



# Disaster Risk Reduction and Climate Change Adaptation in the Koshi River Basin, Nepal

Nepal Development Research Institute

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# Abstract

Global warming is said to lead to abnormal changes in air temperature, rainfall and snow melting, resulting in the increases in frequency and intensity of drought and flood events. While hydrological and meteorological variation in terms of their random stochastic phenomenon is considered natural, abnormal changes such as the non-stationarity of the statistical properties of these random variables may be due to climate and other man-made changes in the atmospheric and catchment conditions. Impact assessments under climate changes was made in the study to develop a better understanding of impact of climate and related stressors on hydro-meteorological regime including snow melt process of the Koshi River basin. Climate change impacts especially on hydro-meteorological regime was carried out through two major steps, namely hydro-meteorological diagnostics and modeling.

Under hydro-meteorological diagnostics, analysis of available historical data on climatological and hydrological variables for any trend and changes in its statistics was made to establish the base line data. Both time series data and satellite images were analyzed to diagnose the changes in the climatic and hydrological regime as well as snow covered area.

The average rate of increase of mean temperature to around 0.066 $^0$C per annum and decrease in mean temperature with elevation at a rate of 4.6 $^0$C per km was observed in the Koshi Basin. On the other hand, annual rainfall was found increasing at a rate of 55 mm per 100 m rise in altitude. Such increasing trend of rainfall is sharp in elevation between 500 to 1500 m above mean sea level. However, temporal trend of rainfall varied with maximum decreasing rate of 47 mm per year at Sarmathang station while increasing at a rate of 7.5 mm per year at Lungthung station. The spatial variation of rainfall was quite high. At Nepalthok station, it was less than 900 mm while at Num station it was almost 4,500 mm. Approximately 80% of the rainfall in this basin occurs in the monsoon season. The longest consecutive dry days were around 60 days in an average while the basin receives rain in around 40% of the days in a year.

Koshi River drains an area of about 54,000 sq. km. at Chatara. The mean flow at this gauging station is 1,540 $m^3/s$. However, standard deviation of the annual average flow is 1544 $m^3/s$. It depicts that there is quite a high variation in annual flow in this basin. Furthermore, a great seasonal variation in flow exists in this river. The river has maximum flow in the monsoon season accounting almost 80% of the total annual flow, with the maximum value in month of August. The minimum flow occurs in the month of February and March. Trend analysis of the annual flow showed that the flow at this point was found decreasing at the rate of 4 $m^3/s$ per year. The flows for 0.1% and 1% exceedence at this station are respectively 7,830 and 6100 $m^3/s$ whereas at 99% exceedence, the flow is about 250 $m^3/s$.

The snow cover is high in the months of February, March and April and low in June, July, August and September because ablation of snow starts in March and continues until September after which it starts to accumulate. However, the annual variation of the snow cover is not found prominent.

The trend of maximum temperature of historic data was found to be 0.114 $^0$C increase per annum while that of minimum temperature was 0.014 $^0$C increase per year. Bias corrected ECHAM05/ HADCM3 data also showed the increasing trend on maximum as well as minimum temperatures in the future too. The trend value was about 0.05 $^0$C per annum in both RCM data sets for maximum temperature whereas minimum temperature trend showed 0.053 $^0$C per annum increase in ECHAM05 and 0.061 $^0$C per annum in HADCM3.

Climate data projection made in this study was based on IPCC A1B SRES scenario. It was observed that there has been a visible shift in the peak rainfall pattern. Historic data (1976 - 2000) showed the existence of such pattern in July-August while our study showed such occurrence in June-July in projected period from 2030 to 2060. The amount of rainfall occurring during those peak months (June to August) was observed to be increased in ECHAM05 model while it was almost evenly distributed in the HadCM3.

Monthly average of ECHAM05 showed that most of the rain was occurring during the peak months while that of HadCM3 showed wider temporal spread of annual rainfall. It showed the existence of uncertainties in climate model predictions. However, both models predicted that there would be more rainfall in the future than that occurring at present.

The bias corrected precipitation data indicated 7.5 % increase in annual precipitation during 2025 - 2060 with a 36% increase in the last decade for the ECHAM05 series whereas a 5.7 % overall increase for 2035 - 2060 was observed with the HADCM3 series. Similarly, increased monsoon and post-monsoon precipitation was observed for both ECHAM05 and HADCM3 series. Winter and pre-monsoon rain showed negative trends for both the series. ECHAM05 data showed 32% and 8% increased precipitation during June and July whereas October and November showed 27% and 40% increase. 7.2% and 54.5% decrease in July and November precipitation was observed with HADCM3 data whereas June and October showed increase of 21% and 77%. The maximum value of the rainfall averaged over the basin was 116 mm in historical data set while the predicted values by ECHAM05 and HADCM3 were 403 mm and 227 mm respectively. The average rainfall days with intensity more than 100 mm/day were 4 days in 25 years i.e. 0.16 days per annum in historic case (1976-2000 used for HINDCAST simulation), 62 days in 41 years, i.e. 1.51 days per annum for ECHAM05 and 27 days in 31 years, i.e. 0.87 days per annum for HADCM3. It is evident even from frequency analysis of rainfall that occurrence of extreme events would have been increased in future compared to the historical trend.

Impact of climate change on snowmelt runoff generation was analyzed by Snowmelt Runoff Model (SRM) and that on hydrological regime i.e. flow and sediment yield, was assessed by hydrologic simulation study using SWAT model. The results of the hydrologic modeling were utilized to assess the capacity dead storage to accommodate the soil to be deposited and estimation of design flood with and without climate change scenario. Implication of design standard under climate change was made by evaluating the relationship between the magnitudes of floods corresponding to various return periods under climate change.

Simulation of snowmelt runoff processes was carried out separately in five sub-basins of Koshi river basin. Based on the simulation results from 2000 to 2008, largest annual average contribution from snow melt was found from Arun river basin i.e. 21.61% of the total flow while contribution of snow melt ranges from 9% to 17% to the total flow in other sub-basins. The simulation result based on two different projected data (ECHAM and HadCM3) scenario clearly showed the significant effect of increased temperature on snow melt phenomena. The major changes observed are redistribution of seasonal snow melt contribution and intensification of snow melt rate during the last decade and even shift in snow melt period, especially in Tamakoshi sub-basin. Increase in the winter and pre-monsoon snow melt was found in both scenarios due to rise in temperature during those periods. Based on base year average of the flow contributed by snowmelt (2000- 2008), the increase in snowmelt flows were, generally, found increasing. Especially it is prominent during 2050-2060 period in which the increase percentage ranges from 4.6 to 112 in ECHAM05 and 12 to 72% in HADCM3.

The bias corrected RCM data were used in the SWAT model to assess the future hydrologic scenarios and sediment fluxes in the basin. Increase in annual flows after 2040 for both ECHAM05 and HADCM3 series was observed, with pronounced increase in the late 2050s. ECHAM05 simulations suggested a shift in average annual peak flow from August under existing conditions to July in the future, with 26% and 3% increase in June and July and a 15% decrease in August flows. However HADCM3 data only showed 10% and 9% increase in June and October flows without any shifts in peak flow. Similarly increase in the extreme flows (1% probability of exceedance) in all the decades was observed for both ECHAM05 and HADCM3 simulations (54 and 61% increase respectively in the 2050s) whereas the dependable flows (80 - 95% probability of exceedance) were found to be on a decreasing trend. Likewise increase in sediment yield was clearly seen from both ECHAM05 and HADCM3 simulations. All the decades unanimously show increasing sediment yields to as high as 215% under ECHAM05 and 124% under HADCM3 data in the 2050s.

The observed maximum value of the daily flow (historic data) was 11900 $m^3/s$ while the predicted values for the future by ECHAM05 and HADCM3 came to be 36020 $m^3/s$ and 19830 $m^3/s$ respectively. Similarly extreme flood values with 1% exceedance probability were respectively 6120, 9462 and 9899 $m^3/s$ for historic, ECHAM05 and HADCM3 projections. These figures indicate the possibility of high increase in flood events with higher magnitude in the future. To analyze the impacts of climate change on the design flood for the proposed dam, various return period floods for the historic maximum instantaneous series were considered and compared with the respective return period floods in the future. To incorporate the impact of climate change in the design of hydraulic structures, the analysis showed that the design flood values should be increased by 2.6 times the values being adopted under existing climatic condition. Similarly, due to the increase in sediment load in the future, the capacity of the dead storage of the proposed Koshi High Dam should be increased by more than 100% to make it functioning for the envisioned design life.

Hydraulic simulation with HEC-RAS for flood inundation mapping with floods of various return periods, with and without climate change, was done. Similarly simulation studies of Dam and Embankment breaching cases were also carried out. Flood hazard maps for different return period were prepared. Simulation showed that the existing embankments could contain the historical 100 and 1000 year return period floods i.e. 23074 and 47,445 $m^3/s$ . Likewise model simulations with 100 year and 1000 year return period floods for ECHAM and HADCM3 series, i.e. 100 year floods: 69,758 and 46,042 $m^3/s$ and 1000 year flood: 178,538 and 96,165 $m^3/s$, also showed that only the 1000 year return period flood predicted by ECHAM05 would overtop the embankments. HEC-RAS model was run under the same floods without embankments too. The results showed that under 100yr historical return period flood, VDCs in Sunsari would be more severely inundated. Results suggested that in the absence of embankments, 29 VDCs and Koshi Tappu Wildlife Reserve would be under inundation. Almost 187 $km^2$ area would be inundated with more than 1m depth followed by 69 $km^2$ under 0.5 - 1m inundation and 61 $km^2$ under less than 0.5m depth. To capture the flooding conditions under climate change, flow generated from ECHAM and HADCM3 data series was used in the model. The results of the simulation showed that the area under more than 1m inundation was found to be increased to 375 $km^2$ for ECHAM and 326 $km^2$ for HADCM3. Area inundated with more than 5m depth was also found to be increased from 4$km^2$ with historic flood to 34$km^2$ for ECHAM05 and 18 $km^2$ for HADCM3 floods. The depths for 1-5 m and > 5 m inundations were found increased highly for 1000 year projected floods when compared with historical floods. Dam breaching analysis was also carried out with model dam resembling the proposed Koshi High Dam under ECHAM05 100 year flood with piping mode of failure. The simulation showed that the reservoir would be emptied in 5 days and the flood waves reached the Indian border in 10 hours for the given condition of dam break.

For flood risk assessment, information on flood hazard, vulnerability and exposure of the population in the flood plain of Koshi river were required. For this purpose, vulnerability assessment survey was carried out to assess the vulnerability of communities considering five major indictors: the demographic, economic, social, the degree of preparedness and recovery capacity. Household surveys using structured questionnaires, focus group discussions and key information interviews were undertaken in the flood prone areas of the river basin lying in Nepal. The calculated overall socio-economic vulnerability index was found to be 2.7 (min. 2.49 to max 2.89) which implies that the overall vulnerability level of the households of the study area can be said to be in moderate level. However, among the considered five indicators the study area is more vulnerable to preparedness, the economic and demographic aspects.

Based on the flood hazard, vulnerability and exposure of the population, composite risk maps were prepared for existing historic as well as climate change conditions. Four risk classes were defined to demarcate risk zones in the study area. Risk values of 0 - 0.2 was considered as very low risk zone, 0.2 - 0.4 as low risk zone, 04 - 0.6 as moderate risk zone, 0.6 - 0.8 as high risk zone and 0.8 - 1.0 as very high risk zones. Two study wards lying in Narsimha and Ramnagar Bhutaha VDCs were found to be in the low risk zones whereas all the other wards were found to be in the very low risk zone for current condition.

However, the risk zones under climate change conditions showed that the very low risk conditions in Mahendranagar, Dumraha, Bhardaha and Ghuski VDCs under historic climatic conditions had increased to low risk conditions. Likewise very low risk level existed in Bairawa and low risk level in Ramnagar Bhutaha were changed to Medium risk levels under climate change. High risk zone was observed in Narsimha.

The study showed that the projected climate change would impact the flows and sediment fluxes, though at different magnitudes and directions under different climate models. It indicates the need for the change on disaster risk reduction and climate change adaptation approaches in the future to deal with the impact of climate change phenomena. A number of policy recommendations and strategies to be undertaken were made to improve the existing government policies based on literature review and research findings of this study regarding water resource infrastructure development works in the face of climate change. The major ones are need of revisiting of design standards/values for water resources development works to safely dispose the extreme floods and watershed management to reduce the sediment inflow into the reservoir. Strategies on structural and non structural measures to be undertaken to keep the people living in the study area safe from floods that may occur naturally or embankment or dam breaching, are proposed.

Awareness building of stakeholders including local communities was made through dissemination workshops. The participants were the policy and decision makers of national and local levels. Training of new generation on the application of advance technology and tools to assess the impact of climate change on water resources was made by involving four research associates and five Master Level thesis students.

# Acknowledgement

Nepal is one of the most disaster prone countries in the world which has been suffering from recurring natural hazards causing a heavy annual loss of lives and properties. The climate change phenomenon is going to impact the hydrological regime of the country, placing the country in additional stress especially in terms of flood risk. Design of hydraulic structures such as dams and embankments on the basis of the analysis of historical hydrological data is simply not a good design in face of climate change. To assess the impact of climate change on water resources development works in Koshi River Basin due to increased variation of extreme hydrological events and to propose adaptation measures and policy innovations for disaster risk reduction and climate change adaptations, a study on "Disaster Risk Reduction and Climate Change Adaptation in Koshi River Basin of Nepal was carried out by Nepal Development Research Institute (NDRI).

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Laxmi P. Devkota, D.Eng.

Principal Investigator

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# List of Acronyms

| | | |
|---|---|---|
| ADPC | - | Asian Disaster Preparedness Center |
| APHRODITE | - | Asian Precipitation Highly-Resolved Observational Data Integration towards Evaluation of Water resources |
| ASTER | - | Advanced Spaceborne Thermal Emission and Reflection |
| CBO | - | Computer Based Organization |
| CBS | - | Central Bureau of Statistics |
| CC | - | Climate Change |
| CCA | - | Climate Change Adaptation |
| CCIA | - | Climate Change Impact Assessment |
| CDC | - | Convention Depletion Curve |
| CSI | - | Composite Socio-economic Index |
| DDR | - | Disaster Risk Reduction |
| DEM | - | Digital Elevation Model |
| DHM | - | Department of Hydrology and Meteorology |
| DRM | - | Disaster Risk Management |
| DWIDP | - | Department of Water Induced Disaster Preparation |
| ECHAM05 | - | European Centre for medium-range weather forecasts, Hamburg |
| ENS | - | Efficiency (Nash-Sutcliff) |
| EOS | - | Earth Observation System |
| EWS | - | Early Warning System |
| FAO | - | Food and Agricultural Organization |
| FGD | - | Focus Group Discussion |
| FMIS | - | Farmer Managed Irrigation System |
| GCM | - | Global Climate Model |
| GDEM | - | Global Digital Elevation Model |
| GIS | - | Geographical Information System |
| GLOF | - | Glacial Lake Outburst |
| GON | - | Government of Nepal |
| GPS | - | Global Positioning System |
| HadCM3 | - | Hadley Centre Coupled Model, version 3 |
| HEC-RAS | - | Hydrological Engineering Corporation – River Analysis System |

| | | |
|---|---|---|
| HFA | - | Hyogo Framework of Action |
| HH | - | Household |
| HKH | - | Hindu-Kush Himalaya region |
| HRU | - | Hydrological Modeling Unit |
| ICIMOD | - | International Centre for Integrated Mountain Development |
| IEE | - | Initial Environmental Examination |
| IPCC | - | Intergovernmental Panel on Climate Change |
| IT | - | Information Technology |
| IWRM | - | Integrated Water Resources Management |
| KII | - | Key Informant Interview |
| LAPA | - | Local Adaptation Plan of Action |
| LH-OAT | - | Latin Hypercube Sampling and One-at-a-time Sensitivity analysis |
| MBE | - | Mean Bias Error |
| MODIS | - | Moderate Resolution Imaging Spectroradiometer |
| MoEST | - | Ministry of Environment, Science and Technology |
| NAPA | - | National Adaptation Program of Action |
| NASA | - | National Aeronautics and Space Administration |
| NBS | - | Nepal Biodiversity Strategy |
| NDSI | - | Normalized Difference Snow Index |
| NGO | - | Non-government Organization |
| NPC | - | National Planning Commission |
| NRM | - | Normal Ratio Method |
| NSE | - | Nash Sutcliff Efficiency |
| OCHA | - | Office for the Coordination of Humanitarian Affairs |
| PRECIS | - | Providing Regional Climates for Impacts Studies |
| RCM | - | Regional Climate Model |
| RMSE | - | Root Mean Square Error |
| SCA | - | Snow cover area |
| SLC | - | School Leaving Certificate |
| SPSS | - | Statistical Package for the Social Sciences |
| SRES | - | Special Report on Emissions Scenarios |
| SRM | - | Snowmelt Runoff Model |
| SVA | - | Socio-Economic Vulnerability Assessment |

| | | |
|---|---|---|
| SVI | - | Socio-economic Vulnerability Index |
| SWAT | - | Soil Water Assessment Tool |
| UN | - | United Nations |
| UNFCCC | - | United Nations Framework Convention on Climate Change |
| USLE | - | Unified Soil Loss Equation |
| VDC | - | Village Development Committee |
| WECS | - | Water and Energy Commission Secretariat |
| WMO | - | World Meteorological Organization |
| WRS | - | Water Resources Strategy |

# Chapter 1: Introduction

## 1.1 Background

Rugged terrain, steep topography and fragile geology, tectonically active zone, intense precipitation during the monsoon and very low amount of rainfall in other months are some of the physio-climatic feature of Nepal. All these factors make Nepal a disaster prone country which has been suffering from recurring natural hazards like floods and landslides, drought and forest fire, earthquakes and epidemics etc. causing a heavy annual loss of lives, and properties. The study carried out in 2004 by UNDP/BCPR, among 200 countries of the world, Nepal stands at 11th and 30th respectively with regard to relative vulnerability to earthquake and flood. Because of this prevailing conditions World Bank in 2005 has placed Nepal as one of the global 'hot-spots' for natural disasters (NSDRM, 2008). Further, the so called climate change phenomenon is going to impact the hydrological regime of the country, placing the country in additional stress especially in terms of flood risk.

Koshi River, one of the largest tributaries of the Ganges River System in South Asia, is a trans-boundary river. It originates in China, passes through Mountains and Hills of Nepal, and flows through the plains of Terai of Nepal and India before meeting Ganga-River near Kursela (Bihar) in India. The devastating flood events in Koshi have claimed huge damage in property, agriculture and loss of lives in Nepal and Bihar (India) in different points of time; the recent one being the flood event of August 2008. The event of the 2008 flood is regarded as the man-made failure because the embankment of the river breached in August 2008 when the river discharge was about 4,200 $m^3/s$, less than the average mean monthly flow for August (ICIMOD, 2008). The flood event, thus resulted, caused the death of 4-6 persons, affected 6,000 ha of agricultural land damaging crop worth USD 3.7 million, displaced 40,378 persons from 7102 families and damaged 4 km of the east-west highway in Nepal (ICIMOD, 2008). In India, the devastation was much bigger claiming 42 lives (as of 25 August 2008), destroying 35,000 ha of crop, affected more than 1 million people with more than 70,000 displaced people (ICIMOD, 2008).

Due to the frequent flooding in Koshi River and its damages, there have been efforts to control flood in both India and Nepal viz. Koshi River Agreement in 1954. However, Koshi Flood in 2008 has alerted both the countries regarding the functioning of the barrage and the embankments. As a result, Koshi High Dam, which was envisioned in 1937 to permanently "cure" the flooding problem, has once again been revitalized at present for flood control, irrigation and hydropower generation. Koshi High Dam, the concrete dam of 239m height, is proposed to be constructed in Barahkshetra with live storage of 4,420 million cubic meters (mcm) and gross storage of 8,500 mcm. The expected benefit from the dam is irrigation of 66,450 ha of land in Nepal, flood control and 3,489 MW of hydropower. As such, Nepal (the upper riparian), India (middle riparian), and even Bangladesh (lower riparian–Ganga River Basin) has shown interest in the construction of the High Dam. Recently, the first meeting of the India Nepal Joint Ministerial Commission on

Water Resources (JMCWR), held on 15th February, 2012 at New Delhi, agreed to expedite the completion of Detailed Project Report of Sapta Kosi High Dam Multipurpose Project.[1].

The beneficial aspects of the Koshi High Dam is promising, however, it is not simple as it seems. Apart from the different socio-political issues, the proposed Koshi High Dam is going to face the challenges and uncertainties brought upon by the changing climate. Climate Change is surely going to impact the hydrological regime of the entire South Asia. Different researches have shown the changes in the pattern of temperature and precipitation. According to *Thematic Assessment Report on Climate Change* (2008) prepared under the National Capacity Self Assessment (NCSA) project (as cited in ADB (2009)), the mean annual temperature is estimated to have increased by 0.06°C from 1977 and 1994, and is projected to increase by another 1.2°C by 2030, 1.7°C by 2050, and 3.0°C by 2100 and precipitation extremes show an increasing trend in intense precipitation events at most recording stations. The assessment indicates more occurrence of water related disasters, floods and landslides in future (as cited in ADB, 2009). Besides, rising temperature due to climatic variation in the region is expected to melt the glaciers causing the retreat of the glaciers that greatly enhances the possibility of the GLOF events (ADB, 2009). Hence, it is for sure that the climate is changing and so do the hydrological response. As such, the Koshi High Dam needs to face the uncertainties brought upon by such changing hydrological regime. Hence, it becomes prudent to analyze the likely changes in future precipitation/ temperature pattern using downscaled global climate change projections and predict the changes in the hydrological cycle including the extreme events under climate change scenario using appropriate hydrological models. The results from such analysis will aid in the hard and soft approaches to face and overcome the challenges of the Koshi High Dam and aid in making wise and rational decision.

The rapid development including urbanizations of the towns in the lower part of the basin have made the communities and infrastructure more vulnerable to the increasing flood hazards including the risks of GLOFs. Unplanned development, encroachment of flood plains and lack of climate-proof design guidelines have put more infrastructures and assets at risk of flood damages. Design of hydraulic structures such as dams, embankments and bridges based the analysis of historical hydrological data is simply not a good design considering the non-stationarity of the hydrological time series due to the impacts of climate change. Hence, the changing development trajectories coupled with the impacts of climate change have rendered communities and vital sectors like water resources and agriculture more prone to the adverse impacts of disasters.

It is thus imperative that proper Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) policies are in place to manage and mitigate the increasing flood disaster risks in basins like the Koshi River Basin. Within this backdrop, Nepal Development Research Institute (NDRI) submitted a study proposal on "Disaster Risk Reduction and Climate Change Adaptation in Koshi River Basin, Nepal" to Climate and Development Knowledge Network (CDKN) and global change SysTem for Analysis Research and Training (START) on February 29, 2012.

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[1] www.Kathmandumetro.com (http://66.7.193.115/news/nepal-india-ministerial-level-meeting-on-water-resources) (accessed 28 Feb 2012)

START/CDKN awarded a grant to carry out the research to NDRI and an agreement was signed between the two institutions in June 2012.

## 1.2 Objectives

The overall objectives of the research program is to assess the impact of climate change on current and future development in Koshi River Basin due to increased variation of extreme climate and hydrological events and to propose adaptation measures and policy innovations for disaster risk reduction and climate change adaptations.

The specific objectives of the program are:

**Advancing knowledge** that develops a better understanding of climate and related stressors on hydro-meteorology of the Koshi River basin including floods and droughts and glacier melting process;

**Assessment of flood risks in the context of climate change** by combining the different hazard scenarios with socio-economic vulnerability of communities;

**Revisiting the design standard/values** of proposed infrastructure i.e. the Koshi High Dam and embankments;

**Contributing to policy formulation process** that help to improve the existing government policies on water resource infrastructure development works in the face of climate change; and

**Awareness building** of stakeholders including local communities and **training of new generation** on the application of advance technology and tools to assess the impact of climate change on water resources.

## 1.3 Components of the Study

In order to achieve the objectives, the study was divided into the following five components

**Component 1**: Advancing Knowledge on Climate Change

The Hydro-meteorological Diagnostics and Modeling are two major activities under this component of the study.

**Component 2**: Revisiting the Design Standards/Values of the Proposed Koshi High Dam

The results of hydrologic and sediment yield modeling was used to assess the design values of the proposed dam.

**Component 3**: Assessment of Socio-economic Vulnerability

To obtain primary information required for vulnerability assessment three methods i.e. Household Survey, Focus Group Discussion (FGD) and Key Informant Interview (KII) were employed.

**Component 4**: Contributing to Policy Formulation Process

Based on the model results and analysis on design values, socio-economic assessment of the study area, policy recommendations for constructing heavy water resources structures were made. Similarly, policy recommendations at national and community levels on land use management planning as well as DRR and CCA were made based on the hazard, vulnerability and risk maps.

**Component 5**: Awareness building and training of new generation

Awareness building to stakeholders including local communities was accomplished through three stakeholders' consultations workshop and one dissemination seminar. Training of new generation was done by involving three full-time Research Associates, and providing grants to five master's level theses researchers.

## 1.4 Limitation of the Study

The study has following limitations.

i. The study was carried out up to Nepali territory.
ii. Two regional climate model data for one IPCC SRES climate scenario (A1B) were used to assess the future climatic conditions.
iii. Land use change in the watershed was not taken into account.
iv. Impact of climate change was focused on the basin hydrology.
v. Vulnerability assessment was carried out only in the Terai Region, i.e. probable flood affected area, considering limited number of indicators.

## 1.5 Structure of the Report

The report is organized in the following headings.

**Chapter 1**: It presents the brief introduction of the projects that includes the objectives, major components of the study and the limitations of the study.

**Chapter 2**: It contains the general features of the Koshi River Basin focusing on the basin hydrology.

**Chapter 3**: It provides the methodology employed in the study

**Chapter 4**: Hydro-meteorological analysis of historical data are presented in this chapter.

**Chapter 5**: This chapter deals with the preparation of climate data required for future snowmelt runoff and hydrological models using regional climate model data. The methods used in bias correction and the comparison of statistics of projected climate data and the historic date are covered in this chapter.

**Chapter 6**: Development of Snowmelt Runoff Model (SRM) and its use to assess the snowmelt contribution in the basin is the main focus of Chapter 6. It includes calibration and validation of the SRM model, and assessment of future runoff attributed to snowmelt process.

**Chapter 7**: Development and Use of Soil and Water Assessment Tool (SWAT model) for flow and sediment yield assessment in the Koshi River Basin is the main contents of this chapter. It employed the model result of SRM as upstream boundaries to assess the river yield in the future using the calibrated and validated model. Change in flow duration curves including flow extremes with and without climate change impacts are presented. Based on the flood flow analysis design values and design standards for Koshi High Dam are discussed briefly. The sediment yield analysis and its implications in the design of dam are also briefly covered.

**Chapter 8**: This chapter deals with the hydraulic part of the study covering flood inundations under different flow conditions. It contains the cases of embankment and dam breached conditions. Hazard maps based on the inundation depth are presented here.

**Chapter 9**: Vulnerability assessment based on field survey considering five main indicators: Demographic, Economic, Social, Degree of preparedness and Recovery capacity are made in this chapter. Flood risk assessment to the people is also made and risk maps are also presented.

**Chapter 10**: It presents the policy implications of the climate change regarding the water resources development works.

**Chapter 11**: Conclusion of the study and some issues for future research are presented in this chapter.

References and Appendices are kept in the last part of the report.

# Chapter 2: Study Area: The Koshi River Basin

## 2.1 General

The Koshi River is a trans-boundary river. It originates in China passes through Nepal and finally meets Ganga-River in India **(Figure 2-1)** . The total catchment area of the river at its confluence with Ganga is 74,030 km$^2$ (FMIS, 2012). Out of this about 43% lies in China, 42% in Nepal and remaining 15% lies in India (Sharma, 1997; FMIS, 2012). The Koshi River drains most of the eastern part of Nepal.

In Nepal, the Koshi River Basin covers an area of three major ecological zones within the transverse length (north-south) of about 150 km: i) Snow covered Himalaya in the north ii) Hilly region in the middle and iii) Plain region of Terai in the south. The variation of altitude in this short reach is quite sharp i.e. from 95 m to 8848 m. The High Himalaya region of the Koshi basin within Nepal is about 8,220 km$^2$ (> 3,000 m) where the presence of glacial lakes is common. According to ICIMOD (2011), 599 glacial lakes were mapped in the Koshi Basin covering an area of 26 km$^2$. The catchment area of the Koshi Basin in the hilly part is about 17,620 km$^2$ which is mainly covered with forests and agricultural land. This region is high rainfall receiving zone. The Koshi River Basin covers the area of 2,000 km$^2$ in the Terai region of Nepal before it enters into Indian territory. The Terai region is highly populated. Agricultural land occupies the main part of this plain. Because of the diverse hydro-ecological characteristic of the basin, hydrological and hydraulic analysis demand separate dealing for each region.

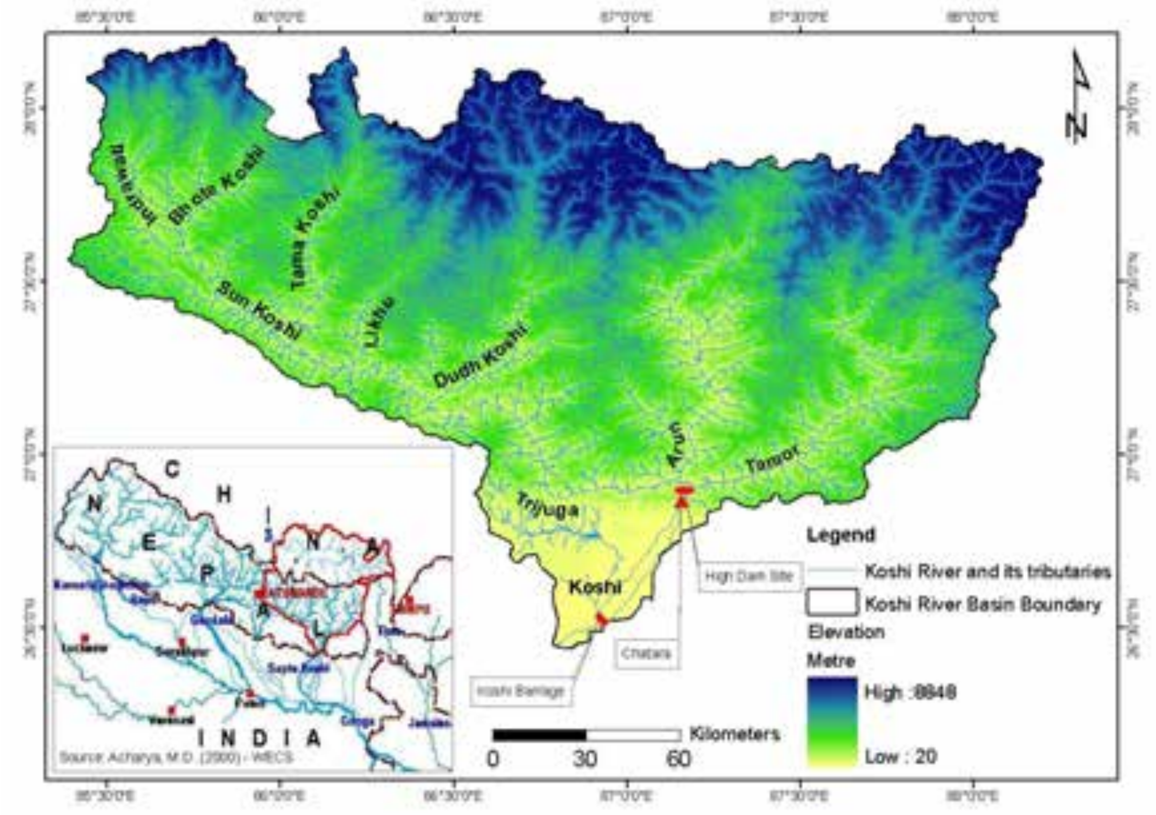



**Figure 2-1 : Koshi River Basin in Nepal**

## 2.2 River System

The Koshi River has three main tributaries viz. Tamor in the eastern part, Arun in the middle and Sunkoshi in the western part of the basin. The Sunkoshi River consists of 5 major tributaries: the Indrawati, the Bhote-Koshi, the Tama Koshi, the Likhu and the Dudh Koshi (

). The Sun-Koshi, the Arun and the Tamor meets at Tribeni-ghat, flow through Barahkshetra gorge for a length of about 15 kms and enters into the Terai Region (plains) of Nepal at Chatara.

## 2.3 Climatology

### 2.3.1 Precipitation

Precipitation occurs in the form of rainfall in the lower altitude and in the form of snow in higher altitude lying in the northern Himalayan region. There are 61 rain-gauge stations inside the Koshi River Basin as shown in **Figure 2-2** and tabulated in **Appendix A-1**. The data available in these gauge stations are daily and 24-hr maximum. The annual average precipitation of the basin is about 2,000 mm. However, annual variability in the precipitation values is quite high for a given location. For example, the long term (1976-2005) mean annual precipitation at Chatara (Station No. 1316) is 2098 mm. It received a rainfall as high as 2,780 mm in 1975 and as low as 1,431 mm in 1994. Since the rainfall in Nepal occurs due to the south-west monsoon which lasts between the months of June to September, almost 80% of the rainfall occurs in the monsoon season. The rest eight months receives merely 20% of the total precipitation. Location wise variation in the precipitation is also significant in this basin. For example Num Station (1301) it is greater than 3500 mm per annum and less than 900 mm at Dhankuta (Station 1307).

### 2.3.2 Temperature

There are 17 meteorological stations with daily temperature records in the Koshi River Basin. The data available are of daily maximum temperature and daily minimum temperature. **Figure 2-3** and **Appendix A-2** shows the meteorological stations in the Koshi River Basin.

### 2.3.3 Evaporation Data

Evaporation data in the Kosi River Basin are available only in two agro-meteoro stations namely at Jiri (Station no. 1103) and at Pakhribas (Station no. 1304).

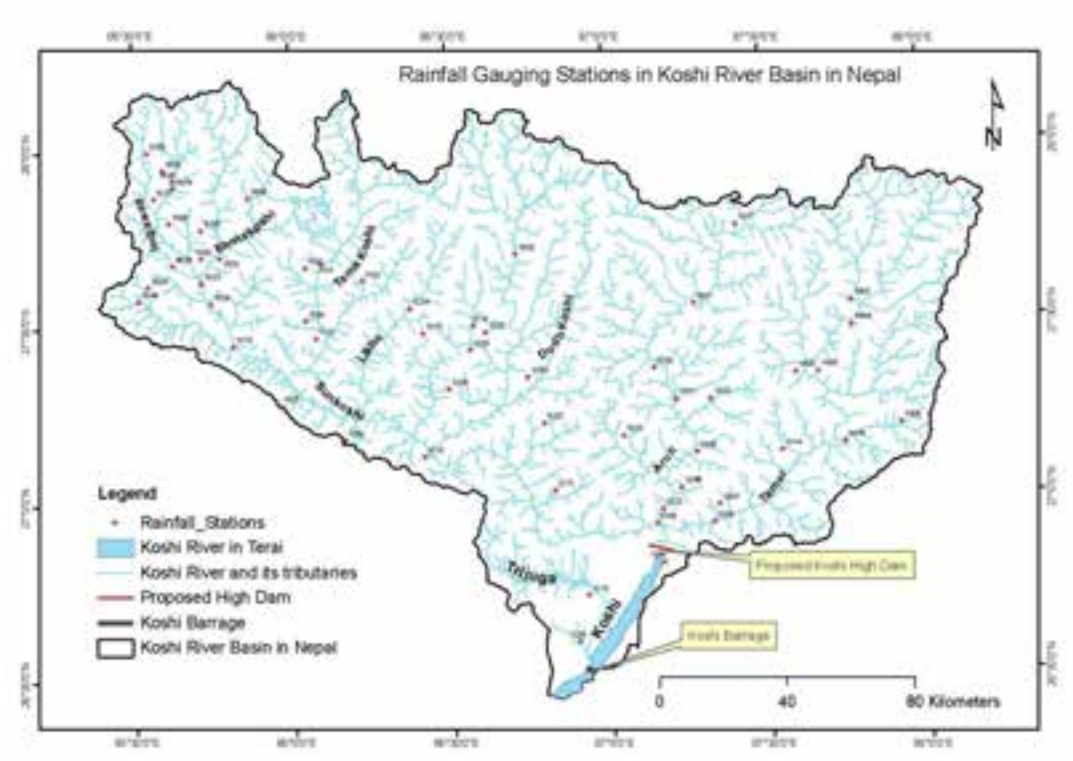



**Figure 2-2 : Rainfall Gauging Stations within Koshi River Basin in Nepal (Source: DHM, 2012)**

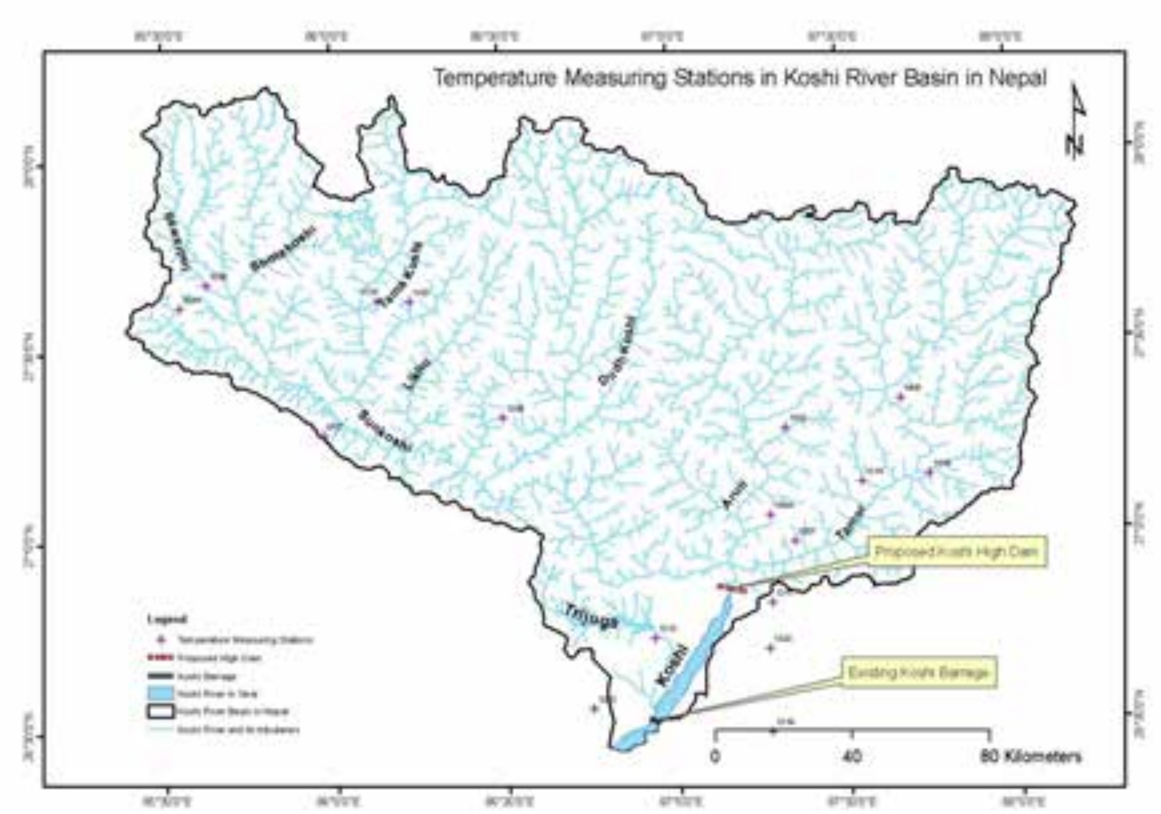



**Figure 2-3: Temperature measuring station in Koshi River Basin (Source: DHM, 2012)**

## 2.4 Snow and Glacial Hydrology

Glaciers and snow contribute significantly to the runoff of the major rivers including the Koshi River. Accumulated snow acts as the reservoir which release water after melting. About 8% of the of the country's area is estimated to be under permanent snow cover (Thapa and Pradhan, 1995). However, snow covered areas was estimated to be about 3.26 % of the Koshi Basin (Gyawali, 2011). Imja Tsho (the Imja Khola River) and Tsho Rolpa (the Rolwaling Khola) are some of the Glacial Lakes in the Koshi Basin which are in the threat to cause Glacial Lake Outburst Flood (GLOF). Out of 24 recorded GLOF events in Nepal, 16 GLOF events were in the Koshi River Basin (ICIMOD, 2011). The numbers and areas of the glacier lakes those lie in Koshi Basin [inside the dotted rectangle] are given in **Table 2-1** and shown in **Figure 2-4**.

**Table 2-1: Inventory of Glacier Lakes in the Koshi Basin**

| Sub-basin | Lakes in 2001 inventory | | Lakes in 2009 inventory | | % Change in Area |
|---|---|---|---|---|---|
| | Number | Area ($km^2$) | Number | Area ($km^2$) | |
| **Tamor** | 356 | 7.32 | 209 | 6.57 | -0.21 |
| **Arun** | 109 | 2.53 | 81 | 3.28 | 0.69 |
| **Dudh Koshi** | 473 | 13.1 | 243 | 13.19 | 0.02 |
| **Likhu** | 14 | 0.22 | 13 | 0.31 | 0.64 |
| **Tama Koshi** | 57 | 1.26 | 24 | 2.15 | 1.56 |
| **Bhote Koshi** | 35 | 0.41 | 17 | 0.31 | -0.29 |
| **Indrawati** | 18 | 0.28 | 12 | 0.11 | -0.94 |
| **Total** | 1062 | 25.1 | 599 | 25.92 | 0.08 |

Source: ICIMOD (2011)

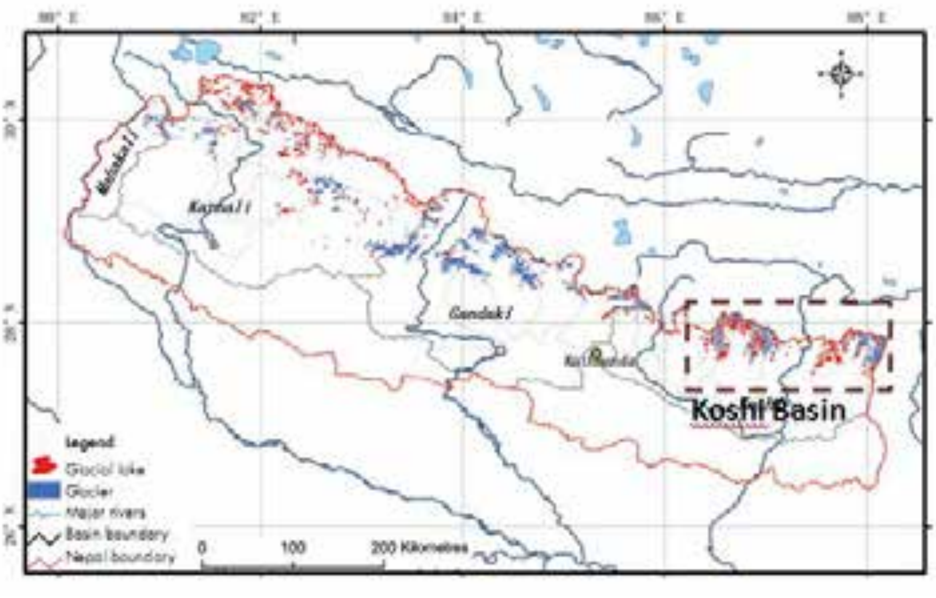



**Figure 2-4: Location of Glacier and Glacial Lakes in Koshi Basin (Source: ICIMOD, 2011)**

## 2.5 River Hydrology

There are 22 hydrometric stations in the Koshi River Basin. The mean daily flow data as well as instantaneous maximum flow data in these stations are available. In **Figure 2-5**, the locations of the hydrometric stations in the basin are given. **Appendix B** lists the station and their corresponding attributes.

The Koshi River is a perennial river with an annual average flow at Chatara of 1,540 $m^3/s$ (DHM, 2008). However annual variability even in the average flow is significant: 2,070 $m^3/s$ in 1999 and 1,230 $m^3/s$ in 1982. The annual hydrograph of this station for this station of 2000 is given in **Figure 2-6**. From this hydrograph, it can be clearly seen that most of the flow occurs in the four monsoon months in this river. It also shows the minimum flow occurs in the month of March while the high flow occurs in August. The daily maximum and minimum flows at this station in 2000 are respectively 294 and 7,540 showing the great variation in flow within a year. It suggests the importance of the water impounding structure for the better management of the water resources of the river and to mitigate the water induced disasters.

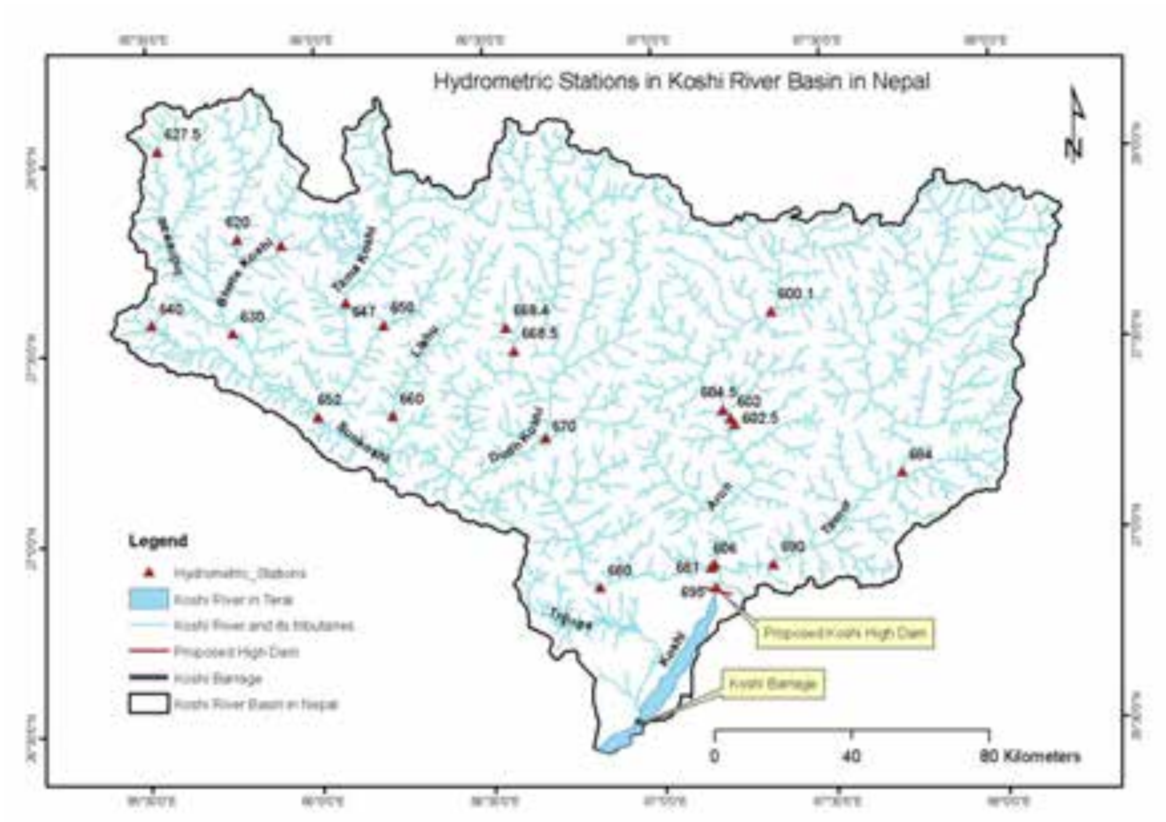



**Figure 2-5: Hydrometric Stations in the Koshi River Basin (Source: DHM, 2008)**

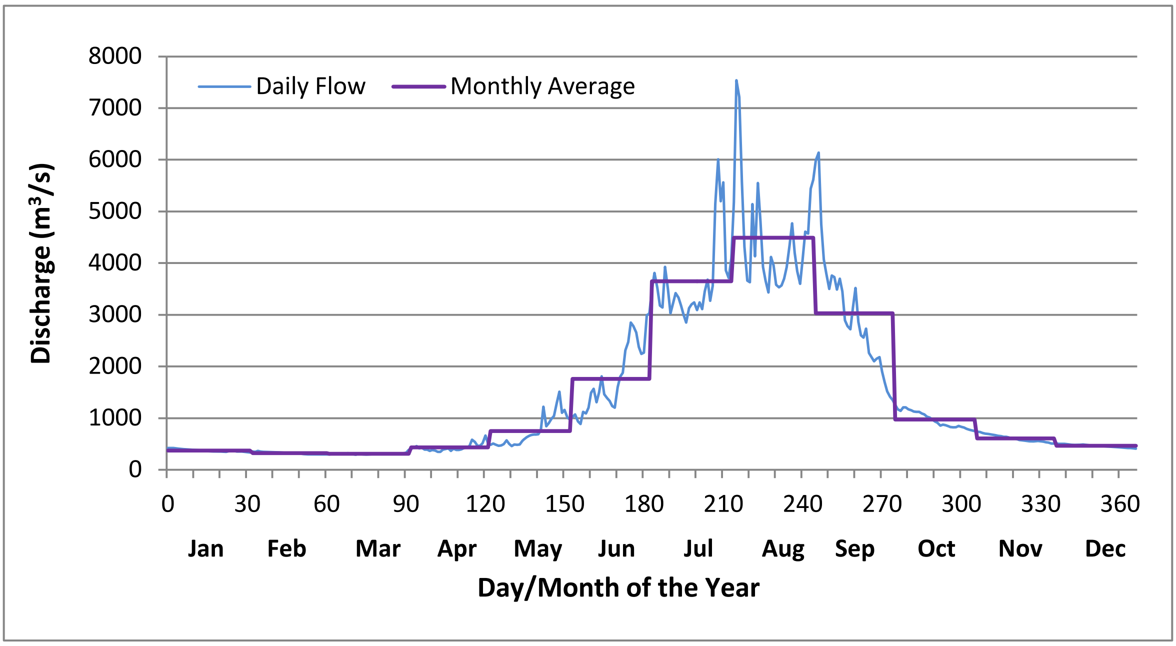



**Figure 2-6: Hydrograph of Chatara (2000) (Source: DHM, 2008)**

## 2.6 Koshi Flood of 2008

The left embankment of the Koshi river at Kusaha was breached on 18th August 2008 when the river discharge was about 4,200 m3/s. The water had flooded significant portions of the Sunsari District (**Figure 2-7**). The greatest recorded flood was of 24,200 $m^3/s$ on 24 August 1954 (www.wikipedia.com, Accessed August, 2013).


**Figure 2-7: Embankment Breached Flood 2008 in Koshi Basin (Source: OCHA (2008))**

## 2.7 Sediment

Koshi River is considered to be one of the highest sediment laden rivers in South Asia. The soil erosion in the basin results a soil loss of about 180 million tonnes annually from the Koshi River basin, while the country as a whole loses about 380 million tonnes annually (Nayak, 1993). The Koshi River has an average suspended concentration of 10 gm/l, compared with the predicted mean concentration of 2.69 gm/l for the Mahabharat region (Nayak, 1992).

## 2.8 Administrative Division

For administrative purpose, Nepal is divided into 5 development regions and 75 districts. There are 17 districts fully or partially lying within the Koshi River Basin as given in **Table 2-2** and shown in Figure 2-8. Out of 17 districts 12 districts are fully within the basin and 5 are partially lying in the basin.

**Table 2-2: Districts in the Koshi Basin**

| S.No. | DISTRICT | Total Area (sq.km) | % of area inside the Koshi River Basin | Physiographic Region |
|---|---|---|---|---|
| **1** | Bhojpur | 1526 | 100 | High Mountains and Middle Mountains |
| **2** | Dhankuta | 900 | 100 | Middle Mountains |
| **3** | Dolakha | 2148 | 100 | High Himalayas, Middle Mountains and Middle Mountains |
| **4** | Kavrepalanchok | 1391 | 75 | Middle Mountains |
| **5** | Khotang | 1591 | 100 | High Mountains and Middle Mountains |
| **6** | Okhaldhunga | 1077 | 100 | High Mountains and Middle Mountains |
| **7** | Panchthar | 1251 | 100 | High Mountains and Middle Mountains |
| **8** | Ramechhap | 1565 | 100 | High Himalayas, High Mountains and Middle Mountains |
| **9** | Sankhuwasabha | 3477 | 100 | High Himalayas, High Mountains and Middle Mountains |
| **10** | Saptari | 1283 | 42 | Siwalik and Terai |
| **11** | Sindhuli | 2483 | 23 | Middle Mountains |
| **12** | Sindhupalchok | 2489 | 100 | High Himalayas, High Mountains and Middle Mountains |
| **13** | Solukhumbu | 3359 | 100 | High Himalayas, High Mountains and Middle Mountains |
| **14** | Sunsari | 1194 | 27 | Siwalik and Terai |
| **15** | Taplejung | 3643 | 100 | High Himalayas, High Mountains and Middle Mountains |
| **16** | Terhathum | 672 | 100 | Middle Mountains |
| **17** | Udayapur | 2300 | 72 | Middle Mountains and Siwalik |
| **Note: Physiographic classifications are based on Kansakar et. al, 2004.** | | | | |


**Figure 2-8: Districts in Koshi River Basin in Nepal**

## 2.9 Demography

### 2.9.1 Total Population and Population Density

The population of 2001 and 2011 of the districts lying in Koshi Basin are given in **Table 2-3**. The growth rate and the density of population based on 2011 census data are also presented in the table. It showed that the total population of the districts in Koshi River Basin is 4.48 million in 2011. This is a decadal growth rate of 3.25% from 4.34 million in 2001 (CBS, 2011).

