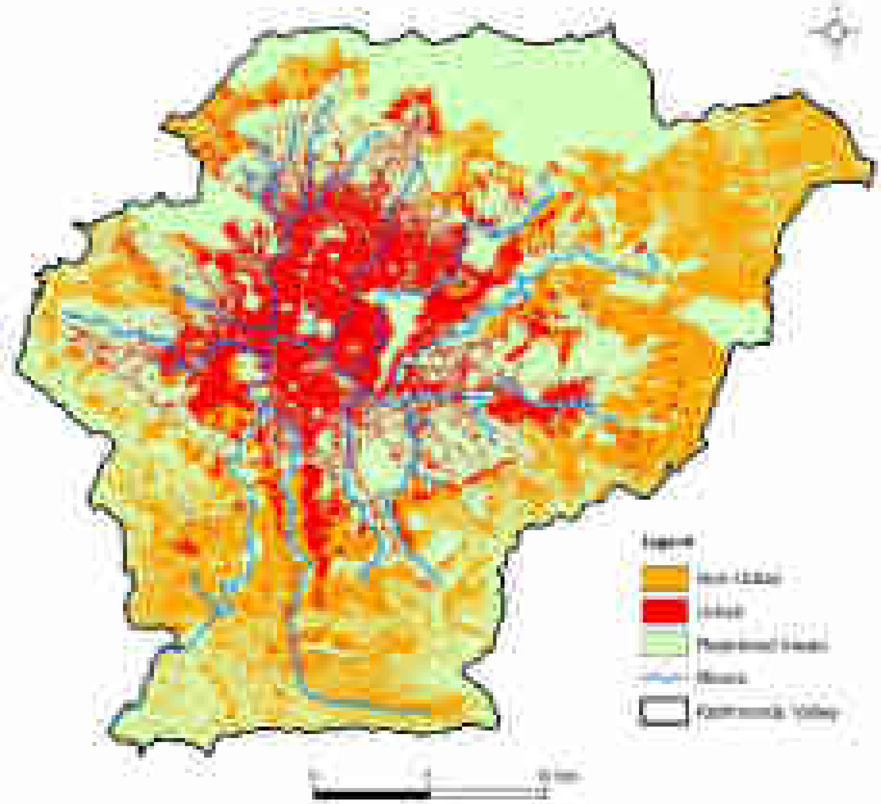


Figure 99 Urban growth trend according to LTDCP model

Figure 99 shows that if regulations in growth control is put into action, it is expected that urban growth will be significantly low i.e. in 2020 there will be 118.2 km^2 built-up area which is around 1.07 times of existing built-up area (*Figure 100*). Similarly, during 2030 it is expected to increase by 1.2 times (i.e. 131.1 km^2).



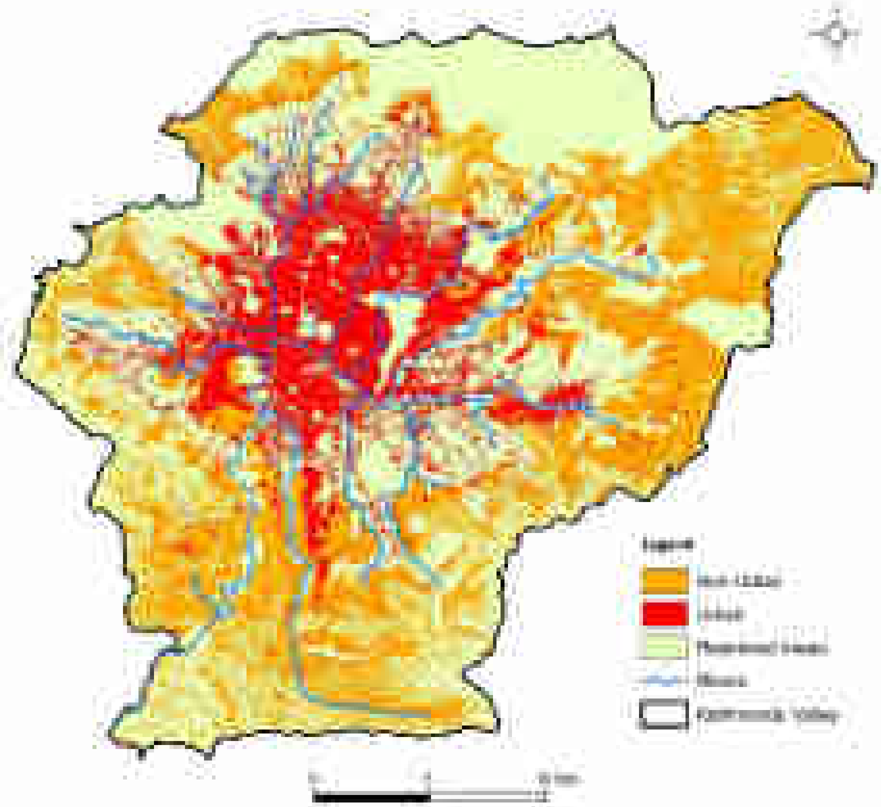


Figure 100 Probability of urban growth in 2020 and 2030 according to LTDCP model

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