### 2.9.2 Population Distribution

Age wise distribution of the population in the Koshi River Basin is shown in **Table 2-3**.**Error! Reference source not found.** About 53% of the population lies in the economically active population range (15-59 years). 5-9 age groups have the highest population followed by population of 10-14 age groups. There is a decreasing trend of population as the age increases.

**Table 2-3 : Population in the Districts of Koshi Basin**

| S.N. | Area | Population 2001 | | | Population, 2011 | | | Ann. Growth Rate (%) | Popn Density (person / sq.km.) |
|---|---|---|---|---|---|---|---|---|---|
| | | Total | Male | Female | Total | Male | Female | | |
| | **Nepal** | **23,151,423** | **11,563,921** | **11,587,502** | **26,620,809** | **12,927,431** | **13,693,378** | **1.40** | **181** |
| | **Districts in Koshi River Basin** | | | | | | | | |
| **1** | Bhojpur | 203,018 | 97,762 | 105,256 | 183,918 | 86,663 | 97,255 | -0.99 | 122 |
| **2** | Dhankuta | 166,479 | 81,841 | 84,638 | 164,133 | 76,980 | 87,153 | -0.14 | 184 |
| **3** | Dolakha | 204,229 | 99,963 | 104,266 | 188,186 | 88,163 | 100,023 | -0.82 | 86 |
| **4** | Kavrepalanchok | 385,672 | 188,947 | 196,725 | 389,959 | 186,544 | 203,415 | 0.11 | 279 |
| **5** | Khotang | 231,385 | 112,821 | 118,564 | 209,130 | 98,860 | 110,270 | -1.01 | 131 |
| **6** | Okhaldhunga | 156,702 | 75,361 | 81,341 | 148,320 | 68,893 | 79,427 | -0.55 | 138 |
| **7** | Panchthar | 202,056 | 99,042 | 103,014 | 198,362 | 93,884 | 104,478 | -0.18 | 160 |
| **8** | Ramechhap | 212,408 | 100,853 | 111,555 | 205,312 | 94,925 | 110,387 | -0.34 | 133 |
| **9** | Sankhuwasabha | 159,203 | 77,853 | 81,350 | 159,649 | 75,973 | 83,676 | 0.03 | 46 |
| **10** | Saptari | 570,282 | 291,409 | 278,873 | 646,250 | 316,888 | 329,362 | 1.25 | 474 |
| **11** | Sindhuli | 279,821 | 139,280 | 140,541 | 294,621 | 141,573 | 153,048 | 0.52 | 118 |
| **12** | Sindhupalchok | 305,857 | 152,012 | 153,845 | 289,455 | 139,602 | 149,853 | -0.55 | 114 |
| **13** | Solukhumbu | 107,686 | 53,173 | 54,513 | 106,772 | 51,885 | 54,887 | -0.09 | 32 |
| **14** | Sunsari | 625,633 | 315,530 | 310,103 | 751,125 | 365,927 | 385,198 | 1.83 | 598 |
| **15** | Taplejung | 134,698 | 66,205 | 68,493 | 128,547 | 61,442 | 67,105 | -0.47 | 35 |
| **16** | Terhathum | 113,111 | 54,932 | 58,179 | 101,709 | 47,357 | 54,352 | -1.06 | 150 |
| **17** | Udayapur | 287,689 | 143,756 | 143,933 | 321,962 | 151,649 | 170,313 | 1.13 | 156 |

Source: CBS (2011)

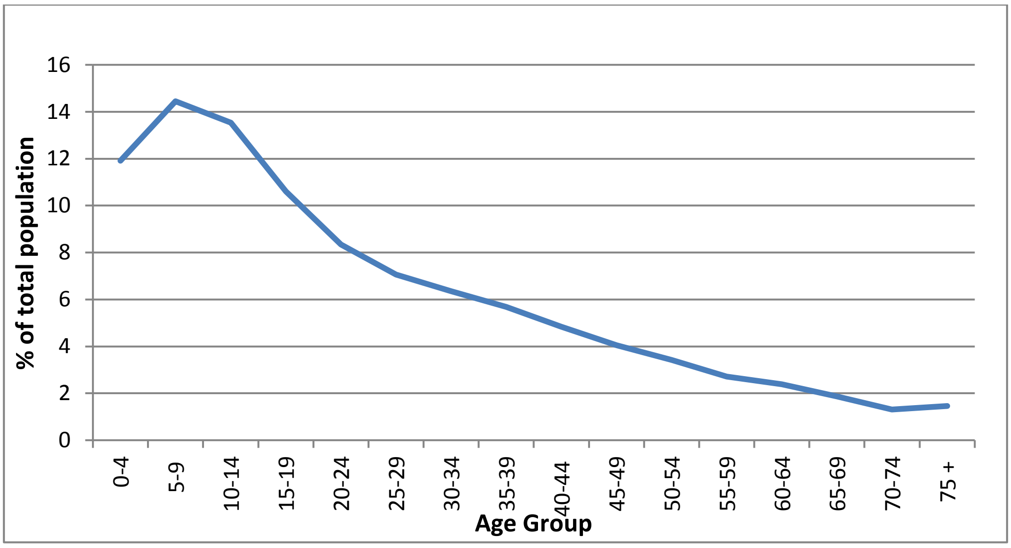
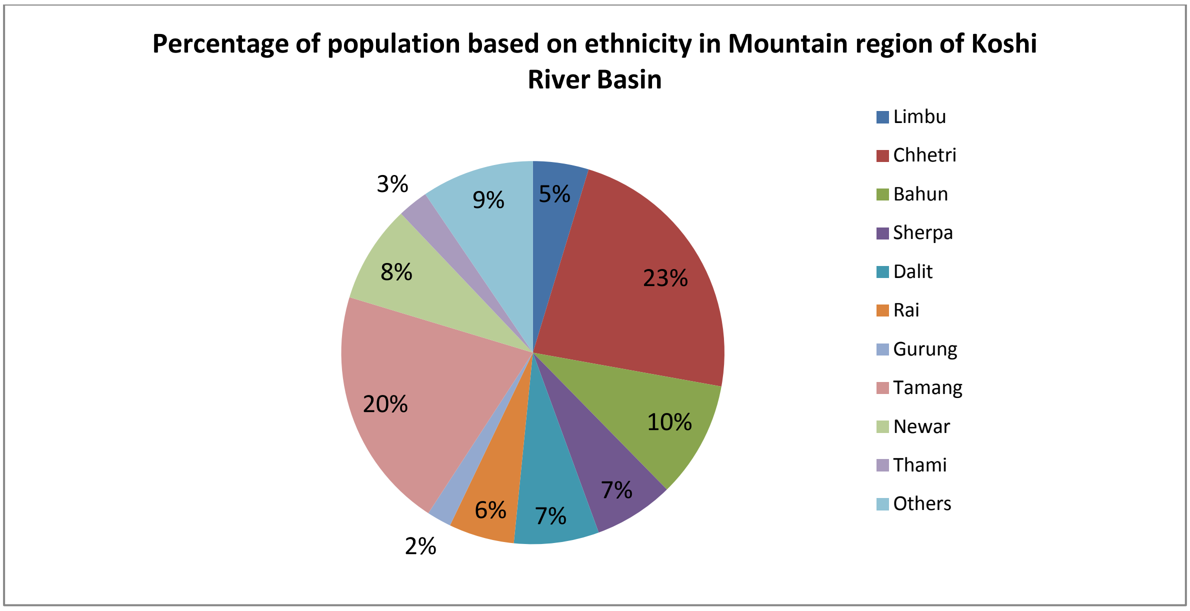



**Figure 2-9: Age wise Population Distribution in the Districts of Koshi River Basin**

(Source: CBS, 2001)

### 2.9.3 Ethnicity

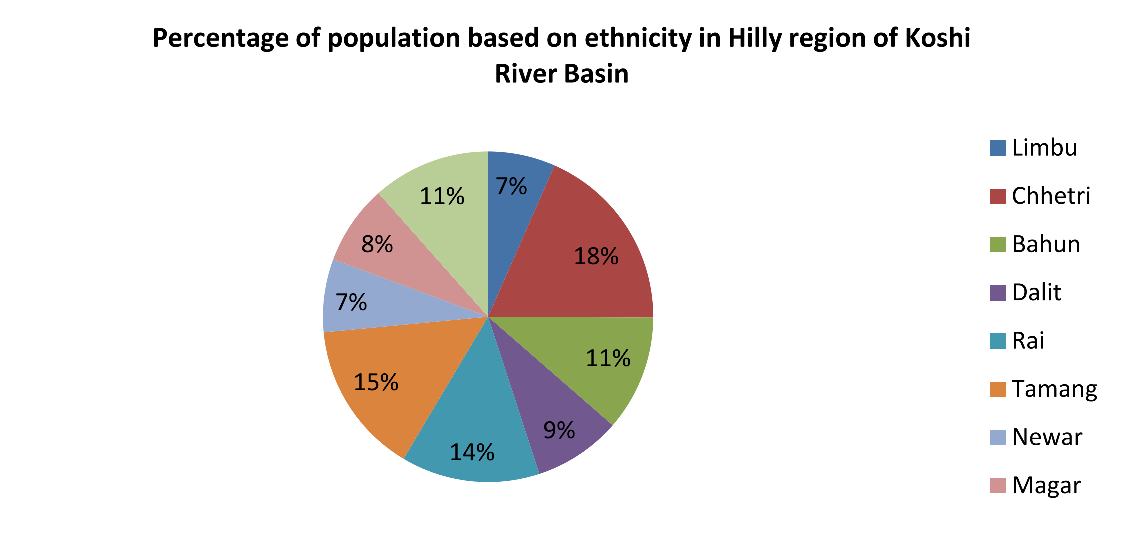
In the five districts districts, Taplejung, Sankhuwasabha, Solukhumbu, Dolakha and Sindhupalchowk, that have High Himalayas, High Mountains and Middle Mountains physio-graphic regions, the major ethinic groups are of Chhetri (23%) and Tamang (20%) as shown in **Figure 2-10.** The other common ethnic groups are Bahun, Newar, Sherpa, Tamang, Rai, Limbu, Dalit and Thami. Other ethnic groups include Yakkha, Majhi, Thakuri, Jirel, Danuwar and others.




Source: CBS, 2001

**Figure 2-10: Ethnic Group in Mountain Region**

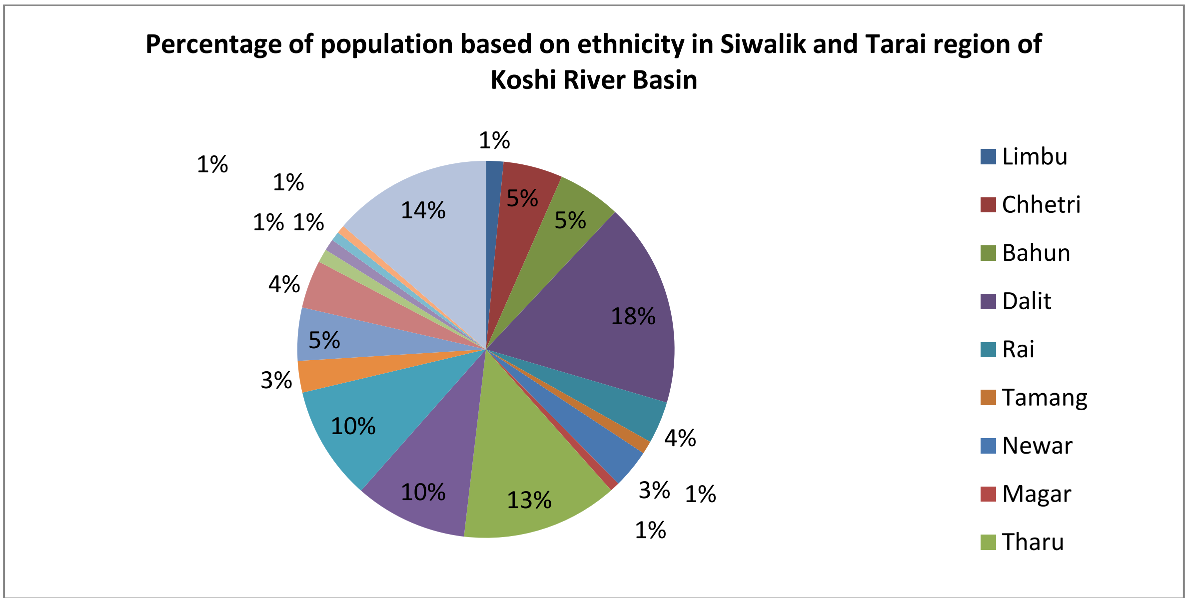
In the 10 districts of hilly region (High Mountains and Middle Mountains) namely, Panchthar, Dhankuta, Terathum, Bhojpur, Okhaldhunga, Khotang, Udayapur, Sindhuli, Ramechhap and Kavrepalanchowk, the major ethnic groups are Chhetri (18%), Tamang (15%) and Rai (14%) as shown in **Figure 2-11**. Other common groups are Bahun, Limbu, Newar, Magar and Dalit. The minor ethnic groups include Gurung, Sunwar, Sanyasi, Gharti/Bhujal, Yakkha, Thami, Majhi, Tharu, Danuwar, Hayu, Thakuri and others. There percentage is less than 2%.




Source: CBS, 2001

**Figure 2-11: Ethnic Group in Hilly Region**

In the districts of Siwalik and Tarai Region, Saptari and Sunsari, the major ethnic group is Dalit (17%) followed by Tharu (13%) and Muslim (10%) and Yadav (10%). Other common groups are Chhetri, Bahun, Teli, Dhanuk, Rai, Newar, and Koiri. There population varies from 3 to 5%. Other ethnic groups include Tamang, Magar, Baniya, Mallah, Hajam, Thakur and others. **Figure 2-12** illustrate the percentage of different ethnic group in the Siwalik and Terai region (districts) in Koshi River Basin in Nepal.




Source: CBS, 2001

**Figure 2-12: Ethnic Group in Terai Region**

# Chapter 3: Approach and Methodology

## 3.1 Approach of the Study

This study attempted to integrate different aspects together to give the sense of wholeness (in **Figure 3-1**). It used modern scientific tools (Hydrological and hydraulic models) to simulate hydrologic and hydraulic process occurring in the basin and employed socio-economic survey to assess the vulnerability of the people living in the flood prone area. Spatially, the study covered snowmelt phenomena of the Himalayan region, rainfall and runoff process of Hilly region and consequent flood flow and inundation of the Terai region of Nepal. Comparison of hydro-climatic parameters of historical data with those projected values is another activity of this research. Obtaining feedback from experienced steering committee members, involving of experts from different field as investigators and research associates, and providing grants and assisting Master's level students in their researches are important aspects of this research. Linking of research to the policy is main focus we gave in this research program.

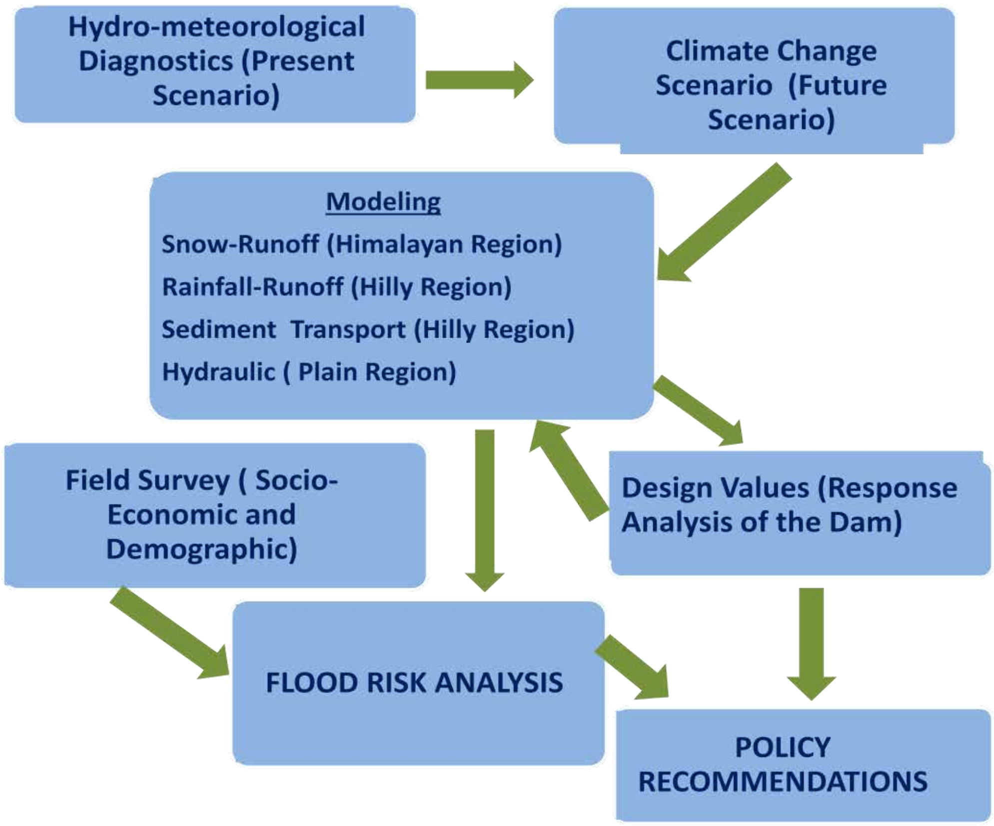



**Figure 3-1: Approach of the Study**

## 3.2 Methodology

Methodology of the study consists the following steps.

1. Collection of the data and information relevant to the study. It includes the collection of both primary and secondary data.
2. Preparation of data required for hydro-meteorological diagnostics and modeling as well as vulnerability and risk assessment. It includes bias correction of the RCM data, filling

of missing data, preparation of spatial physical data using GIS and time series data in required format for modeling or analysis using SPSS.

3 Performing analysis and modeling, interpretation of results and drawing conclusions.

## 3.3 Data and Information Used in the Study

Two types of data were required for this study: Temporal and Spatial. They were acquired either by collecting/extracting them from secondary sources or by collecting them in the field through field survey. They were then directly used or used after certain refinement, e.g. bias correction of RCM data to assess the future climate change, for analysis or modeling. The summary of the data used in the study are given in **Table 3-1**.

**Table 3-1: Data used in the study**

| SN | Type of Data | Nature of Data | Source | Used for | Remarks |
|---|---|---|---|---|---|
| **1** | Historical climate data | Time series | Secondary | i. Hydro-climatic diagnostics<br>ii. Model calibration and validation | Data Provider: Department of Hydrology Meteorology, Government of Nepal |
| **2** | Projected climate data | Time series | Secondary | i. Hydro-climatic diagnostics<br>ii. Model input for flow simulation | RCM data are acquired Bias correction was needed |
| **3** | Hydrological data | Time series | Secondary | i. Hydro-climatic diagnostics<br>ii. Model calibration and validation | Data Provider: Department of Hydrology Meteorology, Government of Nepal |
| **4** | Physical data (Contour map, soil type, snow cover) | Spatial | Secondary | Model input for flow simulation | Data Provider: Contour Map- Department of Survey, Government of Nepal; Soil type-FAO, Snow cover-ICIMOD<br>Data preparation required to fit the model requirement |
| **5** | Socio-economic data | Spatial | Primary | Vulnerability assessment | Field Survey (HH survey, FGD, KII)<br>A level of data preparation is required |
| **6** | Cross cutting information on climate change issues | Spatial | Primary | Analysis of the perception of the people on disaster risk reduction and climate change adaptation | Field Survey (HH survey, FGD, KII)<br><br>A level of data preparation is required |

## 3.4 Regional Climate Model Data

Two Regional Climate Model data were used in this study (**Table 5-12**). These are PRECIS-HadCM3Q0 and PRECIS-ECHAM05. These data are based on IPCC SRES A1B scenario. These data are validated for the period-1960 to 2000 and projected for the future period of 2020s to 2060s.These data were provided by the Department of Hydrology and Meteorology (DHM), Nepal. Detailed discussion of these models are described in 'Technical Approach and Methodology for Projected Data Preparation'-Nepal Climate Data Portal by DHM.

**Table 3-2: Regional Climate Data used in the study**

| RCM | PRECIS | PRECIS |
|---|---|---|
| **Parent GCM** | HADCM3Q0 | ECHAM05 |
| **IPCC Scenario** | A1B | A1B |
| **Validated period** | 1970-2000 | 1970-2000 |
| **Downscaled period** | 2030-2060 | 2020-2060 |
| **Horizontal Resolution** | 25 km | 25 km |
| **Temporal Resolution** | Daily | Daily |
| **Used Variables** | Rainfall, Temperature (Mean, Max and Min) | Rainfall, Temperature (Mean, Max and Min) |

Detail methods on climate data for modeling and statistical analysis are given in **Chapter 5**.

## 3.5 Snowmelt Runoff Model Simulation

SRM is a conceptual, deterministic model that uses an empirically based temperature-index approach to simulate melt, analogous to degree day models that estimate snowmelt as a linear function of average air temperature for time periods of a day or longer (Tekeli et al., 2005).Temperature indices are widely used in the snowmelt estimation because it is generally considered to be the best index of the heat transfer processes associated with snowmelt. Air temperature expressed in Degree-Days is used in snowmelt computations as an index of the complex energy balance leading to snowmelt.

The simplest and the most common expression relating daily snowmelt to the temperature index is shown in equation M =$\boldsymbol{D_f}$ ($\boldsymbol{T_i}$-$\boldsymbol{T_b}$) (3-1).

$$\mathbf{M} = \boldsymbol{D_f}\ (\boldsymbol{T_i}\text{-}\boldsymbol{T_b}) \qquad \mathbf{(3\text{-}1)}$$

Where,

M =Melt produced in cm of water in a unit of time

$D_f$ = Degree-day factor (cm /˚C/ day)

$T_i$-= Index air temperature (˚C)

$T_b$ = Base temperature (usually 0˚C)

The water produced from snowmelt and rainfall from each elevation bands is added, overlaid on recession flow and then converted into daily discharge at the outlet of the basin. The daily discharge is computed using following **Equation (3-2)**:

$$\boldsymbol{Q_{n+1} = [c_{Sn} \,.\, a_n(T_n + \Delta T_n)S_n + c_{Rn}P_n]\frac{A\,.10000}{86400}(1 - k_{n+1}) + Q_n k_{n+1}} \qquad \mathbf{(3\text{-}2)}$$

Where $Q$ is average daily discharge ($m^3/s$); $C_s$ is runoff coefficient for snowmelt; $C_R$ is runoff coefficient for rainfall; $a$ is degree day factor ($cm^oC^{-1}d^{-1}$); $T$ is number of degree days ($^oCd$); $\Delta T$ is the adjustment by temperature lapse rate when extrapolating the temperature for the different elevation zones ($^oCd$); $S$ is ratio of the snow covered area to the total basin area; $P$ is runoff depth formed by precipitation (cm); $A$ is area of the basin or elevation zone ($km^2$); $K$ is recession coefficient indicating the decline of discharge in a period without snowmelt or rainfall; $n$ is sequence of days during the discharge computation period; and 10000/86400 is conversion from runoff depth to discharge. In SRM, $T$, $S$, and $P$ are three model variable. $C_S$, $C_R$, $\Delta T$, $T_{CRIT}$, $K$ and the runoff lag time ($L$) are parameters which are characteristics for a given basin and for a given climate condition.

The flow diagram of the simulation process using SRM is presented **Figure 3-2**.

### 3.5.1 Performance Evaluation

The simulation results performed by the model are generally evaluated through Nash Sutcliffe coefficient of efficiency (NSE) (Equation **3-3**)and percentage of volume difference ($D_v$) (Equation **3-4**) and also through visual inspection of measured and computed discharge. Besides a Pearson correlation coefficient (r) is also used to assess the relationship between the observed and computed hydrograph. The closer $NSE$ and $D_v$ to zero, the more precise is the model simulation and they are defined as:

$$\mathbf{NSE = 1 - \frac{\sum_{i=i}^{n}(Q_i - Q_i')^2}{\sum_{i=1}^{n}(Q_i - \bar{Q})^2}} \qquad \textbf{(3-3)}$$

Where:

$NSE$ is the Nash Sutcliffe Efficiency,

$Q_i$ is the measured daily discharge,

is the computed daily discharge,

$\bar{Q}$ is the average measured discharge of the given year and

n is the number of daily discharge values

The deviation of the runoff volumes, $D_V$ is computed as follows:

$$\boldsymbol{D_v}[\%] = \boldsymbol{\frac{V_R - V_R'}{V_R}.100} \qquad \textbf{(3-4)}$$

Where:

$V_R$ is the measured yearly or seasonal runoff volume,

$V_R'$ is the computed yearly or seasonal runoff volume.

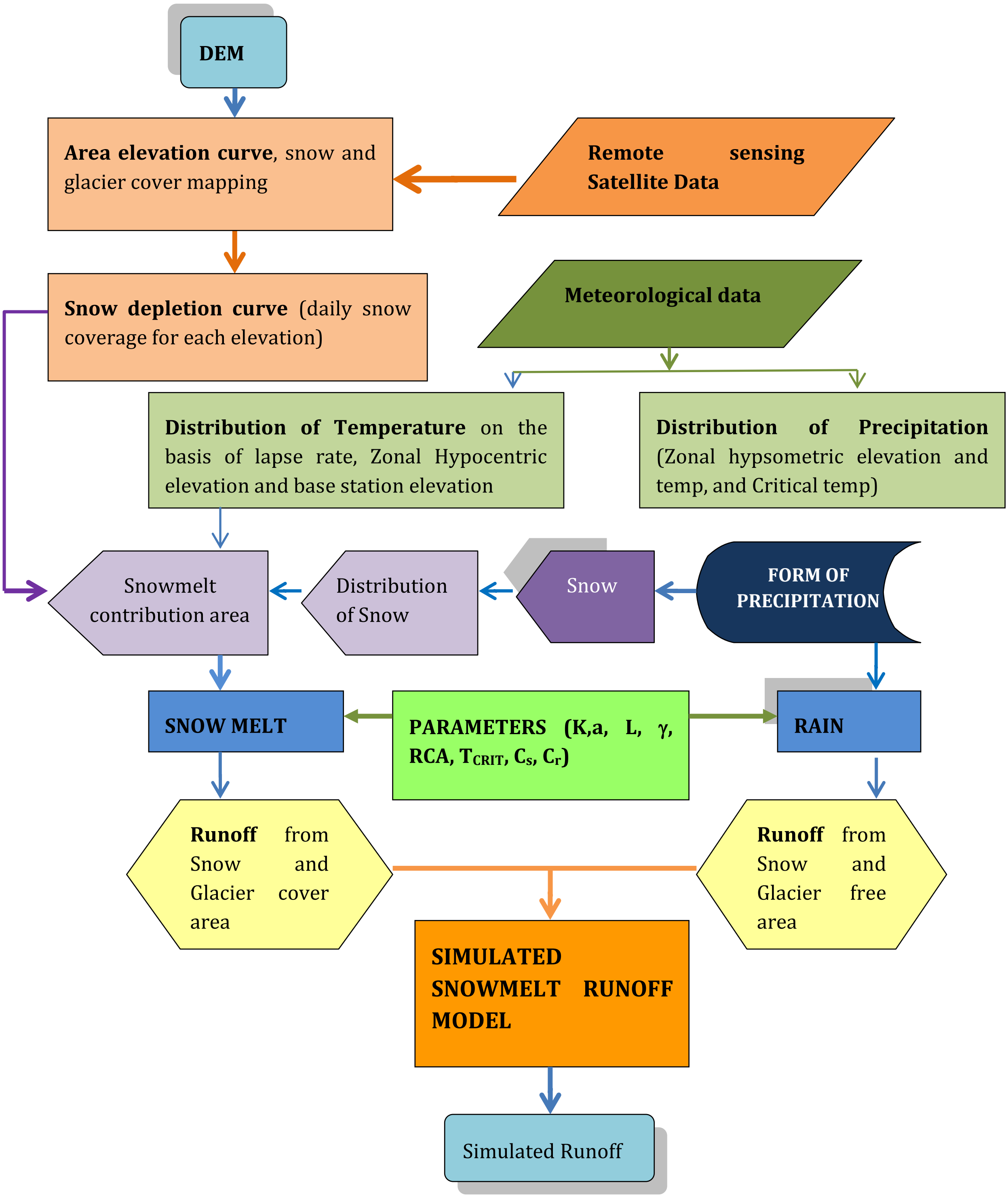



**Figure 3-2: Simulation of Snowmelt Runoff using SRM**

(Source: Modified from Shilpakar et al., 2009)

## 3.6 Hydrologic Simulation

Soil and Water Assessment Tool (SWAT) was used for rainfall- runoff modeling and sediment yield estimation in this study. Conceptually, SWAT divides a watershed into sub-watersheds. Each sub watershed is connected through a stream channel and further discretized into Hydrologic Response Unit (HRU). HRU is a unique combination of soil and vegetation type in a sub watershed, and SWAT simulates soil water content, surface runoffs, sediment yield, and management practices at the HRU level and aggregated by a weighted average. Runoff and Sediment loads are predicted separately for each HRU and routed to obtain the total runoff and sediment load for the watershed at the outlet. The data required for hydrological simulation using SWAT model are:

**A. Spatial Data**

i. Topographic Data: Digital Elevation Model
ii. Landuse Data
iii. Soil Map and associated properties

**B. Time Series Data**

i. Meteorological data: Daily precipitation, daily maximum and minimum temperature, daily relative humidity, and wind speed and sunshine hours.
ii. Hydrologic data
iii. Sediment Data

A brief description of these variables are provided in **Chapter 7.**

Following steps were used for flow and sediment yield simulation using the SWAT Model.

1 **Model Setup**:
   i. Watershed delineation and basin parameterization
   ii. Hydrologic Response Units (HRU) Overlay and Definition
   iii. Importing Climate Data
2 **Sensitivity analysis of the model parameters**
3 **Calibration and validation of the model**
4 **Application of the model**

Details of the processes followed are provided in **Chapter 7.** The simulation subroutine at the HRU/sub-basin level is shown as a flowchart in

**Figure** 3-3**.** Likewise the model calibration process is shown in **Figure 3-4.**

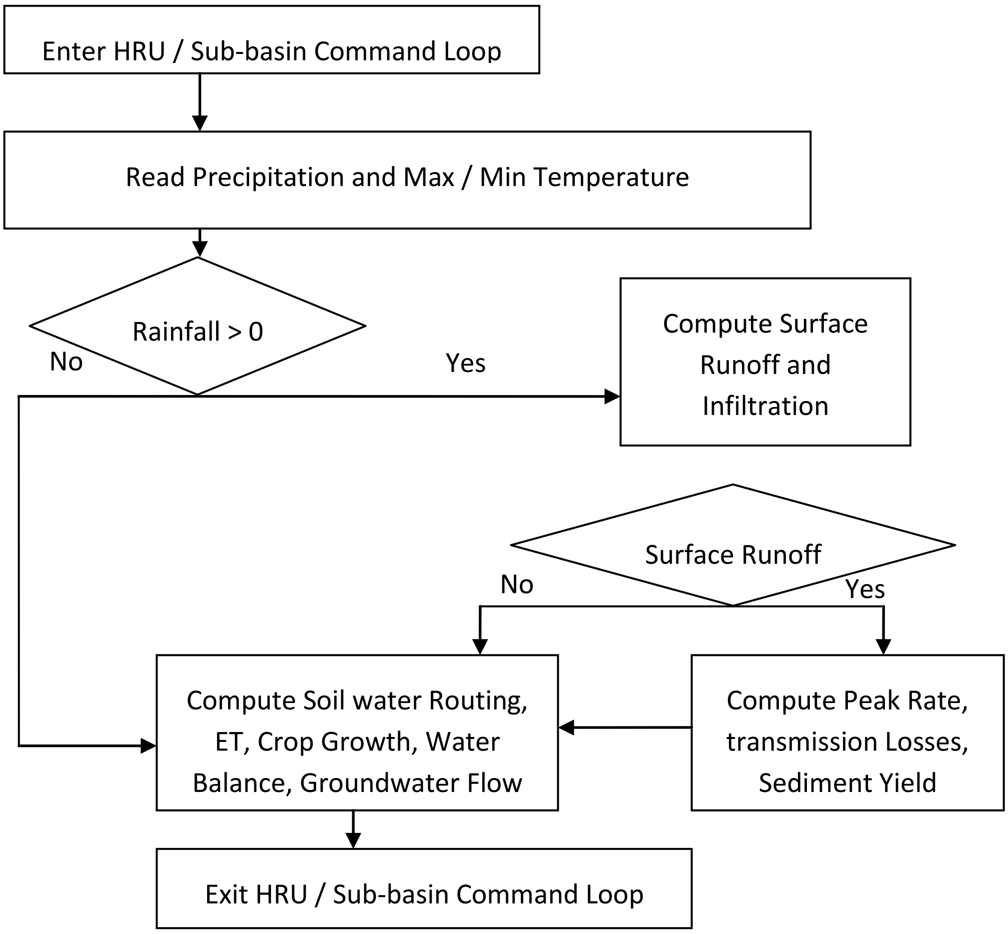



**Figure 3-3: HRU / Sub-Basin Command Loop**

(Source: Modified from SWAT, 2005)

### 3.6.1 Model Evaluation

The performance of SWAT was evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. Coefficient of determination ($R^2$) and Nash-Sutcliffe simulation efficiency (ENS) will be used for the goodness of fit measures used to evaluate model prediction. The $R^2$ value is an indicator of strength of relationship between the observed and simulated values. The Nash-Sutcliffe simulation efficiency (ENS) indicates how well the plot of observed versus simulated value fits the 1:1 line. The $R^2$ and ENS values are explained in Equations **(3-5)** and **(3-6)** respectively.

$$R^2 = \frac{\left(\sum_{i=1}^{n}(O_i - O_{av})(P_i - P_{av})\right)^2}{\sum_{i=1}^{n}(O_i - O_{av})^2 \sum_{i=1}^{n}(P_i - P_{av})^2} \quad \textbf{(3-5)}$$

$$E_{NS} = 1 - \left[ \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - O_{av})^2} \right] \quad \textbf{(3-6)}$$

Where n is the number of observations during the simulation period $O_i$ and $P_i$ are the observed and predicted values at each comparison point i, $O_{av}$ and $P_{av}$ are the arithmetic means of the observed and predicted values.

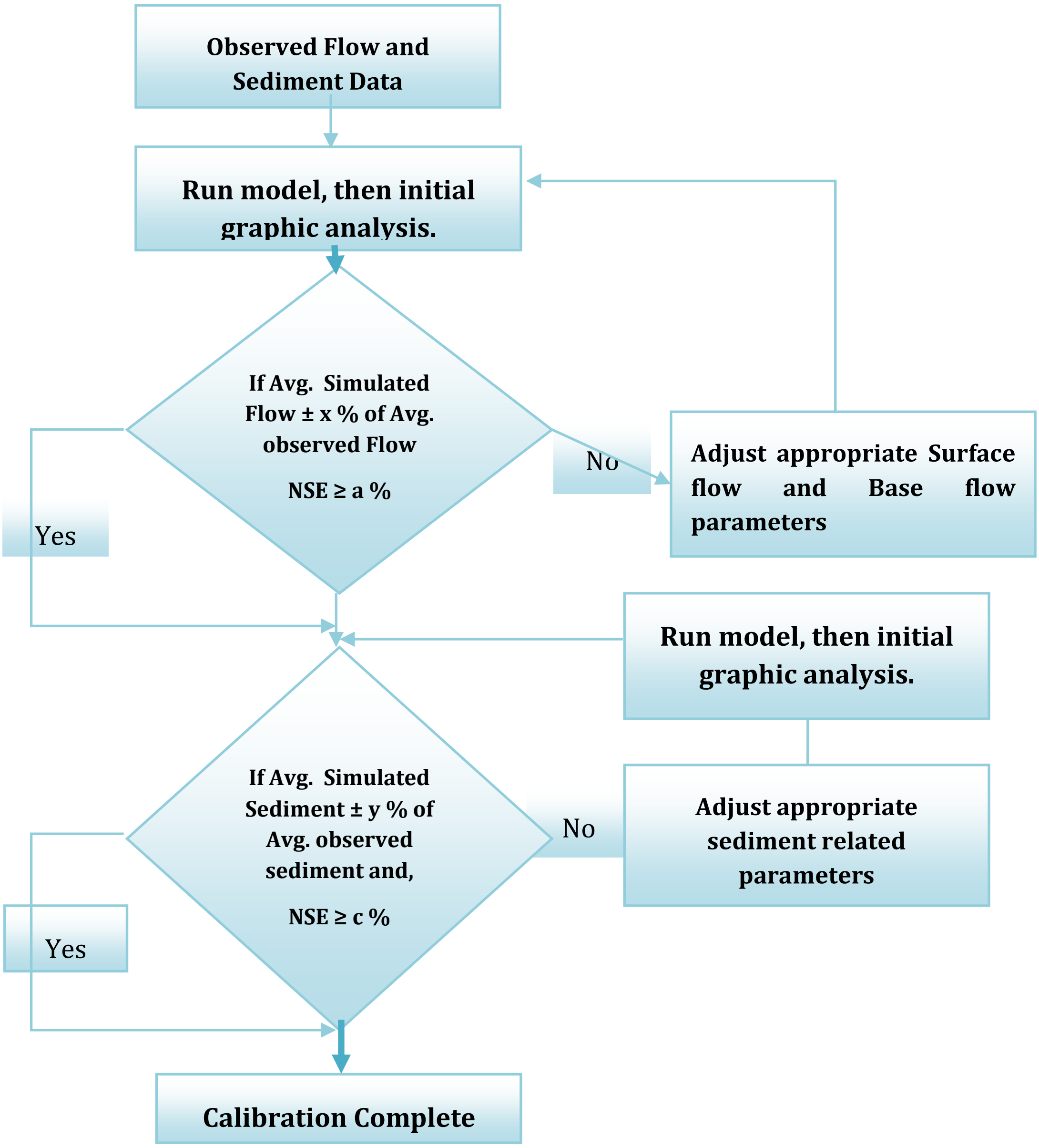



**Figure 3-4: Calibration Process**

(Source: Modified from SWAT, 2005)

## 3.7 Hydraulic Simulation

HEC-RAS model was employed for hydraulic modeling in the Koshi Basin. The Hydraulic simulation was carried out as shown in the flow chart given in

**Figure** 3-5. The simulation process consists of the following four main steps.

A. Pre-RAS Application

B. HEC-RAS Model Application

C. Post-RAS Application

D. Flood-prone Area Delineation

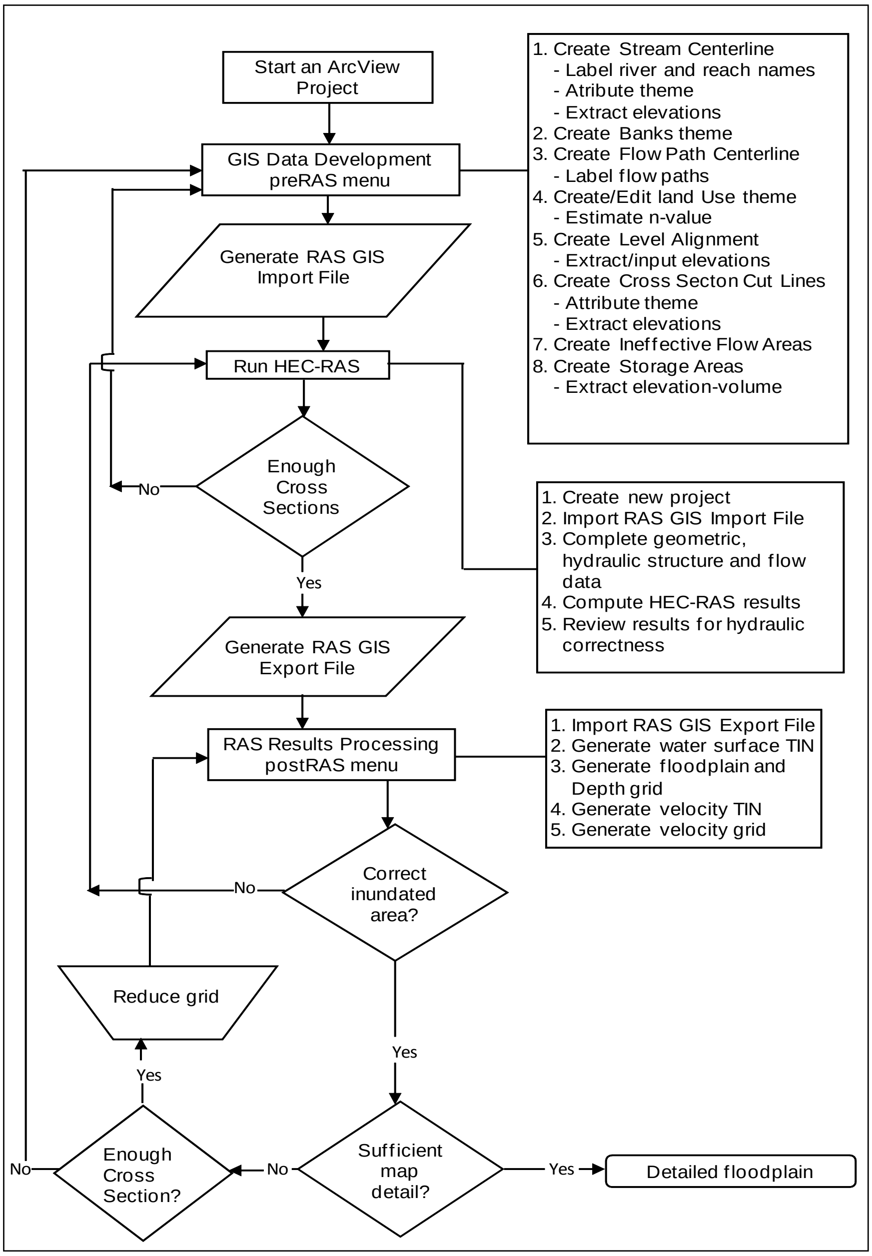



**Figure 3-5: Flow Chart for the Calculation of Flood Inundation**

(Source: HEC-RAS, 2010)

## 3.8 Socio-economic Vulnerability Assessment

Vulnerability assessment of the study area was carried out employing the following steps.

### 3.8.1 Selection of Indicators for Vulnerability Assessment

Even though there are numbers of indicators which need to be considered while assessing the vulnerability of any particular area, the main indicators taken into account for this study are: Demographic, Economic, Social, Degree of preparedness and Recovery capacity which are proposed by Eldsvig *et al.* (2011). Each indicator was weighted form 1 to 3. Furthermore, each indicator was taken as the composite manifestation of sub-indicators ranked from 1: Low vulnerability to 4: high vulnerability (Details of sub-indicators are given in **Table 3-3**).

**Table 3-3: Indicators for Socio-economic Vulnerability Assessment**

| Indicators | Weights (Range 1-3) | Criteria for Indicator Ranking (1: Low vulnerability and 4 high vulnerability) | Remarks |
|---|---|---|---|
| ***Demographic Indicators (weight: $w_1$, Value: $V_1$)*** | | | |
| **Age distribution** | 1 | Less than 20% population aged less than 10 years and above 65 years and disabled population<br>20-30% population aged less than 10 years and above 65 years and disabled population<br>30-50% population aged less than 10 years and above 65 years and disabled population<br>More than 50% population aged less than 10 years and above 65 years and disabled population | Note 1 |
| **House Type (based on construction materials of wall)** | 2 | Concrete/Cement<br>Burnt bricks<br>Un-burnt bricks & mud<br>Grass/ leaves/ reeds/ bamboo/ Wood/ branches | |
| ***Economic Indicators (weight: $w_2$, Value: $V_2$)*** | | | |
| **Income** | 3 | Greater than $ 2 per capita per day<br>Between $ 1-$2 per capita per day<br>Between $ 0.5-$1 per capita per day<br>Less than $ 0.5 per capita per day | |
| **Land holding** | 2 | Less than 20% population is dependent on agricultural land for primary source of income<br>20-40% population is dependent on agricultural land for primary source of income<br>40-60% population is dependent on | |

| Indicators | Weights (Range 1-3) | Criteria for Indicator Ranking (1: Low vulnerability and 4 high vulnerability) | Remarks |
|---|---|---|---|
| | | agricultural land for primary source of income<br>Above 60% population is dependent on agricultural land for primary source of income | |
| ***Social Indicators(weight: $w_3$, Value: $V_3$)*** | | | |
| **Education level** | 2 | More than 50% is literate<br>40%-50% population is literate<br>30%-40% population is literate<br>Less than 20% population literate | |
| **Access to communication** | 3 | Access to more than one unit of telephone/mobile<br>Access to at least one unit of telephone/mobile<br>Not access to telephone/mobile in own home<br>No telephone/mobile in the community | |
| **Mobility** | 1 | Access to private car<br>Access to motorbike<br>Access to cycle<br>None | |
| **Market facility** | 2 | Less than 1 km distance<br>Within 2 km distance<br>Within 2-4 km distance<br>More than 4 Km distance | Note: 2 |
| **Drinking water** | 3 | Access in own house<br>Access in neighbor's house<br>Available in community<br>None | |
| ***Preparedness Indicators(weight: $w_4$, Value: $V_4$)*** | | | |
| **Awareness of Hazard Evaluation Map** | 2 | Each and every HH member is aware<br>Some of the HH members are aware<br>Single HH member is aware<br>None of the HH member is aware | |
| **Emergency response** | 2 | Good transportation (road) and organized response group in place<br>Good transportation or organized response group in place | Note 3 |

| Indicators | Weights (Range 1-3) | Criteria for Indicator Ranking (1: Low vulnerability and 4 high vulnerability) | Remarks |
|---|---|---|---|
| | | Self-organized local group only<br>None | |
| **Early warning system** | 3 | Advanced (24 hrs Radio, TV, Automatic siren, 1 day ahead)<br>Average (24 hrs Radio, TV, Manual Siren, same day)<br>Basic (Telephone, Mike)<br>None | |
| **Evacuation place** | 2 | Less than 1 km distance<br>1-2 km distance<br>Greater than 2 km distance<br>None | Note: 2 |
| **Insurance ( life/property/any kind of insurance)** | 1 | Life and all Property<br>Life of > 50% family members<br>Life of < 50% family members<br>None | |
| **First aid services** | 1 | Adequate and in own home<br>Adequate and in community level<br>Limited<br>None | |
| ***Recovery Indicators (weight: $w_5$, Value: $V_5$)*** | | | |
| **Health institution** | 2 | Less than 1 km distance.<br>1-2 km distance<br>2-4 km distance.<br>More than 4 Km distance. | Note: 2 |
| **Disaster fund** | 2 | Both local level and government<br>Government only<br>Local only<br>None | |

**Note 1:** Considering population aged less than 10 years or over 65 years or all aged disabled population are most vulnerable.
**Note 2:** 1 km distance is equivalent to approximately 15 minutes walk.
**Note 3:** Organized refers to having well coordination between the rescue group and the community. Similarly, self-organized refers to having no formal rescue group but community acts on their own in the time of disaster i.e. flood.

Source: Modified from Eldsvig *et al.* (2011)

### 3.8.2 Survey Site Selection and Sample Size Distribution

The inundation depth for 100 year return period flood under the absence of existing embankments was considered for survey site selection. Multistage sampling technique was used to select sampled sites. Sunsari and Saptari districts were purposively selected based on the

NAPA Report, 2010 as high flood risk districts. Sample areas within the two districts were selected based on the inundation pattern under the flood in three distinct categories as follows;

a) Less affected (< 0.5 m inundation depth)
b) Moderately affected (0.5 m to 1.0 m inundation depth)
c) Highly affected ( > 1.0 m inundation depth)

Following steps were followed for selection of wards (smallest administrative unit) and sample size distribution;

a) Listed out all the VDCs of both the districts considering the above mentioned categories i.e. inundation depth.
b) Only wards equal and above 50 % area affected (in all three categories) were considered. (Total wards sort listed = 70) (
c) **Table** 3-4)
d) Proportionate sampling technique is applied to distribute sample for all three categories within two districts considering 30 samples must fall per ward and must fall at least one VDC in each district.
e) Total number of VDC and ward selected=13 (10 from Sunsari and 3 from Saptari) (**Table 3-5**)
f) Households were selected randomly.

Selected VDCs are shown in **Figure 3-6**.

**Table 3-4: Number of ward selected and sample size distribution**

| Categories | Less affected wards | Moderately affected wards | Highly affected wards | Total |
|---|---|---|---|---|
| **Sunsari** | 7 | 9 | 39 | **55** |
| **Saptari** | 2 | 8 | 5 | **15** |
| Total | **9** | **17** | **44** | **70** |
| **% of total** | 13 | 24 | 63 | **100** |
| **No. of Sample** | 49 | 93 | 241 | **384** |
| Nearest sample (30/ward) | **60** | **90** | **240** | **390** |
| Total no. of wards selected | **2** | **3** | **8** | **13** |
| **Sunsari (ward selected)** | 1 | 2 | 7 | **10** |
| **Saptari (ward selected)** | 1 | 1 | 1 | **3** |

**Table 3-5: Selected VDCs and wards**

| Categories | VDCs of Sunsari | Ward No. | Sample HH | VDCs of Saptari | Ward No. | Sample HH |
|---|---|---|---|---|---|---|
| **Less affected** | Laukahi | 8 | 30 | Bairawa | 5 | 30 |
| **Moderately affected** | Dumraha | 2 | 30 | Inarwa | 9 | 30 |
| | PaschimKusaha | 3 | 30 | | | |
| **Highly affected** | Ghuskee | 9 | 30 | Bhardaha | 9 | 30 |
| | Harinagara | 5 | 30 | | | |
| | Madhuvan | 2 | 30 | | | |
| | Mahendranagar | 3 | 30 | | | |
| | Narshimha | 4 | 30 | | | |
| | PaschimKusaha | 1 | 30 | | | |
| | RamnagarBhutaha | 8 | 30 | | | |

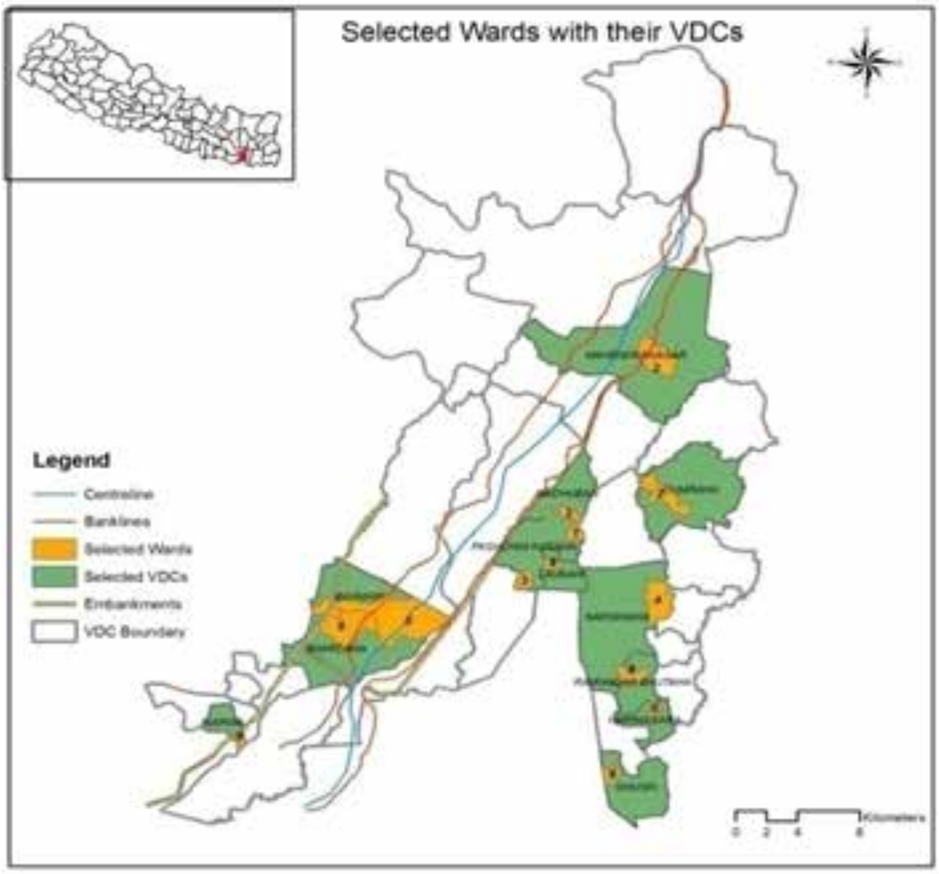



**Figure 3-6 : Map of the selected VDCs from the two districts**

### 3.8.3 Conduction of Socio-economic survey

To assess socio-economic vulnerability a detail socio-economic survey was conducted in two highly flood prone districts in the Koshi river basin. In order to conduct survey following three survey tools were employed to obtain primary information/data required for vulnerability assessment:

**A. Household survey**

Household survey was conducted from June 7 to June 18, 2012. A semi-structured questionnaire was prepared for household survey in such a way that necessary information required to assess socio-economic vulnerability can be captured. Household survey was conducted in two sampled districts, which were selected purposively. The total of 384 household was determined with 95% confidence level and 5% error (degree of accuracy) in the districts by using Equation (**3-7**)

$$\boldsymbol{Size} = \frac{X^2NP(1-P)}{d^2(N-1)+X^2P(1-P)} \quad \textbf{(3-7)}$$

$X^2$ = table value of Chi-Square @ d. f. = 1 for desired confidence level 0.1 = 2.71, .05 = 3.84, .01 = 6.64, .001 = 10.83

N = population size

P = population proportion (assumed to be .50)

d = degree of accuracy (expressed as a proportion)

**B. Focus Group Discussion (FGD)**

A total of three FGDs were conducted in two districts considering one FGD in each highly affected area, moderately affected area and less affected area. Primarily, FGD was conducted in flood prone area to incorporate gender-wise perception regarding the impact of flood. FGD was also focused to determine household accessibility to available resources during the flood and natural disaster.

**C. Key Informant Interview (KII)**

Some knowledgeable local dwellers, such as VDC secretary, school teacher, village headperson, old people and so on were selected for KII. KII was determined during the household survey. This technique was used to collect the historical information about the flood, its impacts, and shifting of river. This helps us to carry out a flood hazard analysis through local perception.

### 3.8.4 Vulnerability Index Estimation Method and Vulnerability Map

Vulnerability Index was estimated as a weighted average of above mentioned indicators. It is noted here that Vulnerability Index was estimated semi-quantitatively, with additive aggregation of the indicators similar to proposed by Eidsvig (2011). Proposed weightage for each variable are also given in **Table 3-3**. Equation (**3.8**) was used to estimate the level of vulnerability corresponding to a given indicator while Vulnerability Index (V) was estimated using Equation (**3.9**).

$$v_1 = \frac{w^1v^1+w^2v^2+w^3v^3+w^4v^4}{w^1+w^2+w^3+w^4} \quad (3\text{-}8) \qquad V = \frac{w_1v_1+w_2v_2+w_3v_3+w_4v_4+w_5v_5}{w_1+w_2+w_3+w_4+w_5} \quad (3\text{-}9)$$

Here w= weight and v= value (Refer **Table 3-3** for symbols)

# Chapter 4: Hydro-Meteorological Diagnostics

Trend and statistical analysis of historical data on climatological and hydrological variables were done in this study. Trend analyses of precipitation and temperature with respect to altitude and time were done whereas trend of the flow at Chatara with respect to time was carried out to see if there existed any long term trends in these variables. Key statistics of these key variables were evaluated to establish the base line data. Analysis of snow cover data was made to see if there is any change in snow cover seasonally or annually. Results of these analysis are presented in this chapter.

## 4.1 Trends with Elevation

### 4.1.1 Precipitation Trends

Koshi Basin receives a seasonally confined precipitation with almost 80% rain falling during the monsoon season spanning a period of four months viz. June, July, August and September. Rest of the year, very little rainfall is observed in the basin. Apart from the temporal variation, a very high spatial variation in annual precipitation exists in the basin, with Station 1301 (Num) getting the highest annual average precipitation of 4450mm and the lowest being 882.5 mm at Nepalthok (Stn 1115) at an altitude of 1098m (**Figure 4-1: Isohyetal map of the Koshi river basin**

Table 4-1). **Figure 4-1** shows the isohyetal map of the Koshi River Basin**.**

To analyze the precipitation trends with elevation, 42 precipitation stations from all over the basin were selected and used to compare the annual precipitation values (1976-2008) with station elevation.

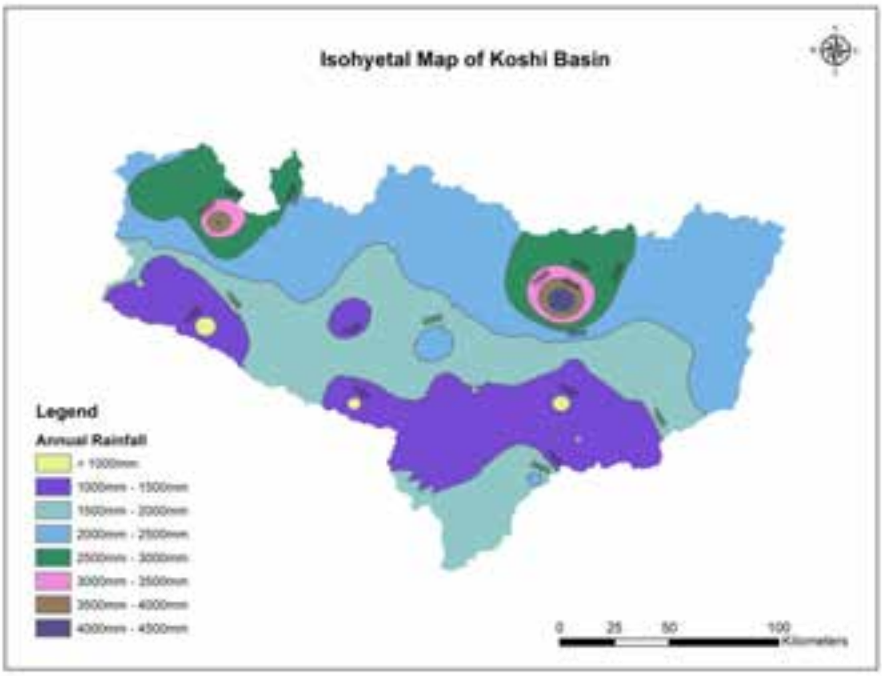
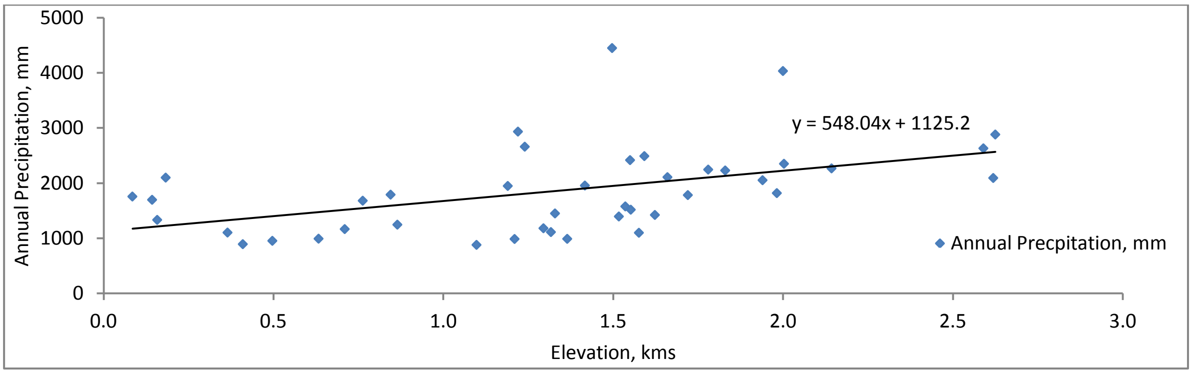



**Figure 4-1: Isohyetal map of the Koshi river basin**

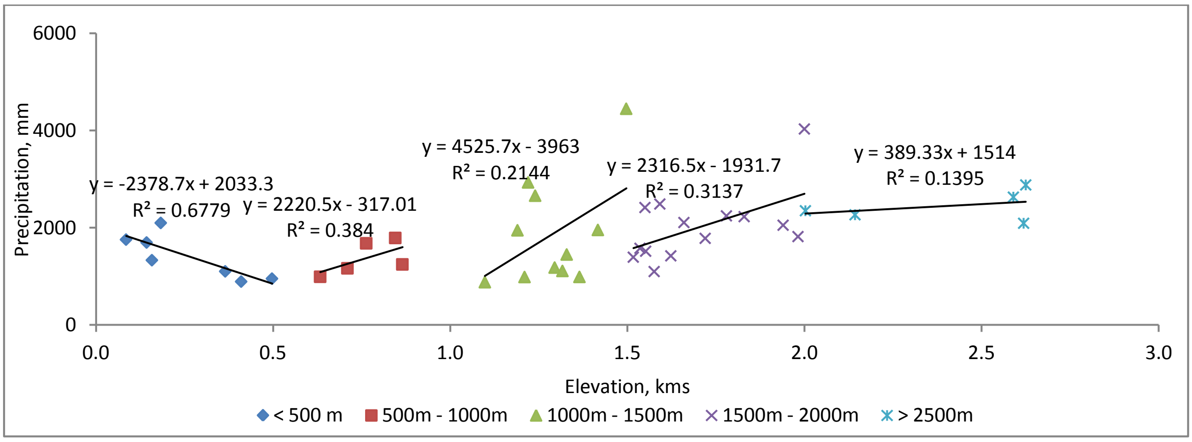
**Table 4-1: Precipitation Stations selected for the study**

| ID | NAME | LOCATION | LAT | LONG | ELEVATION | Elevation, km | Annual Precipitation, mm |
|---|---|---|---|---|---|---|---|
| **1** | 1115 | Nepalthok | 27.45 | 85.82 | 1098 | 1.098 | 882.5 |
| **2** | 1305 | Leguwa Ghat | 27.13 | 87.28 | 410 | 0.41 | 895.3 |
| **3** | 1210 | Kurule Ghat | 27.13 | 86.43 | 497 | 0.497 | 956.0 |
| **4** | 1307 | Dhankuta | 26.98 | 87.35 | 1210 | 1.21 | 989.4 |
| **5** | 1020 | Mandan | 27.7 | 85.65 | 1365 | 1.365 | 991.5 |
| **6** | 1028 | Pachuwar Ghat | 27.57 | 85.75 | 633 | 0.633 | 994.5 |
| **7** | 1207 | Mane Bhanjyang | 27.48 | 86.42 | 1576 | 1.576 | 1102.1 |
| **8** | 1308 | Mulghat | 26.93 | 87.33 | 365 | 0.365 | 1105.6 |
| **9** | 1306 | Munga | 27.03 | 87.23 | 1317 | 1.317 | 1114.3 |
| **10** | 1023 | Dolal Ghat | 27.63 | 85.72 | 710 | 0.71 | 1168.9 |
| **11** | 1211 | Khotang | 27.03 | 86.83 | 1295 | 1.295 | 1183.7 |
| **12** | 1036 | Panchkhal | 27.68 | 85.63 | 865 | 0.865 | 1248.8 |
| **13** | 1322 | Machuwaghat | 26.97 | 87.17 | 158 | 0.158 | 1335.8 |
| **14** | 1049 | Khopasi | 27.58 | 85.52 | 1517 | 1.517 | 1397.6 |
| **15** | 1222 | Diktel | 27.22 | 86.8 | 1623 | 1.623 | 1425.1 |
| **16** | 1303 | Chainpur | 27.28 | 87.33 | 1329 | 1.329 | 1452.6 |
| **17** | 1024 | Dhulikhel | 27.62 | 85.55 | 1552 | 1.552 | 1520.4 |
| **18** | 1104 | Melung | 27.52 | 86.05 | 1536 | 1.536 | 1579.8 |
| **19** | 1420 | Dovan | 27.35 | 87.6 | 763 | 0.763 | 1683.3 |
| **20** | 1309 | Tribeni | 26.93 | 87.15 | 143 | 0.143 | 1699.5 |
| **21** | 1226 | Barmajhayia | 26.6 | 86.9 | 85 | 0.085 | 1759.3 |
| **22** | 1206 | Okhaldhunga | 27.32 | 86.5 | 1720 | 1.72 | 1785.2 |
| **23** | 1018 | Baunepati | 27.78 | 85.57 | 845 | 0.845 | 1793.0 |
| **24** | 1203 | Pakarnas | 27.43 | 86.57 | 1982 | 1.982 | 1821.2 |
| **25** | 1325 | Dingla | 27.37 | 87.15 | 1190 | 1.19 | 1950.5 |
| **26** | 1108 | Bahun Tiplung | 27.18 | 86.17 | 1417 | 1.417 | 1957.8 |
| **27** | 1102 | Charikot | 27.67 | 86.05 | 1940 | 1.94 | 2055.0 |
| **28** | 1202 | Chaurikharka | 27.7 | 86.72 | 2619 | 2.619 | 2095.3 |
| **29** | 1316 | Chatara | 26.82 | 87.17 | 183 | 0.183 | 2102.2 |
| **30** | 1009 | Chautara | 27.78 | 85.72 | 1660 | 1.66 | 2110.5 |
| **31** | 1406 | Memeng Jagat | 27.2 | 87.93 | 1830 | 1.83 | 2231.4 |
| **32** | 1403 | Lungthung | 27.55 | 87.78 | 1780 | 1.78 | 2247.8 |
| **33** | 1204 | Aiselukharka | 27.35 | 86.75 | 2143 | 2.143 | 2269.4 |
| **34** | 1103 | Jiri | 27.63 | 86.23 | 2003 | 2.003 | 2353.1 |
| **35** | 1017 | Dubachaur | 27.87 | 85.57 | 1550 | 1.55 | 2419.4 |
| **36** | 1008 | Nawalpur | 27.8 | 85.62 | 1592 | 1.592 | 2491.9 |
| **37** | 1317 | Chepuwa | 27.77 | 87.42 | 2590 | 2.59 | 2632.9 |
| **38** | 1025 | Dhap | 27.92 | 85.63 | 1240 | 1.24 | 2662.5 |
| **39** | 1016 | Sarmathang | 27.95 | 85.6 | 2625 | 2.625 | 2883.7 |
| **40** | 1027 | Bahrabise | 27.78 | 85.9 | 1220 | 1.22 | 2936.4 |
| **41** | 1006 | Gumthang | 27.87 | 85.87 | 2000 | 2 | 4035.1 |
| **42** | 1301 | Num | 27.55 | 87.28 | 1497 | 1.497 | 4451.1 |

Annual Precipitation plotted against elevation is shown in **Figure 4-2**(a). Since rainfall data is not available for stations with elevation higher than 3000m, the analysis is limited to a maximum elevation of 2883.7m. However, it is clear from the figure that there is an overall increasing trend in annual precipitation throughout the basin along with increase in elevation.




**a. Annual Precipitation Trend with Elevation**




**b. Trends Annual Precipitation for various elevation ranges**

**Figure 4-2: Trends Annual Precipitation for various elevation ranges**

Similarly, **Figure 4-2** (b) shows the annual precipitation trends within various elevation ranges. The figure suggests a decreasing trend for elevation below 500m. However the trend then follows increasing pattern with the increase in elevation for zones above 500m.

### 4.1.2 Temperature Trends

Annual average maximum, minimum and mean temperature from 15 climatological stations (refer **Table 4-2**) were plotted against their respective elevations. All the stations unanimously depict decreasing trends of -6.3°C /km, -5 °C /km and -4.6 °C /km for maximum, minimum and mean temperatures. **Figure 4-3** shows the temperature trends against elevation. Overall decrease in temperature with increase in elevation is observed in the basin.

**Table 4-2: Temperature Stations Selected for the Study**

| Stations | Latitude | Longitude | Elevation | Elevation, kms | Annual Avg. Max. Temp (°C) | Annual Avg. Min Temp. (°C) | Annual Avg. Mean Temp. (°C) |
|---|---|---|---|---|---|---|---|
| **1223** | 26.55 | 86.75 | 91 | 0.091 | 31.24 | 19.08 | 25.19 |
| **1212** | 26.73 | 86.93 | 100 | 0.1 | 31.47 | 18.71 | 19.72 |
| **1311** | 26.82 | 87.28 | 444 | 0.444 | 29.70 | 18.87 | 24.29 |
| **1323** | 26.82 | 87.28 | 444 | 0.444 | 28.23 | 20.20 | 24.22 |
| **1036** | 27.68 | 85.63 | 865 | 0.865 | 28.16 | 14.46 | 21.32 |
| **1419** | 27.15 | 87.75 | 1205 | 1.205 | 26.12 | 15.83 | 21.09 |
| **1307** | 26.98 | 87.35 | 1210 | 1.21 | 23.69 | 14.78 | 19.24 |
| **1303** | 27.28 | 87.33 | 1329 | 1.329 | 24.70 | 13.96 | 19.33 |
| **1024** | 27.62 | 85.55 | 1552 | 1.552 | 22.19 | 11.80 | 17.02 |
| **1324** | 27.18 | 87.05 | 1595 | 1.595 | 20.39 | 12.57 | 16.40 |
| **1314** | 27.13 | 87.55 | 1633 | 1.633 | 22.87 | 12.92 | 17.96 |
| **1304** | 27.05 | 87.28 | 1680 | 1.68 | 20.76 | 12.28 | 16.52 |
| **1206** | 27.32 | 86.5 | 1720 | 1.72 | 21.18 | 12.83 | 17.01 |
| **1405** | 27.35 | 87.67 | 1732 | 1.732 | 20.34 | 11.82 | 16.07 |
| **1103** | 27.63 | 86.23 | 2003 | 2.003 | 20.28 | 8.42 | 14.35 |

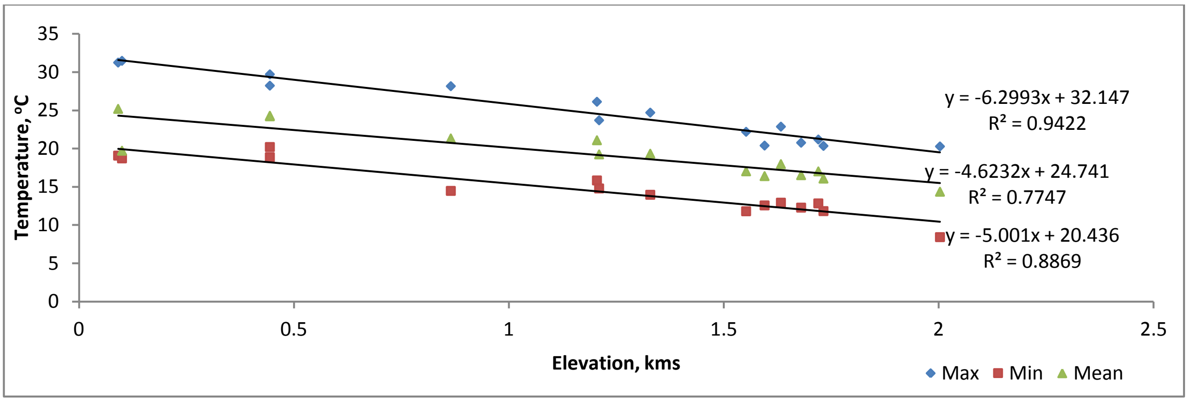



**Figure 4-3: Temperature trends with elevation**

## 4.2 Temporal Trends

### 4.2.1 Precipitation

Seven precipitation stations were selected from Tamor, Arun, DudhKoshi, TamaKoshi and Sunkoshi-Bhotekoshi subbasins to cover the temporal and spatial heterogeneity of the entire Koshi basin. Locations of the selected stations are shown below in **Figure 4-4** and **Table 4-3.**

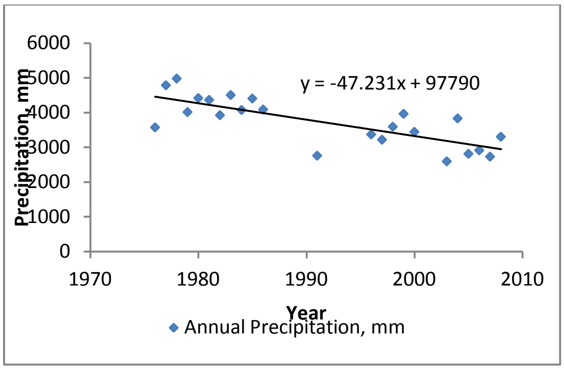
**Figure 4-4: Selected Precipitation Stations in The Koshi Basin**

**Table 4-3: Precipitation Stations Selected for the meteorological analysis**

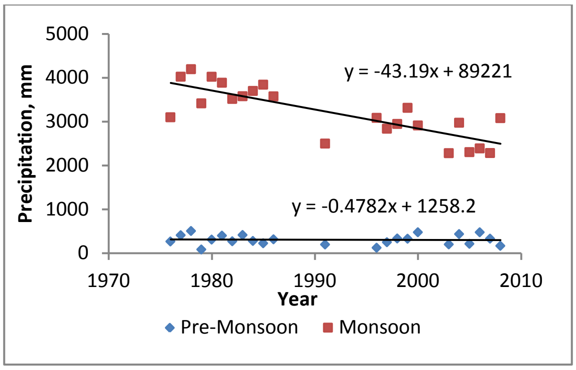
| Station | Location | Lat | Long | Elevation, m | Average Annual Precipitation, mm | Monsoon Contribution% | Avg. No. of Consecutive dry days | Avg. % of Rainy days |
|---|---|---|---|---|---|---|---|---|
| **1016** | Sarmathang | 27.95 | 85.6 | 2625 | 3729 | 86 | 59 | 43 |
| **1115** | Nepalthok | 27.45 | 85.82 | 1098 | 884 | 76 | 63 | 40 |
| **1102** | Charikot | 27.67 | 86.05 | 1940 | 2072 | 81 | 101 | 19 |
| **1202** | Chaurikhark | 27.7 | 86.72 | 2619 | 2086 | 84 | 55 | 42 |
| **1317** | Chepuwa | 27.77 | 87.42 | 2590 | 2657 | 66 | 35 | 53 |
| **1307** | Dhankuta | 26.98 | 87.35 | 1210 | 988 | 72 | 66 | 29 |
| **1403** | Lungthung | 27.55 | 87.78 | 1780 | 2248 | 77 | 46 | 50 |

### *A. Station 1016*

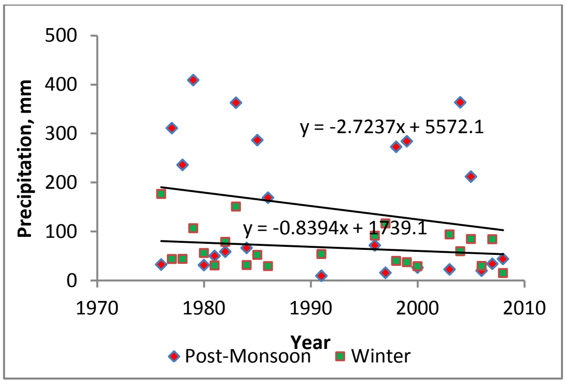
Located in the mountainous region of Eastern Nepal at an altitude of 2625m, the Sarmathang station (Stn1016) receives an annual rainfall of about 3730mm. The station lies in the Sunkoshi-Bhotekoshi subbasin. Annual as well as seasonal precipitation trends for the station are shown in **Figure 4-5**(a,b,c,d).



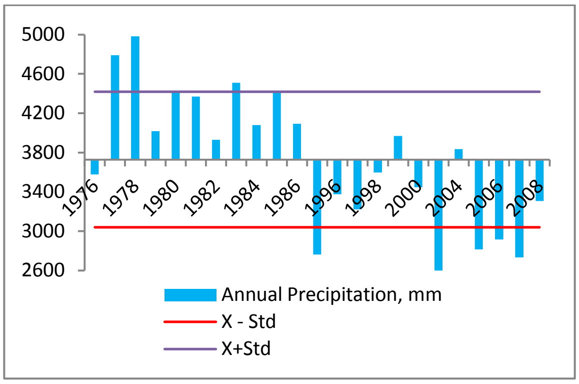

**a: Annual Precipitation Trend**



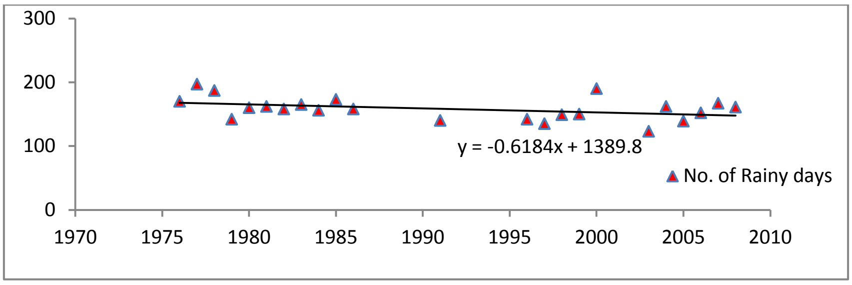

**b: Monsoon and Pre-monsoon Precipitation Trend**




**c: Post Monsoon & Winter Precipitation Trend**




**d: Annual Precipitation Anomalies**



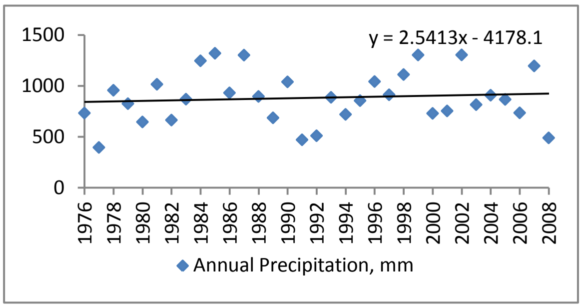

**e: No. of Rainy DaysTrend**

**Figure 4-5: Precipitation trend for station 1016**

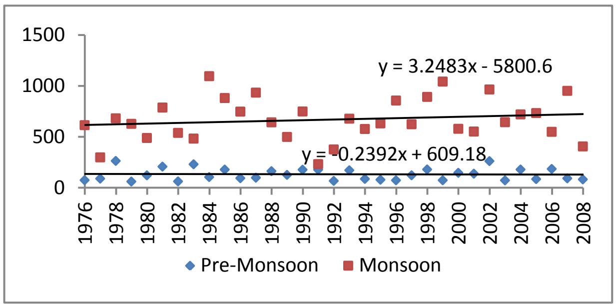
From the figures, it is apparent that annual as well as monsoon, pre-monsoon, post-monsoon and winter precipitation trends are in a declining pattern. Apart from few anomaly years such as 1977 and 1978, the annual rainfall is decreasing. This decline is distinctly clear in 1991, 2003, and 2005-2008. Years 1977 and 1978 respectively have 216 and 187 rainy days with seven events higher than 100mm in 1978, which easily exceeds the average number of rainy days of 163. However during 2003-2008, the average number of rainy days is limited to 150 days with the least number being in 2003 with 124 days. **Figure 4-5 (e)** shows that the number of rainy days is also in a declining trend.

### *B. Station 1115*

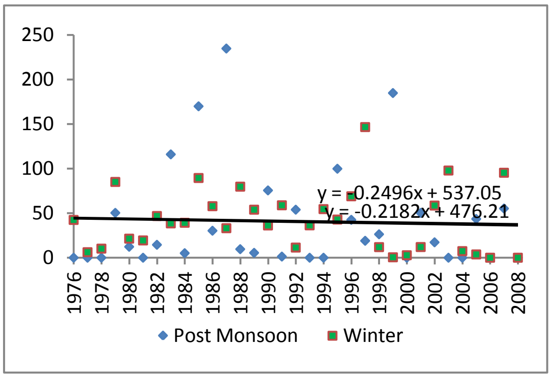
Station 1115 (Nepalthok) is located at an elevation of 1098m amidst the eastern hills of Nepal. Average annual precipitation at this station is about 884mm whereas the monsoon solely contributes 670mm of rainfall. From **Figure 4-6 (a,b,c and d)**, it is clear that the annual and monsoon precipitation follow an increasing trend whereas the pre-, post-monsoon and winter precipitation is on a slightly decreasing trend.



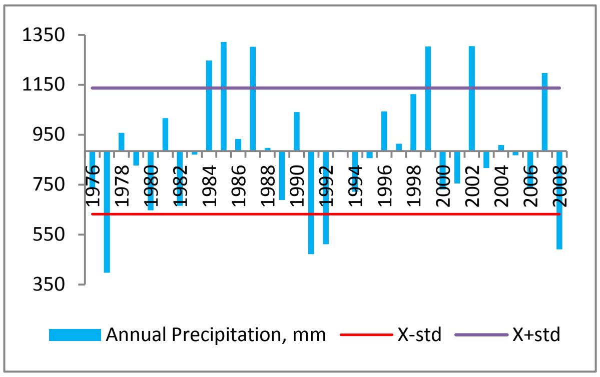

**a: Annual Precipitation Trend**



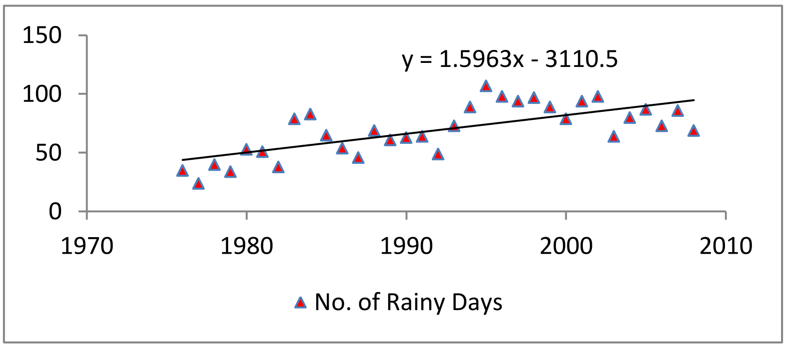

**b: Monsoon & Pre-monsoon Precipitation Trend**




**c: Post Monsoon & Winter Precipitation Trend**




**d: Annual Precipitation Anomalies**



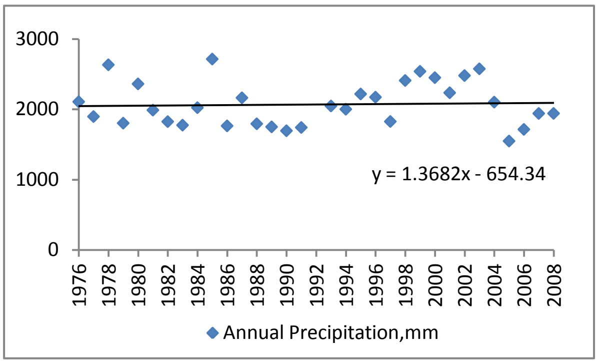

**e: No. of Rainy DaysTrend**

**Figure 4-6: Precipitation trend for station 1115**

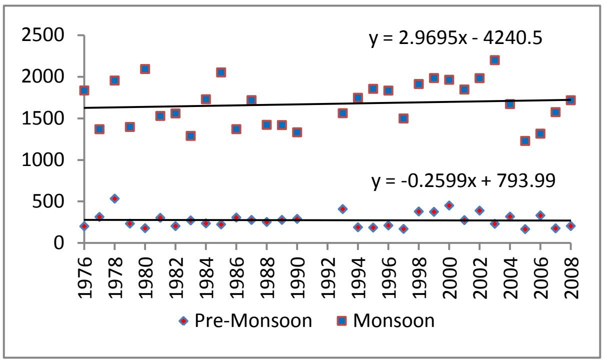
The anomaly graph shows that annual rainfall during 1983, 1984, 1985, 1999, 2002 and 2007 are found to be higher than average whereas the annual precipitation decreases to as low as 397 mm in 1977 with 341 dry days in the year. This station receives the lowest amount of rainfall in the basin. The no. of rainy days per annum is increasing for this station as shown by **Figure 4-6(e)**.

### *C. Station 1102*

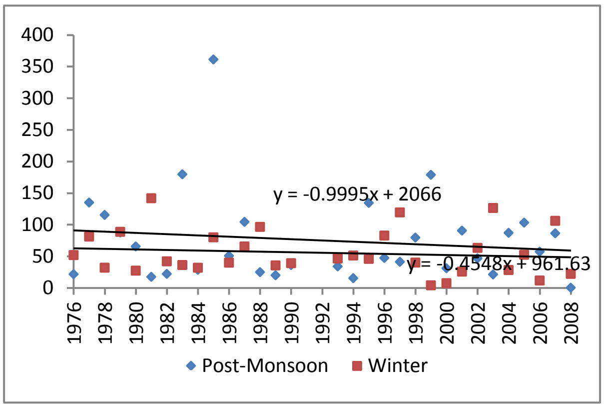
Station 1102 in Charikot, Dolakha lies along the hills of the Tamakoshi Basin at an altitude of 1940 m. Average annual precipitation amounts to about 2070mm and monsoon precipitation reaches to an average of 1670mm. Various precipitation trends are shown below in **Figure 4-7 (a,b,c,d and e)**. The figures exhibit increasing trend in monsoon precipitation with a subsequent increase in the annual rainfall trend. However, the pre-monsoon, post-monsoon and winter precipitation follow a slight decreasing trend.



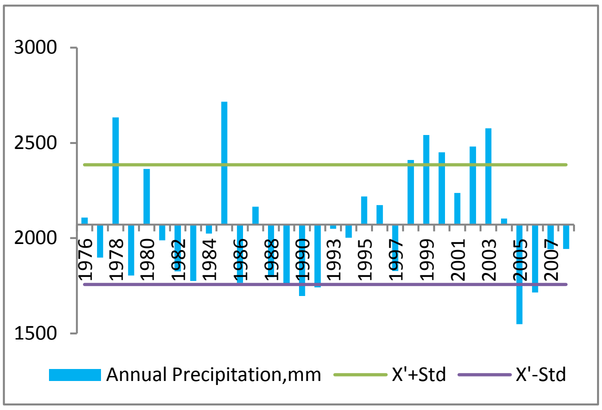

**a: Annual Precipitation Trend**



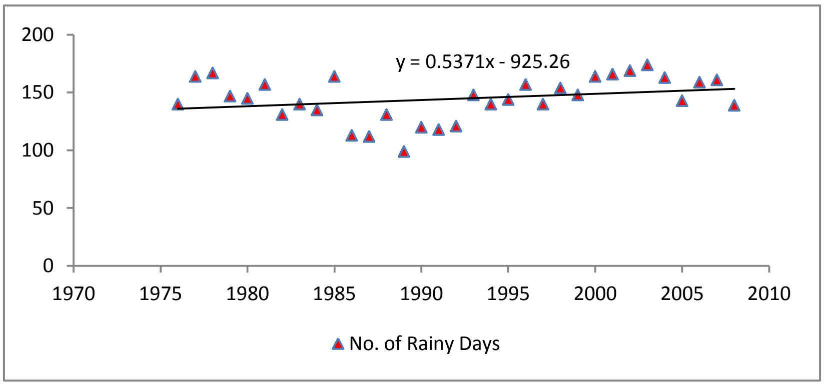

**b: Monsoon & Pre-monsoon Precipitation Trend**




**c: Post Monsoon & Winter Precipitation Trend**




**d: Annual Precipitation Anomalies**



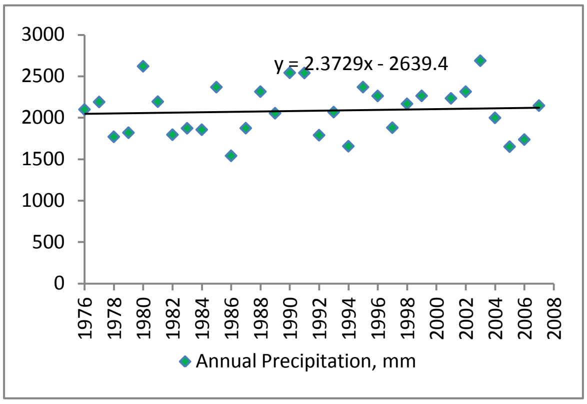

**e: No. of Rainy DaysTrend**

**Figure 4-7: Precipitation trend for station 1102**

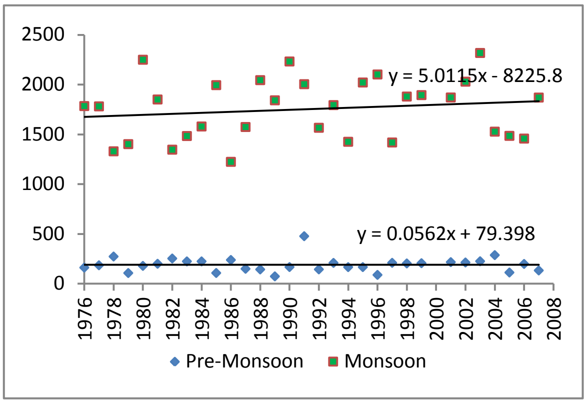
Years 1978, 1985, 1998, 1999, 2000, 2002 and 2003 show the highest amounts of rainfall recorded with a total number of rainy days of 175, 164, 172, 157, 177, 182 and 187 respectively. Likewise, 1990 and 2005 have experienced the least amount of precipitation with a total number of dry days of 216 days. The average trend of rainy days is increasing for this station.

***D. Station 1202:***

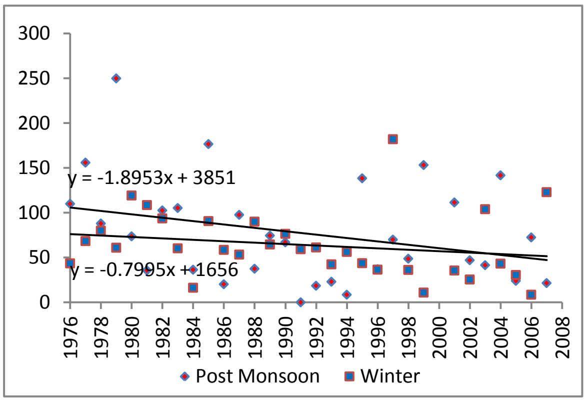
Chaurikharka Station lies centrally in the middle mountain zone of the Koshi Basin at an elevation of 2619m. This station receives an annual rainfall of about 2085 mm and a monsoon rainfall of about 1750mm. **Figure 4-8** (a,b,c, and d) below suggest the increasing annual, monsoon and pre-monsoon trends whereas the winter and post monsoon precipitation is decreasing. **Figure 4-8** (e) shows decreasing trend in the number of rainy days.



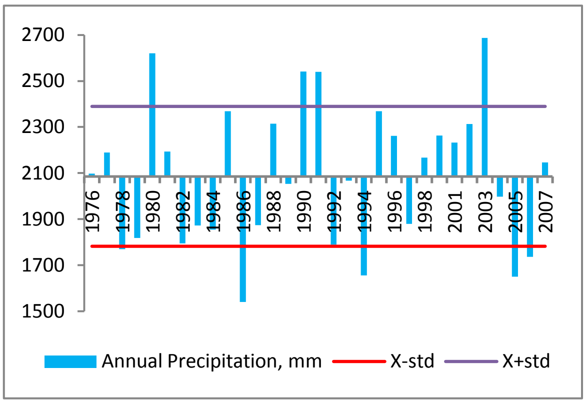

**a: Annual Precipitation Trend**



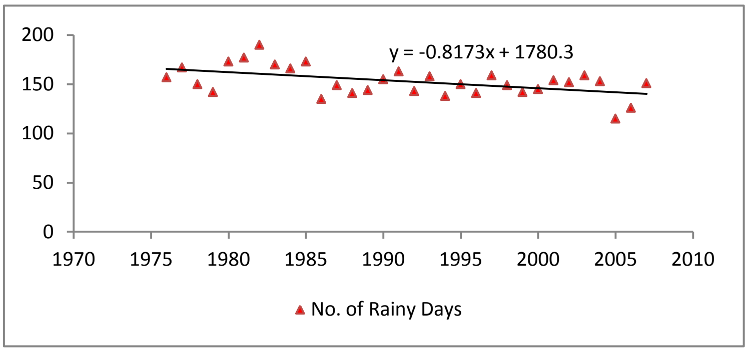

**b: Monsoon & Pre-monsoon Precipitation Trend**




**c: Post Monsoon & Winter Precipitation Trend**




**d: Annual Precipitation Anomalies**



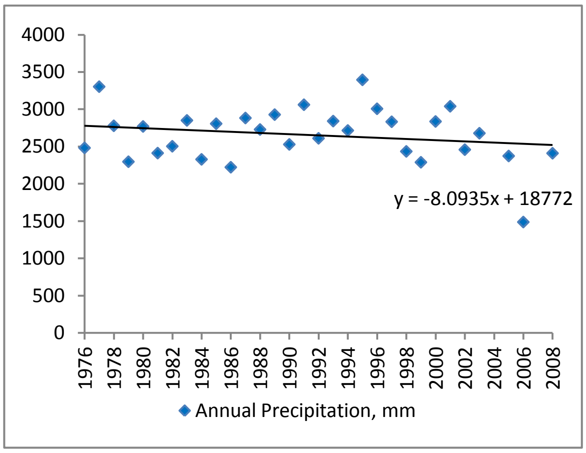

**e: No. of Rainy DaysTrend**

**Figure 4-8: Precipitation trends for station 1202**

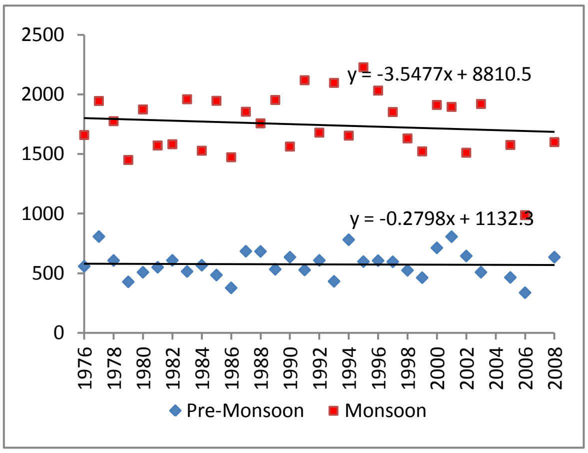
Similarly, the number of rainy days is declining. Years 1980, 1990, 1991 and 2003 show a high annual precipitation values with 173, 156, 163 and 159 numbers of rainy days the average number of rainy days being 155. Similarly 1986, 1994 ,2005 and 2006 are observed to be drier than average years with 230, 227, 250 and 239 dry days.

### *E. Station 1317*

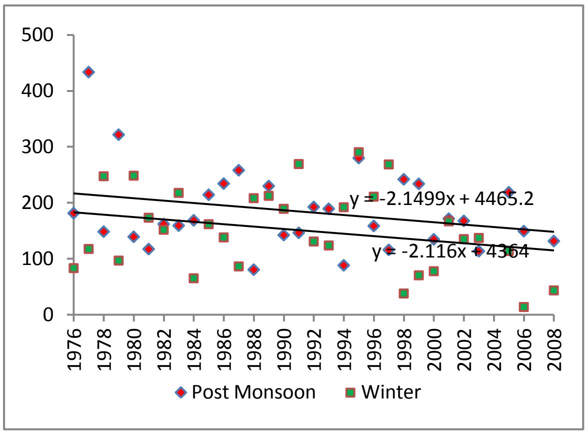
This station is located at Chepuwa in the mountainous region of the Arun Subbasin at an elevation of 2590m. Average annual precipitation observed is about 2630mm with monsoon rainfall contributing about 1750mm. Decreasing trends have been observed in annual as well as seasonal precipitation at this station, shown in the **Figure 4-9 (a,b,c and d)**.



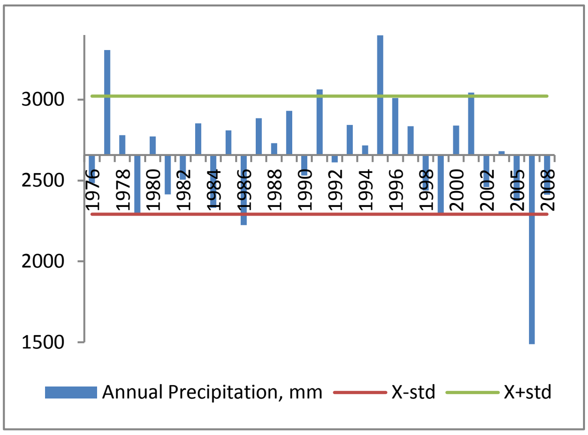

**a: Annual Precipitation Trend**



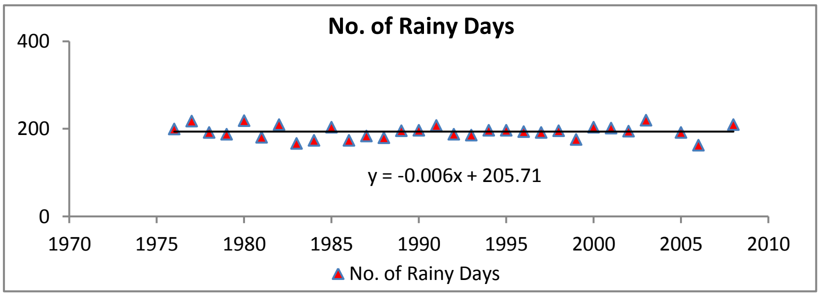

**b: Monsoon & Pre-monsoon Precipitation Trend**




**c: Post Monsoon & Winter Precipitation Trend**




**d: Annual Precipitation Anomalies**




**e: No. of Rainy DaysTrend**

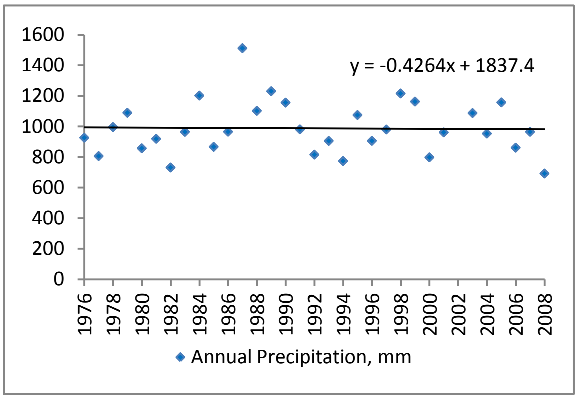
**Figure 4-9: Precipitation trend for station 1317**

Years 1977 and 1995 receive very high amounts of rainfall whereas 2006 is found to be the driest of all years with an annual average precipitation of about 1450mm. Number of dry days during that year is 202. No. of rainy days trend is not so distinct as shown in **Figure 4-9 (e).**

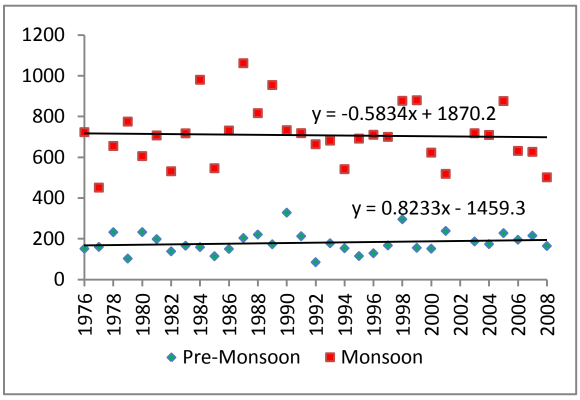
### *F. Station 1307*

Situated among the hills of the Tamor Subbasin in Dhankuta at an elevation of 1210m, this station receives an annual rain of about 990mm. Apart from pre-monsoon rainfall, annual as well as other seasonal rainfall are on a declining trend over the years which is shown in **Figure 4-10 (a,b,c and d).**

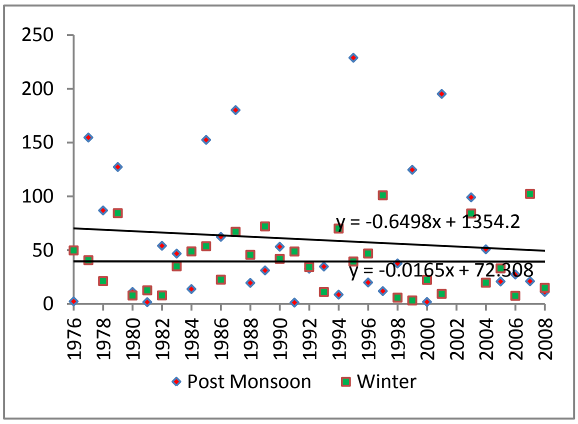
The anomaly chart shows 1987 as the wettest year with an annual precipitation of about 1500mm whereas 1982 and 2008 are the drier years with annual rainfall limited to about 730 and 690 mm respectively. **Figure 4-10 (e)** shows that the no. of rainy days have been decreasing during 1976 - 2008.



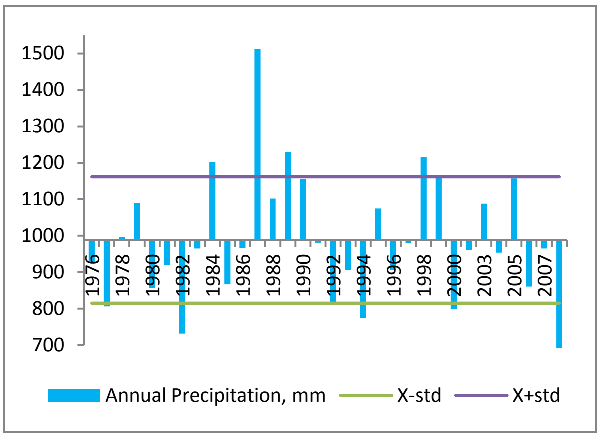

**a: Annual Precipitation Trend**



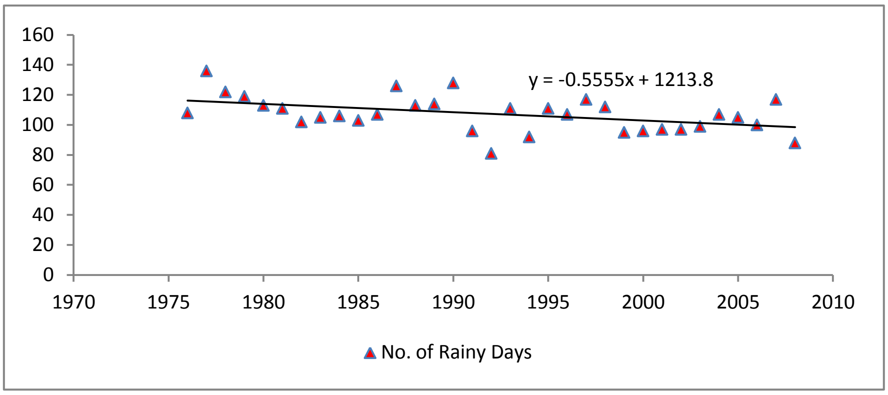

**b: Monsoon & Pre-monsoon Precipitation Trend**




**c: Post Monsoon & Winter Precipitation Trend**




**d: Annual Precipitation Anomalies**

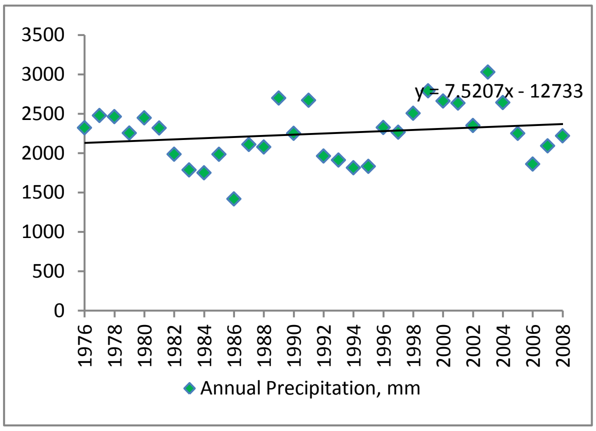



**e: No. of Rainy DaysTrend**

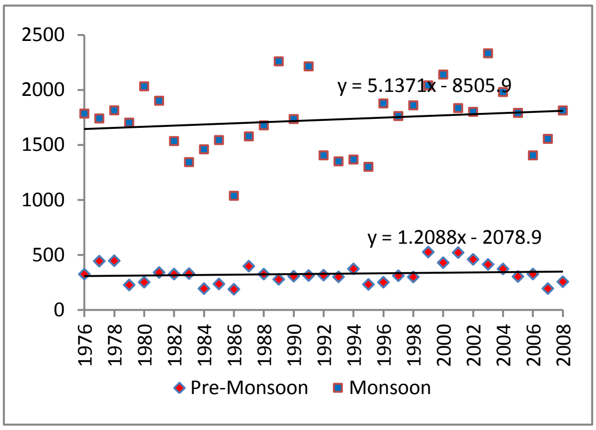
**Figure 4-10: Precipitation trend for station 1307**

### *G. Station 1403*

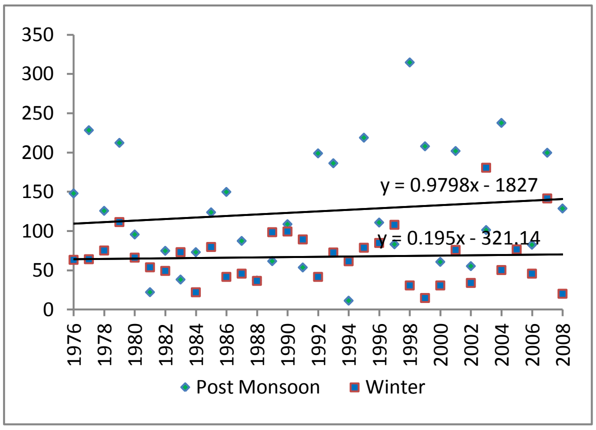
The Lungthung station is at an elevation of 1780m in the Tamor Subbasin. Average annual precipitation at this station is about 2250mm. Similarly this station receives an average monsoon precipitation of about 1730mm. Where **Figure 4-11(a,b,c and d)** show an overall increasing trend in annual as well as seasonal precipitation.



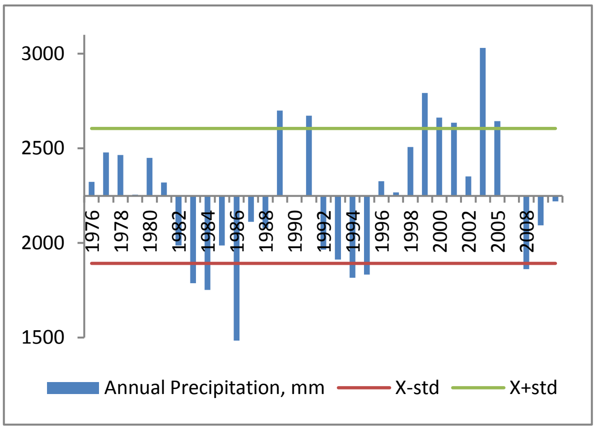

**a: Annual Precipitation Trend**



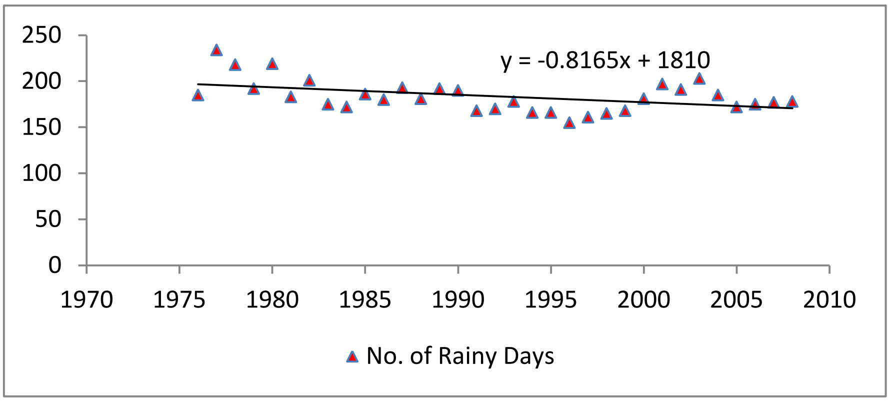

**b: Monsoon & Pre-monsoon Precipitation Trend**




**c: Post Monsoon & Winter Precipitation Trend**




**d: Annual Precipitation Anomalies**




**e: No. of Rainy DaysTrend**

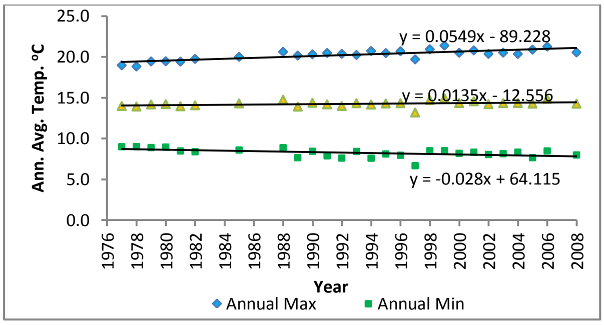
**Figure 4-11: Precipitation trend for station 1403**

Year 2003 receives the highest amount of precipitation with 3030mm. This year has 205 rainy days. Year 1986 is the driest year with a annual average precipitation of about 1420mm with 182 dry days. **Figure 4-11(e)** shows decreasing trends in no. of rainy days.

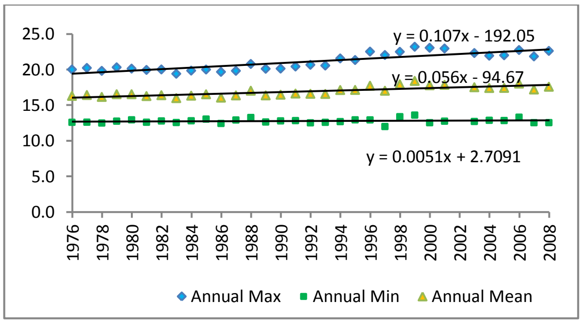
### 4.2.2 Temperature Trends:

To analyze the annual trends in temperature, three climatological stations viz. 1103, 1206 and 1212 from **Table 4-2** were selected. Annual average maximum, minimum and mean temperatures from each stations were then plotted against the respective years to observe temperature trends. In addition to this, daily maximum, minimum and average temperature from 1987 - 2008 for the Khumbu Station was also considered to represent the temperature trends in the high mountainous belt of the Koshi basin.

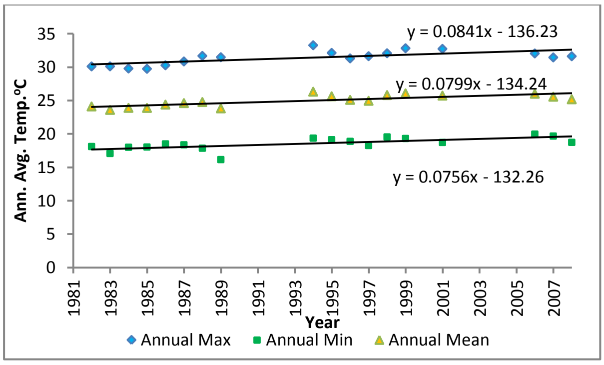
Jiri station (1103), at an altitude of about 2003 m, shows increasing trends in maximum and mean temperatures by 0.055 °C and 0.014°C annually shown in the **Figure 4-12** (a). However the minimum temperature trend is decreasing by 0.028 °C per annum.

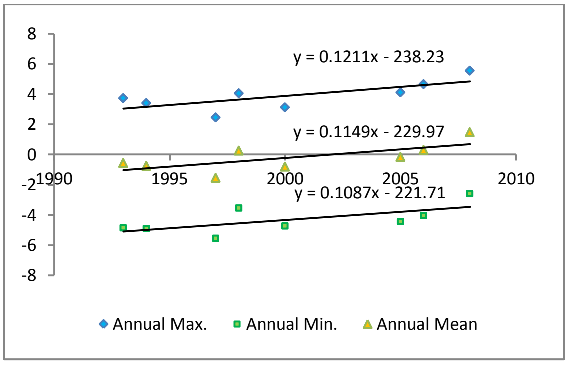



**a: Temperature trends at Jiri Station**




**b: Temperature trends at Okhaldhunga Station**




**c: Temperature trends at Phatepur Station** **d: Temperature trends at Khumbu Station**

**Figure 4-12: Temperature trend for selected stations**

Simlarly, the Okhaldhunga station (1206), observes increasing trends in all of maximum, minimum and mean temperature with the gradients of 0.107, 0.0051 and 0.056 $^{o}$C per year respectively in the **Figure 4-12** (b). Station 1212 in Phatepur lies along the Terai belt of the basin. Maximum, minimum and mean annual temperature is observed to be increasing by about 0.08 $^{o}$C every year for this station **Figure 4-12** (c). Finally Khumbu station which lies at an altitude of about 4355m among the mountains of the central Koshi Basin, observes increasing trends in all of maximum, minimum and mean annual average temperature by 0.12, 0.11, and 0.108$^{o}$C per year **Figure 4-12** (d).

## 4.3 Flow Trends at Chatara

Gauged flow data at the Chatara station is considered here for hydrologic analysis. Elevation of the station is 140m. Koshi River drains an area of about 54000 sq. km. at Chatara. Mean annual flow at this station, during 1977 to 2008 is about 1540 $m^3/s$. Similarly the standard deviation for the annual values is 1544 $m^3/s$. Annual average flow trend suggest a gradual decrease in flows by a gradient of about 4 $m^3/s$ per year (**Figure 4-13**).

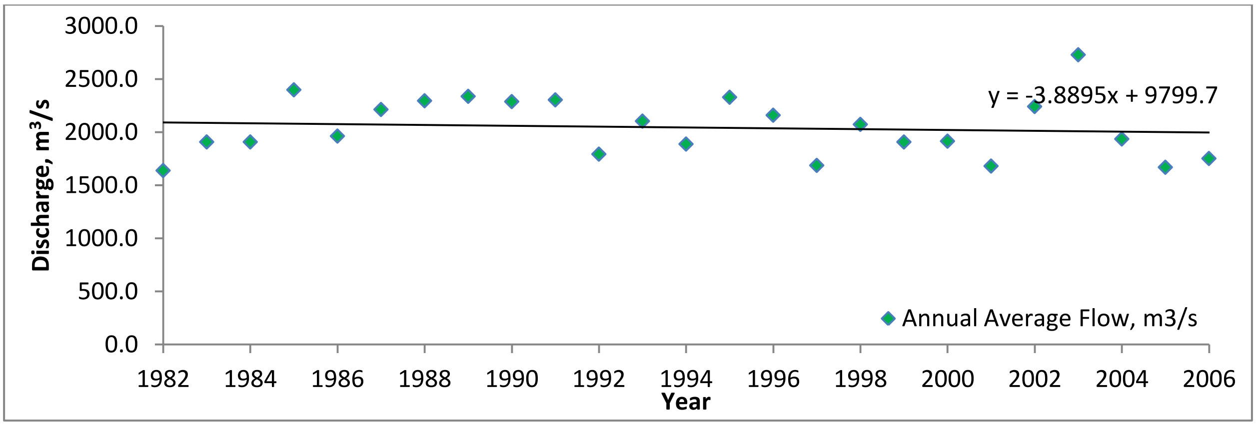



**Figure 4-13: Annual Average flow trend at Chatara**

**Figure 4-14** below shows the distribution of long term average monthly precipitation at Chatara (Station 1316) and monthly flow at the station. Maximum rainfall is observed during July whereas maximum flow is observed during August.

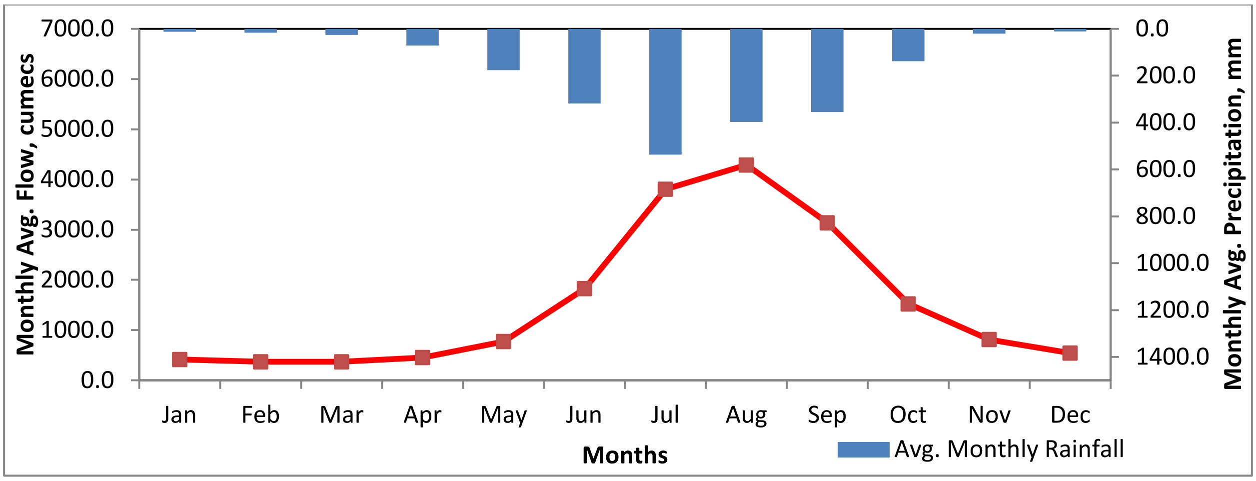



**Figure 4-14: Average Monthly precipitation and flow trends at Chatara**

**Figure** 4-15 shows the Annual Flow Duration Curve for the Koshi River at Chatara. As can be read from **Table 4-4**, 0.1 and 1% exceedance flows are found to be 7830 and 6100 m³/s whereas the minimum flows (99% and 95%) are observed to be 248 and 295 m³/s.

**Table 4-4 : Flows at different exceedance probabilities**

| Exceedance Probability | Flow, m³/s |
|---|---|
| **0.1** | 7830 |
| **1** | 6100 |
| **5** | 4720 |
| **10** | 3910 |
| **25** | 2310 |
| **45** | 825 |
| **50** | 696 |
| **75** | 404 |
| **90** | 327 |
| **95** | 295 |
| **99** | 248 |

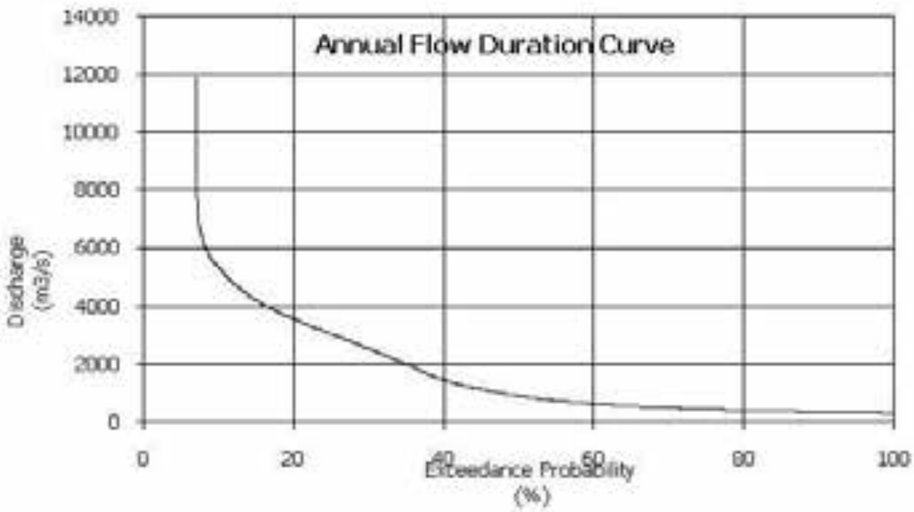



**Figure 4-15: Annual Flow Duration Curve for flow in Koshi**

Similarly maximum instantaneous discharge data from 1977 to 2006 is shown in **Figure 4-16**. The highest instantaneous discharge recorded was in 1980 with a magnitude of 24000 cumecs.

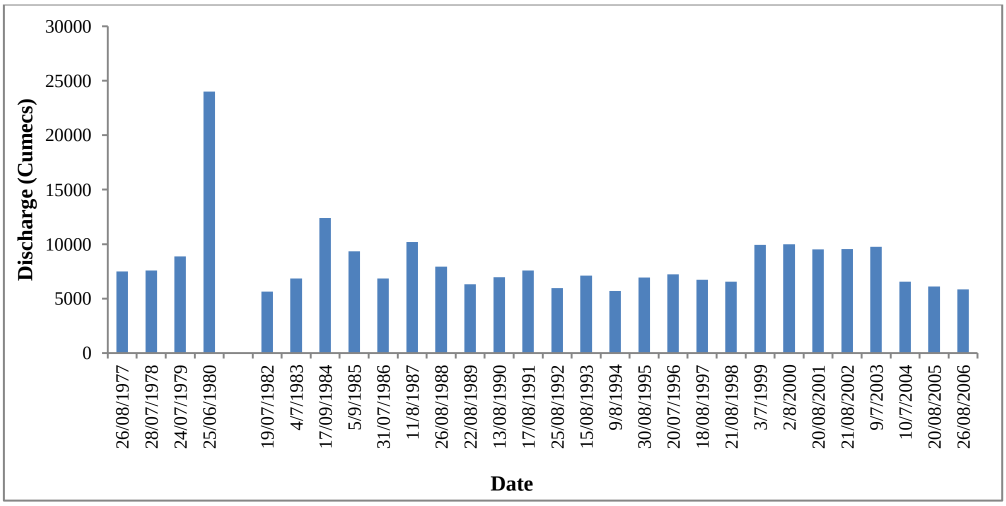



**Figure 4-16: Maximum Instantaneous discharge values at Chatara**

## 4.4 Snow cover trend

The snow cover data is derived from MODIS/MOD10A1 dataset from the year 2000 to 2011 for five sub-basins. To understand the snow cover distribution in sub-basins, it was classified into several elevation bands with an equal interval of 500m above 3000m. The SCA data extracted for 12 years for each sub-basin is shown in **Figure 4-17**.

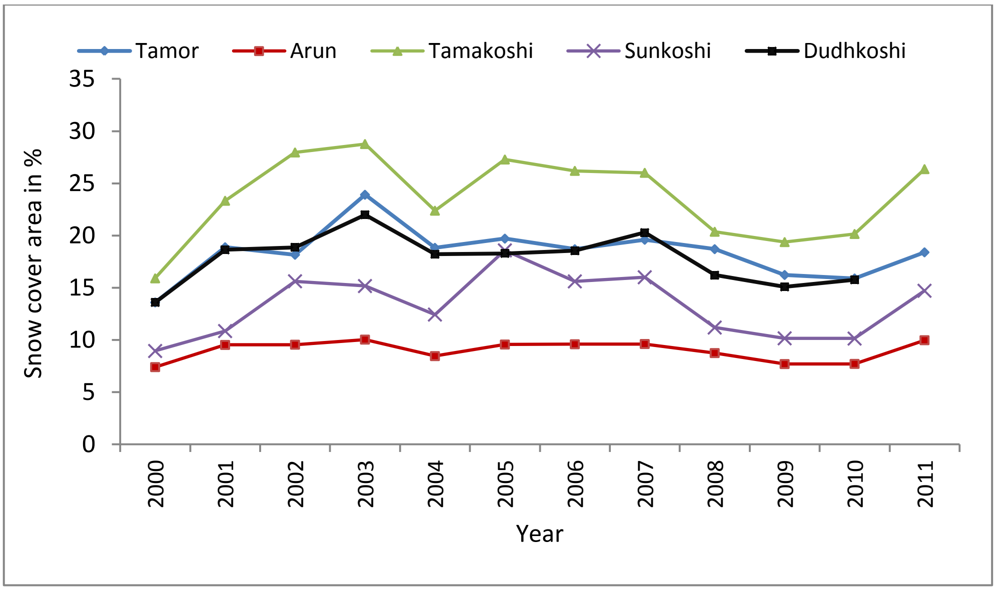



**Figure 4-17: Annual average variation of Snow cover area of sub-basins**

The average SCA of the HKH region from 2002 to 2010 is 0.76milllion sq.km (18.2%) of the total land area (Gurung et al., 2011). On the basis of annual average snow cover area, maximum snow cover percentage is found to be 23.67% in Tamakoshi basin with respect to its basin size, followed by Tamor (18.45%), Dudhkoshi (17.77%), Sunkoshi (13.29%) and Arun (8.99%).The maximum SCA is in 2003 for all basins except for Sunkoshi basin (18.58%) while the minimum coverage is in 2010 for all basins excluding Tamakoshi (19.38%) basin. The minimum SCA was also found in the year 2010 in HKH region (Gurung et al., 2011).

Based on linear regression equation, the annual average variation of snow cover data in **Table 4-5** depicts a negative trend for all basins except for Sunkoshi basin which is increasing at rate of 0.023% per year. Amongst all sub-basins a greater percentage of decrease is observed in Dudhkoshi basin (-0.131% or -5.20 $km^2$/year). The seasonal variation in snow data (in **Table 4-5** and **Figure 4-17)** reveals a decreasing trend in snow cover area during pre-monsoon season in all sub-basins which is prone to melting during this season. The average precipitation trend analysis in each sub-basins during pre-monsoon from 2000-2011 shows a decreasing trend. Similarly the temperature trend analysis during this season and year shows increasing trend mostly in Taplejung, Pakhribas and Panchkhal station while a rising trend is shown during winter season in Syangboche, Dingboche, Jiri, TshoRolpa stations. This coupled effect of increasing temperature and decreasing precipitation could be the possible reason for decline in SCA during pre-monsoon season. Besides maximum decline of SCA trend in Dudhkoshi basin, the data also reveals a decrease in all seasons except during winter.

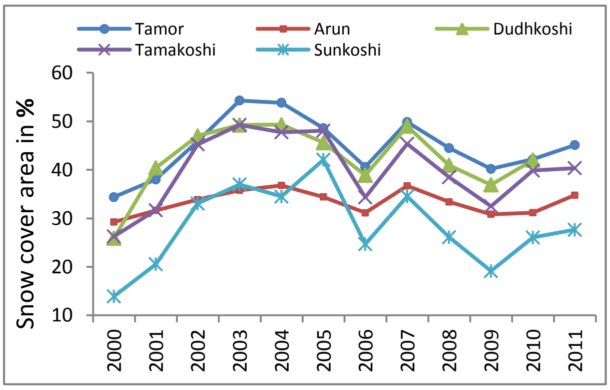
The SCA area for HKH region is estimated to have been more or less stable or have only decreased slightly during the decade 2000 to 2010 (Singh, et al., 2011).Although a 12 year record of SCA is short to make concrete conclusion for trend analysis, the annual SCA trend in sub-basins of Koshi basin signifies a tendency towards a declining trend.

**Table 4-5 : Snow cover area trend analysis (2000-2011) and statistics**

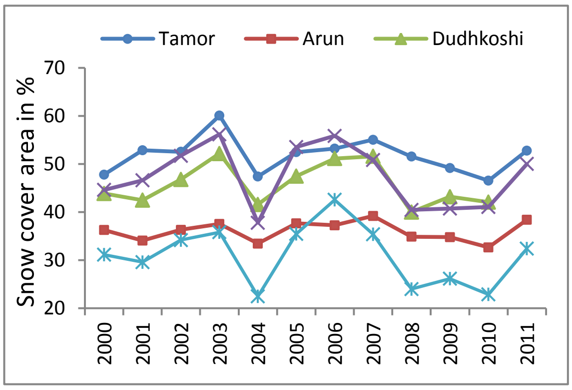
| Statistics | Sub-basins | | | | |
|---|---|---|---|---|---|
| | Tamor | Arun | Dudhkoshi | Tamakoshi | Sunkoshi |
| Mean | 784.36 | 2537.33 | 705.18 | 741.52 | 689.17 |
| S.D. | 106.26 | 268.39 | 95.81 | 126.84 | 157.54 |
| **Season** | **Linear Trend ($km^2$/year)** | | | | |
| Annual Average | -1.85 | -3.87 | -5.20 | -0.64 | 1.21 |
| Winter | 5.79 | 17.67 | 1.73 | 2.14 | 46.91 |
| Monsoon | 1.13 | 15.44 | -5.64 | 5.25 | 6.80 |
| Pre-monsoon | -12.53 | -24.34 | -10.75 | -18.03 | -18.22 |
| Post-monsoon | 2.14 | 46.91 | -0.09 | 15.08 | 21.27 |

Winter = DJF, Monsoon = MAM, Pre-monsoon = JJAS, Post monsoon = ON,

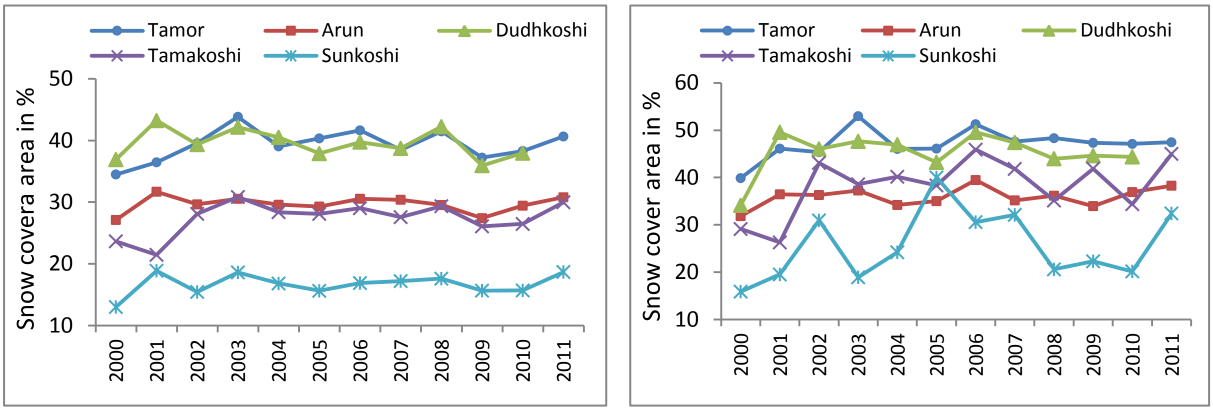
S.D. = Standard Deviation




i. Winter




ii. Pre-monsoon




iii. Monsoon    iv. Post-monsoon

**Figure 4-18: Percentage of seasonal snow cover area for sub-basins**

The mean monthly estimate of snow cover in **Figure 4-19** represents a percentage of peak snow coverage in the month of March followed by February except for Dudhkoshi basin, which is in reverse order. While the least extent of snow cover is in the month of June for all basins except for Sunkoshi basin which is in the month of July. Gurung et al. found a similar estimate for HKH region- maximum during the month of February but minimum during July. In the Himalayan regions, the snow cover gradually increases from

September to March, and afterwards it depletes due to melting (Thapa, 1993) i.e. the accumulation period is observed from the rise of September to March and the ablation starts after March to the end of August. The **Figure 4-19** clearly represents the seasonal trend of accumulation and ablation in the whole annual cycle.

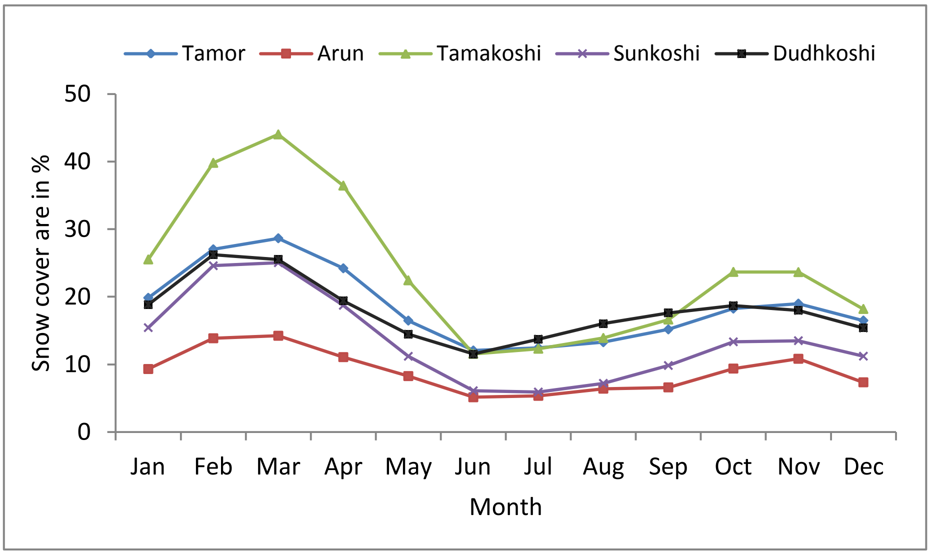



**Figure 4-19: Monthly mean variation in SCA, 2000-2011**

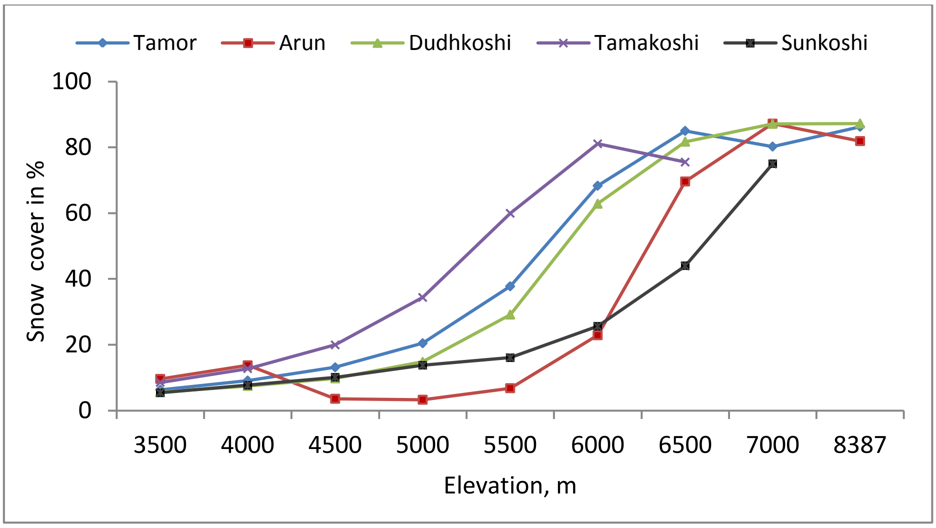
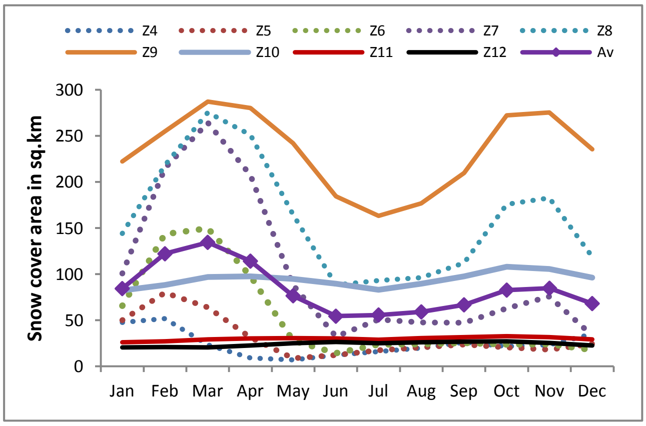
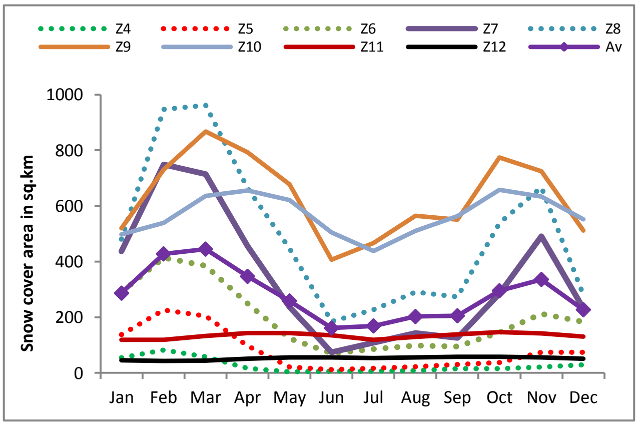



**Figure 4-20: Snow elevation curve of sub-basin**

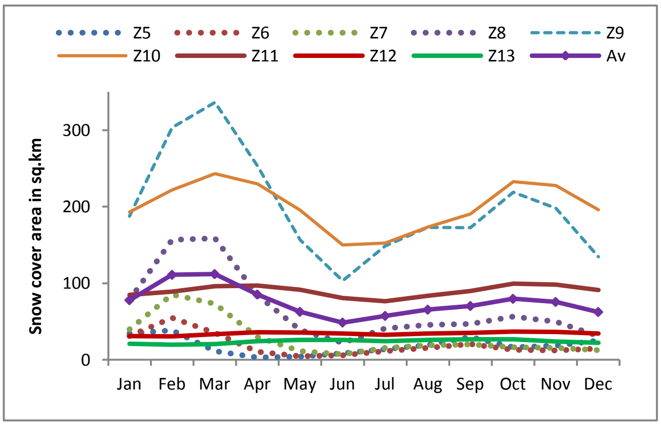
Elevation plays a significant role in snow accumulation and ablation. With reclassification of Dem of each sub-basin at an equal interval of 500m, the SCA for elevation above 3000 m is analyzed **(Figure 4-19** and **Figure 4-20).** An abrupt increase in snow cover area beyond the permanent snowline of about 5000m could be seen in **Figure 4-20** for most of the basin which indicates the SCA in lower elevation temporally varies significantly. Based on simulation results maximum melting is observed up to an elevation of 5500m illustrated by the dotted lines in a plot of monthly zonal SCA (**Figure 4-21**) that signifies snow cover transition zones for all basins. Of the total area of each sub-basin, the snow coverage above a permanent snowline of 5000m are 58.61%, 16.95%, 46.95%, 31.53% and 27.50% for Tamor, Arun, Dudhkoshi, Tamakoshi and Sunkoshi basin respectively.



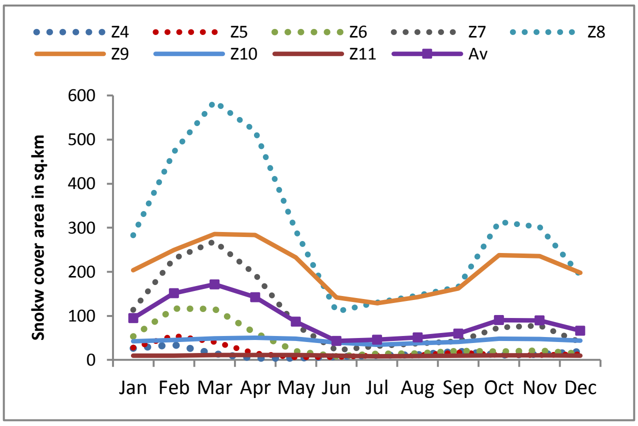

i. Tamor



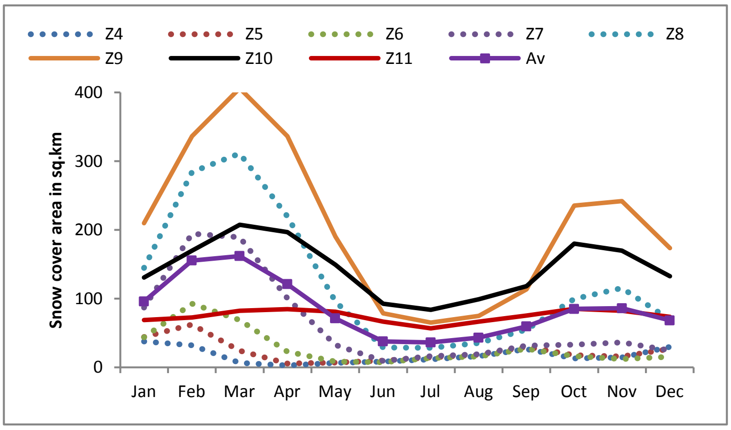

ii. Arun




iii. Dudhkoshi




iv. Tamakoshi




v. Sunkoshi

**Figure 4-21: Zonal monthly mean variation in snow cover area**

(Z4 = 3000-3500 m, Z5 = 3500-4000 m, Z6 = 4000-4500 m, Z7 = 4500-5000 m, Z8 = 5000-5500 m Z9 = >5500 m)

# Chapter 5: Application of Regional Climate Model data

## 5.1 Description of data from Regional Climate Model used in this study

Two Regional Climate Model data were used in this study (**Table 5-1**). These are PRECIS-HadCM3Q0 and PRECIS-ECHAM05. These data are based on IPCC SRES A1B scenario. Bias correction of these data were made using hindcast data for the period-1960 to 2000 and projection for the future period of 2020s to 2060s was made. These data were provided by the Department of Hydrology and Meteorology (DHM), Nepal. Detailed discussion of these models are described in 'Technical Approach and Methodology for Projected Data Preparation'-Nepal Climate Data Portal by DHM.

**Table 5-1: Regional Climate Data used in the study**

| RCM | PRECIS | PRECIS |
|---|---|---|
| Parent GCM | HADCM3Q0 | ECHAM05 |
| IPCC Scenario | A1B | A1B |
| Validated period | 1970-2000 | 1970-2000 |
| Downscaled period | 2030-2060 | 2020-2060 |
| Horizontal Resolution | 25 km | 25 km |
| Temporal Resolution | Daily | Daily |
| Used Variables | Rainfall, Temperature (Mean, Max and Min) | Rainfall, Temperature (Mean, Max and Min) |

## 5.2 Application of the gridded RCM data for Koshi River Basin

Two models were used in the study for hydrological modeling of the basin; Soil and Water Assessment Tool (SWAT) and Snow-melt Runoff Model (SRM). SRM was applied for the Himalayan catchments where the snow hydrology was dominant which included the five sub-basins. At the lower altitudes SWAT model was used for the study. The gridded climate dataset were needed to convert into the point dataset for its application in the study because both these models used the point data sets. Therefore, these climate datasets were derived at the point locations (at the observed climatic stations) using the following approaches for precipitation and temperature.

### 5.2.1 Precipitation

The stations inside the basin were considered to be used in the hydrological model. One of the criteria for selecting the observed stations was the quality of the observed data. Other criteria were availability of long-term datasets and the selection of the climatic stations by hydrological models based on nearest proximity of the climate stations to the centroid of the basin. After the selection of the stations, Thiessen polygon was created in order to represent the spatial distribution of the rainfall over the catchment except for Arun sub-basin of SRM model area (**Figure 5-1)**.

As there were no observed station data available for the Arun subbasin of Koshi Basin in China, the APHRODITE data was used as an alternative. However, due to lack of precipitation observation stations, Thiessen's approach was not possible. A different approach was considered based on the elevation band. For each of the elevation band used for the study, the corresponding weighted average of RCM precipitation was computed taking precipitation values of those grids lying within the elevation band inside the sub basin. While for Thiessen's approach the precipitation from RCM climate data for each of the point location (location of the rainfall station) was computed as the weighted average of RCM precipitation represented by RCM grids inside the Thiessen polygon represented by that station. The stations in

**Table 5-2** are the selected stations for precipitation included in the models.

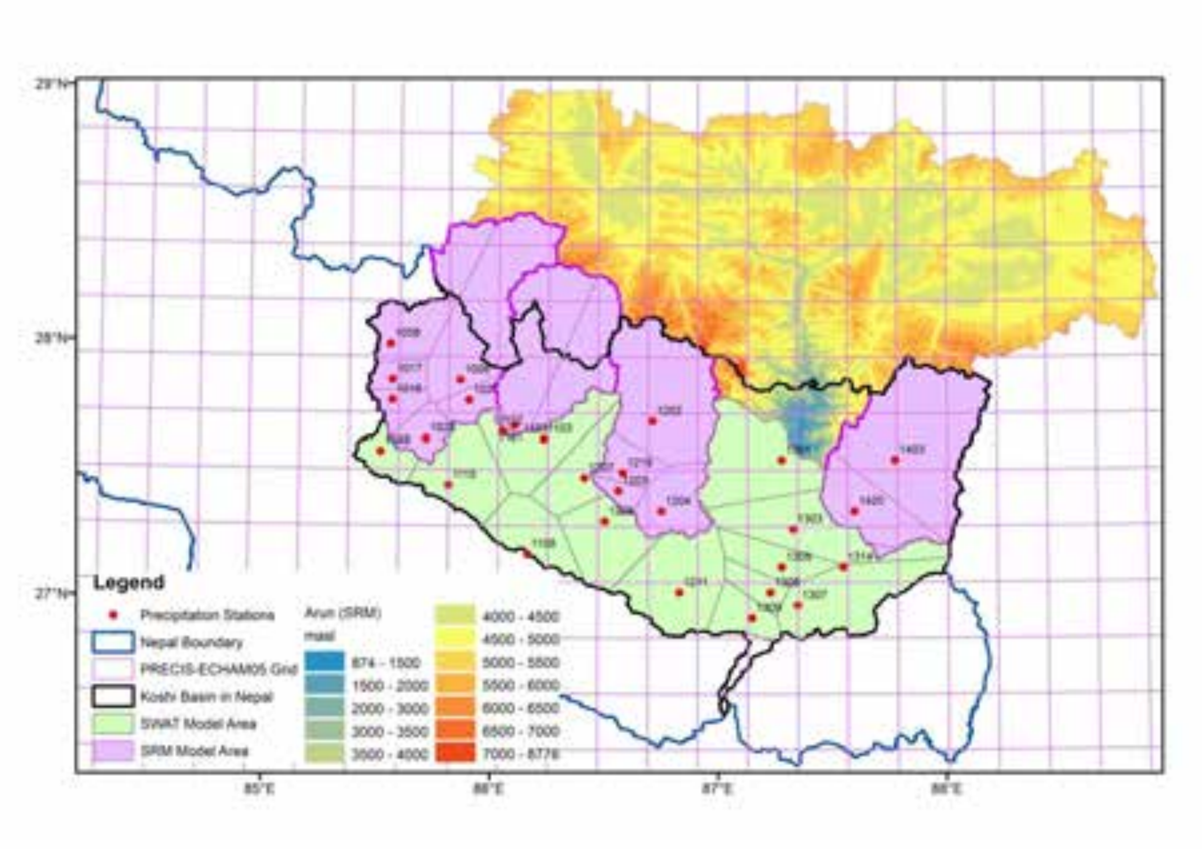



**Figure 5-1: Koshi River Basin with precipitation stations; SWAT model area and SRM model Area**

**Table 5-2: Precipitation stations incorporated**

| S. N. | Station Index | Hydrological Model | Basin | S. N. | Station Index | Hydrological Model | Basin |
|---|---|---|---|---|---|---|---|
| 1 | 1049 | SWAT | Sunkoshi | 15 | 1018 | SRM | Sunkoshi |
| 2 | 1103 | SWAT/SRM | Tamakoshi | 16 | 1023 | SRM | Sunkoshi |
| 3 | 1108 | SWAT | Sunkoshi | 17 | 1027 | SRM | Sunkoshi |
| 4 | 1115 | SWAT | Sunkoshi | 18 | 1006 | SRM | Sunkoshi |
| 5 | 1206 | SWAT | Dudhkoshi | 19 | 1017 | SRM | Sunkoshi |
| 6 | 1207 | SWAT | Likhu | 20 | 1101 | SRM | Tamakoshi |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7 | 1211 | SWAT | Dudhkoshi | 21 | 1102 | SRM | Tamakoshi |
| 8 | 1301 | SWAT | Arun | 22 | 1202 | SRM | Dudhkoshi |
| 9 | 1303 | SWAT | Arun | 23 | 1203 | SRM | Dudhkoshi |
| 10 | 1305 | SWAT | Arun | 24 | 1219 | SRM | Dudhkoshi |
| 11 | 1306 | SWAT | Arun | 25 | 1204 | SRM | Dudhkoshi |
| 12 | 1307 | SWAT | Tamor | 26 | 1403 | SRM | Tamor |
| 13 | 1309 | SWAT | Arun | 27 | 1420 | SRM | Tamor |
| 14 | 1058 | SRM | Sunkoshi | | | | |

### 5.2.2 Temperature

In case of the SWAT model area, the basin was divided into different sub-basins area following the Thiessen's approach as in case with precipitation (**Figure 5-2**). However, for the SRM model area the elevation band approach was again utilized. The elevation bands of 1000m interval below altitude of 3000m and 500m interval above 3000m altitude were used for SRM model areas. Since the density of temperature stations are low for altitude above 3000m, the lapse rate was taken into account for extrapolation of temperature. The stations in **Table 5-3** are the selected stations for temperature included in the models.

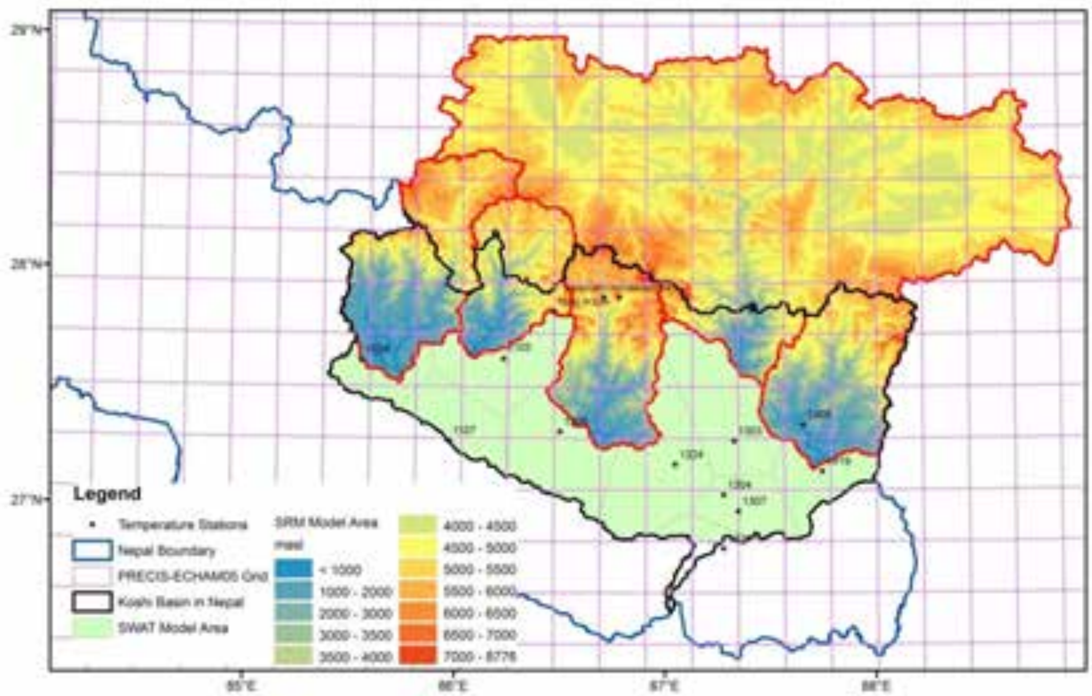



**Figure 5-2: Koshi River Basin with Temperature Stations; SWAT model area and SRM model Area**

**Table 5-3: Temperature stations incorporated**

| S.No | Station Index | Hydrological Model | Basin | S.No | Station Index | Hydrological Model | Basin |
|---|---|---|---|---|---|---|---|
| 1 | 1024 | SWAT/SRM | Sunkoshi | 9 | 1419 | SWAT | Tamor |
| 2 | 1103 | SWAT/SRM | Tamakoshi | 10 | 1036 | SRM | Sunkoshi |
| 3 | 1107 | SWAT | Sunkoshi | 11 | Tsho Rolpa | SRM | Tamakoshi |
| 4 | 1206 | SWAT | Dudhkoshi | 12 | Dingboche | SRM | Dudhkoshi |
| 5 | 1303 | SWAT | Arun | 13 | Syangboche | SRM | Dudhkoshi |
| 6 | 1324 | SWAT | Arun | 14 | 1304 | SRM | Arun |
| 7 | 1307 | SWAT | Tamor | 15 | 1405 | SRM | Tamor |
| 8 | 1311 | SWAT | Tamor | | | | |

## 5.3 Bias correction of the RCM data

Various methods for bias correction of the RCM data (precipitation and temperature) found in the previous research works. Some of the methods for correction of the precipitation are linear scaling (Lenderink et al., 2007), delta correction, power transformation method (Terink et al 2010, Leander and Busihand 2007, Shabalova et al 2003), local intensity scaling (Ines and Hansen 2006), probability distribution mapping (quantile distribution, gamma transformation) (Piani et al 2009). These methods have been analyzed in Teutschbein and Seibert (2012). Methods applied for the correction of temperature are delta change approach, approach of mean and standard deviation adjustment and distribution mapping.

One thing common in all of these methods is that all of them follow the stationarity assumption. This implies that the properties (parameters and computational algorithms) are same in both the present and future climatic conditions, regardless of the possibility that they are subject to change in future climatic scenarios. Out of the various methods, the *power transformation method* for precipitation and the *mean and standard deviation adjustment* for temperature were followed in this study.

### 5.3.1 Precipitation

Power transformation approach for the bias correction of precipitation was selected for this study. This method is non-linear method used in different researches - Leander and Buishand (2007) for simulation of extreme river flow for river Meuse in western Europe; Terink et al (2010) for the Rhine Basin. It adjusts both the mean (central tendency) and variance (scatteredness) of the future climatic scenario with those that of the observed value. This method performs better than delta approach and linear scaling approaches which adjust the mean only. Besides, it is easier to apply compared to the probability distribution mapping methods due to the simplicity of the method.

The power transformation approach uses following **Equation (5-1).**

$$P^* = a\ PRCMb \quad \textbf{(5-1)}$$

Where P* is the corrected precipitation, 'a' and 'b' are the transformation parameters and $P_{RCM}$ is precipitation from the climate data. For their determination, the whole year was divided into the block of consecutive five days period, which means, there were 73 blocks of 5 days in a year (refer **Figure 5-3**). The data series were arranged into 65 days window for all years considering the preceding 30 days and succeeding 30 days of the 5 days block, for each of the 73 blocks. For each block the parameters 'a' and 'b' were determined.

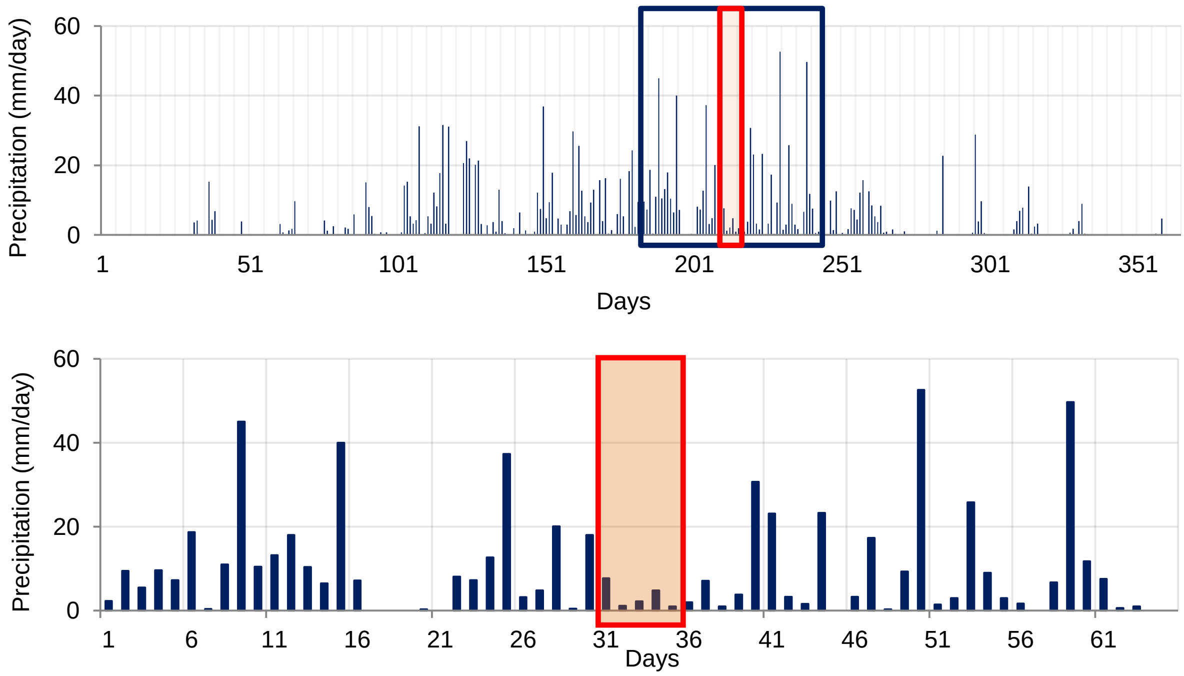



**Figure 5-3: Top – Annual time series divided into 73 blocks of 65 days window each, 43rd block shown (in black border) with its 65 days window (in red border); Bottom – The 43rd block**

Parameter 'b' is power factor and it relates to the coefficient of variation (CV) (**Equation 5-2**). For each block, it was determined such that the CV of historical observed series matched with the historical hindcast data series of the climate model. Mathematically,

$$b{=}CVPobs{-}CVPRCMb{=}0 \quad (5\text{-}2)$$

Likewise, parameter 'a' is multiplicative factor and it relates to the mean (**Equation 5-3**). Once the parameter 'b' was determined for each block, parameter 'a' was determined such that the mean of historical observed series matched with the historical hindcast data series of the climate model. Mathematically,

$$a{=}meanPobs{-}mean\,a\,PRCMb{=}0 \quad (5\text{-}3)$$

Both the equations were solved using the Secant root finding algorithms. Once the parameters 'a' and 'b' were determined for each of the 73 blocks using 65 days window, these were applied for de-biasing the future climate data series.

### 5.3.2 Temperature

The approach discussed by Leander and Buishand (2007) was used for bias correcting the temperature. This approach basically shifts and scales mean and variance of the climate data to match with the observed data series. Refer Equation (**5-4).**

$$T_{corr} = T_{RCM} + \sigma T_{obs} \sigma T_{RCM} \times T_{RCM} - T_{RCM} + (T_{obs} - T_{RCM}) \qquad \textbf{(5-4)}$$

where, $T_{corr}$ is the corrected temperature, $T_{obs}$ is the observed temperature, $T_{RCM}$ is temperature for the climate data, $\sigma$ denotes the standard deviation and an overbar represents the mean. These statics were derived for each of the 73 blocks as described previously.

## 5.4 Results and Analysis

In the following sub-sections the RCM data are analyzed spatially and temporally. The bias correction method has been evaluated based upon the results following the methodology as demonstrated in Terink et al. (2010). In the end, the bias corrected forecast RCM data is analyzed in comparison with the observed historical data.

### 5.4.1 Bias Correction Parameters

**Rainfall**

The determined *a* and *b* parameters affect the corrected daily precipitation value. **Figure 5-4** and **Figure 5-5** show boxplots for the *a* and *b* parameters throughout the year for SWAT and SRM model area respectively for both the RCM datasets.

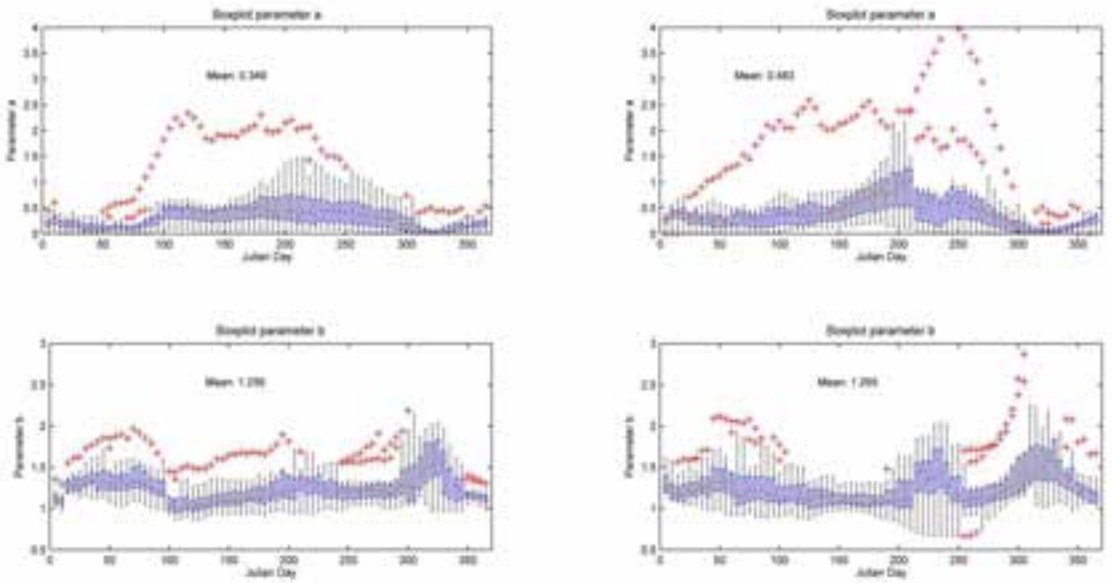


**Figure 5-4: Boxplot for parameter a and b for each block of 5 days for the SWAT model area (Left – ECHAM05, Right – HadCM3)**

These boxplots are calculated for each block of 5 days, taking into account the values from all sub-basins. Outliers are defined as values larger than 1.5 times the interquartile range and are indicated with red crosses. It is seen that the parameter *a* has a value of less than one for almost entire year for both the model areas. It can be concluded that the average precipitation of the uncorrected RCM rainfall datasets were too wet for the region for almost entire year. This over estimation is lowest for the monsoon and higher for all other three seasons. However, the spread of parameter *a* is highest for monsoon and lowest for winter. This implies a large variation in the parameter *a* amongst the sub basins and its uncertainty in monsoon.

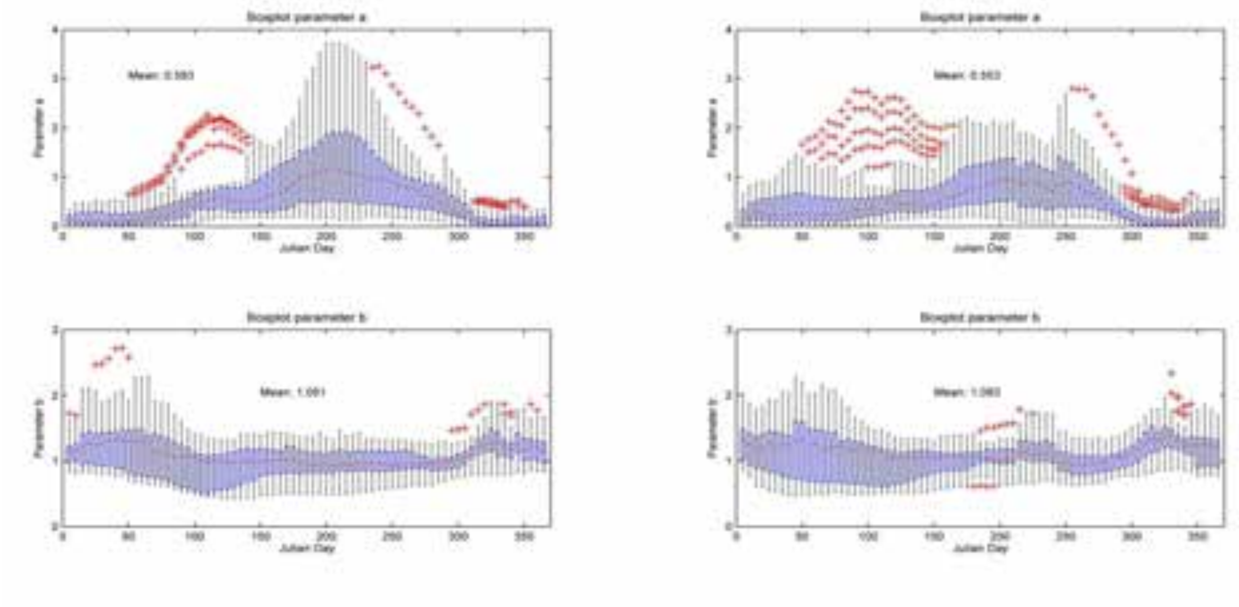


**Figure 5-5 :Boxplot for parameter a and b for each block of 5 days for the SRM model area (Left – ECHAM05, Right – HadCM3)**

The spread in the *b* parameter is smaller than that for parameter *a*. The greater uncertainty in parameter *a* in contrast to *b* can be justified from the histograms shown in **Figure 5-7**. The histograms for SRM area can be referred to in **Appendix C-1**. Parameter *b* is larger than one during almost the entire year for SWAT model area while it is nearer to one for SRM model area. The CV has to be corrected most during the winter and post monsoon months. Outliers can be found throughout the entire year in SWAT model area while in SRM model area they are restricted to pre- and post-monsoon for parameter *a* and post-monsoon for parameter *b*.

### Temperature

In case of temperature the ratio of the RCM dataset standard deviation over the observed standard deviation for temperature were analyzed. The spread in ratios in SWAT model area, before the application of correction for maximum daily temperature is represented in the boxplot of **Figure 5-6.**

A seasonal pattern can be distinguished from this figure. From January on, there is an upward trend until April for ECHAM05 maximum temperature dataset, which suggests an increasing variation in maximum daily temperature for ECHAM05 when approaching mid of pre-monsoon. After that the ratio plunges and becomes lesser than one in the monsoon suggesting lack of variation in the RCM maximum temperature dataset during this period. This lack of variability during monsoon is greater in HadCM3 dataset. Both the dataset catch the variability to their best during the post monsoon and December. The area-weighted average ratios of 1.048 and 1.032 suggest that the average spread in maximum temperature for both the datasets is larger than that for the observations.

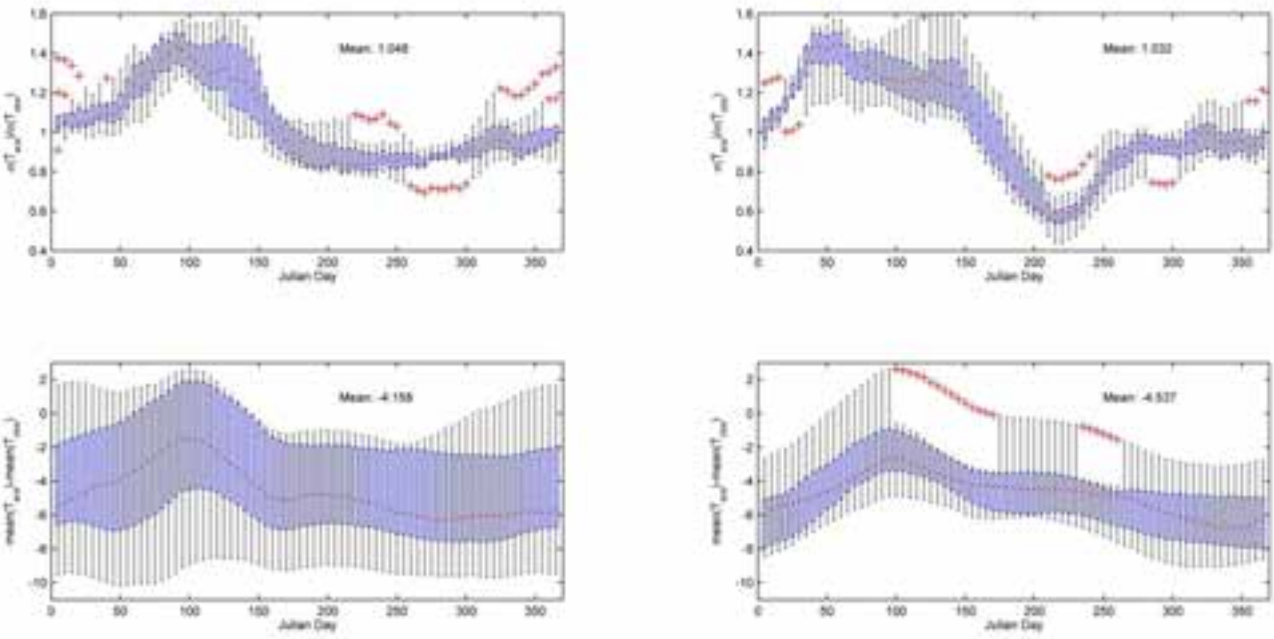



**Figure 5-6 Top: Boxplot for the ratios of the RCM data standard deviations over the observed standard deviations. Bottom: Boxplot for the differences between the RCM data average maximum temperatures and observed average maximum temperatures (SWAT model area; Left – ECHAM05, Right – HadCM3)**

The bottom panel of **Figure 5-6** represents the spread in average temperature differences between the RCM maximum daily temperature and observed maximum daily temperature. The area-weighted average differences of -4.158 $^{0}$C and -4.537 $^{0}$C suggest that the maximum temperature for both the datasets is smaller than that for the observations and that the average is much colder than for the observations. Similar graphical analysis for the minimum daily temperature (SWAT model area) and average daily temperature (SRM model area) can be referred to (corresponding boxplots of parameters) in **Appendix C-2 and C-3**.

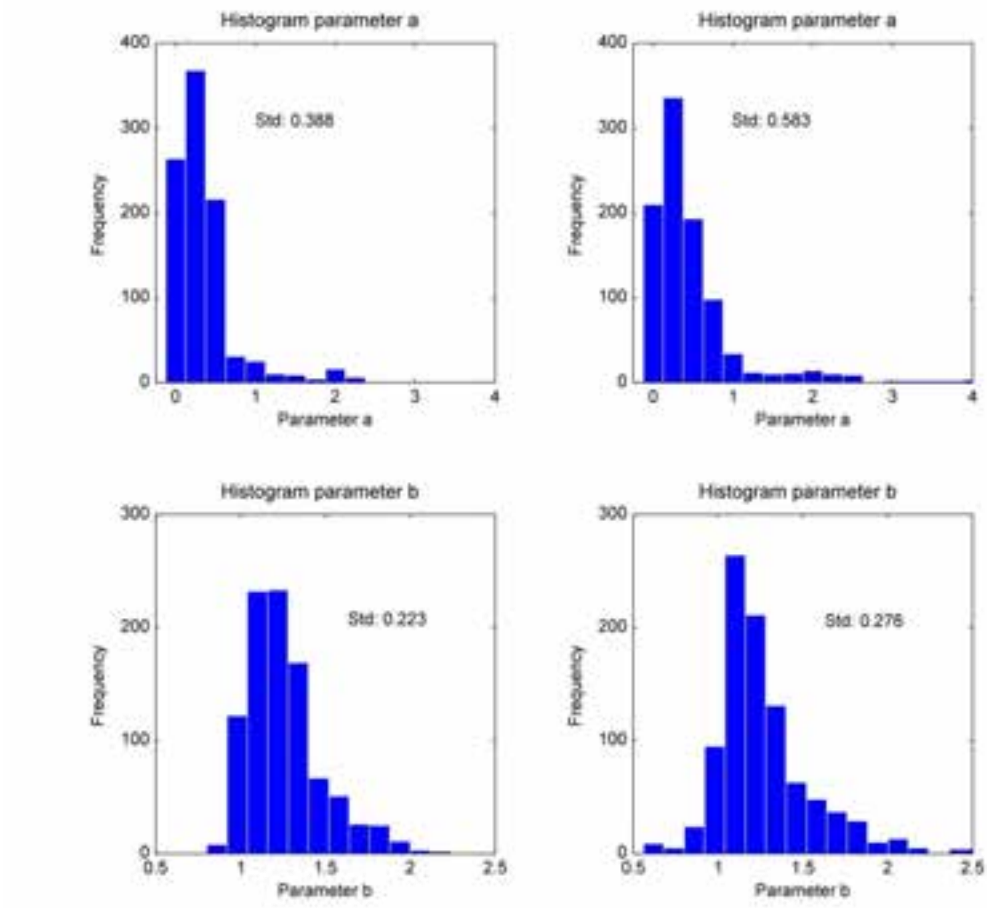



**Figure 5-7 Histograms with corresponding standard deviation of parameters a and b for the SWAT model area (Left – ECHAM05, Right – HadCM3)**

### 5.4.2 Performance Evaluation

**Rainfall**

**a. Spatial precipitation difference**

The average daily precipitation difference between the observations and ECHAM05/ HadCM3 is given by **Equation (5-5)**.

$$\frac{1}{N}\sum_{i=1}^{N} P_{RCM,i}-P_{obs,i} \qquad \textbf{(5-5)}$$

Where MBE is the Mean Bias Error, N the number of days, $P_{RCM,i}$ the precipitation for ECHAM05/ HadCM3 at day i and $P_{obs,i}$ the precipitation for the observations at day i. The MBE for the uncorrected and corrected situation for SWAT model area is shown in the **Figure 5-8** for each sub-basin separately.

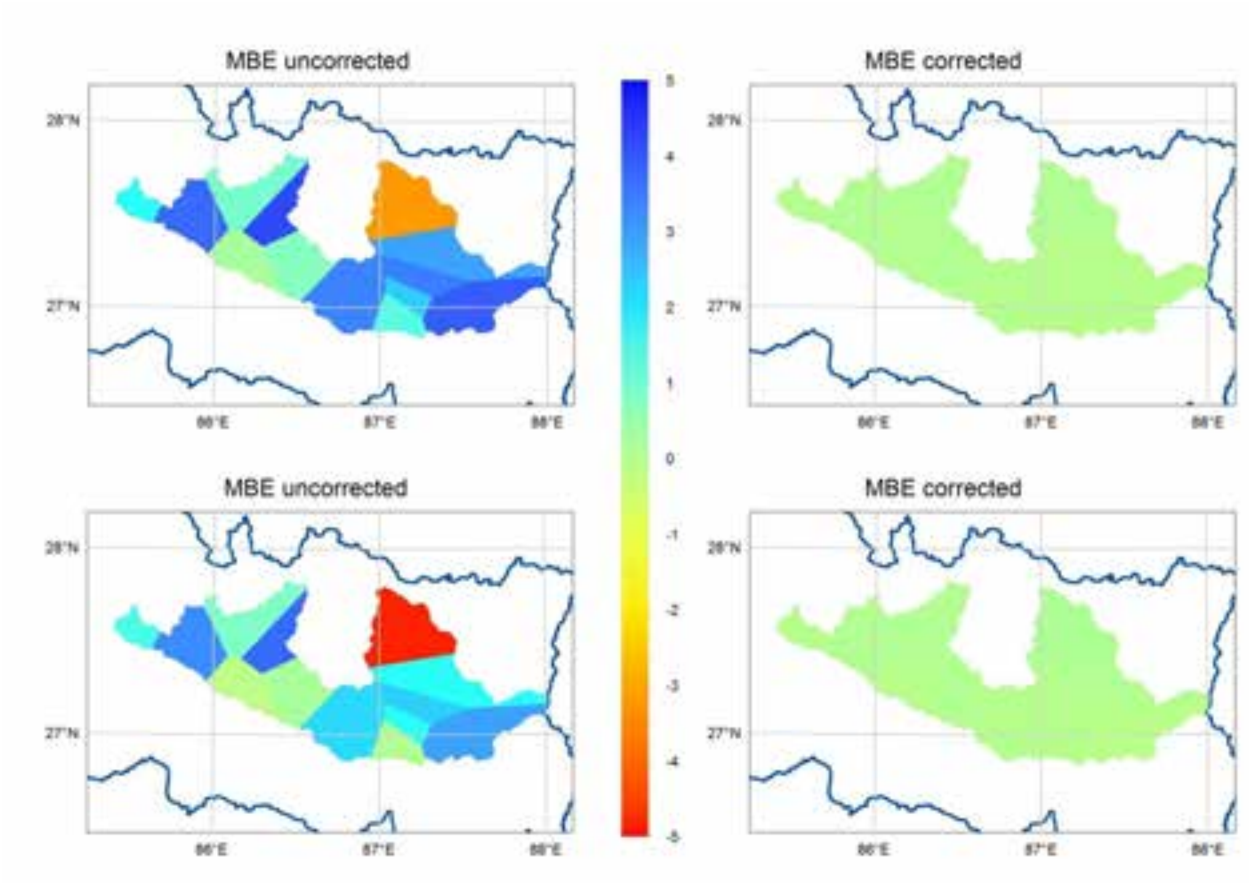



**Figure 5-8 MBE for the uncorrected and corrected RCM precipitation [mm] per sub-basin of the SWAT model area for the period 1976-2000 (Top – ECHAM05, Bottom – HadCM3)**

A positive difference means that ECHAM05/ HadCM3 is wetter than the observed precipitation value for that specific sub-basin. As can be seen, the difference between the uncorrected ECHAM05/ HadCM3 and the observations varies between −5 and +5 $mmd^{-1}$. The uncorrected ECHAM05/ HadCM3 precipitation is too wet for most of the Koshi Basin - SWAT and SRM model area (refer **Appendix C-4**), except for sub area corresponding to the station 1301 at Num. From the right panel **Figure 5-8**, it can be concluded that the bias correction leads to satisfactory results. Differences between the corrected ECHAM05/ HadCM3 and the observations have decreased notably.

The spatial variation in the spread of daily precipitation differences per sub-basin is quantified by the root-mean-square-error (RMSE) of the daily precipitation difference between ECHAM05/ HadCM3 and the observations (**Figure 5-9**) and is given by **Equation 5 -6.**

1N i=1N P RCM, i-P obs, i2 **(5-6)**

There is lesser difference in the RMSE of the uncorrected and corrected situation for most of the Koshi basin (refer **Appendix C-5** for SRM model area). The RMSE appears to have decreased in most of the sub-basins. Based on these results it looks like the correction method is highly capable of correcting the average daily precipitation while moderately capable of correcting the daily precipitation amount.

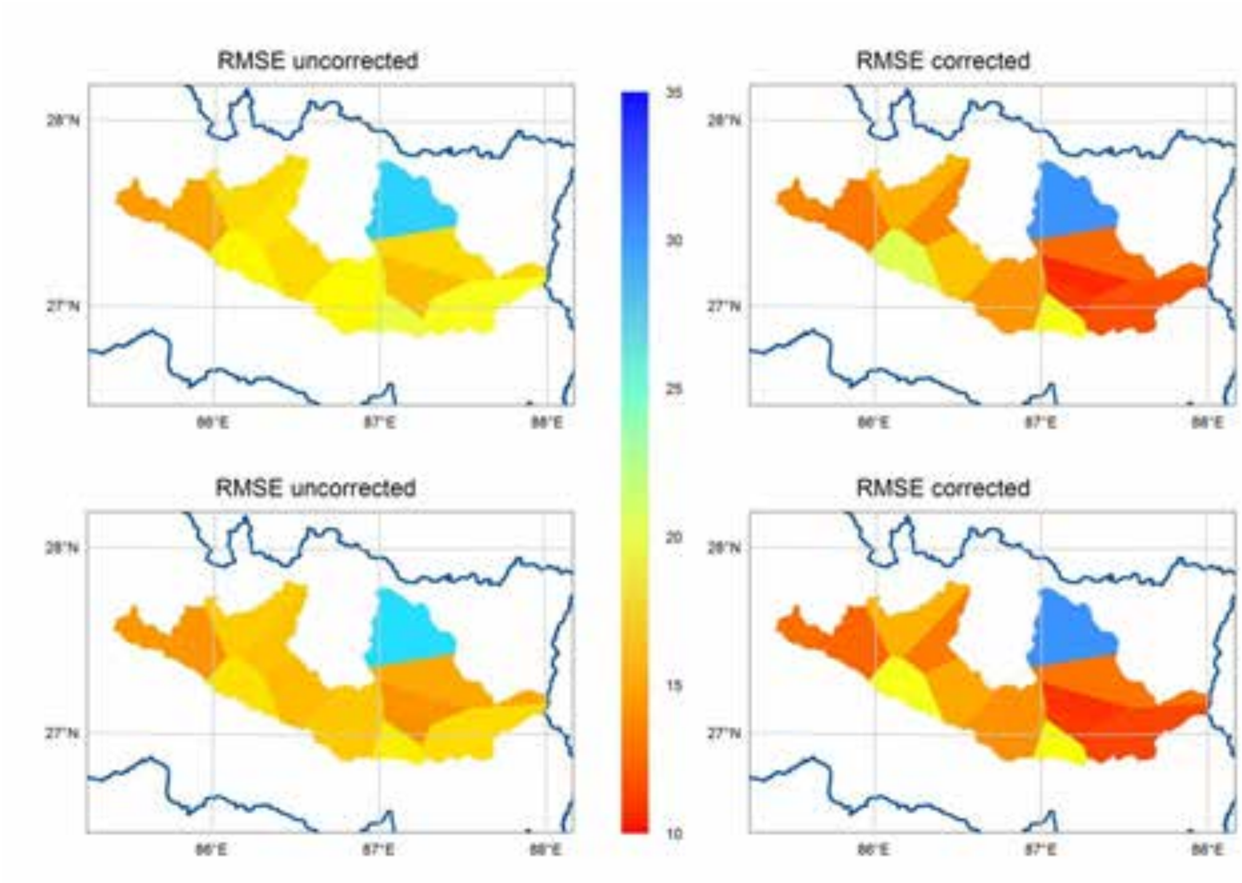



**Figure 5-9: RMSE for the uncorrected and corrected RCM precipitation [mm] per sub-basin of the SWAT model area for the period 1976-2000 (Top – ECHAM05, Bottom – HadCM3)**

### b. Temporal precipitation difference

The Koshi basin is subjected to a strong seasonal pattern with a characteristic monsoon. This aspect is important for the correct timing of flood peaks. Therefore, we are interested to evaluate how well the bias corrected ECHAM05/ HADCM3 precipitation performs temporally.

It is already noticed that the daily average over the entire period has improved considerably. However, it is certainly possible that the average monthly precipitation sums of the corrected ECHAM05/ HADCM3 data differ from those of the observations, although the average ECHAM05/ HADCM3 precipitation over the entire period is unbiased. Average monthly precipitation sums for the observations and the uncorrected and corrected ECHAM05/ HADCM3 data are shown in **Figure 5-10**. Averages are calculated as weighted (based on sub-basin size) averages over the period 1976 – 2000.

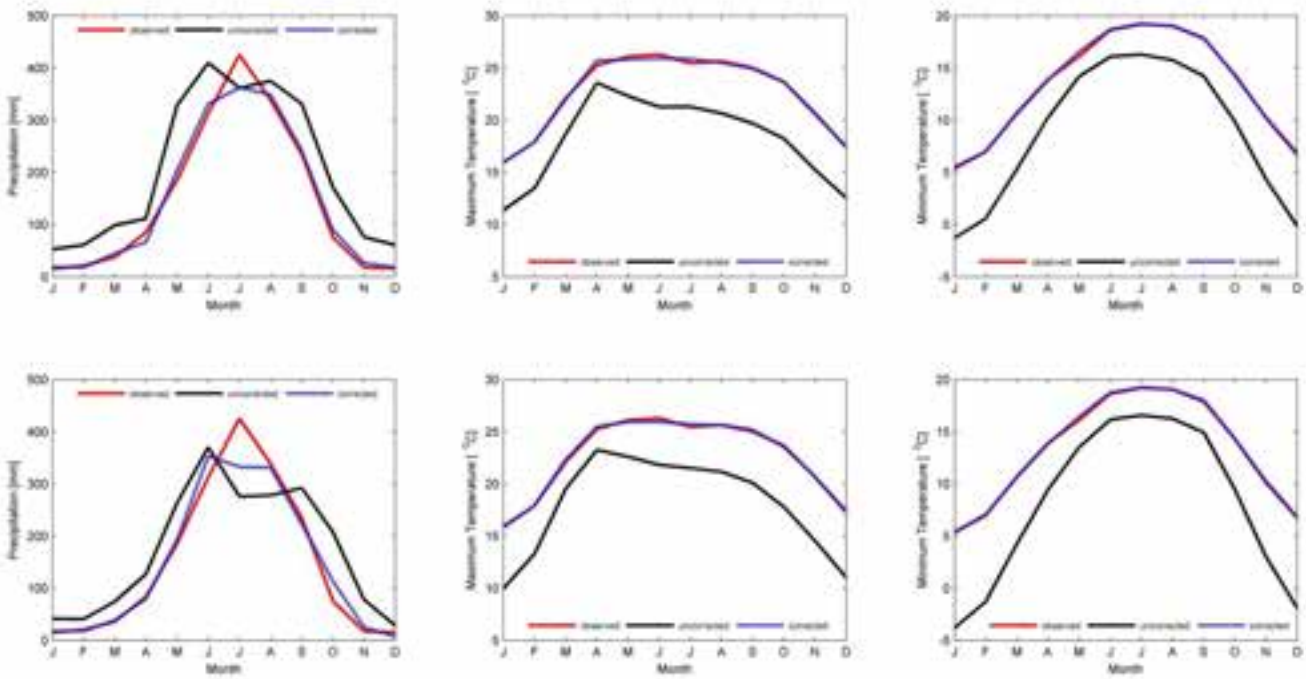


**Figure 5-10: Left - Average monthly precipitation sums [mm] for the observations and the uncorrected and corrected RCM data; Middle - Average monthly maximum temperature [$^0$C]; Right - Average monthly minimum temperature [$^0$C] (SWAT model area; Top – ECHAM05, Bottom – HadCM3)**

Large differences between the observations and the uncorrected ECHAM05/ HADCM3 can be seen during all seasons, too wet for all months except for the month/s of July for ECHAM05 and July and August for HadCM3. However, the bias correction seems to work very well except for the month of July.

To consider both the monthly performance for each year and the performance per sub-basin for SWAT model area, **Figure 5-11** represents the relation between the observed and ECHAM05/ HADCM3 monthly precipitation sums for each year per sub-basin, both for the uncorrected (left plot) and corrected (right plot) situation in a scatter plot. It can be noticed that the monthly precipitation sums for the corrected situation match those of the observations better than those of the uncorrected situation. Based on these results we conclude that the overall performance of the ECHAM05/ HADCM3 precipitation has improved. Similar results for SRM model area can be referred to in **Appendix C-6**.

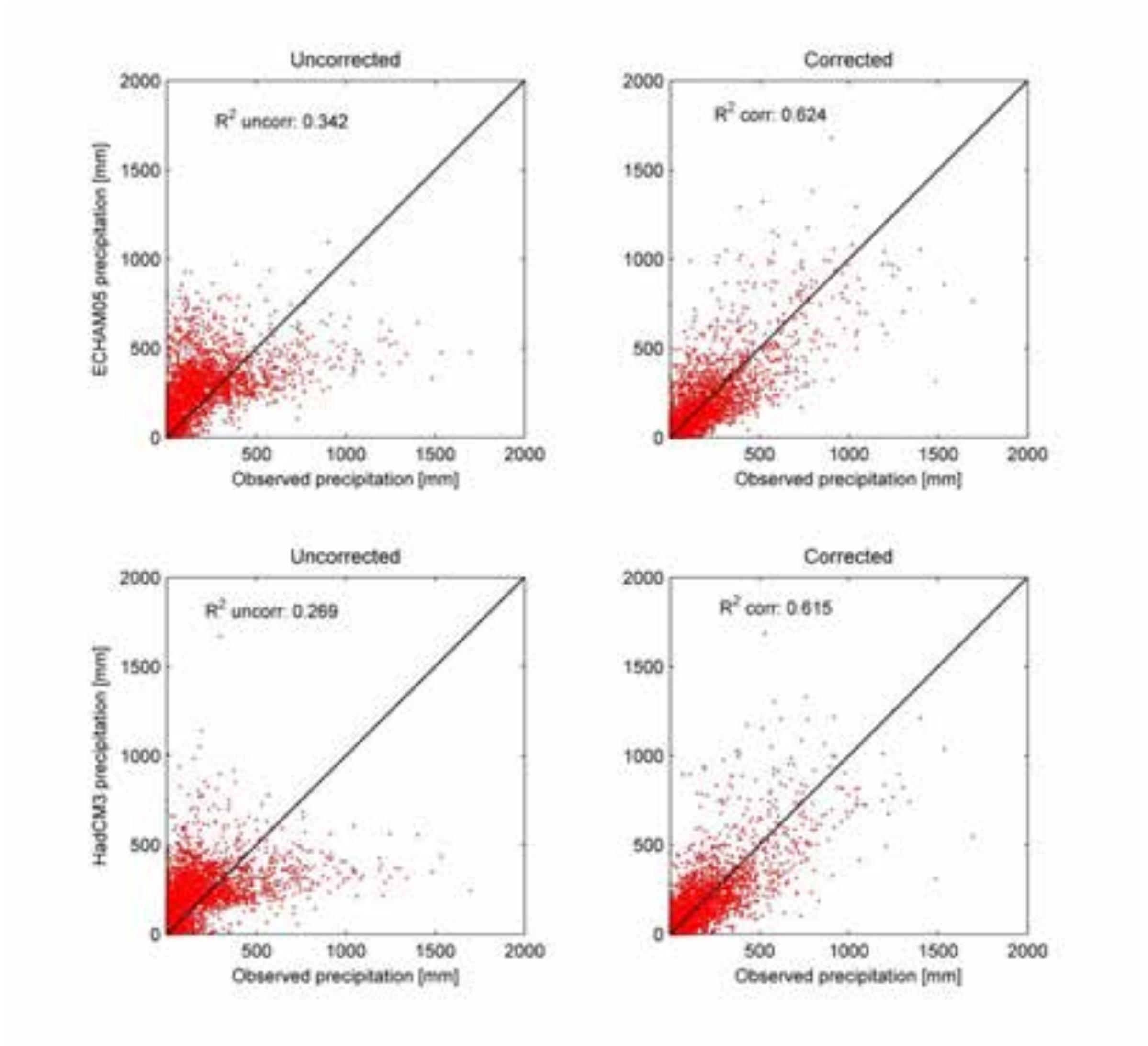



**Figure 5-11: Scatter plots for the uncorrected and corrected RCM data and observed monthly precipitation sums for each year per sub-basin for the SWAT model area (Top – ECHAM05, Bottom – HadCM3)**

### Temperature

#### a. Spatial temperature difference

The MBE for the uncorrected and corrected ECHAM05/ HADCM3 maximum temperature for each sub-basin of the SWAT model area is shown in **Figure 5-12**. A negative value corresponds to a lower maximum temperature for the uncorrected ECHAM05/ HADCM3 data set. Differences in MBE vary between -11 $^0$C and +1 $^0$C for the uncorrected ECHAM05/ HADCM3 data. The MBE is negative for the largest part of the Koshi basin (refer **Appendix C-7** for SRM model area), which means that the uncorrected ECHAM05/ HADCM3 is less warm than the observations for most of the Koshi basin. The right panel of **Figure 5-12** shows the differences between both data sets after the correction has been applied. It can be concluded that the bias correction for temperature leads to good results. Differences have decreased substantially to values between −0.019 to +0.016 $^0$C and -0.038 to -0.004 $^0$C for corrected HadCM3 and corrected ECHAM05 datasets respectively.

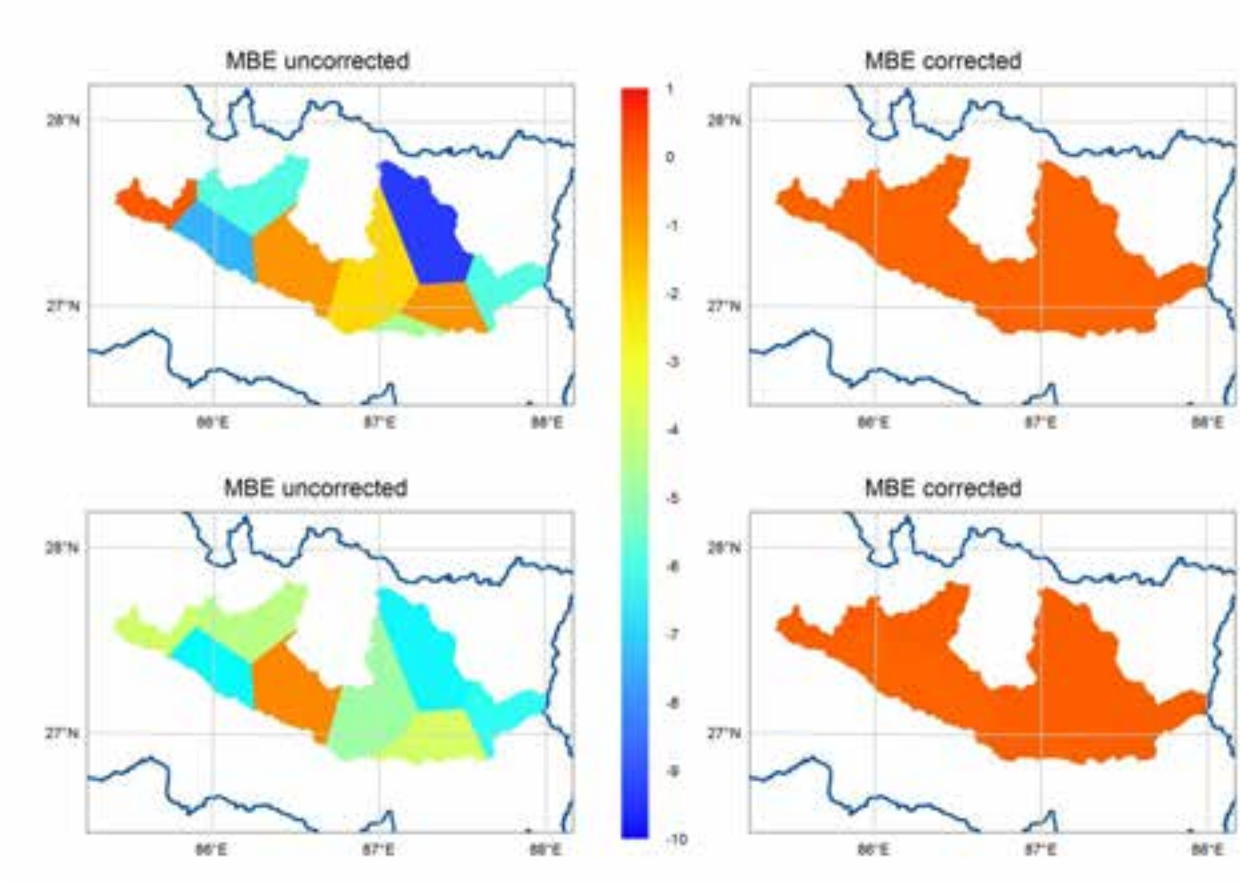



**Figure 5-12: MBE for the uncorrected and corrected RCM maximum temperature [$^{0}$C] per sub-basin of the SWAT model area for the period 1976-2000 (Top – ECHAM05, Bottom – HadCM3)**

Another point of interest is the spatial variation in the spread of daily temperature differences per sub-basin. This is quantified by the RMSE of the daily maximum temperature difference between ECHAM05/ HADCM3 and the observations **(Figure 5-13**). In the uncorrected situation the RMSE is quite large for some sub-basins. However, the RMSE for the corrected maximum temperature has decreased significantly. Similar results are found for minimum temperature for SWAT model area (refer **Appendix C-8** ). Based on these results it can be concluded that the applied correction method adjusts the daily temperature values very well.

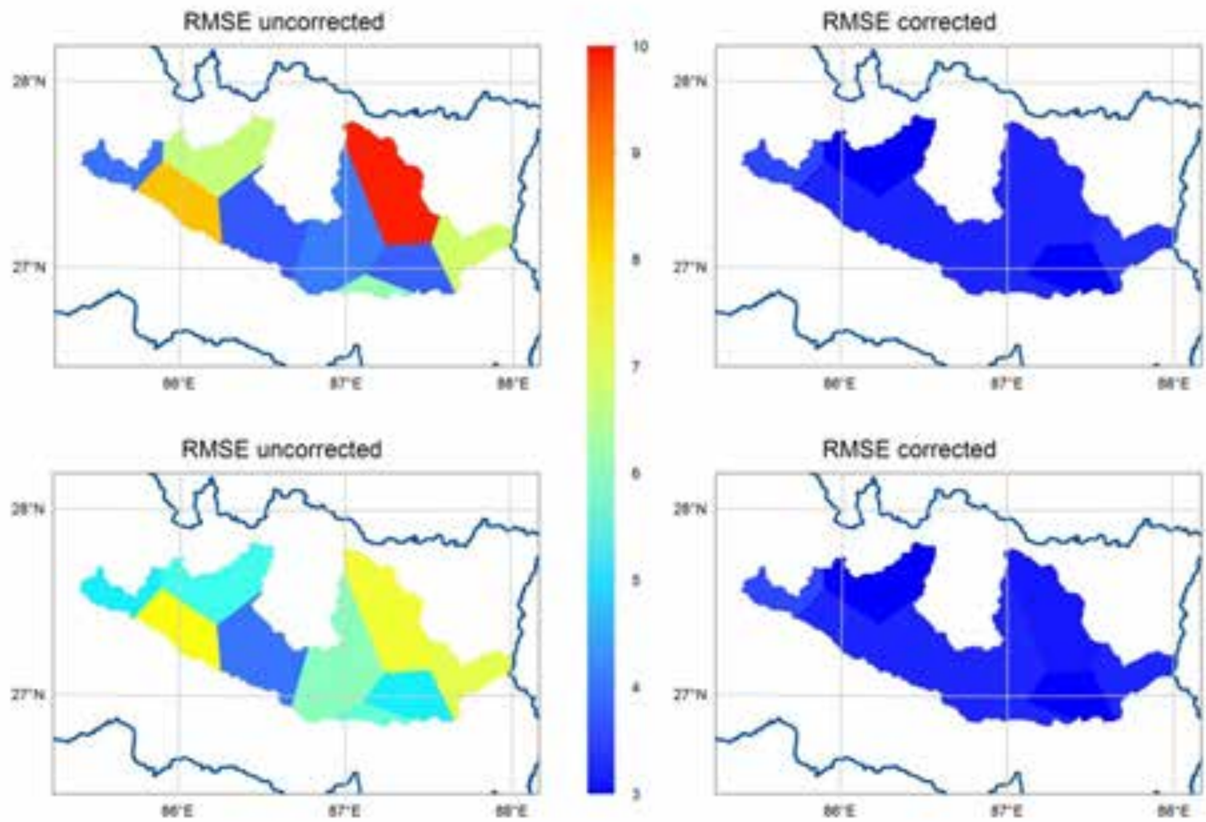



**Figure 5-13: RMSE for the uncorrected and corrected RCM maximum temperature [$^0$C] per sub-basin of the SWAT model area for the period 1976-2000 (Top – ECHAM05, Bottom – HadCM3)**

**b. Temporal temperature difference**

Average monthly maximum and minimum temperatures for the period 1976–2000 are shown in **Figure 5-10**. Averages are calculated as area-weighted averages over the entire Koshi basin. It can be concluded that the bias correction for temperature leads to satisfactory results even with respect to seasonality. The bias-corrected ECHAM05/ HADCM3 temperature matches the observed temperature very well for each month. Corrections are smallest during the initial pre-monsoon months for maximum temperature while it is smallest during later pre-monsoon months for minimum temperature. However, it can be seen that the uncorrected RCM temperature datasets (both maximum and minimum) are colder compared to the observed data.

### 5.4.3 Bias Corrected Projected RCM data

**Rainfall**

**a. Monthly Rainfall**

From **Figure 5-14**, it was observed that there has been visible shift the peak rainfall pattern from the July-August (in historic pattern from 1976 to 2000) to the June-July in future time period from 2030 to 2060. The amount of the rainfall during those peak months (June to August) was observed to have increased in ECHAM05 model while it was almost evenly distributed in the HadCM3 in comparison to the historic pattern. Monthly average of ECHAM05 shows most of the rain falling during the peak months while that of HadCM3 shows wider temporal spread of annual rainfall.

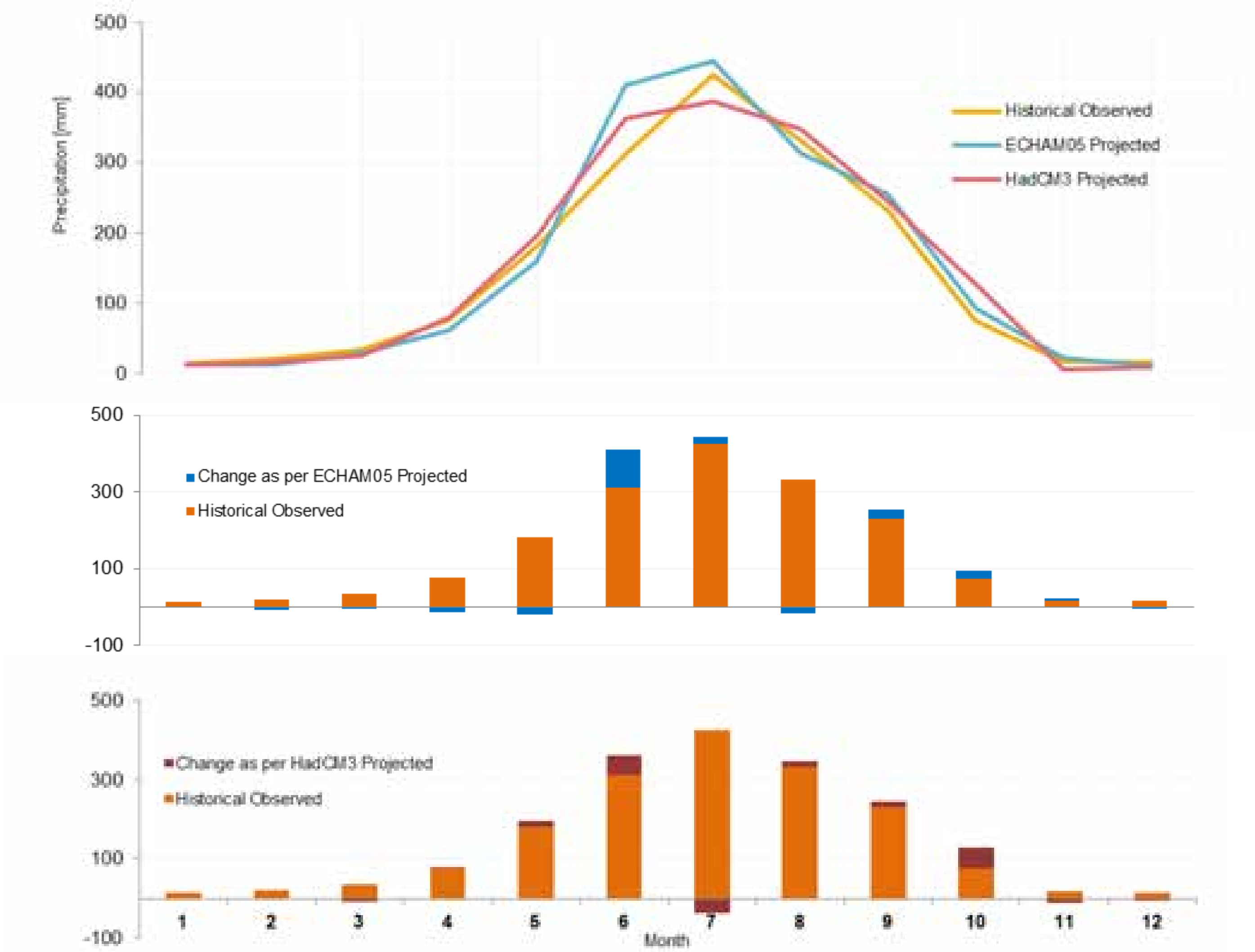



**Figure 5-14: Top: Basin averaged average monthly rainfall values for the SWAT model area for historical/ observed data and the RCM data. Middle: Change in the average monthly precipitation values from the observed data for ECHAM05. Bottom: Same for HadCM3**

## b. Annual Rainfall

**Figure 5-15** shows that the increasing precipitation trend of the historic data has been further enhanced in both the RCM projections. The average values have also increased by 89 mm and 78 mm for ECHAM05 and HadCM3 respectively. However, both the RCM data show a decrease in the amount of rainfall from 2020/2030 to 2050 but significant increase from 2050-2060 such that overall trend from 2030 to 2060 is increasing.

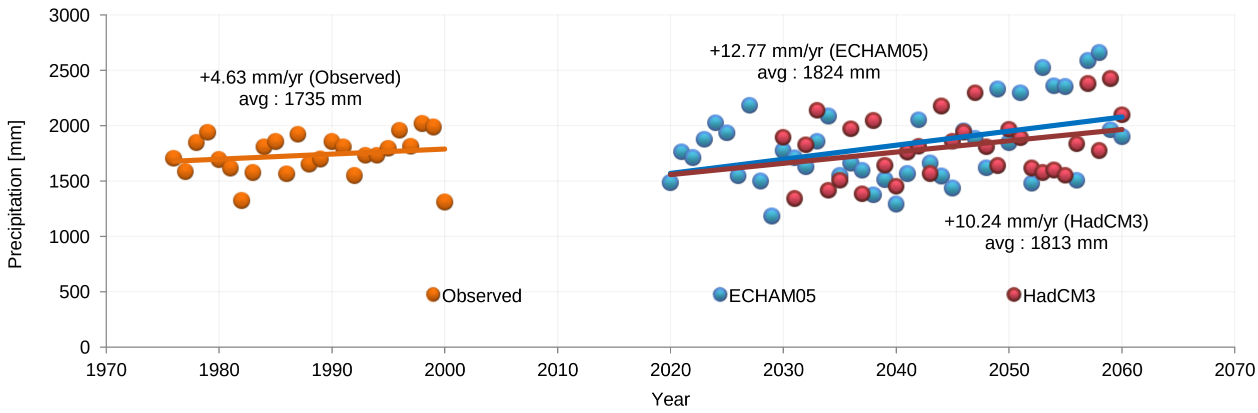



**Figure 5-15: Basin averaged annual precipitation comparison between historical and RCM projected data (including trend and average values) for the SWAT model area**

## c. Extreme Events

The occurrence of extreme events of precipitation is analyzed using probability of exceedance curve as shown in Figure 5-16. The historical and the projected trends exhibit opposite behavior of occurrence. It can be seen that the frequency of extreme events have increased in the RCM projections compared to the historical trend. While the more frequent magnitudes in the historical data (%exceedance > 5) appear to occur less frequently in the projected RCM data. Moreover, a comparison between the RCM projections shows that this inversion of occurrence is more pronounced in ECHAM05 projection.

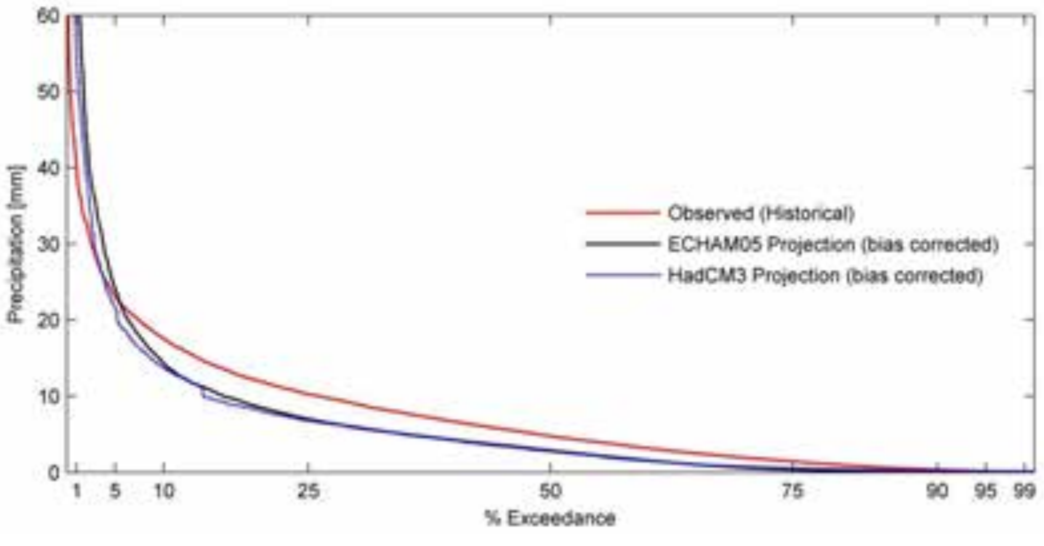



**Figure 5-16: Percentage Exceedance graph for precipitation values from historical and bias corrected RCM data sets for the SWAT model area**

## Temperature

### a. Monthly Temperature

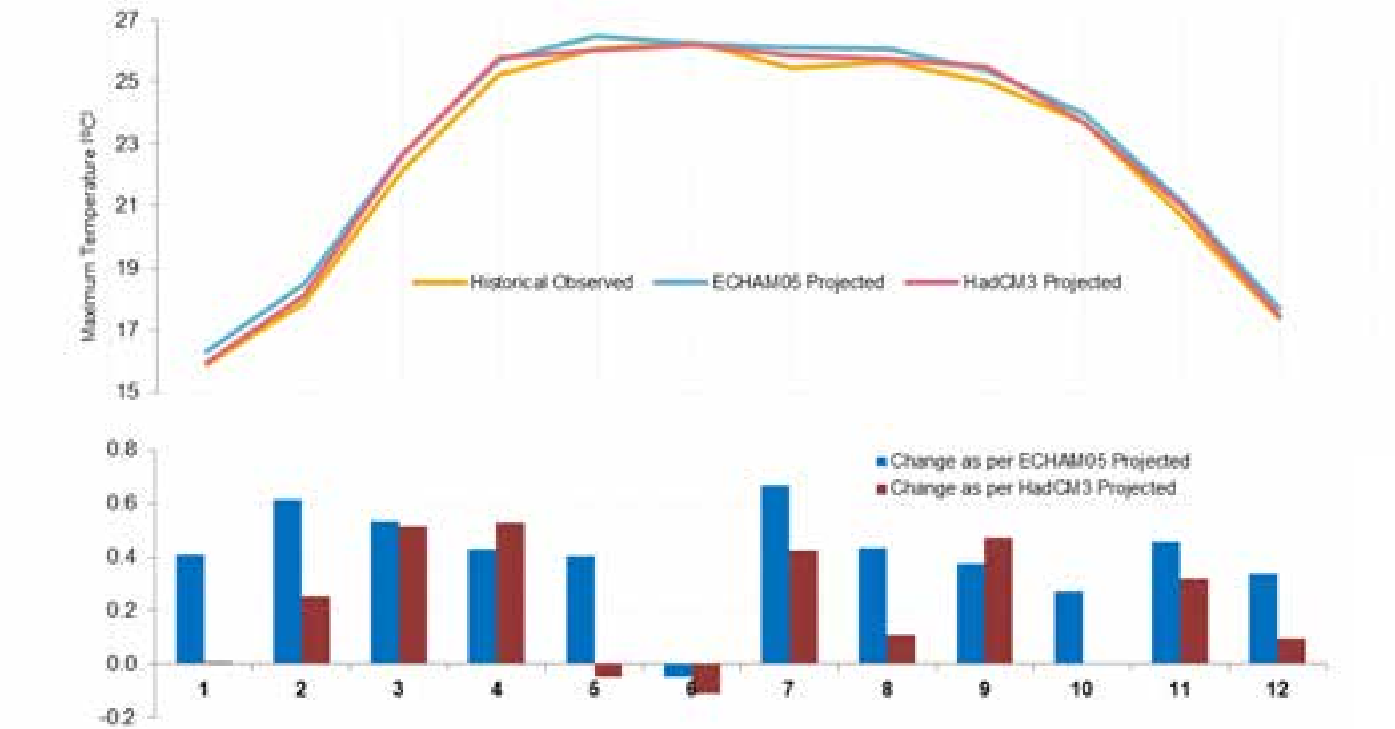



**Figure 5-17: Top: Basin averaged average monthly maximum temperature values for the SWAT model area for historical/ observed data and the RCM data. Bottom: Change in the average monthly maximum temperature values from the observed data for ECHAM05 and HadCM3**

There has been clear increase in the average monthly maximum temperature in the future from 2030-2060 except for the month of June (refer **Figure 5-17**). The rise in monthly averages is more pronounced for ECHAM05 with the increase ranging from 0.27 to 0.67 $^{0}$C. Same can be observed for the average monthly minimum temperature (refer **Figure 5-18**) with values increasing for all months. It can be concluded that both HadCM3 and ECHAM05 projections of temperature (both min and max) are warmer compared to the observed data, the latter one again being the warmer of the two.

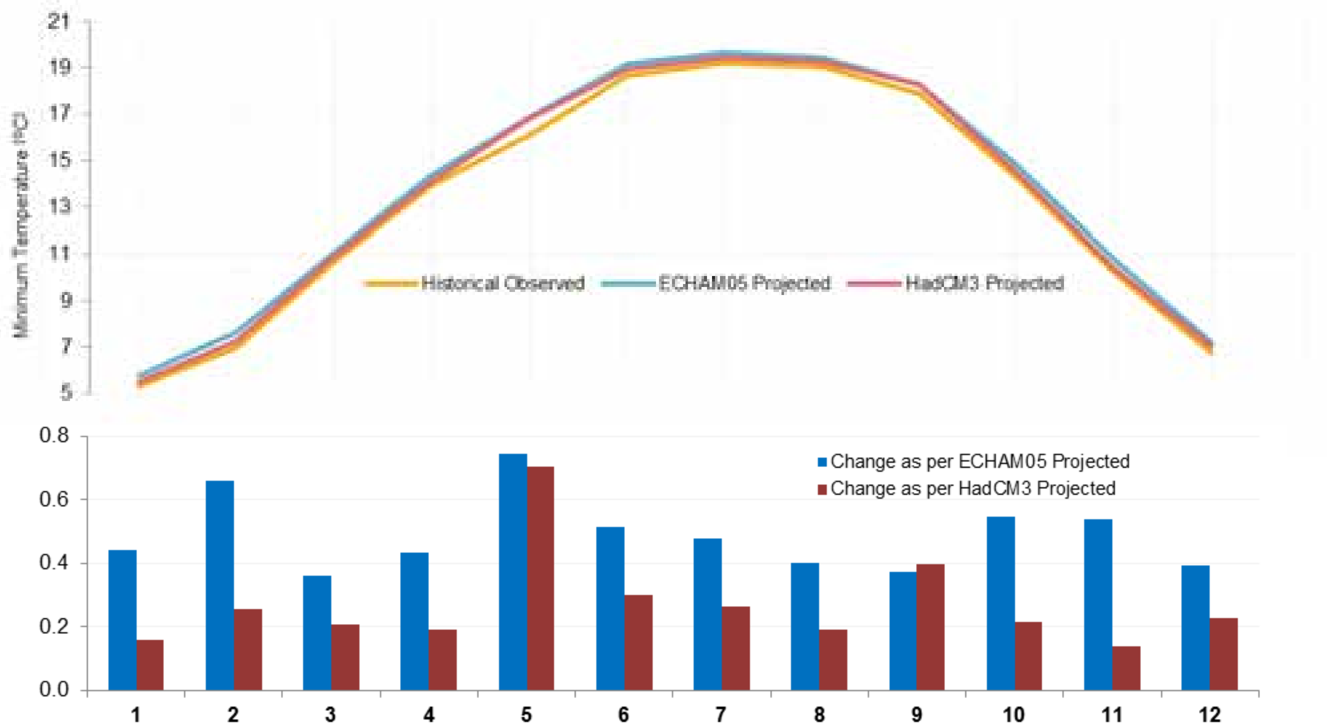



**Figure 5-18: Top: Basin averaged average monthly minimum temperature values for the SWAT model area for historical/ observed data and the RCM data. Bottom: Change in the average monthly minimum temperature values from the observed data for ECHAM05 and HadCM3**

### b. Annual Temperature

Due to the rise in annual average maximum temperature in the last decade of the 20$^{th}$ century (**Figure 5-19**) the historical data shows an average trend of 0.114 $^0$C rise in maximum temperature per annum. In spite of a dip in the decade 2030-40, both RCM projections values of maximum temperature rise in the last decade 2050-60 to maintain a positive but much flatter trend . However, both models shows the increase in average of daily mean temperature of 0.39 $^0$C (ECHAM05) and 0.21 $^0$C (HadCM3).

The case with trend for annual average minimum temperature is different. The annual rise is increasing from 0.014$^0$C/year of the historical data to 0.053$^0$C/year and 0.049$^0$C/year for ECHAM05 and HadCM3 while the average values have also been found to be increasing. Thus RCM projections suggest that the average annual maximum and minimum temperature will come closer in future (2020-2060).

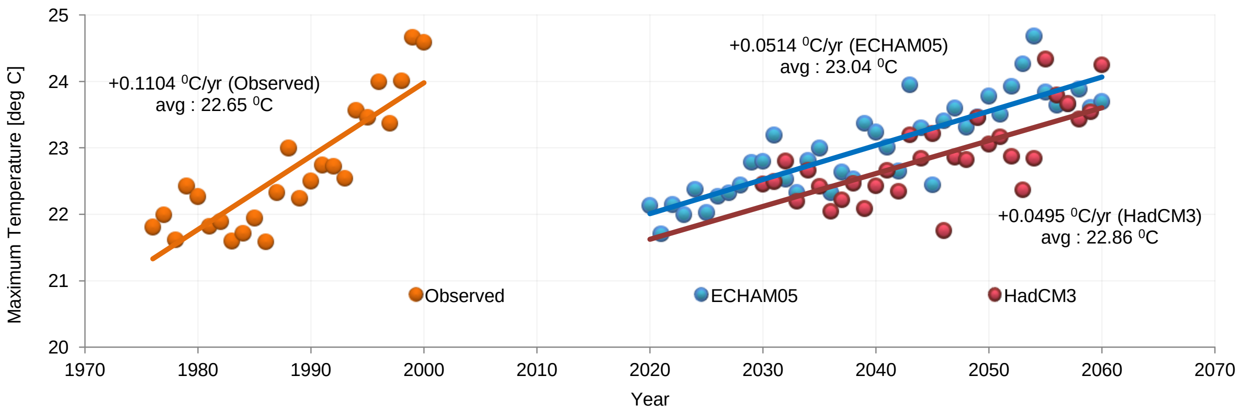



**Figure 5-19: Basin averaged annual average maximum temperature comparison between historical and RCM projected data (including trend and average values) for the SWAT model area**

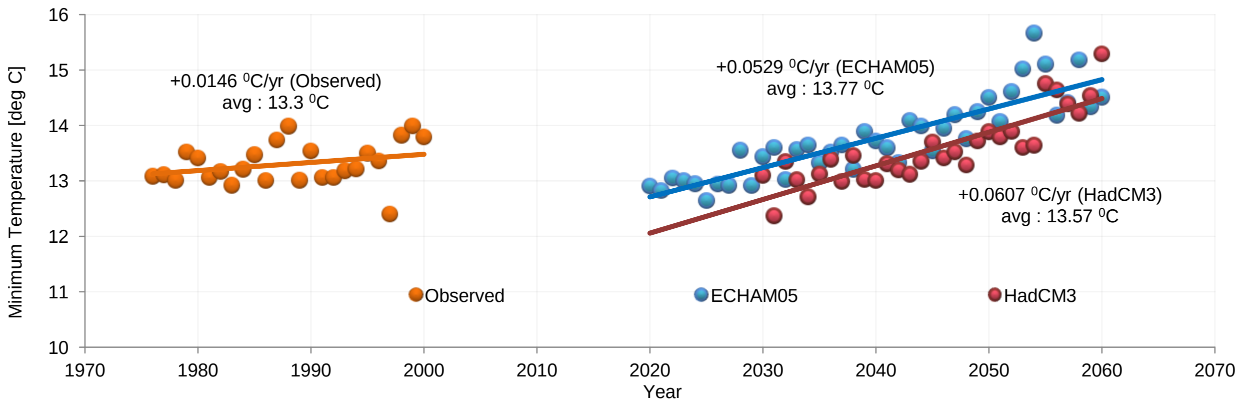



**Figure 5-20: Basin averaged annual average minimum temperature comparison between historical and RCM projected data (including trend and average values) for the SWAT model area**

# Chapter 6: Snow Melt Runoff Modeling

## 6.1 Study area:

The investigated five sub-basins are located in Koshi river basin, starting from Tamor in the East to Sunkoshi at west of the Koshi river basin. These basins are situated from lowest elevation of 432m to high mountainous region above 7000m with large area of perennial snow and ice. The physical characteristics of each sub-basins and the network of stations within are displayed in **Table 6-1** and **Figure 6-1**. Area of the basin, elevation zones and the SRM parameters are the main characteristics of a basin. So each sub-basin is divided into several elevation bands from which snow melt is calculated. The drainage basin is divided with an equal interval of 500m at elevation above 3000m and approximately by 1000m below an elevation of 3000m of the basin.

**Table 6-1: Characteristic of subbasins**

| Sub-basins | Tamor | Arun | DudhKoshi | Tamakoshi | Sunkoshi |
|---|---|---|---|---|---|
| **Gauging Station** | Majhitar | Uwagaon | Rabuwabazar | Busti | Pachuwarghat |
| **Latitude** | 27°9'40''-27° 57'10'' | 27°29'42''- 29° 00'04'' | 27°14'09''- 28° 06'23'' | 27°37'32''- 28° 19'06'' | 27°31'30''- 28° 30'56'' |
| **Longitude** | 87°26'39''- 88° 11'48'' | 85°52'27''- 88° 56'55'' | 86°26'05''- 87° 00'46'' | 85°59'56''- 89° 34'32'' | 85°26'30''- 86° 19'01'' |
| **Elevation of gauging station (m)** | 432 | 1294 | 460 | 849 | 589 |
| **Elevation range, m** | 358-8387 | 874-8776 | 432-8763 | 797-7311 | 545-7938 |
| **Drainage area, Km²** | 4267.03 | 28225.43 | 3968.46 | 3132.23 | 5187.45 |
| **Precipitation[i], mm** | 1741 | 1224 | 1965 | 2051 | 2666 |
| **Snow cover area, Km²** | 787.30 | 2536.72 | 712.60 | 744.98 | 692.36 |
| **% of Snow cover area,** | 18.45 | 8.99 | 17.96 | 23.78 | 13.35 |
| **No. of Glacier lakes[ii]** | 209 | 81 | 243 | 13 | 29 |
| **% of Basin area above 5000m** | 21.58 | 39.18 | 29.47 | 55.75 | 37.98 |
| **% of SCA above 5000m** | 58.61 | 16.95 | 46.59 | 31.53 | 27.50 |
| **% of Basin area (3000-5000 m)** | 37.01 | 59.18 | 32.72 | 38.45 | 25.32 |
| **% of SCA (3000-5000m)** | 12.99 | 3.74 | 10.02 | 14.07 | 9.78 |
| **No. of Meteorological Stations** | | | | | |
| **Precipitation** | 3 | Aphrodite | 4 | 4 | 6 |
| **Temperature** | 1 | 1 | 2 | 2 | 2 |
| **No. of elevation zones** | 12 | 11 | 13 | 11 | 11 |

i- Average precipitation from the network of stations available, ii-ICIMOD, March 2011

## 6.2 Data used:

### 6.2.1 Hydro-meteorological data

Daily observed hydro-meteorological data available from DHM is used in the basins. The daily records of discharge, temperature and precipitation data from the year 2000 to 2008 is used for model input. The year 2001 is used for calibration and the other years are used for validation in all sub-basins. Altogether17 precipitation stations and 8 temperature stations are used in the basin. The details of hydro-meteorological stations used for each sub-basin is listed in **Table 6-2**.


**Figure 6-1: Hydro-Meteorological stations for sub-basins**

Good-quality climatic data observations ensure successful model performance while station data from less favorable conditions in larger basins would deteriorate model efficiency with the decreasing quality of basic data (Rango and Martinec, 1981). The missing values in the data were hence interpolated by following arithmetic procedure from neighboring stations know as Normal ratio method (NRM).Normal ratio method (NRM) is used when the normal annual precipitation at any of the index station differs from that of the interpolation station by more than 10%. But for simplicity, it is assumed that all the annual precipitation differ by more than 10%. The traces (T) available in the data indicate an event of precipitation that is usually below the detectable limit so these values are replaced by zero in this study. While interpolation of missing air temperature data is done by using monthly lapse rate value, generated from known and missing temperature stations located at specific elevation. The precipitation amounts at the index stations are weighted by the ratios of their normal annual precipitation data in a relationship form (Equation (**6-1**)):

$$P_m = \frac{1}{n}\sum_{i=1}^{n}\left[\frac{N_m}{N_i}P_i\right] \qquad \textbf{(6-1)}$$

Where,

$P_m$ = Precipitation at missing location

$P_i$ = Precipitation at index station

$N_m$ = Average annual rain at 'missing data' gauge

$N_i$ = Average annual rain at gauge

n = Number of rain gauges

For climate change assessment in the future, bias corrected temperature and precipitation data of PRECIS –ECHAM (2020-2060) and HadCM3 (2030-2060) is being used for all the stations listed in **Table 6-2.** The available stations at different elevation are used for measuring the snow melt rates from respective sub-basins while the hydrological stations (discharge data) are used for the purpose of calibration and validation.

**Table 6-2: Hydro-meteorological stations for sub-basins**

| Sub-basins | Station Id. | Station | Type | Elevation | Latitude | Longitude |
|---|---|---|---|---|---|---|
| **Tamor** | 1420 | Dovan | P | 763 | 27.35 | 87.6 |
| | 1403 | Lungthung | P | 1780 | 27.55 | 87.78 |
| | 1314 | Terathum | P | 1633 | 27.13 | 87.55 |
| | 1405 | Taplejung | T | 1732 | 27.35 | 87.67 |
| | 684 | Majhitar | Q | 432 | 27.16 | 87.71 |
| **Arun** | 1304 | Pakhribas | T | 1680 | 27.03 | 87.17 |
| | 600.1 | Uwagaon | Q | 1294 | 27.6 | 87.33 |
| **Dudhkoshi** | 1204 | Aisealukharka | P | 2143 | 27.35 | 86.75 |
| | 1203 | Pakarnas | P | 1982 | 27.43 | 86.57 |
| | 1219 | Salleri | P | 2378 | 27.5 | 86.58 |
| | 1202 | Chaurikharka | P | 2619 | 27.7 | 86.72 |
| | | Syangboche | T | 3833 | 27.81 | 86.71 |
| | | Dingboche | T | 4355 | 27.89 | 86.78 |
| | 670 | RabuwaBazar | Q | 460 | 27.27 | 86.66 |
| **Tamakoshi** | 1101 | Nagadaha | P | 850 | 27.68 | 86.1 |
| | 1102 | Charikot | P | 1940 | 27.67 | 86.05 |
| | 1103 | Jiri | T | 2003 | 27.63 | 86.23 |
| | | TshoRolpa | T | 4580 | 27.83 | 86.47 |
| | 647 | Busti | Q | 849 | 27.63 | 86.08 |
| **Sunkoshi** | 1023 | Dolalghat | P | 710 | 27.63 | 85.72 |
| | 1018 | Baunepati | P | 845 | 27.78 | 85.57 |
| | 1006 | Gumthang | P | 2000 | 27.87 | 85.87 |
| | 1058 | Tarkeghyang | P | 2480 | 28 | 85.55 |
| | 1027 | Barabhise | P | 1220 | 27.78 | 85.9 |
| | 1017 | Dubachaur | P | 1550 | 27.87 | 85.57 |
| | 1036 | Panchkhal | T | 865 | 27.68 | 85.63 |
| | 1024 | Dhulikhel | T | 1552 | 27.62 | 85.55 |
| | 630 | Pachuwarghat | Q | 589 | 27.56 | 85.75 |

*P = Precipitation, T = Temperature, Q = Discharge

### 6.2.2 Snow cover satellite data

Satellite derived snow cover data is one of the important input in snow melt runoff modeling. Properties of snow are used as a basis for snow mapping procedure. The snow cover data for each sub-basin is derived using Moderate Resolution Imaging Spectroradiometer (MODIS) with a spatial resolution of 500m by 500m and high spectral resolution ranging from 0.4 to 2.4 μm wavelength on NASA Earth Observing System (EOS) platform. The MODIS snow-mapping algorithm is fully automated and is based on the Normalized difference snow index (NDSI) and a set of thresholds (Hall et. al., 2002). Based on NDSI and threshold values, snow cover pixels are separated from non-snowy areas. The data set used is the L3 global 500m grid, a daily product from both MOD10A1Aqua and Terra Version (Gurung, et al., 2011) extracted from 4$^{th}$ March of 2000 to 2011.

The snow cover area (SCA) includes snow, lake ice and lake in the study. The SCA for each sub-basin is extracted with respect to its reclassified elevation zones and is then used for generating convention depletion curve (CDC). The proportion of snow coverage to its total area on each day for each zoneis calculated as snow depletion data and is used as input into snowmelt model. The snow cover data is extracted from the year 2000 to 2011 for each sub-basin (**Figure 4-17**) and the zonal snow cover area derived for each basins is shown in **Table 6-1**.Generally the precipitation in country falls as snow at an elevation above 3000m (WECS, 2011) and the snow data extracted above this elevation is only considered in the model.

### 6.2.3 Topographical data

Area and elevation zone of the basin can be determined by using topographic map at any scale or can be determined using DEM of the basin. The topographical data is derived from The Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) DEM of 30m by 30m spatial resolution. This DEM is used to delineate catchment boundaries and further used for reclassifying into several elevation bands using 3D Analyst tools in ArcGIS9.3 as displayed in **Figure 6-2**. These reclassified bands of respective basins are also used for extraction of Snow Cover Area (SCA).

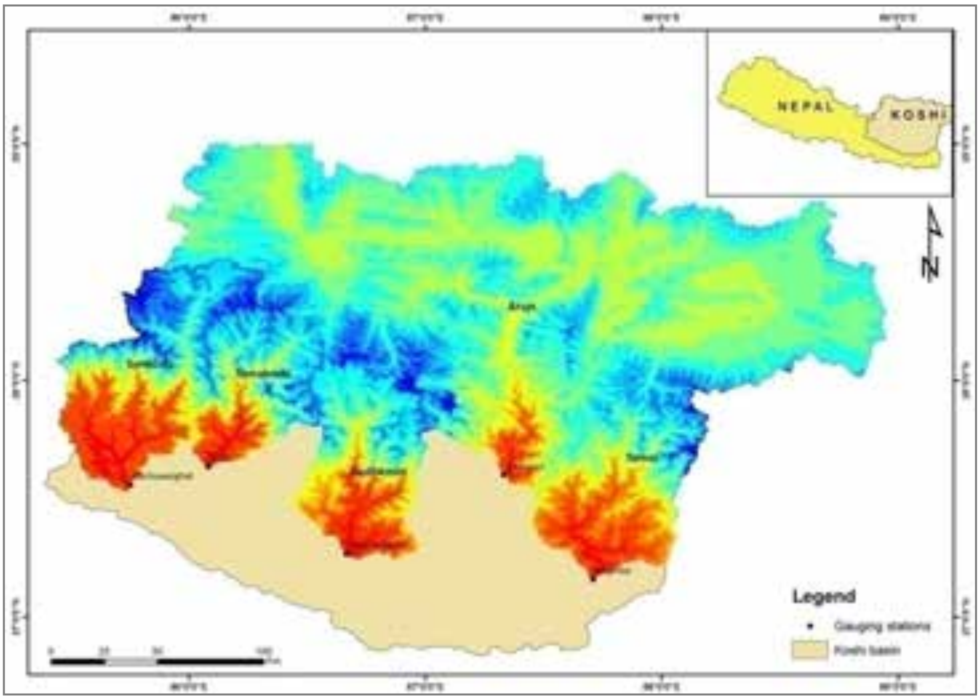



**Figure 6-2: ASTER derived DEM of sub-basins**

The area elevation and hypsometric data extracted is used to extrapolate temperature and precipitation from the base station to its respective hypsometric elevation. The zonal hypsometric mean elevation is determined by calculating half area of each zone as well as adding it to total area of zones below it. The area elevation curve for sub-basins is shown in **Figure 6-3.**

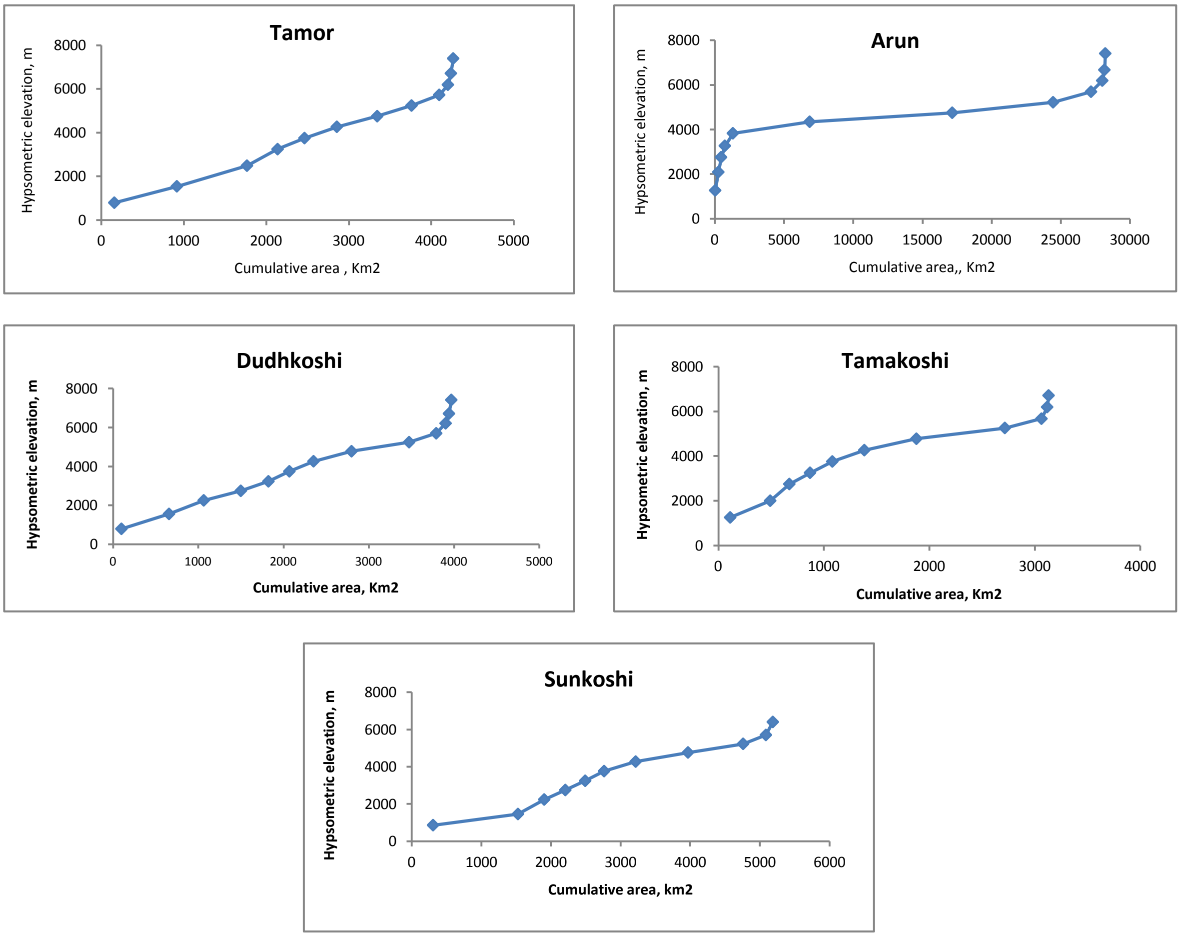



**Figure 6-3: Area elevation curve of sub-basins**

## 6.3 Model input

### 6.3.1 Estimation of temperature

Temperature is an important input of SRM. An average of maximum and minimum temperature is used in the model. The available temperature data in the basin is lapsed with hypsometric mean elevation of the zone and this extrapolated temperature data is used to estimate daily snow melt depth for each elevation band. The adjustment value of number of degree day for each elevation zone is computed by Equation **(6-2)**:

$$\Delta T = \gamma.\left(h_{st} - \bar{h}\right).\frac{1}{100} \qquad (6\text{-}2)$$

Where γ is temperature lapse rate; $h_{st}$ is altitude of the temperature base station; $\bar{h}$is mean hypsometric elevation for a giver zone.

### 6.3.2 Estimation of precipitation

In basin with great elevation range, precipitation distribution and determination are the important factors for determining the accurate estimates of runoff volume. In glacier dominated HKH region, there are five to tenfold increase in precipitation from glacier termini (2500m) to accumulation zones above 4800m (Akhtar et al., 2008**).** Maximum precipitation occurs between 5000 and 6000m (Hewitt, 1993-cited in Akhtar et al., 2008). To estimate the precipitation in the basin, extrapolation of precipitation data to the mean hypsometric elevation of the respective zone by an altitude gradient is suggested. Precipitation is defined as function of altitude in the snow and glacier dominated catchment in Nepal (Higuchi et al., 1982).Precipitation in Langtang valley was found to be 1.3 times greater at 5000m than 4000m (Seko, 1987). The following equation (relating precipitation with elevation) developed by Seko (1987) (Equation ***(*6-3)**)has been used in this study to estimate the zonal precipitation for all basins except for Arun river basin.

$$P_{j,n} = P_{BH,n} \qquad \text{For } h_j < 4000\text{m}$$

$$P_{j.n} = P_{BH,n}\left[1 + 0.0003\left(h_j - 4000\right)\right] \qquad \text{For, } 4000\text{m} \le h_j \le 5000\text{m}$$

$$P_{j\,.n} = 1.3.\,P_{BH.n} \qquad \text{For } h_j > 5000m \qquad \textbf{(6-3)}$$

Where,

$P_j$ is precipitation at hypsometric elevation $h_j$ of the zone j,

$P_{BH,n}$ is the precipitation at base station in the n$^{th}$ day.

For multiple stations within an elevation zone, precipitation data is estimated as an average of daily precipitation records from those multiple stations within a zone.

Due to inadequate coverage of meteorological stations within the Arun river basin, *Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation* of Water resources (APHRODITE) daily gridded precipitation data, with a coarse resolution of 30×30 Km$^2$is used to estimate the precipitation data within the basin. APHRODITE data is long-term continental-scale daily product, available from 1951 to 2007 that contains a dense network of daily rain-gauge data for Asia including the Himalayas, South and Southeast Asia and mountainous areas in the Middle East. The product of 0.25×0.25 gridded data has been extracted from current version of V1101 of Monsoon Asia with domain of 60˚E-150˚E; 15˚S-55˚N from the year 2000 to 2007.This gridded data set is overlaid on watershed boundary and is then extracted with respect to elevation zones using ArcGIS9.3. The data has been downloaded from the APHRODITE water resources project web page ***(http://www.chikyu.ac.ip/precip).***

### 6.3.3 Estimation of parameters

Besides the daily temperature, precipitation and snow cover data the basic input variables, there are eight important parameters used in the model. Because the quality of the input data is directly related to the model accuracy and efficiency, the calculation and determination of variables and parameters is also equally important to SRM. However, the methods for calibration of the SRM model variables vary largely, depending on the data availability in a specific study watershed **(Abudu et al., 2012**). Some of these parameters are derived from measurements and some are estimated by hydrological judgement taking the basin characteristics, physical laws, and theoretical relations or empirical regression relations into account (Martinec and Rango, 1986).

Though lapse rate in mountain terrains show great diurnal and seasonal variations around the mean (Barry, 1992), a global mean lapse rate of approximately 6.5°C/Km is used in all sub-basins due to scarce climatological station within the basin except for Tamakoshi (5.32°C/Km). The lapse rate for Tamakoshi sub-basin was generated using temperature data from Jiri and TshoRolpa station. The lapse rate calculated is usually applied to extrapolate temperature using hypsometric elevation to different elevation zones. The source of melting is generally temperature and the degree-day factor that determines the melt depth from snow. It is generally different for snow and ice. A degree day factor ranging from 0.7-1.05cm/°C/day (Kayastha et al., 2003) was taken into account and was distributed with respect to elevation zones of the basin. For elevation below 4000m and above 6000m, the value for degree day factor was taken as snow. Similarly for the elevation range of 4000-6000 m, it was taken as ice where a large number of glaciers are available (ICIMOD, 2011). The different value used with respect to elevation for basins are shown in **Table 6-3a**.

Based on different statistics of meteorological observation, critical temperature is usually found to be higher than the freezing point and shrink close to 0°C as snow melt season proceeds (Hong et al., 2003). However a critical temperature of 0°C was assumed in this study that helps in distinguishing the precipitation event to be rain or snow. For rainfall contributing area a value of 1 was used for elevation up to 4500m and also during the month of May to September at an elevation range of 4500-5500m. This indicates the ripe condition of the snowpack that is ready to melt and all precipitation that falls during the simulation period will immediately transformed into runoff and is not stored in the snowpack. A zero value was used for elevation above 5500m because all precipitation above this elevation was considered as snowfall. This signifies the dry condition of the snow pack and that all fall will be absorbed and added to the snowpack. The degree day factor, critical temperature and RCA (rainfall contributing area or not) are given in **Table 6-3a**.

**Table 6-3 a: Basin Parameters**

| Elevation (m) | a | Tcrit | Lapse rate | RCA |
|---|---|---|---|---|
| **<3500** | 0.7 | 0 | 0.65 | 1 |
| **3500-4500** | 0.75,0.8 | 0 | 0.65 | 1 |
| **4500-5000** | 0.95 | 0 | 0.65 | 1/0* |
| **>5000** | 1.05 | 0 | 0.65 | 1/0* |

*** May-Sept=1; Oct-Apr = 0**

*** Elevation <4000m &> 6000m = Snow; Elevation 4000-6000 = ice**

**a = degree day factor; Tcrit = Critical temp; RCA = Rainfall contributing area**

Time Lag is the time difference between the start of increasing temperatures and the corresponding increase in runoff from the basin. It's an important parameter because snowmelt and its measurements on the gauging station don't correspond to the same instant and is generally determined directly from the hydrographs of the past years. The parameter in this study was computed with respect to time lag in WMO inter-comparison test (WMO, 1986) by using a regression plot of WMO basin area verses time lag as shown in **Figure 6-4.** The lag value for 5 sub-basins is shown in **Table 6-3b**.

**Table 6-3 b: Basin Parameters**

| Sub-basins | Area in $Km^2$ | Time lag (hr) |
|---|---|---|
| **Tamor** | 4267.03 | 13.33 |
| **Arun** | 28225.43 | 15.92 |
| **Dudhkoshi** | 3968.46 | 13.10 |
| **Tamakoshi** | 3132.23 | 12.77 |
| **Sunkoshi** | 5187.45 | 13.48 |

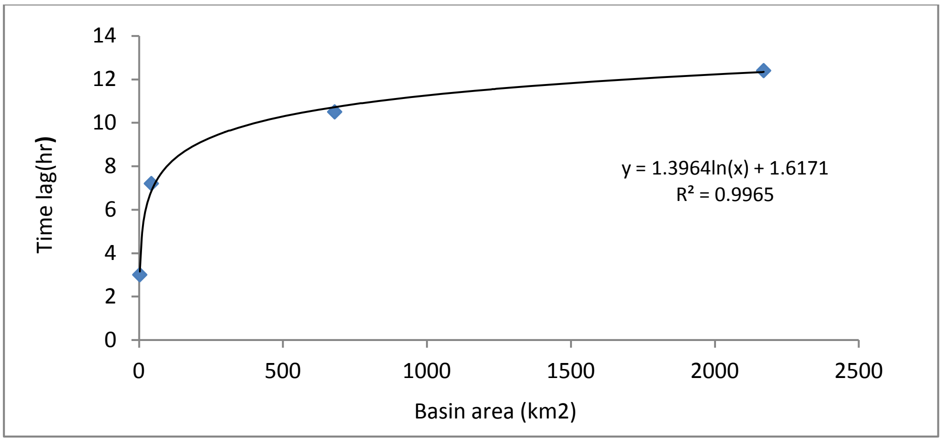



**Figure 6-4 : A regression plot of basin area and time lag**

Runoff and recession coefficient are the most important and sensitive parameters of the model that needs frequent adjustment. Runoff coefficient determines the losses and is generally two type viz. runoff coefficient due to snow and rain. An average monthly runoff coefficient is calculated through historical precipitation and discharge data and is different for each sub-basin and the parameters are illustrated in **Table 6-4**.

**Table 6-4 : Runoff Coefficient for Different Sub-basins**

| Month | Tamor | Arun | Dudhkoshi | Tamkoshi | Sunkoshi |
|---|---|---|---|---|---|
| **Jan** | 0.72 | | 0.339 | | 0.486 |
| **Feb** | 0.66 | | 0.339 | | 0.486 |
| **Mar** | 0.63 | | 0.339 | | 0.486 |
| **Apr** | 0.62 | | 0.339 | | 0.384 |
| **May** | 0.65 | | 0.539 | | 0.421 |
| **Jun** | 0.85 | **0.458** | 0.648 | **0.432** | 0.537 |
| **Jul** | 0.9 | | 0.74 | | 0.558 |
| **Aug** | 0.9 | | 0.64 | | 0.487 |
| **Sep** | 0.9 | | 0.64 | | 0.386 |
| **Oct** | 0.9 | | 0.539 | | 0.386 |
| **Nov** | 0.84 | | 0.339 | | 0.386 |
| **Dec** | 0.83 | | 0.339 | | 0.386 |
| **Average** | 0.783 | 0.458 | 0.482 | 0.432 | 0.449 |

Realistic value of runoff coefficient due to snow is 0.3 in semi-arid climates to 1.0 for fast snowmelt (Martinec, et al., 1986). A coefficient value ranging from 0.7 to 0.9 is used in Beas basin in India. Yichi, Z. et al (2007) used similar values of runoff coefficient for snow and rain in Kaidu river basin (0.5-0.75) with respect to elevation. Similarly Martinec, et al (2008) used equal value of runoff coefficient (0.7 in Jul-Sept/0.8 in Oct) in Illecillewaet basin of Canada. So for simplicity, an equal value of runoff coefficient for rain and snow was used in this study and was optimized according to the basin.

Recession Coefficient indicates the proportion of daily melt water of snow contribution to the daily runoff (Hong et al., 2003). It was determined through historical discharge data based on equation **(6-4)**,

$$\boldsymbol{k_{n+1} = x \cdot Q_n^{-y}} \qquad \textbf{(6-4)}$$

Where,

x and y are two constant to be determined and $Q_n$is the discharge on the nth day. The parameters x and y are calculated for each month by plotting values of $Q_n$and $Q_{n+1}$ against each other and the values for each basin are shown in **Table 6-5**. However a slight adjustment of parameter within a range was made to generate a best fit result for the basins.

**Table 6-5: Recession Coefficient**

| **Sub-basin** | **Tamor** | | **Arun** | | **Dudhkoshi** | | **Tamakoshi** | | **Sunkoshi** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Month** | X | Y | X | Y | X | Y | X | Y | X | Y |
| **Jan** | 1.2551 | 0.055 | 1.1535 | 0.034 | 1.0205 | 0.004 | 1.253 | 0.064 | 1.2168 | 0.049 |
| **Feb** | 1.3783 | 0.159 | 1.1535 | 0.034 | 1.184 | 0.048 | 1.253 | 0.064 | 1.4139 | 0.092 |
| **Mar** | 1.3738 | 0.087 | 1.1535 | 0.034 | 1.1108 | 0.038 | 1.253 | 0.064 | 1.1603 | 0.045 |
| **Apr** | 1.0963 | 0.036 | 1.1535 | 0.034 | 1.5818 | 0.138 | 1.253 | 0.064 | 1.4268 | 0.091 |
| **May** | 1.0058 | 0.035 | 0.9777 | 0.008 | 1.1663 | 0.057 | 1.1408 | 0.053 | 1.0305 | 0.011 |
| **Jun** | 1.0058 | 0.041 | 0.9777 | 0.008 | 1.1162 | 0.041 | 1.0076 | 0.029 | 1.0669 | 0.026 |
| **Jul** | 1.0058 | 0.026 | 0.9777 | 0.008 | 1.1606 | 0.076 | 1.253 | 0.064 | 1.0032 | 0.027 |
| **Aug** | 1.0058 | 0.065 | 0.9777 | 0.008 | 1.1706 | 0.076 | 1.253 | 0.064 | 1.0028 | 0.057 |
| **Sep** | 1.0538 | 0.029 | 0.9777 | 0.008 | 1.0479 | 0.021 | 1.253 | 0.064 | 1.0628 | 0.029 |
| **Oct** | 1.0477 | 0.022 | 0.9777 | 0.008 | 1.0752 | 0.029 | 1.253 | 0.064 | 1.0102 | 0.008 |
| **Nov** | 1.0072 | 0.005 | 1.1535 | 0.034 | 1.4317 | 0.097 | 1.253 | 0.064 | 1.034 | 0.016 |
| **Dec** | 1.0839 | 0.022 | 1.1535 | 0.034 | 1.6173 | 0.118 | 1.253 | 0.064 | 1.0577 | 0.081 |
| **Average** | 1.1433 | 0.049 | 1.0656 | 0.021 | 1.2236 | 0.062 | 1.223 | 0.06 | 1.1238 | 0.044 |

## 6.4 Results

### 6.4.1 Snowmelt runoff Simulation

With the range of parameters assessed and optimized for the basin, and with an input of temperature, precipitation and snow cover area, a zone wise and a year round simulation is performed for nine years (2000 to 2008). The year 2001 is used for calibration for all sub-basins and the model efficiency for the simulation from the year 2000 to 2008 is illustrated in **Table 6-6**. The daily and monthly hydrograph of simulated and observed flow of from the year 2000 to 2008 is graphically represented in **Figure 6-5** and **Figure 6-6**. Simulation for the year 2002 in not carried out in Tamakoshi basin due to missing hydrological data for that year. Though the extreme peaks during summer month could not be simulated exactly, the base flow has been well captured by the model. A fair correlation is shown by $R^2$ or NSE and volume difference evaluation criteria as displayed in **Table 6-6.**

**Table 6-6: A zone wise evaluation of Model for different basins**

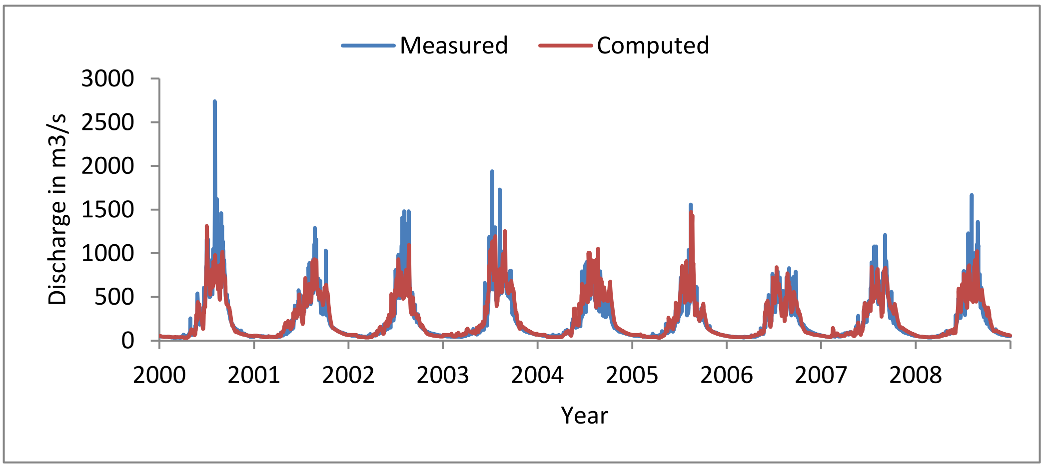
| Year | Tamor | | Arun | | Dudhkosi | | Tamakosi | | Sunkoshi | |
|---|---|---|---|---|---|---|---|---|---|---|
| Calibration Year | $R^2$ | $D_v$ % | $R^2$ | $D_v$ % | $R^2$ | $D_v$ % | $R^2$ | $D_v$ % | $R^2$ | $D_v$ % |
| 2001 | 0.8377 | -4.731 | 0.8474 | 6.2806 | 0.8727 | -3.44 | 0.9081 | 9.3798 | 0.884 | 7.321 |
| Validation year | | | | | | | | | | |
| 2000 | 0.754 | 14.20 | 0.818 | 15.75 | 0.725 | -1.27 | 0.827 | 18.14 | 0.910 | 3.06 |
| 2002 | 0.828 | 5.08 | 0.776 | 6.66 | 0.788 | 12.69 | - | - | 0.853 | 5.86 |
| 2003 | 0.818 | -10.84 | 0.734 | -5.02 | 0.839 | 0.67 | 0.806 | 11.36 | 0.736 | 2.73 |
| 2004 | 0.591 | -20.18 | 0.796 | -1.46 | 0.774 | 23.04 | 0.856 | -1.47 | 0.886 | 11.89 |
| 2005 | 0.689 | -15.73 | 0.769 | -5.11 | 0.779 | 2.63 | 0.779 | 6.01 | 0.690 | 5.56 |
| 2006 | 0.813 | -2.88 | 0.793 | 7.69 | 0.571 | 12.15 | 0.728 | 15.68 | 0.752 | 9.03 |
| 2007 | 0.825 | -2.55 | 0.862 | 7.40 | 0.739 | -4.91 | 0.837 | 8.06 | 0.771 | 4.98 |
| 2008 | 0.785 | -0.13 | - | - | 0.533 | -20.46 | 0.847 | 6.44 | 0.827 | -7.81 |
| Average | 0.7715 | -4.196 | 0.800 | 4.02 | 0.736 | 2.35 | 0.823 | 9.20 | 0.812 | 4.74 |

*$R^2$ = Coefficient of determination,$D_v$= Volume Difference,

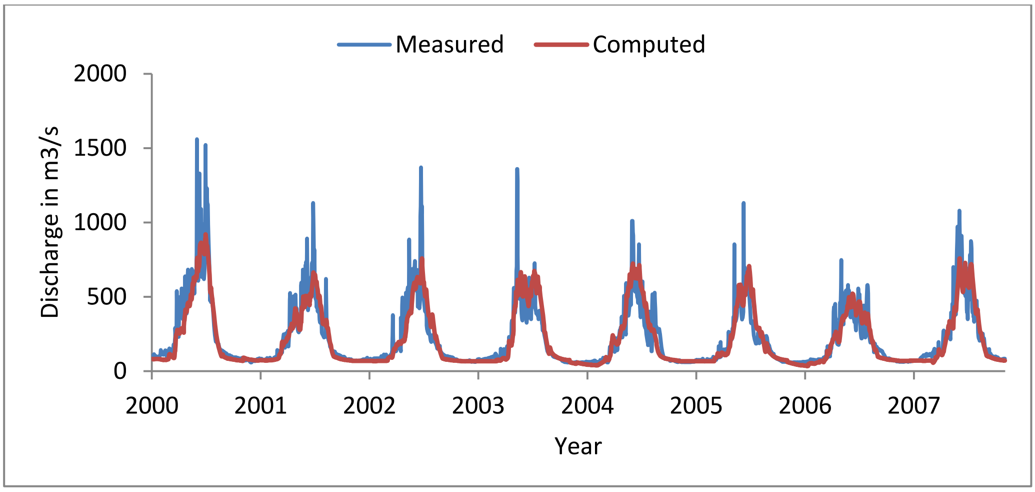
To evaluate the relationship between observed and computed hydrograph Pearson correlation coefficient is also used for daily and monthly average data as demonstrated in **Table 6-7** that showed a good correlation lying within a range from 0.8 to 0.99 for daily and monthly flow data sets.

**Table 6-7: Pearson correlation coefficient (r) for flow data**

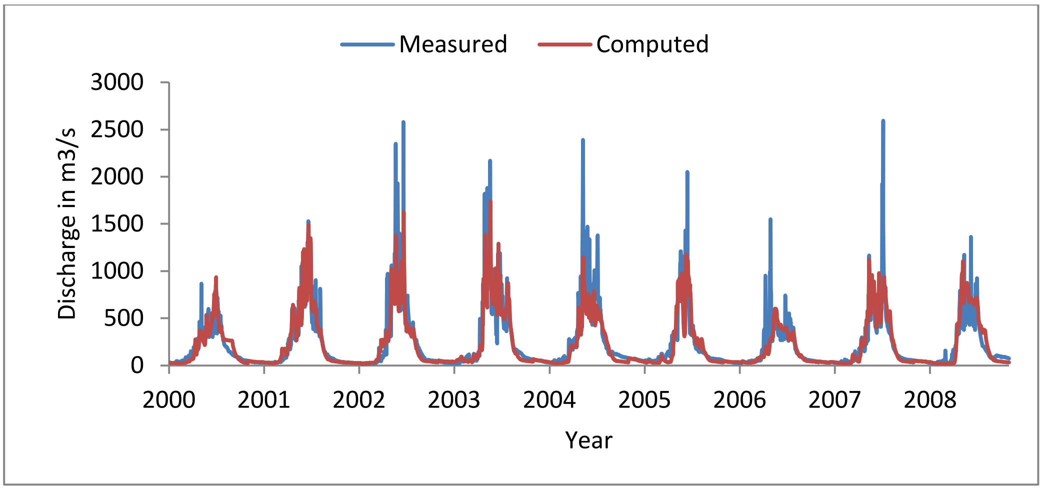
| Basins | Tamor | | Arun | | Dudhkoshi | | Tamakoshi | | Sunkoshi | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | r-daily | r-monthly | r-daily | r-monthly | r-daily | r-monthly | r-daily | r-monthly | r-daily | r-monthly |
| 2000 | 0.886 | 0.947 | 0.927 | 0.992 | 0.874 | 0.965 | 0.929 | 0.989 | 0.955 | 0.998 |
| 2001 | 0.917 | 0.982 | 0.926 | 0.965 | 0.939 | 0.997 | 0.960 | 0.999 | 0.944 | 0.986 |
| 2002 | 0.915 | 0.982 | 0.884 | 0.960 | 0.900 | 0.995 | - | - | 0.925 | 0.995 |
| 2003 | 0.911 | 0.998 | 0.874 | 0.968 | 0.917 | 0.986 | 0.907 | 0.967 | 0.858 | 0.972 |
| 2004 | 0.910 | 0.986 | 0.906 | 0.963 | 0.927 | 0.989 | 0.925 | 0.968 | 0.951 | 0.988 |
| 2005 | 0.900 | 0.993 | 0.895 | 0.970 | 0.891 | 0.992 | 0.884 | 0.964 | 0.894 | 0.978 |
| 2006 | 0.913 | 0.995 | 0.887 | 0.966 | 0.764 | 0.901 | 0.885 | 0.948 | 0.927 | 0.973 |
| 2007 | 0.909 | 0.980 | 0.932 | 0.979 | 0.866 | 0.979 | 0.925 | 0.962 | 0.897 | 0.948 |
| 2008 | 0.887 | 0.960 | - | - | 0.903 | 0.976 | 0.922 | 0.954 | 0.963 | 0.991 |
| Avge. | 0.91 | 0.98 | 0.90 | 0.97 | 0.89 | 0.98 | 0.92 | 0.97 | 0.92 | 0.98 |



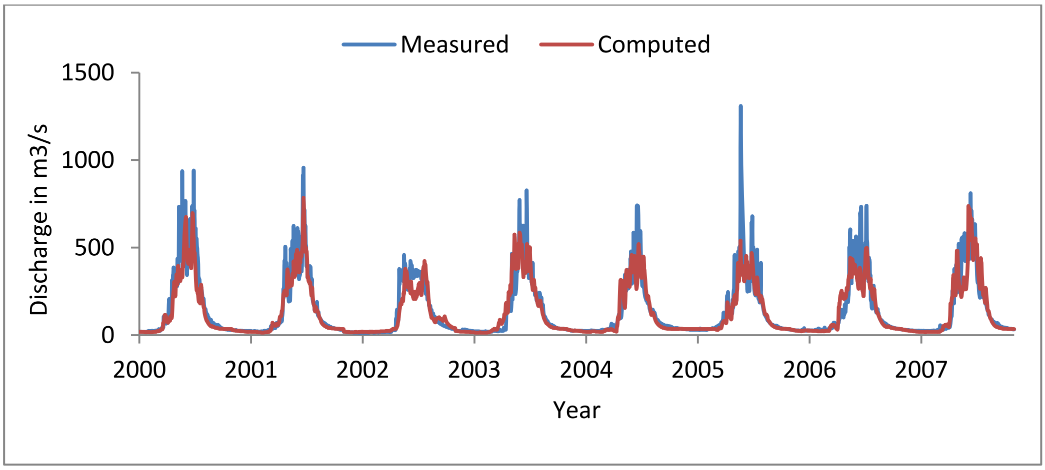

i. Tamor



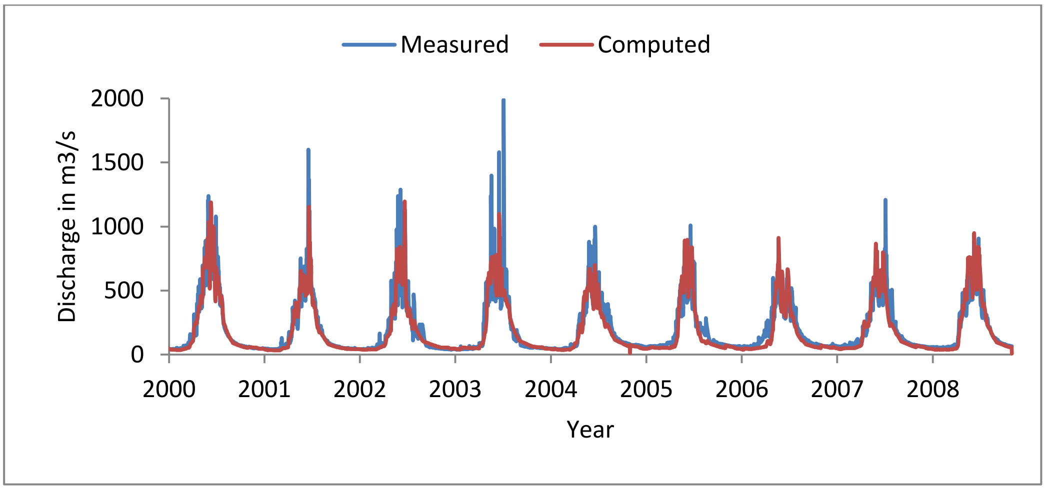

ii. Arun




iii. Dudhkoshi

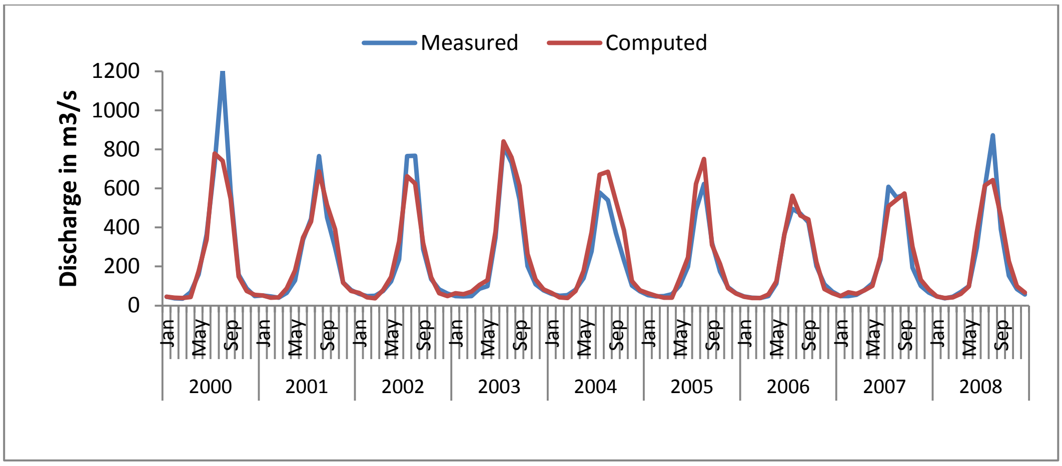



iv. Tamakoshi

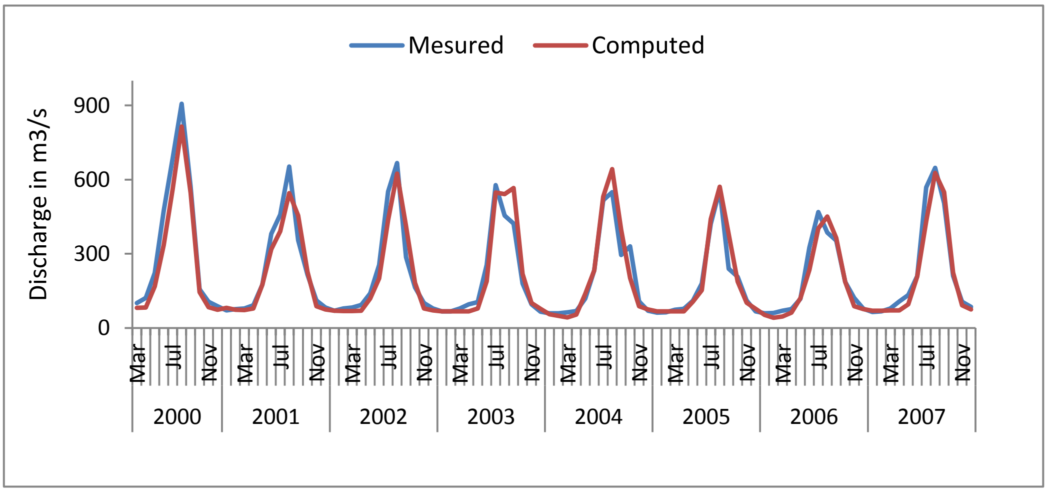



v. Sunkoshi

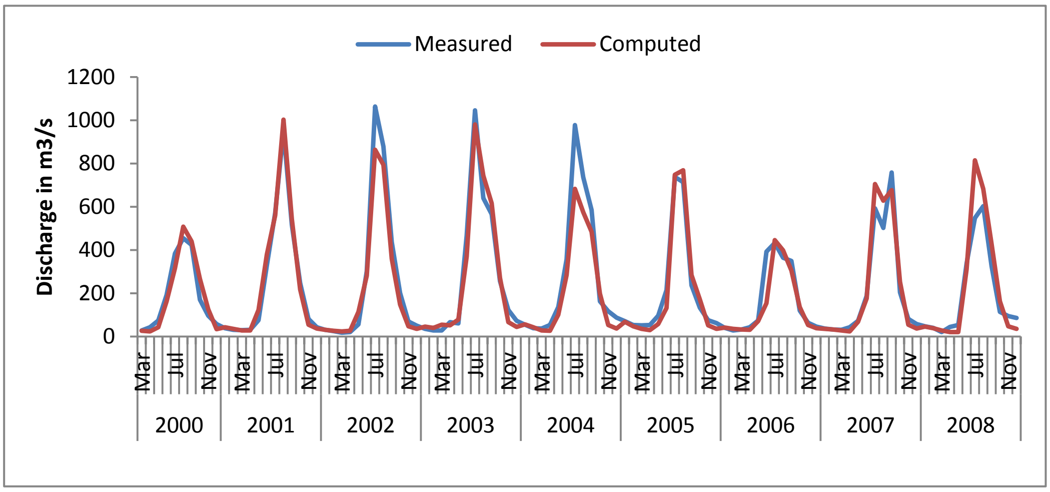
**Figure 6-5: Daily simulated hydrograph of observed and computed data**



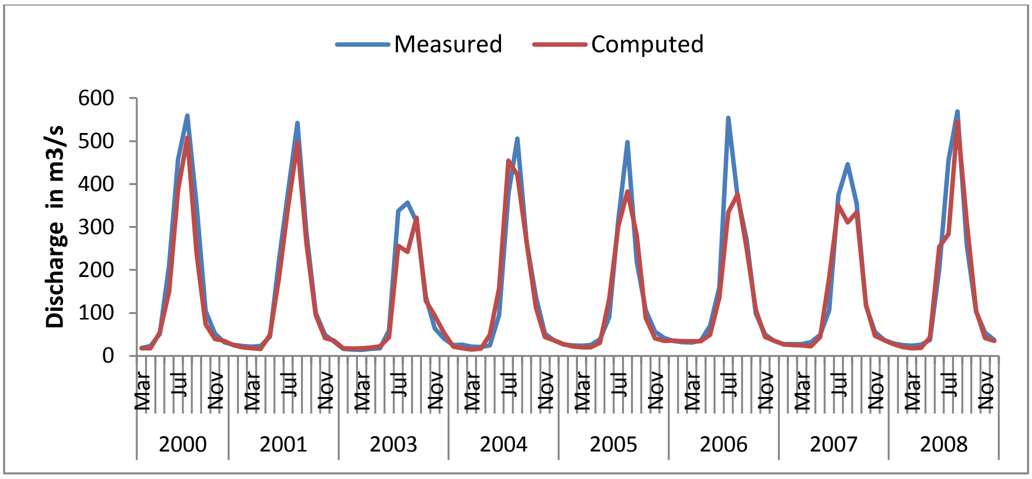

i. Tamor



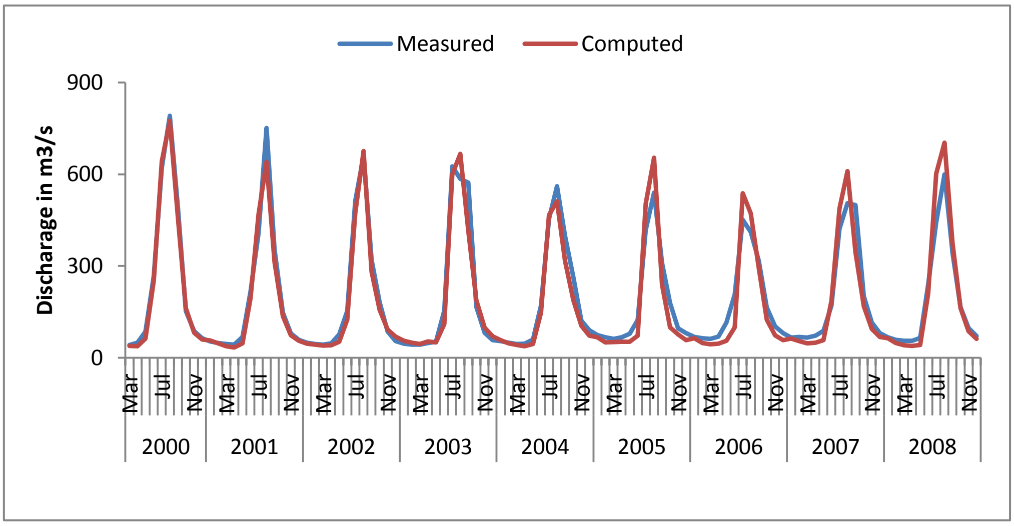

ii. Arun




iii. Dudhkoshi




iv. Tamakoshi




v. Sunkoshi

**Figure 6-6: Monthly simulated hydrograph of observed and computed data**

### 6.4.2 Snowmelt contribution in stream flow

Though all five sub-basins are monsoon dominated, there is a significant contribution of melt water during dry season from the entire basin. Based on the simulation results from 2000 to 2008, largest annual average contribution from snow melt is from Arun river basin (21.61%), though with only 8.99% of SCA – the basin contains largest number of glaciers compared to other basins. The Tamor basin contributes approximately 9% while Sunkoshi basin contributes approximately 10% of snow melt to the total flow. Similarly Dudhkoshi and Tamakoshi supply 17% of total annual runoff **(**Table 6-8**).** Based on J2000 hydrological model, Nepal, et al. (2012) also found 17% contribution from snow melt in Dudhkoshi basin which is similar to the result obtained from this study. Similarly Shilpakar, et al. (2010) found 13.5% of snowmelt contribution on average for the year 2002 and 2003 in Tamakoshi basin using SRM model.

**Table 6-8: Percentage of snowmelt contribution**

| Contribution | Tamor | Arun | Dudhkoshi | Tamakoshi | Sunkoshi |
|---|---|---|---|---|---|
| Annual % | 8.6 | 21.6 | 17.4 | 17.4 | 9.4 |
| Pre-monsoon % | 12.5 | 42.7 | 17.2 | 15.9 | 21.7 |
| Monsoon % | 7.0 | 11.1 | 16.4 | 14.2 | 6.2 |
| Post-monsoon % | 19.4 | 35.0 | 26.7 | 55.6 | 29.3 |
| Winter % | 13.5 | 28.6 | 19.9 | 30.3 | 29.3 |

The hydrology of snow-fed river system is distinctive during the melting season. During lean season, snow and glacier melts have significant effect on the hydrology of the river system. The model result shows large melt contribution to the total flow during the post-monsoon season in all sub-basins except in Arun river basin where the pre-monsoon snow melting is found to be the most pronounced. Also an increase in melting during the winter season is observed in all sub-basins after the post-monsoon season except in Arun sub-basin where the prominent contribution during the post monsoon season is found. The least contribution during the monsoon season is observed in all sub-basins as illustrated in **Table 6-8**. To understand the snowmelt contribution and also to assess the variation in stream flow in the future, the two climate scenarios are used and are described as follows:

- Scenario 1: The daily projected data of precipitation and mean temperature based on ECHAM05 data (2020-2060).
- Scenario 2: The daily projected data of precipitation and mean temperature based on HadCM3 data (2030-2060).

The **Figure 6-7** and **Figure 6-8** demonstrations the annual average snowmelt depth in different decades based on Scenario 1 and Scenario 2 compared to present base year of snow melt (2000 – 2008). There is gradual increase in melt contribution in each subsequent decade for both the scenarios. But the melt contribution from Scenario 2 is less compared to Scenario 1. Nevertheless both the scenarios indicate the snowmelt contribution to the total runoff to be in increasing trend and will speed up during last decade (2050-2060) for both the scenarios in all sub-basins. Based on the snow melt computed from classified elevation zone of five sub-basins, the snowmelt contribution is observed up to an elevation of 5500 m. Hence most contribution is found to occur from mid elevation snow cover transition zone (3000-5500 m). In catchments below3000m, there is no contribution from snow.

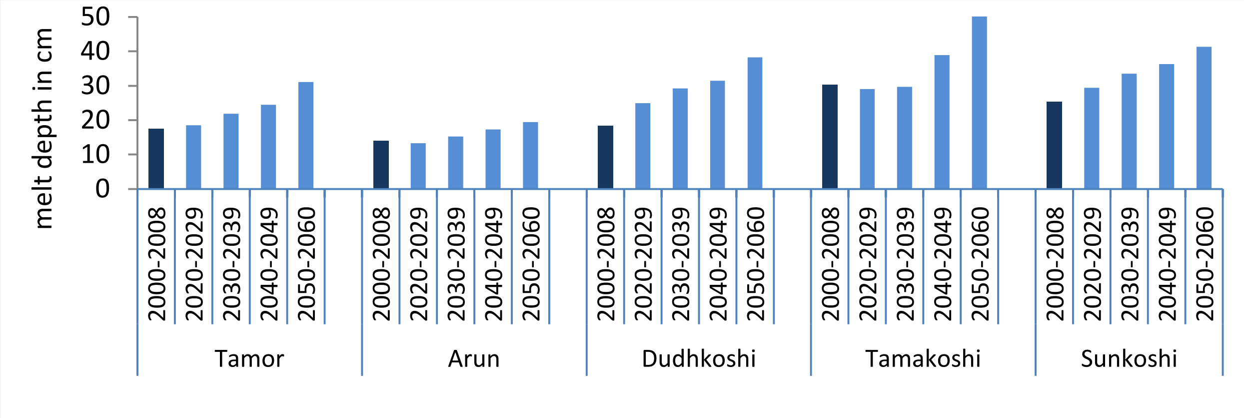



**Figure 6-7: Snowmelt in different decades based on Scenario 1 (ECHAM05)**

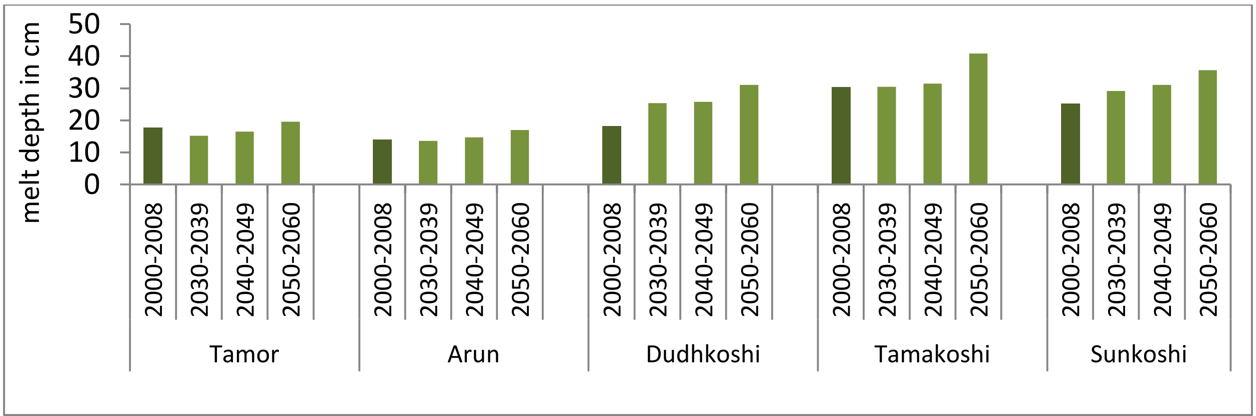
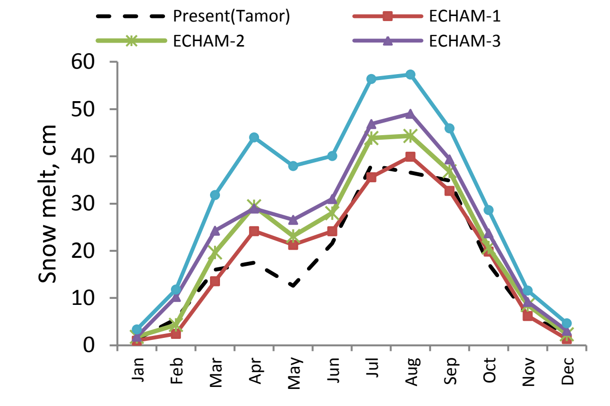



**Figure 6-8: Snow melt in different decades based on Scenario 2 (HadCM3)**

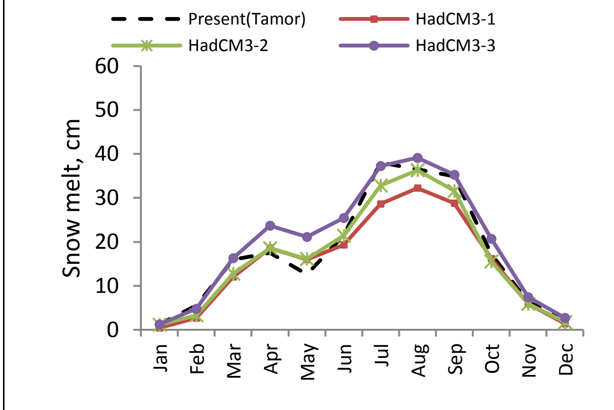
### 6.4.3 Impact on runoff pattern

SRM is used to study the impact of climate change on each sub-basin after calibration and validation from 2000 to 2008. This nine year period is considered as base year to understand the changes in snow melt pattern and in total stream flow in comparison to future climate data results. The variation of river runoff is mainly influenced by two factors: time and space distribution change of the precipitation and snow and glacier melting which is caused by rising temperature (Huang, et al. 2010). So to assess the implication of climate change on runoff pattern in future scenario, a daily bias corrected climate data viz. temperature and precipitation is extracted from PRECIS (Providing REgional Climates for Impacts Studies)- ECHAM05 (2020-2060) and HadCM3 (2030-2060). With no significant changes in annual trend in SCA but with monthly variation being observed, daily SCA is interpolated on the basis of average annual monthly SCA from 2000-2011 and used as input for the model. The implication in runoff pattern is analyzed with respect to aforementioned scenario 1 and scenario 2.

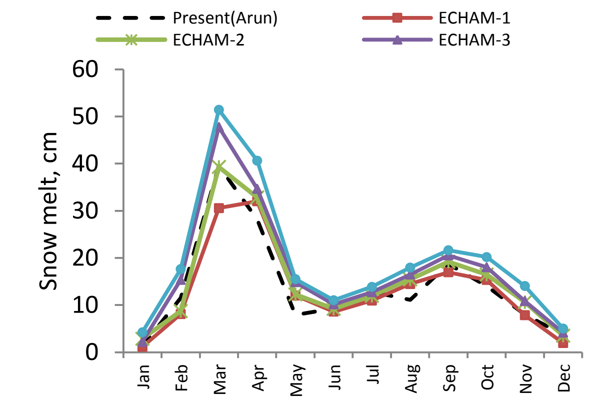
The **Figure 6-9** shows different characteristic behavior of snowmelt contribution for different seasons in each sub-basin based on scenario1 and 2 .The future climate data projects progressive increase in snow melt in all sub-basins for both the scenarios with each decade. The maximum increment is observed especially during last decade (2050 to 2060) for both the scenarios. This monthly graph also shows a shift in snow melt pattern for Tamakoshi sub-basins during the pre-monsoon season while a decrease during monsoon and the post-monsoon season could also be seen in **Figure 6-9**.



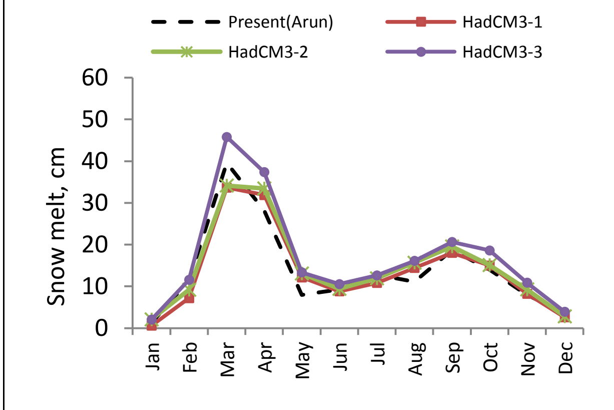

i. **Tamor– ECHAM05**



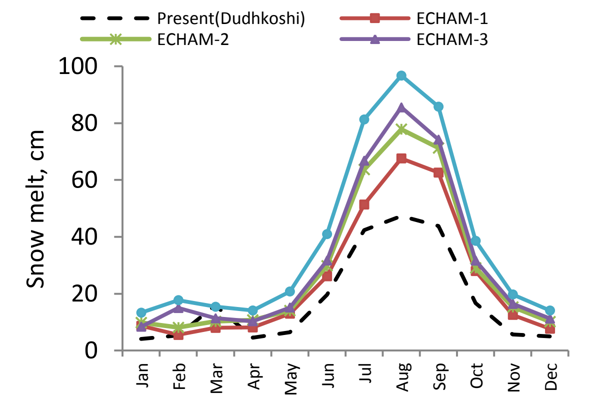

i. **Tamor – HadCM3**



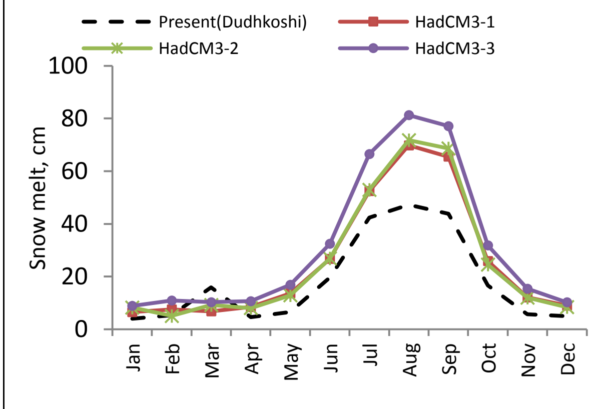

ii. **Arun - ECHAM05**




ii. **Arun– HadCM3**




iii. **Dudhkoshi - ECHAM05**




iii. **Dudhkoshi – HadCM3**

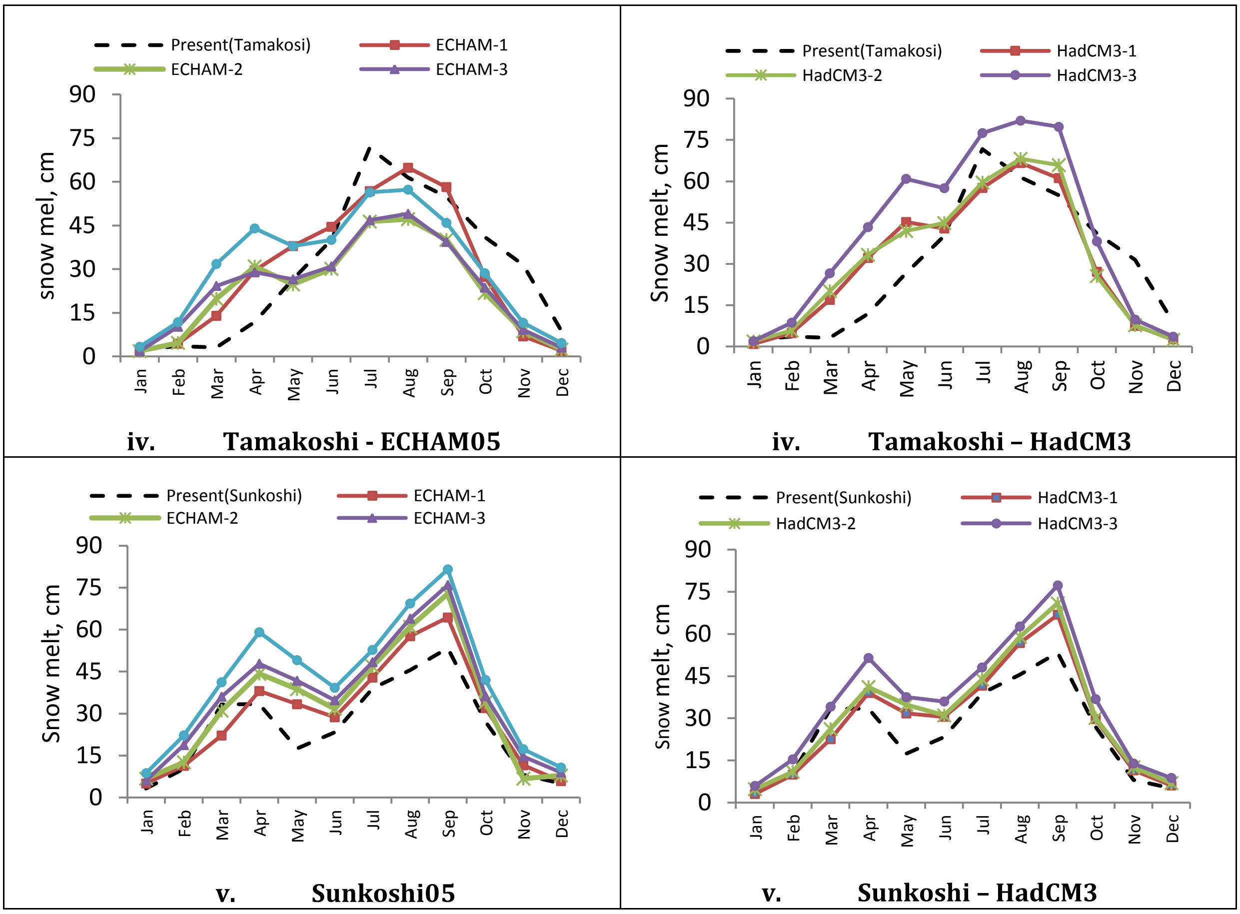



**Figure 6-9**: **Snow melt based on Scenario1** (ECHAM-1= 2020-2029, ECHAM-2=2030-2039, ECHAM-3 =2040-2049, ECHAM-4=2050-2060) and Scenario2 (HadCM3-1=2030-2039, HadCM-2=2040-2049, HadCM3-3 =2050-2060)

The **Table 6-9** presents the percentage change in contribution of snow melt in different decade in future compared to our base year of 2000 to 2008. The SRM simulation result for both the scenarios in each sub-basin reveal an increase in melting in future. On average all sub-basins shows increase in snow melt contribution except in Tamakoshi sub-basin (-9.02 %) based on scenario 1. However the same basin presents maximum increase during the pre-monsoon season (112.14 %). On the contrary, the result for Tamor sub-basins based on scenario 2 shows decrease in annual average contribution from snow melt (-1.95 %). But on seasonal basis the Tamor sub-basin also shows increase in snow melt during the pre-monsoon season.

Though with largest contribution of snow melt is from Arun sub-basin in present condition, the simulation result predicts least contribution in scenario 2 compared to other sub-basins of Koshi. While in scenario 1 there is less contribution from the same basin after Tamakoshi sub-basin. Amongst all sub-basins the data projects significant contribution from Dudhkoshi basin followed by Sunkoshi sub-basin in scenario 1. Likewise, a maximum increase is shown by Sunkoshi sub-basin followed by Dudhkoshi sub-basin in scenario 2.

The seasonal result for snow melt in two scenarios shows varied responses in each sub-basin in subsequent decades. Though a decrease in annual average contribution has been predicted in Tamakoshi and Tamor sub-basin for the scenario 1 and scenario 2, the decadal analysis for both the scenarios exhibit an increasing tendency of snow melt in all sub-basins during last decade (2050-2060) as shown in **Table 6-9**. The differential amount of snow melt contribution in both the scenarios is mostly due to uncertainty in temperature and precipitation data of ECHAM05 and HadCM3 data.

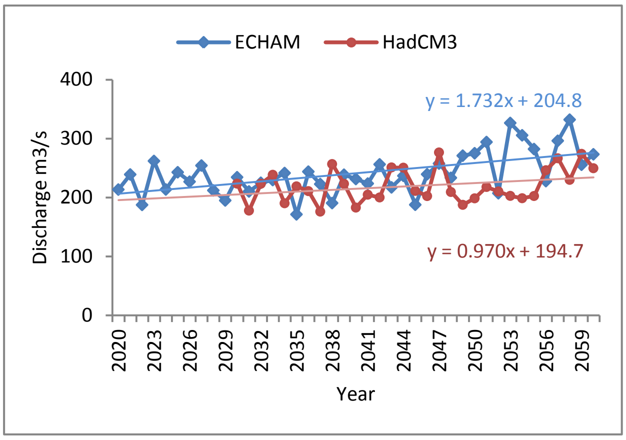
The application of SRM with projected data in scenario 1 and scenario 2 depicted an overall reduction in annual average stream flow compared to the base year in four sub-basins viz. Tamor, Arun, Dudhkoshi and Sunkoshi sub-basin. However on average an increase in the mean discharge during the winter and the pre-monsoon is observed in those four sub-basins in scenario 1. The total stream flow is only increased in Tamakoshi sub-basin as illustrated in **Table 6-10**. The flow is found to decrease during the winter season in both scenarios of Tamakoshi sub-basin. Also a drop in snowmelt contribution during the winter season is also observed in the same basin. On the contrary, the scenario 2 results shown an increase in total flow during the post-monsoon season in Tamor sub-basin, in Arun it is during winter and the pre-monsoon season and in Sunkoshi sub-basin it is during the pre-monsoon and the post-monsoon season. The result indicates a decrease in monsoon flows in both scenarios. Though the decadal analysis signify decrease in annual average flow in initial decade, the trend analysis for both the scenarios indicate a rising trend in discharge as shown in **Figure 6-10**. This increase is likely due to the significant increase in flow after the year 2050.The warmer temperature trend in future coupled with increased precipitation in each sub-basin is responsible for such enhancement during the last couple of decade in both scenarios.

**Table 6-9: Decadal percentage change in snow melt based on base year (2000-2008) and Future data**

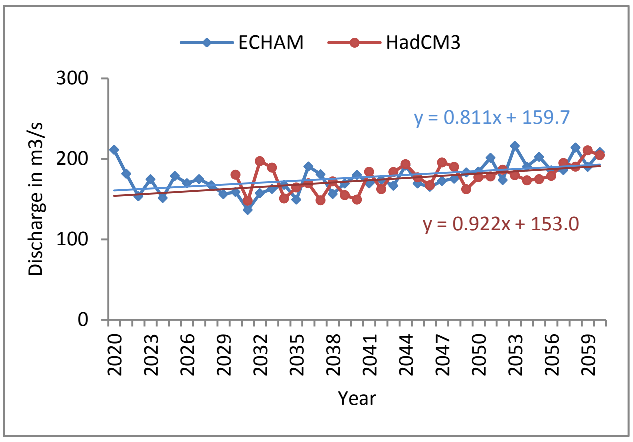
| **Data** | | **ECHAM (Scenario 1)** | | | | | **HadCM3 (Scenario 2)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sub-basins | | | | | | Sub-basins | | | |
| Decade | **Season** | **Tamor** | **Arun** | **Dudhkoshi** | **Tamakoshi** | **Sunkoshi** | **Tamor** | **Arun** | **Dudhkoshi** | **Tamakoshi** | **Sunkoshi** |
| 2020-2060 (ECHAM) & 2030-2060 (HadCM3) | Average | 38.3 | 18.63 | 72.41 | -9.02 | 41.01 | -1.95 | 9.54 | 52.22 | 15.71 | 236.37 |
| | Winter | **31.37** | **15.3** | **129.17** | -11.02 | **69.11** | -29.71 | -13.84 | **75.3** | -27.3 | **209.17** |
| | Pre-monsoon | **78.01** | **20.8** | **41.62** | **112.14** | **44.04** | **12.98** | **12.86** | **20.38** | **158.62** | **64.64** |
| | Monsoon | 24.99 | 11.83 | 66.34 | -17.24 | 35.57 | -5.95 | 8.69 | 51.29 | 12.17 | 367.2 |
| | Post-monsoon | **37.4** | **29.68** | **114.72** | -52.27 | **43.87** | **2.18** | **17.56** | **82.08** | **-46.31** | **62.64** |
| 2020-2030 | Average | 5.84 | -3.51 | 38.11 | -2.41 | 17.88 | | | | | |
| | Winter | -49.21 | -31.64 | 53.04 | -44.58 | 19.45 | | | | | |
| | Pre-monsoon | 28.07 | -1.36 | 8.08 | 95.86 | 11.07 | | | | | |
| | Monsoon | 1.04 | -1.61 | 35.72 | -1.61 | 20.04 | | | | | |
| | Post-monsoon | 10.82 | 5.59 | 80.99 | -52.64 | 23.45 | | | | | |
| 2030-2039 | Average | 25.29 | 9.98 | 61.64 | -21.92 | 31.8 | -13.18 | -1.49 | 40.46 | 2.38 | 16.81 |
| | Winter | -9.3 | -8 | 96.81 | -39.19 | 46.18 | -51.65 | -36.72 | 60.93 | -43.5 | 2.97 |
| | Pre-monsoon | 56.82 | 11.58 | 30.32 | 81.5 | 35.32 | 1.26 | 2.71 | 7.13 | 126.68 | 10.82 |
| | Monsoon | 16.83 | 7.7 | 58.52 | -28.2 | 31.77 | -16.8 | 0.54 | 40.16 | 0.05 | 21.47 |
| | Post-monsoon | 24.34 | 23.3 | 98.22 | -57.98 | 15.91 | -6.08 | 5.67 | 69.54 | -52.22 | 17.11 |
| 2040-2049 | Average | 40.1 | 25.28 | 74.3 | -17.69 | 44.75 | -6.02 | 6.06 | 42.4 | 5.61 | 24.43 |
| | Winter | 62.75 | 32.15 | 142.03 | 1.89 | 81.34 | -33.48 | -13.87 | 51.52 | -32.43 | 22.1 |
| | Pre-monsoon | 73.2 | 28.63 | 36.67 | 91.68 | 49.06 | 3.02 | 6.76 | 11.88 | 129.1 | 21.26 |
| | Monsoon | 26.87 | 15.59 | 68.7 | -27.16 | 38.3 | -6.75 | 9.2 | 43.9 | 4.54 | 27.04 |
| | Post-monsoon | 39.94 | 31.46 | 114.57 | -54.66 | 44.6 | -8.79 | 11.11 | 63.08 | -54.07 | 21.32 |
| 2050-2060 | Average | 78.01 | 40.57 | 111.68 | 4.59 | 64.82 | 11.98 | 22.72 | 71.83 | 37.16 | 43.09 |
| | Winter | 113.06 | 63.83 | 216.12 | 33.39 | 123.98 | -6.35 | 6.99 | 109.97 | -4.52 | 62.06 |
| | Pre-monsoon | 147.05 | 42.2 | 86.87 | 173.41 | 77.37 | 32.67 | 27.64 | 40.15 | 214.49 | 46.24 |
| | Monsoon | 52.48 | 24.38 | 99.13 | -12.46 | 50.65 | 4.64 | 15.63 | 68.14 | 30.11 | 39.01 |
| | Post-monsoon | 71.14 | 55.77 | 160.53 | -44.56 | 68.4 | 19.63 | 34.25 | 110.75 | -33.88 | 44.17 |

**Table 6-10: Decadal percentage change in annual flow based on base year (2000-2008) and Future data**

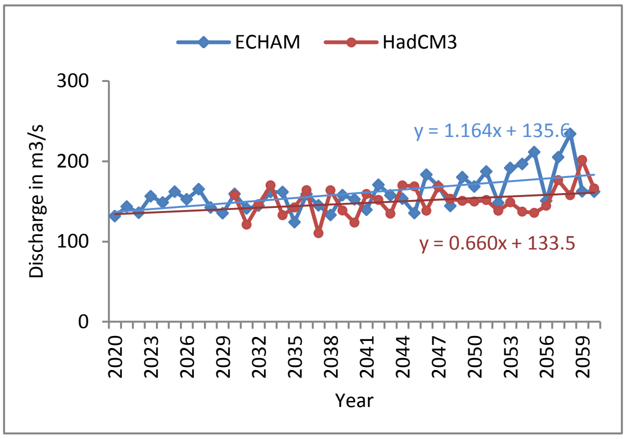
| Data | | ECHAM (Scenario 1) | | | | | HadCM3 (Scenario 2) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sub-basins | | | | | Sub-basins | | | | |
| Decade | **Season** | **Tamor** | **Arun** | **Dudhkoshi** | **Tamakoshi** | **Sunkoshi** | **Tamor** | **Arun** | **Dudhkoshi** | **Tamakoshi** | **Sunkoshi** |
| 2020-2060 (ECHAM)& 2030-2060(HadCm3) | Annual average | -2.12 | -17.8 | -18.17 | 40.47 | -15.51 | -10.77 | -17.6 | -31.59 | 39.14 | -3.23 |
| | Winter | **2.39** | **8.27** | **48.42** | **-5.82** | **-31.40** | **-1.04** | **9.18** | **-1.94** | **-4.45** | **4.60** |
| | Pre-monsoon | **7.24** | **0.10** | **17.49** | **83.57** | -17.12 | -1.79 | 0.31 | -19.17 | 67.55 | 2.97 |
| | Monsoon | -3.39 | -22.0 | -24.43 | 46.77 | -12.04 | -14.33 | -22.5 | -34.38 | 47.05 | -4.96 |
| | Post-monsoon | 11.26 | -8.69 | -6.00 | 21.95 | -11.35 | 12.52 | -4.46 | -19.97 | 14.49 | 17.87 |
| 2020-2029 | Annual average | -8.79 | -20.6 | -23.03 | 27.76 | -22.24 | | | | | |
| | Winter | 0.65 | 9.84 | 49.02 | -8.50 | -32.08 | | | | | |
| | Pre-monsoon | 2.95 | -5.45 | 8.16 | 69.24 | -15.43 | | | | | |
| | Monsoon | -11.34 | -25.1 | -29.82 | 32.03 | -20.73 | | | | | |
| | Post-monsoon | 7.13 | -7.81 | -7.43 | 17.81 | -14.91 | | | | | |
| 2030-2039 | Annual average | -10.35 | -24.2 | -24.74 | 31.11 | -21.50 | -13.15 | -22.0 | -34.32 | 30.34 | -11.74 |
| | Winter | -4.37 | 4.85 | 43.52 | -6.04 | -31.73 | -3.04 | 5.85 | -2.94 | -9.17 | -2.73 |
| | Pre-monsoon | -1.21 | -6.02 | 6.11 | 66.79 | -21.97 | 1.32 | 2.25 | -10.17 | 77.14 | -3.37 |
| | Monsoon | -10.23 | -28.6 | -31.09 | 37.13 | -18.89 | -18.24 | -28.8 | -37.95 | 35.90 | -12.19 |
| | Post-monsoon | -6.97 | -22.5 | -11.09 | 11.60 | -17.30 | 14.55 | -9.08 | -23.37 | 9.47 | -3.25 |
| 2040-2049 | Annual average | -4.41 | -18.3 | -16.30 | 39.31 | -16.33 | -11.64 | -17.3 | -31.10 | 35.89 | -2.89 |
| | Winter | -1.73 | 3.56 | 46.78 | -4.74 | -31.36 | -4.67 | 8.04 | -1.87 | -6.86 | 5.50 |
| | Pre-monsoon | 8.99 | 1.74 | 20.78 | 86.31 | -17.19 | -7.31 | -3.46 | -27.17 | 51.91 | 3.06 |
| | Monsoon | -3.76 | -21.7 | -21.62 | 45.89 | -12.10 | -13.25 | -22.2 | -33.04 | 44.76 | -5.20 |
| | Post-monsoon | -4.57 | -18.0 | -10.28 | 15.08 | -18.51 | 4.84 | -5.87 | -21.35 | 9.59 | 21.99 |
| 2050-2060 | Annual average | 13.50 | -9.01 | -9.49 | 61.58 | -3.20 | -7.82 | -13.8 | -29.56 | 50.12 | 4.22 |
| | Winter | 13.85 | 14.3 | 53.83 | -4.19 | -30.53 | 4.08 | 13.4 | -1.08 | 2.04 | 10.44 |
| | Pre-monsoon | 17.23 | 9.21 | 33.33 | 109.36 | -14.18 | 0.41 | 1.96 | -20.06 | 73.05 | 8.63 |
| | Monsoon | 10.41 | -14.0 | -16.03 | 69.74 | 2.15 | -11.75 | -18.1 | -32.34 | 59.27 | 1.84 |
| | Post-monsoon | 45.96 | 11.6 | 3.83 | 41.37 | 3.83 | 17.65 | 1.03 | -15.62 | 23.52 | 33.33 |



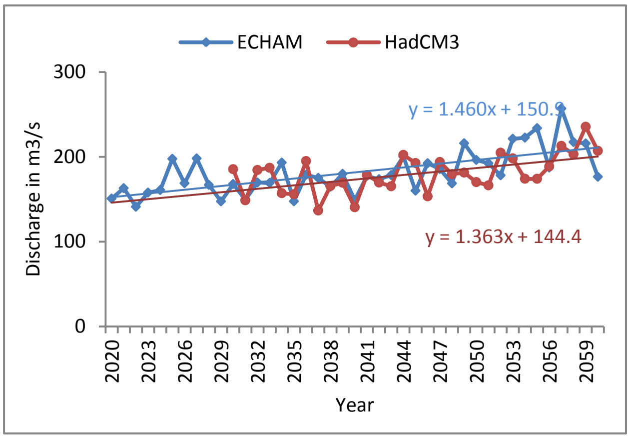

**i. Tamor**



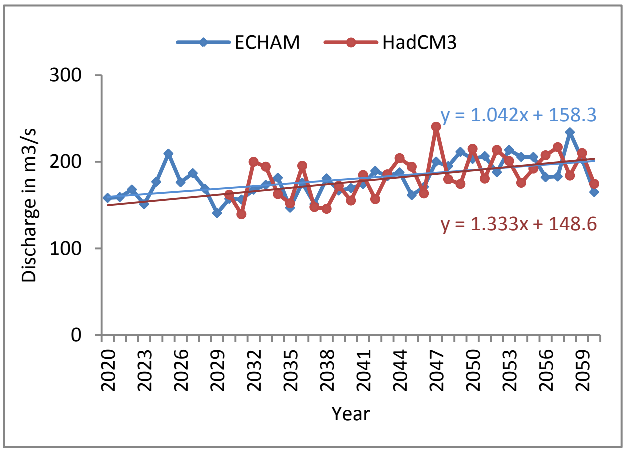

**ii. Arun**



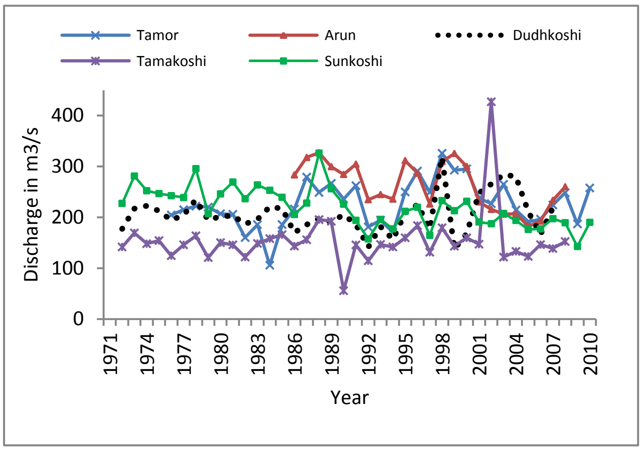

**iii. Dudhkoshi**




**iv. Tamakoshi**




**v. Sunkoshi**




**vi. Observed annual flow – sub-basins**

**Figure 6-10: Annual average flow trend based on A1B scenario**

## 6.5 Conclusion

Many studies are mostly focused on hypothetical increase in temperature only, for snowmelt runoff studies using SRM indicating a positive correlation between temperature and snow melting. However these modeling applications did not take into account the combined effect of precipitation and temperature in understanding the snow melt hydrology with a long term climate data. Therefore this study provides an insight on snow melt dynamics with regionalization of projected climate data based on A1B scenario of IPCC in five sub-basins of Koshi river basin. Based on the simulation results from 2000 to 2008, largest annual average contribution from snow melt is from Arun river basin (21.61%) and other sub-basins contribution of snow melt ranges from 9% to 17% to the total flow. The simulation result based on two different projected data (ECHAM and HadCM3) scenario shows the effect of increased temperature on snow conditions especially melting of snow to be significant in Himalayan catchment. The major changes observed are redistribution of seasonal snow melt contribution and intensification of snow melt rate during last decade and even shift in snow melt period in Tamakoshi sub-basin. Increase in the winter and the pre-monsoon snow melt is expected in both scenarios due to rise in temperature during those periods. Hence the results suggest that the snow cover is sensitive to changing climate especially due to changes in temperature and precipitation in future. Whereas the changes in precipitation in future is highly responsible for the variation in the runoff generated in scenario1 and scenario 2 in each sub-basins.

# Chapter 7: Hydrologic Modeling

A semi-distributed, time continuous watershed model, Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) operating on a daily time step, is chosen for the modeling of hydrology and sediment in the Koshi Basin. It is a long-term load model, using daily average input values, and is not designed to simulate detailed, single-event flood routing. The model is developed for assessing the impact of management and climate on water supplies, sediment, and agricultural chemical yields in watersheds and larger river basins. It is semi-physically based, and allows simulation of a high level of spatial detail by dividing the watershed into a large number of sub-watersheds.

The SWAT model for Koshi Basin was set up with Arc SWAT2009 interface to simulate the hydrology and sediment yield in the Hilly Terrain of the basin. The interface allows the creation of the stream network, delineation of the catchment boundaries and calculation of the various sub basin parameters. Hydrologic response Units (HRUs) were generated using the land use and soil maps. Similarly hydro-meteorological data were also spatially assigned to the sub basins, as the main drivers of the model. Various input data used in the model for the study are as follows:

## 7.1 Input Data Used:

### 7.1.1 Topographic Data:

The topography is defined by DEM that describes the elevation of any point in a given area at a specific spatial resolution. A projected 30mx30m Aster GDEMv2.0[2] for the Koshi basin was downloaded and clipped to be put in the ArcSWAT interface. The projection system used was WGS 1984_UTMzone 45N projection. **Figure 7-1** shows the DEM of the Koshi basin.

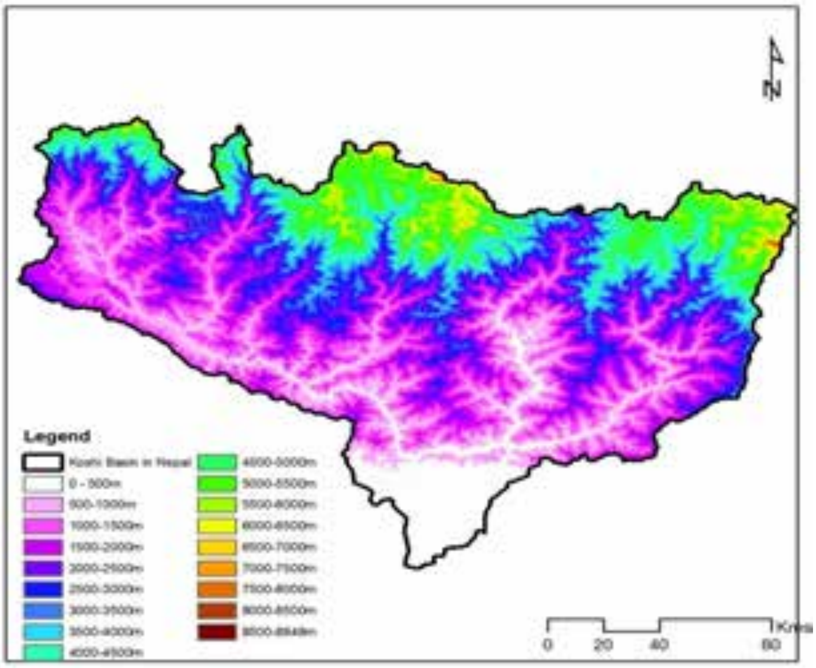



**Figure 7-1: Digital Elevation Model of the Koshi River Basin**

[2] ASTER GDEM v 2.0 is the property of METI and NASA.

### 7.1.2 Landuse Data:

Land use is one of the most important factors that affects runoff, evapotranspiration and surface erosion in a watershed. Land use data for the study area was obtained from Department of Survey. Reclassification of the land use map was done to represent the land use according to the specific land use / cover types and the respective parameters were selected from SWAT database. A look up table that identifies the 4-letter SWAT code for the different categories of land cover/land use were prepared so as to relate the grid values to SWAT land cover/land use classes. **Figure 7-2** shows the landuse map for the Koshi River Basin.

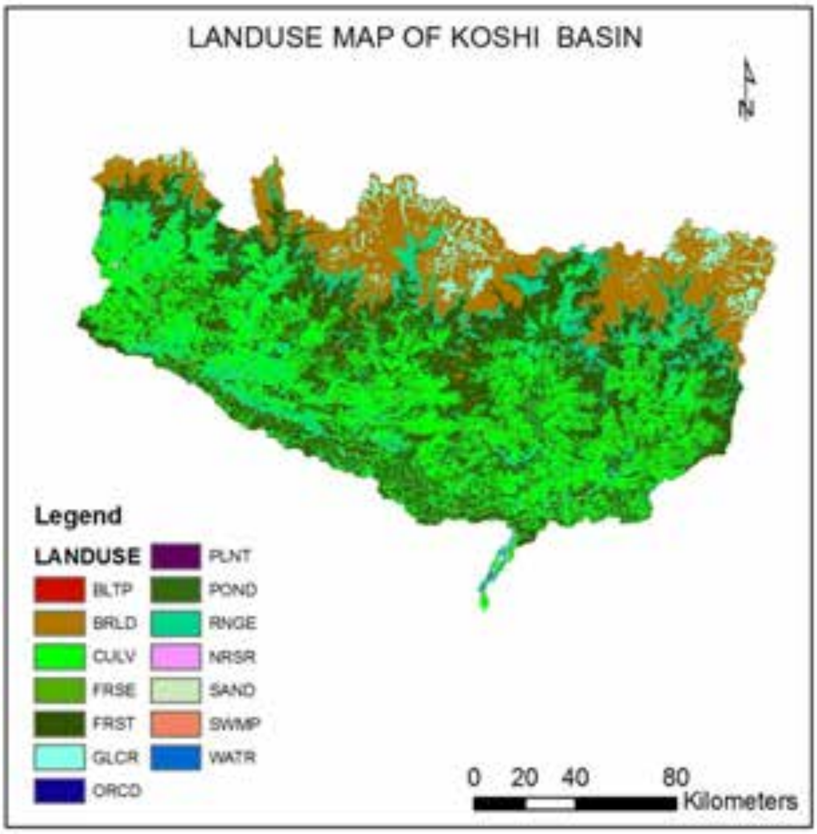



**Figure 7-2: Landuse Map of the Koshi River Basin**

### 7.1.3 Soil Data:

The SWAT model requires different soil textural and physical-chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of soil. These data were obtained mainly from the FAO soil properties database and a FAO Soil map was downloaded and clipped for the Koshi river Basin using ArcGIS spatial analyst tools. **Figure 7-3** shows the FAO soils in the Koshi Basin. The soil types within the basin are identified by the SNAM field in the model's main database which consists of the associated soil properties.

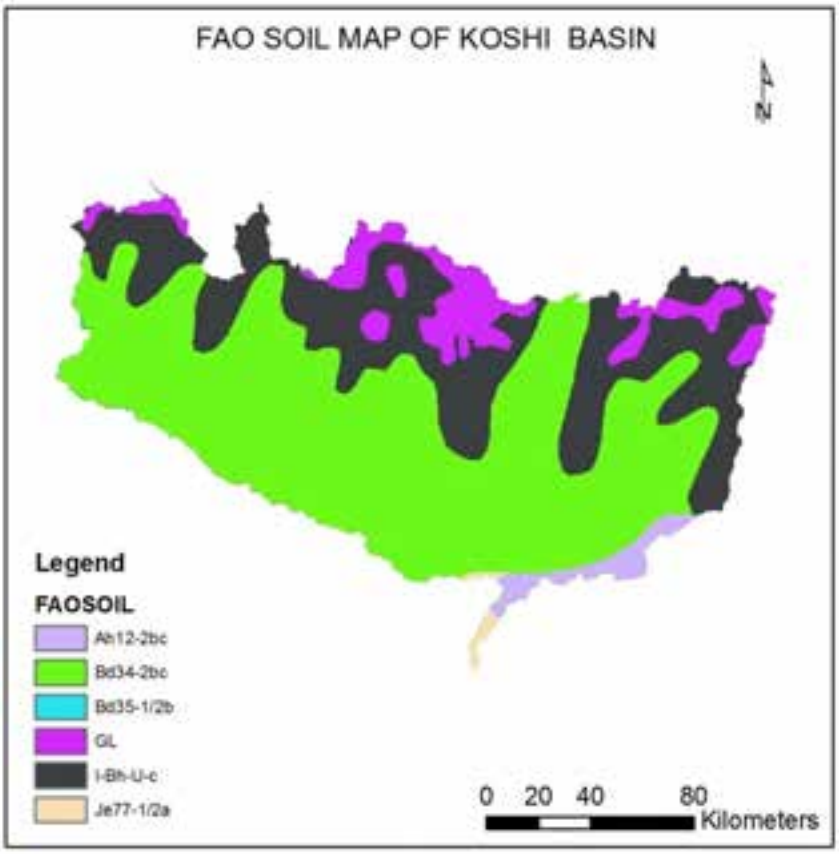



**Figure 7-3: FAO Soil Map of the Koshi River Basin**

### 7.1.4 Meteorological data:

Meteorological data is needed by the SWAT model to simulate the hydrological conditions of the basin. Meteorological data required were obtained from the Department of Hydrology and Meteorology (DHM) of Nepal. The meteorological data collected were daily precipitation, daily maximum and minimum temperature, daily relative humidity, and wind speed and sunshine hours. Data from forty two precipitation stations, sixteen climatological stations (temperature) and three synoptic stations (for windspeed, solar radiation and humidity) within the study area were collected. For all the stations, climatic records during the years (1976 – 2008) were obtained. However, for some of the stations, the missing data mostly for wind and relative humidity were present. '-99.0' values were assigned for the missing data as the SWAT input.

### 7.1.5 Hydrologic data

Gauged flow data was used in the model for two purposes; first to define Inlet discharge points for the basin to simulate the existing conditions and further for performing sensitivity analysis, calibration and validation of the model at the outlet. This data was acquired from the hydrology section of the DHM.

Since the SWAT model was used for the Hilly part of the basin, inlet discharge points were defined in the model at five points to incorporate the flow generated from the mountainous / snow-covered part of the basin.

The outlet at Chatara and inlet stations used in the model are shown below in the **Table 7-1**.

**Table 7-1: Inlets and Outlet Stations Selected**

| Stn ID | Station Name | River | Latitude | Longitude | Elevation | Type |
|---|---|---|---|---|---|---|
| **630** | Pachuwarghat | Sunkoshi - Bhotekoshi | 27° 33′ 30′′ | 85° 45′ 10′′ | 589 m | Inlet |
| **647** | Busti | Tamakoshi | 27° 38′ 05′′ | 86° 05′ 12′′ | 849 m | Inlet |
| **670** | Rabuwa Bazar | Dudhkoshi | 27° 16′ 00′′ | 86° 39′ 50′′ | 460 m | Inlet |
| **600.1** | Uwa Gaon | Arun | 27° 36′ 00′′ | 87° 20′ 06′′ | 1294 m | Inlet |
| **684** | Majhitar | Tamor | 27° 09′ 30′′ | 87° 42′ 45′′ | 533 m | Inlet |
| **695** | Chatara-Kothu | Sapta Koshi | 26° 52′ 00′′ | 87° 09′ 50′′ | 140 m | Outlet |

### 7.1.6 Sediment Data

Sediment data was also required for performing sensitivity analysis, calibration and validation of the model's performance to simulate sediment yield at the outlet. The data was also collected from the hydrology section of the DHM. The data collected was monthly sediment load at the Chatara gauging station. However, unlike flow data, sediment data was limited to few months for the years 1996-2005.

## 7.2 Model Setup

### 7.2.1 Watershed Delineation:

A projected 30mx30m Aster GDEM v 2.0 of the Koshi basin was loaded in the ArcSWAT interface. The projection system used was WGS 1984_UTMzone 45N projection. A mask was then delineated over the basin so as to focus on the study area. Stream network generation was carried out by drainage threshold area approach, which allows the model to define the minimum drainage area to form the origin of the stream.

Outlet of the basin at Chatara was then added to the interface. To account for the flow contribution from the mountainous part of the basin, 5 inlet points were added for the five major tributaries viz., Majhitar (Tamor R.), Uwagaon (Arun R.), Rabuwa Bazar (Dudh Koshi R.), Busti (Tama Koshi R.), and Pachuwarghat (Sunkoshi-Bhotekoshi R.). These inlet points were assigned as "outlets of the draining watersheds". SWAT doesn't directly model the portion of the watershed area drained by the stream network upto these inlet locations. Daily discharge data from 1976 – 2008 were provided at the inlet locations.

Once the basin outlet was selected, sub basin delineation was carried out and the basic parameters were calculated. The delineation resulted in 17 hydrologically connected sub-basins. The sub basins with the river reaches, inlet and outlet points are shown in the **Figure 7-4.**

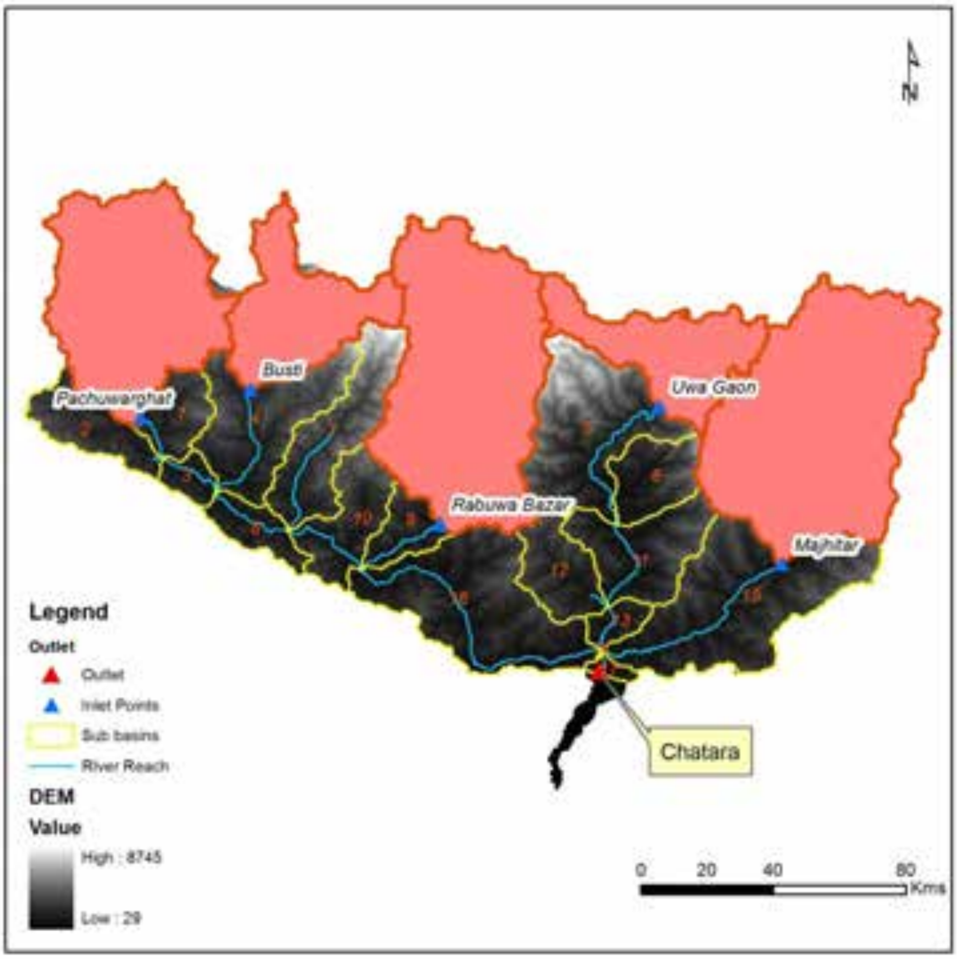



Figure 7-4: Delineation of the Catchment Area

### 7.2.2 HRU Overlay and Definition:

Landuse and soil maps in projected grid formats were loaded in the ArcSWAT interface. Look-up tables identifying the SWAT code for different categories of land use and soil were prepared so as to relate the grid values to the SWAT land use and soil classes. Reclassification for both land use and soil grids was done in order to calculate the area covered by each of the land use and soil layer. A multiple slope discretization technique was applied to define the wide range of land slopes using the DEM data. Five slope classes (0-5%, 5-10%, 10-20%, 20-50% and >50%) were applied and the slope grids were reclassified. The final step was to overlay the landuse, soil and slope grids.

Next, HRU definition was carried out by assigning the multiple HRUs to each subbasins. In order to eliminate the minor land use, soil or slope classes in each subbasin, threshold levels of 5% for landuse and 10% for each of soil and slope classes were applied to encompass most of the spatial details. The overlay and definition resulted in 157 HRUs.

### 7.2.3 Importing Climate Data:

The climatic variables required by SWAT daily precipitation, maximum and minimum temperature, solar radiation, wind speed and relative humidity were prepared in the appropriate dbase IV format. Daily rainfall data from 16 stations for the period of 1976 to 2008 was used. Similarly daily maximum and minimum temperature data for 12 stations within the area were considered. The missing data were assigned as "-99.0". Missing temperature data for various stations were infilled using a elevation correction approach with the data from a reference station and monthly lapse rate. Likewise, daily windspeed, relative humidity and solar radiation data for three synoptic stations were used as the input to the weather generating module embedded in the model. **Figure 7-5** shows the selected Meteorological stations.

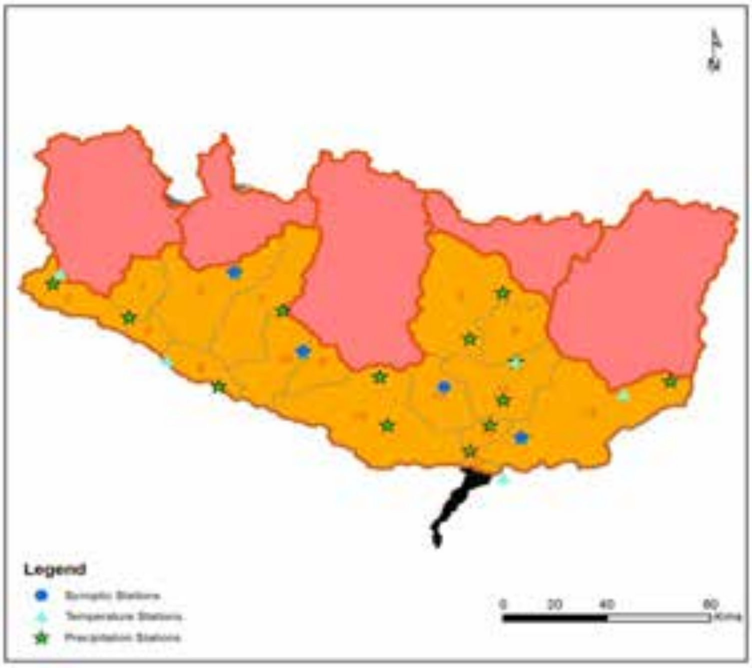



**Figure 7-5: Selected Meteorological Stations**

## 7.3 Sensitivity Analysis:

Sensitivity Analysis was then carried out in order to evaluate the response of model output with reference to change in various flow and sediment related parameters. A Latin Hypercube Sampling and One-at-a-time Sensitivity analysis (LH-OAT) method was applied using the observed monthly flow and sediment data. Top ten sensitive parameters affecting each of flow and sediment were then recognized and these parameters were further used in calibrating the model. The sensitive parameters along with their respective rankings are shown below in **Table 7-2** and **Table 7-3.**

**Table 7-2: Sensitive Parameters for hydrology**

| Ranking | Parameters | Location |
|---|---|---|
| **1** | Initial SCS runoff curve number for moisture condition II (CN2) | *.mgt |
| **2** | Soil Evaporation Compensation factor (ESCO) | *.hru |
| **3** | Maximum Canopy Storage (Canmx) | *.hru |
| **4** | Effective Hydraulic conductivity in main channel alluvium (Ch_K2) | *.rte |
| **5** | Surface Runoff Lag Coefficient (Surlag) | *.bsn |
| **6** | Available water capacity of the soil layer (Sol_Awc) | *.sol |
| **7** | Groundwater Delay (Gw_delay) | *.gw |
| **8** | Depth from soil surface to bottom of layer (Sol_Z) | *.sol |
| **9** | Manning's N value for the main channel (Ch_N2) | *.rte |
| **10** | Baseflow Alpha Factor (Alpha_Bf) | *.mgt |

**Table 7-3:Sensitive Parameters for sediment**

| Ranking | Parameters | Location |
|---|---|---|
| **1** | Linear parameter for sediment re-entrained in channel sediment routing (Spcon) | *.bsn |
| **2** | Manning's N value for the main channel (Ch_N2) | *.rte |
| **3** | Surface Runoff Lag Coefficient (Surlag) | *.bsn |
| **4** | Initial SCS runoff curve number for moisture condition II (CN2) | *.mgt |
| **5** | Effective Hydraulic conductivity in main channel alluvium (Ch_K2) | *.rte |
| **6** | USLE Equation Support Practice Factor (USLE_P) | *.mgt |
| **7** | Maximum Potential Leaf area Index (Blai) | |
| **8** | Baseflow Alpha Factor (Alpha_Bf) | *.mgt |
| **9** | Exponential parameter for sediment reentrained in channel sediment routing (Spexp) | *.bsn |
| **10** | Slope | *.hru |

## 7.4 Model Calibration and Validation:

Calibration is the process of gathering the conceptual parameters, and is done as a forerunner to testing of the model hypothesis. The observed time series for flow at the outlet, Chatara was divided into distinct periods, the 'warming-up', 'calibration' and 'validation' periods from 1986-90, 1990-2000 and 2001-2006, respectively. The provision of the warming up period is to initialize unknown variables such as moisture content.

Calibration was done using a combination of auto- and manual calibration techniques. First auto-calibration of the model was done and based on the best fit parameter values, manual calibration was then carried out in the basin using sensitive parameters to simulate flow.

### 7.4.1 Calibration Period (1991 - 2000):

For the calibration period, the simulated values are observed to be very close to the observed flow data with the Nash-Sutcliffe efficiency, $E_{NS}$ = 0.974 and Coefficient of determination, $R^2$ as 0.975. Volume difference between the observed and simulated values is just 0.21 %, suggesting a very strong predictive capability of the model. It can be observed from **Figure 7-6** and **Figure 7-7** that the model simulates flow very well and are in good agreement with the rainfall pattern.

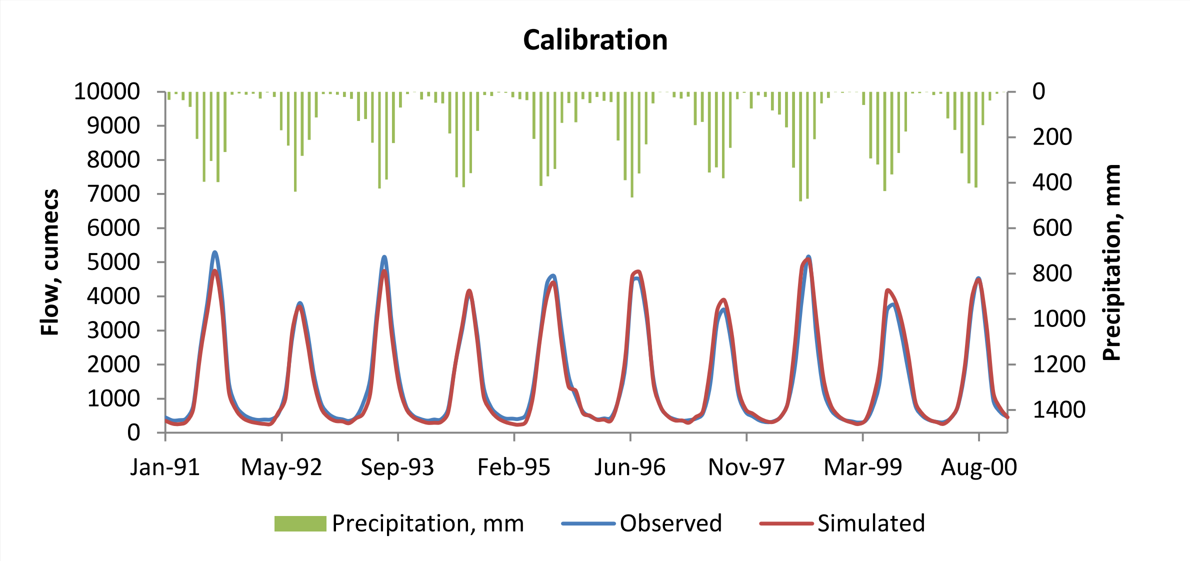



**Figure 7-6: Observed vs. Simulated Hydrographs for calibration**

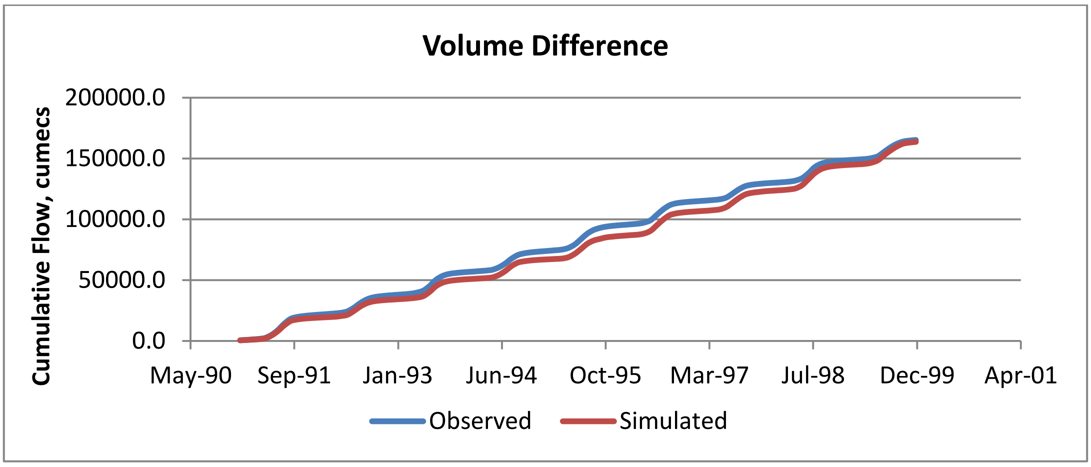



**Figure 7-7: Comparison of Observed and Simulated Volumes**

### 7.4.2 Validation Period (2001 - 2006):

Similarly to check the effectiveness of the model prediction against an independent data series, a validation period from 2001 to 2006 was considered. The simulated values are again found to be in good correlation with the observed values. The Nash-Sutcliffe efficiency was calculated to be 0.87 and a coefficient of determination of 0.875. Apart from the year 2003, the model simulates flow very accurately. This underestimation maybe due to erroneous data in the observed flow values. Volume difference between the observed and simulated values is 6.5 %. **Figure 7-8** and **Figure 7-9** show the comparison between observed and simulated flows for the validation period.

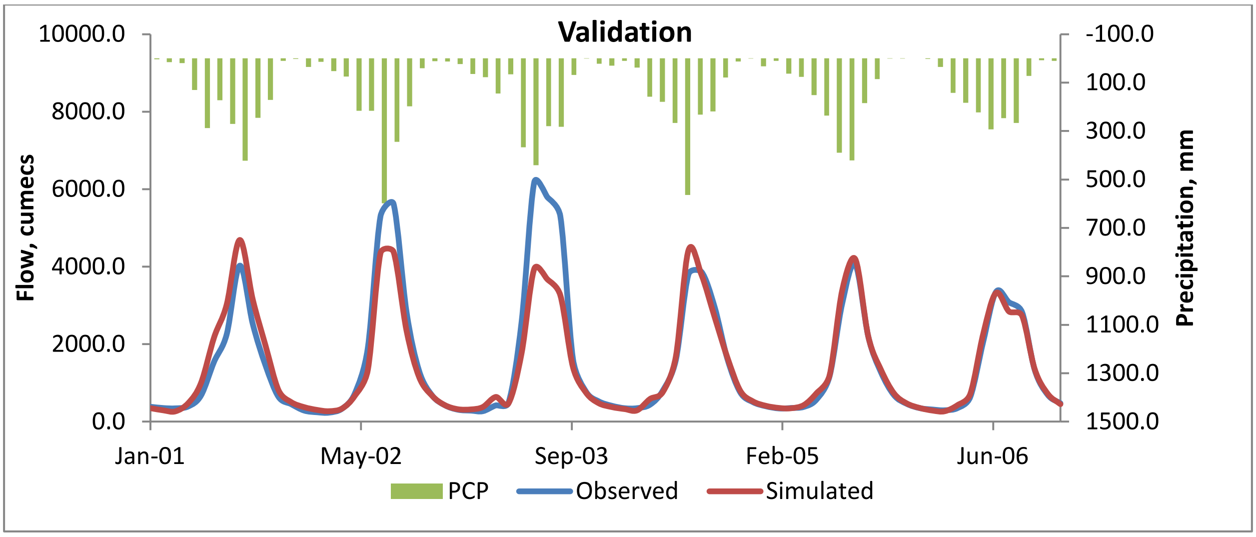



**Figure 7-8: Observed vs. Simulated Hydrographs**

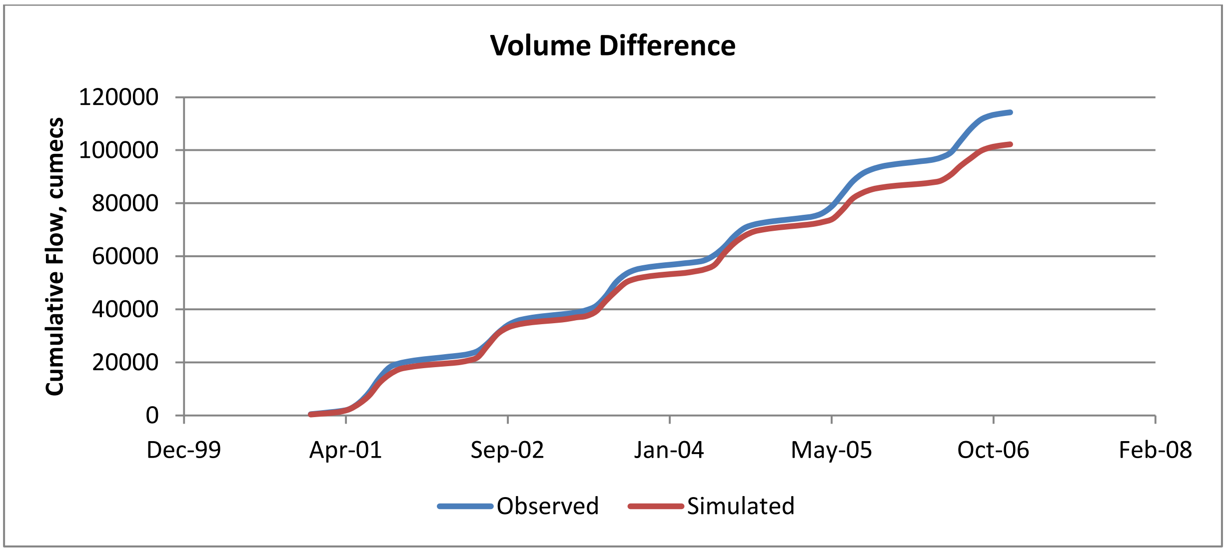



**Figure 7-9: Comparison of Observed and Simulated Volumes**

**Table 7-4** below shows the calibration and validation statistics.

**Table 7-4: Calibration and Validation Summary**

| Summary | Calibration | Validation |
|---|---|---|
| Nash Sutcliffe Efficiency, $E_{NS}$ | 0.974 | 0.87 |
| Coefficient of Determination, $R^2$ | 0.975 | 0.875 |
| Volume Difference, % | 0.21 | 6.5 |

## 7.5 Calibration and Validation of Sediment Yield:

Due to highly intermittent pattern of the sediment data, calibration and validation process was limited to only few months of 2002 - 2005 for sediment yield. Calibration was done for 2002 to 2003. The calibration results showed good correlation of $E_{NS}$ = 0.66 and $R^2$= 0.76 despite the irregularities in the data. **Figure 7-10** shows the observed and simulated yield values.

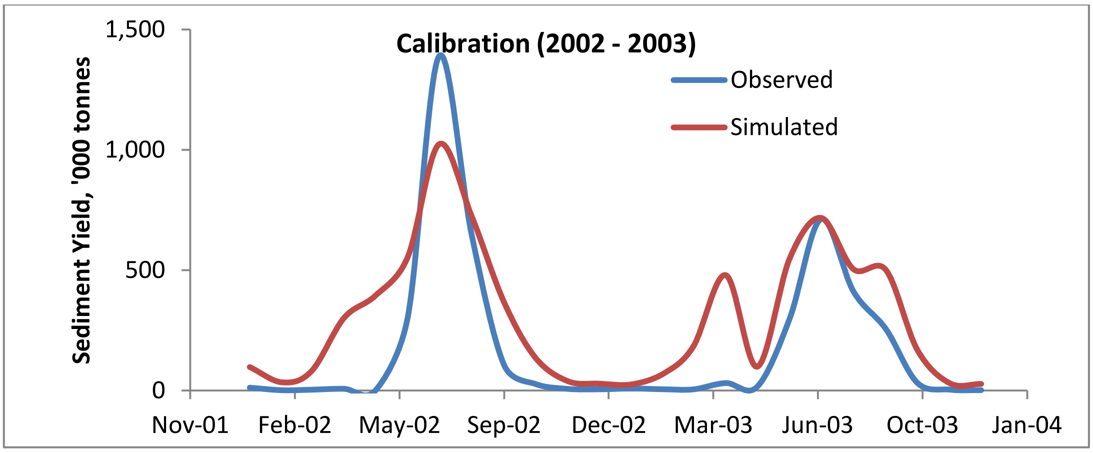



**Figure 7-10: Comparison of Observed and Simulated Sediment Yield (Calibration)**

Similarly the model was validated for the period of 2004 -2005 with $E_{NS}$ = 0.38 and $R^2$= 0.78. Refer **Figure 7-11**. Considering the discrepancy in the sediment data, this result was considered to be satisfactory.

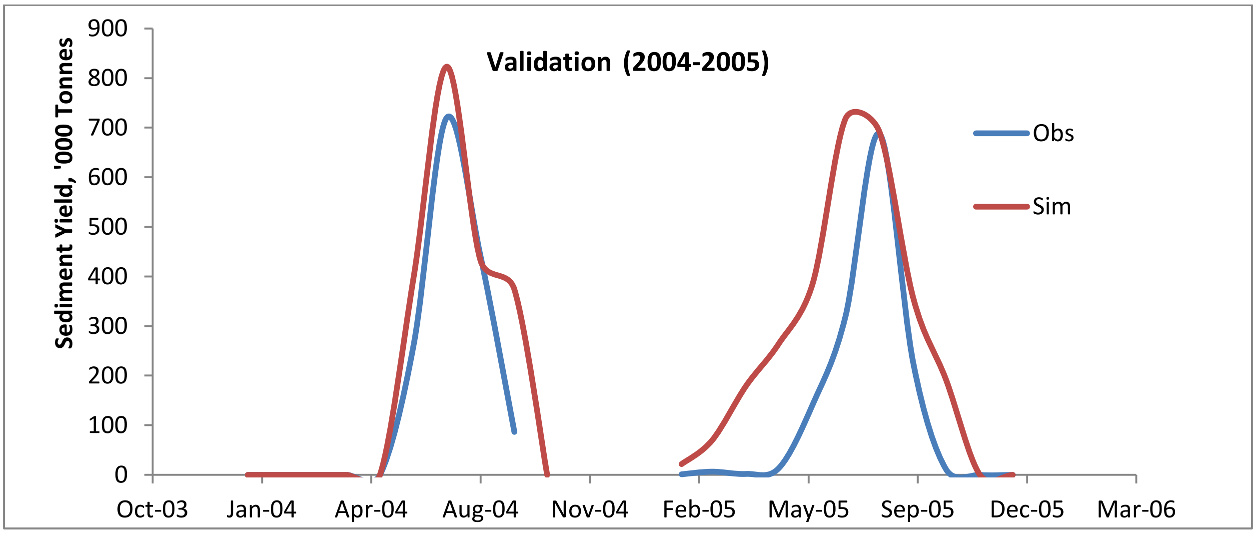



**Figure 7-11: Comparison of Observed and Simulated Sediment Yield (Validation)**

SWAT model was thus successfully calibrated and validated against stream flow where parameters that were deemed needing adjustment were adjusted based on the sensitivity analysis. The parameter CN2, which highly affects the surface runoff , was found to be the most sensitive for adjusting peak flows. Similarly, hydraulic conductivity of the channel alluvium, Ch_K2, was found to be very sensitive in adjusting the shape of the hydrograph.

As can be read from the figure, the hydrological processes have followed the trend of precipitation. Higher precipitation is clearly reflected by the response on water and sediment yield. In general, very good agreement between measured and simulated monthly stream flows shows the strong capability of the model to simulate hydrology in a large complex watershed like the Koshi Basin. Similarly, despite the inconsistencies present in the sediment data, the model adequately simulated the sediment yield during the calibration period and then showed satisfactory results during the validation period. USLE support practice factor (USLE_P) was found to be the most sensitive parameter regarding the sediment calibration.

## 7.6 Incorporation of the RCM Data in SWAT Model

### 7.6.1 PRECIS - ECHAM05 Flows:

Bias corrected ECHAM05 dataset downscaled using PRECIS was used in the calibrated SWAT model for a projection period of 2025 - 2060. The data used were daily precipitation and daily maximum and minimum temperature for the projected period. **Figure 7-12** below shows the daily hydrographs for the period of 2025 - 2060. As can be read from the figure, there is an indication of increased frequency of extreme floods which are in agreement with increased extreme rainfall events. Similarly **Figure 7-13** shows the trends of annual average flow for observed (1980 - 2008) and projected (2025 - 2060).

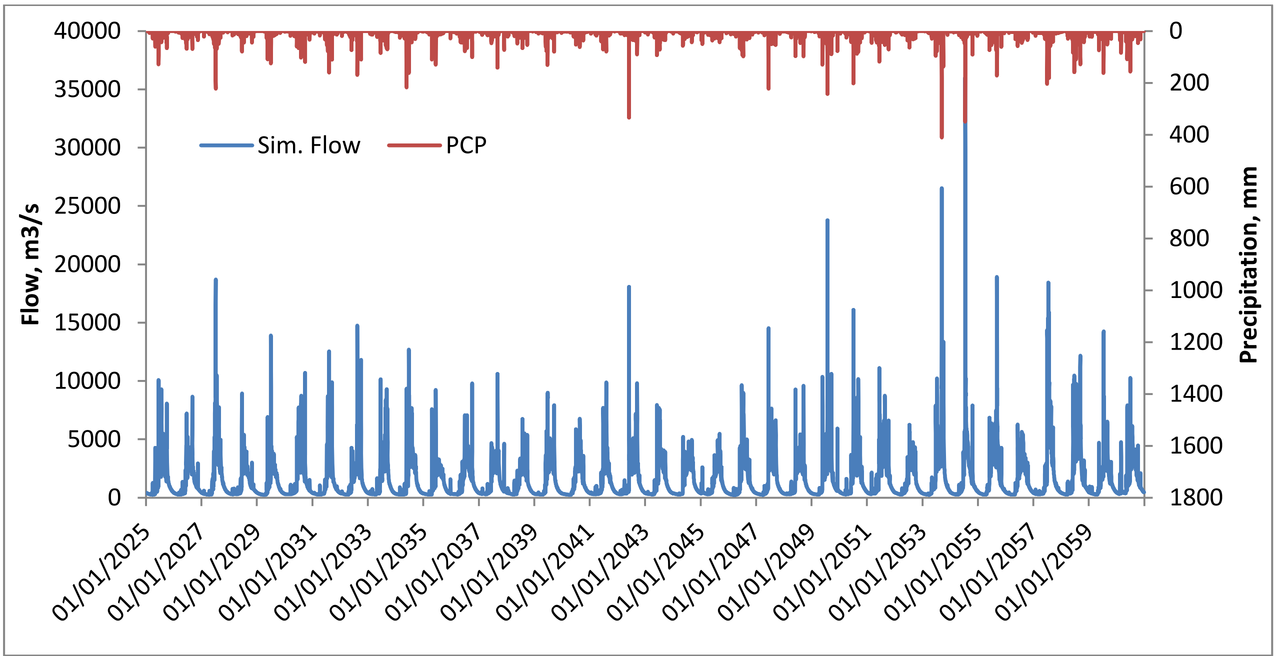



**Figure 7-12: Daily Hydrographs for Projected Periods**

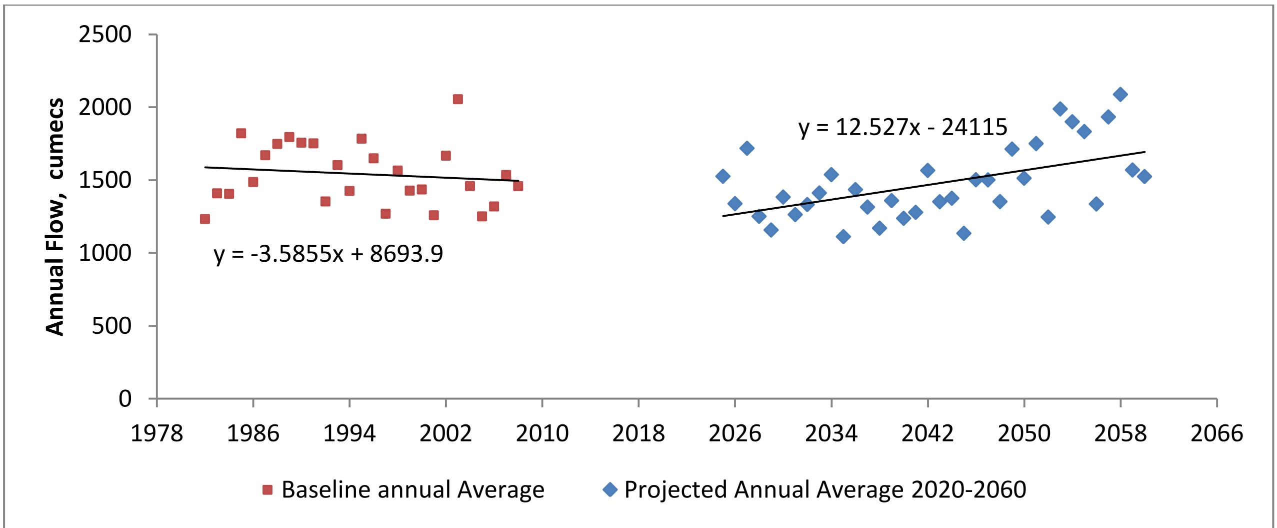



**Figure 7-13:Average Annual Flow Trends**

From the figure, it is evident that whilst there is a slightly decreasing trend of annual flow during the historical series till 2010 and is likely to decrease gradually during the early part of the projected series, annual flow will abruptly increase during the late 2040s and 50s.

Similarly, **Figure 7-14** shows the average monthly flow hydrographs for the present and projected scenario under ECHAM05 data. The figure suggests shift of peak monthly flow from August under existing conditions (baseline) to July during the projected period.

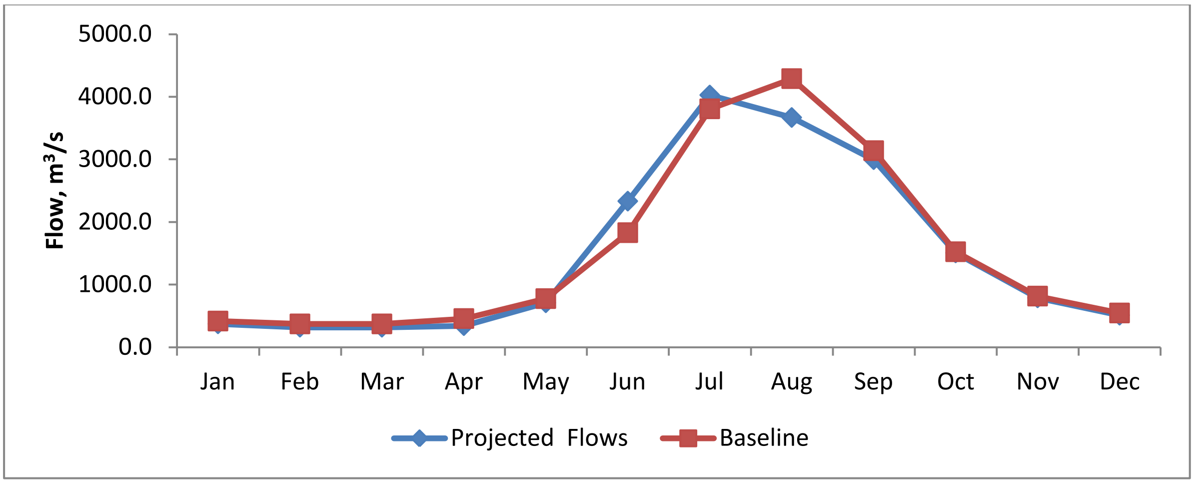



**Figure 7-14:Average Monthly Flow Trends**

**Table 7-5** and **Figure 7-15** show the percentage change in monthly flows for the projected period from the baseline average monthly values. The figures suggest decrease in flows for all the months except June and July. Flow during June is observed to be increased by 26% whereas maximum decrease in flow is observed during the month of April. This result indicates the shift in long term peak monthly flow.

**Table 7-5: Percentage Change in Monthly Flow from Historic Series**

| Months | Baseline 1980 - 2008 | Projected 2025-2060 | % Change from baseline |
|---|---|---|---|
| **Jan** | 415.5 | 367.6 | -11.5 |
| **Feb** | 369.9 | 315.4 | -14.7 |
| **Mar** | 369.9 | 311.2 | -15.9 |
| **Apr** | 455.5 | 343.7 | -24.5 |
| **May** | 773.9 | 694.5 | -10.3 |
| **Jun** | 1827.3 | 2305.8 | 26.2 |
| **Jul** | 3805.4 | 3920.1 | 3.0 |
| **Aug** | 4287.6 | 3622.2 | -15.5 |
| **Sep** | 3137.0 | 2928.5 | -6.6 |
| **Oct** | 1522.7 | 1500.2 | -1.5 |
| **Nov** | 814.1 | 770.8 | -5.3 |
| **Dec** | 544.4 | 503.0 | -7.6 |

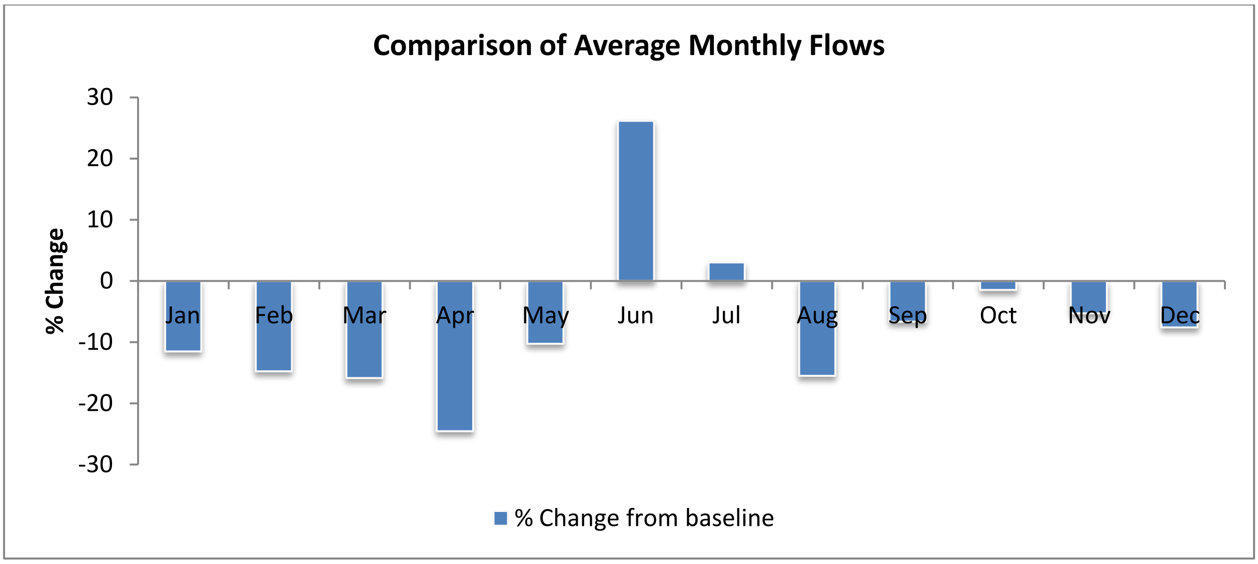



**Figure 7-15: Percentage Change in Monthly Flow from Historic Series**

Likewise, the Flow duration curves (FDCs) for both observed and projected flows were compared. **Figure 7-16** and **Figure 7-17** represent the FDC for observed flow data and projected flow data for different decades, respectively.

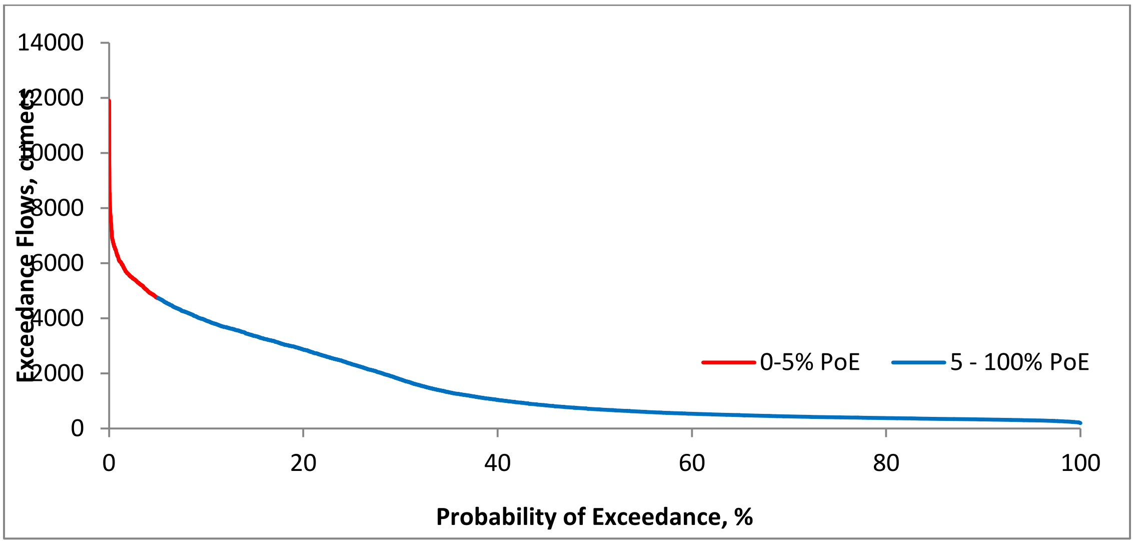



**Figure 7-16: Flow Duration Curve for Historic Series**

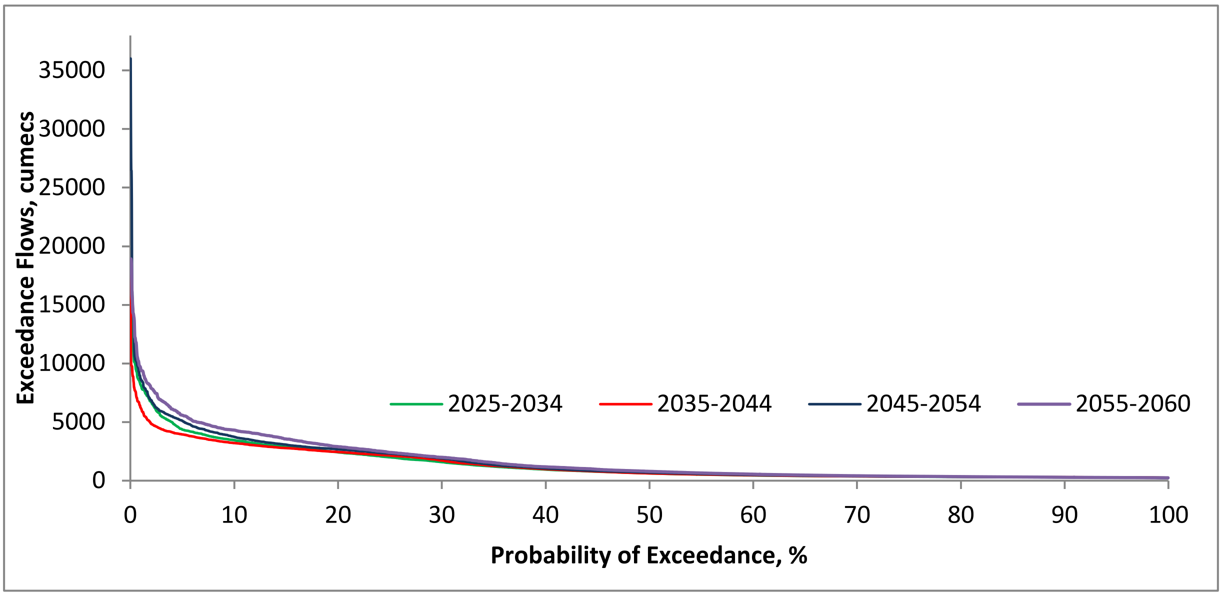



**Figure 7-17: Decadal Flow duration Curves for Projected Series**

**Figure 7-18** and **Table 7-6** present the comparison in Flow durations under various probabilities of exceedance. The figures show significant increase in 1% exceedance flows to as high as 58% in the late 2050s, thus suggesting increase in extreme flood events. However, 95% dependable flows are observed to be decreasing in almost all decades.

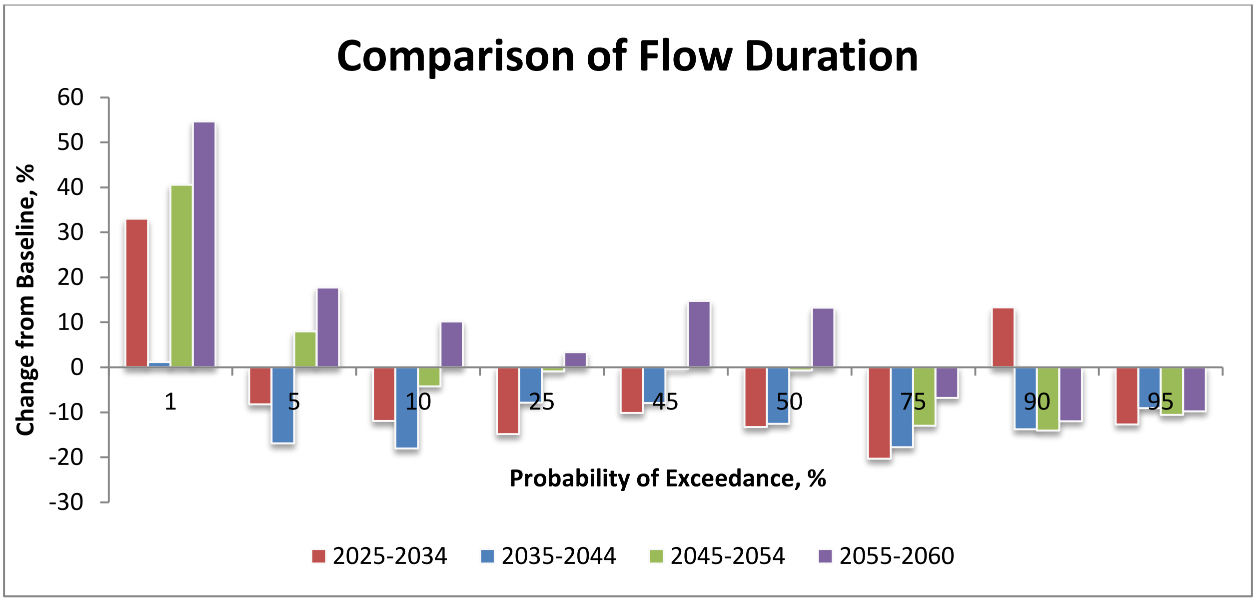



**Figure 7-18: Percentage Change in Flow Duration**

**Table 7-6: Percentage Change in Flow Duration**

| PoE % | 2025-2034 | 2035-2044 | 2045-2054 | 2055-2060 | Baseline |
|---|---|---|---|---|---|
| **1** | 33.0 | 1.1 | 40.5 | 54.6 | 6120 |
| **5** | -8.3 | -16.9 | 8.0 | 17.7 | 4740 |
| **10** | -12.0 | -18.1 | -4.2 | 10.2 | 3910 |
| **25** | -14.9 | -7.9 | -0.9 | 3.3 | 2330 |
| **45** | -10.2 | -8.0 | -0.3 | 14.7 | 842 |
| **50** | -13.3 | -12.6 | -0.7 | 13.3 | 703 |
| **75** | -20.3 | -17.8 | -13.0 | -6.8 | 408 |
| **90** | 13.3 | -13.8 | -14.1 | -12.0 | 332 |
| **95** | -12.7 | -9.1 | -10.6 | -9.8 | 299 |

### 7.6.2 PRECIS - HADCM3 Flow:

Bias corrected HADCM3 data for daily precipitation and temperature, was used in the SWAT model for a projection period of 2035 - 2060. **Figure 7-19** below shows an increase by almost 13 cumecs per year for the projected period.

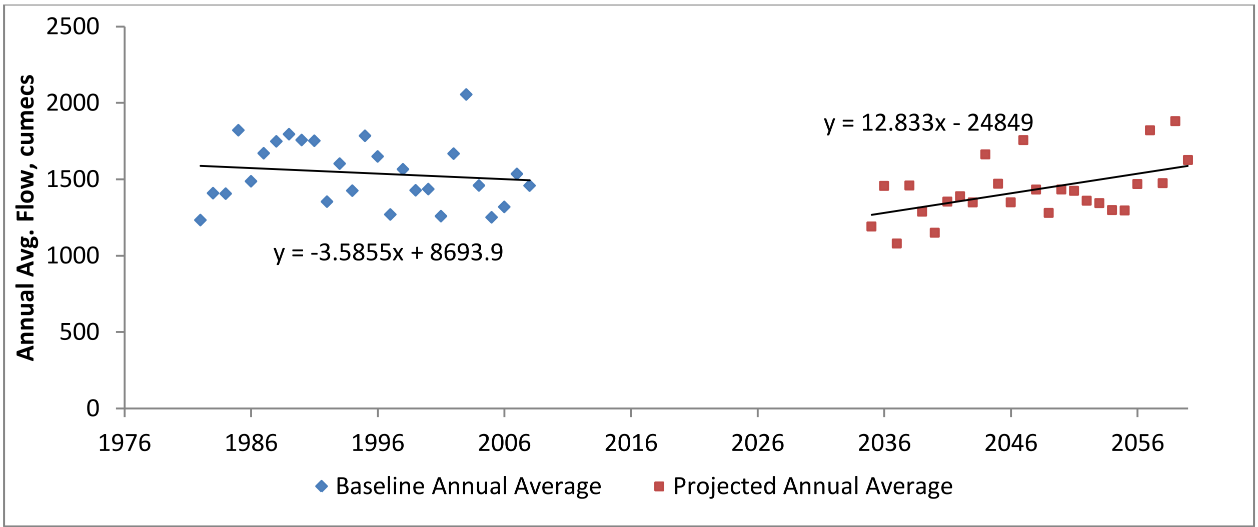



**Figure 7-19: Average Annual Flow Trend**

**Figure 7-20** shows the average monthly flows for the observed series and HADCM3 projected flows. The figure suggests decrease in the peak monthly flow during August. However, though a clear shift in peak monthly flow is not observed, August flow is reduced to nearly as the flow in July. This indicates a possible shift in the future. As for the rest of the months, a clear decline in average monthly flows is observed apart from June and October (**Figure 7-21** and

**Table** 7-7).

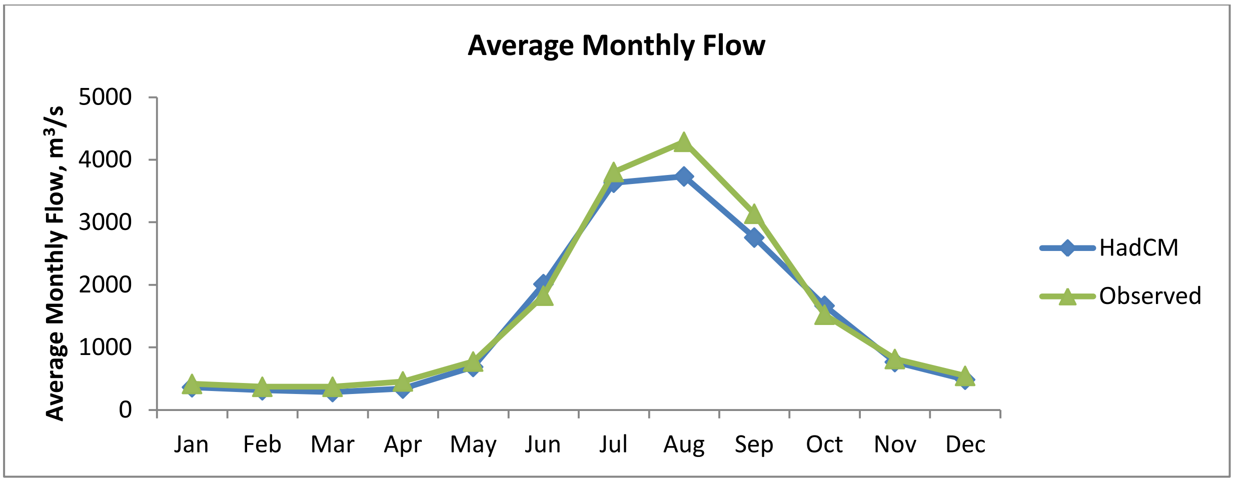



**Figure 7-20: Average Monthly Flow Trend**

**Table 7-7: Percentage Change from Historical Series**

| Months | Baseline 1980 - 2008 | HadCM3 2035 - 2060 | % Change |
|---|---|---|---|
| **Jan** | 415.5 | 361.6 | -13.0 |
| **Feb** | 369.9 | 313.5 | -15.3 |
| **Mar** | 369.9 | 285.3 | -22.9 |
| **Apr** | 455.5 | 340.4 | -25.3 |
| **May** | 773.9 | 686.8 | -11.3 |
| **Jun** | 1827.3 | 2010.9 | 10.0 |
| **Jul** | 3805.4 | 3632.6 | -4.5 |
| **Aug** | 4287.6 | 3733.1 | -12.9 |
| **Sep** | 3137.0 | 2755.3 | -12.2 |
| **Oct** | 1522.7 | 1664.8 | 9.3 |
| **Nov** | 814.1 | 764.8 | -6.1 |
| **Dec** | 544.4 | 482.9 | -11.3 |

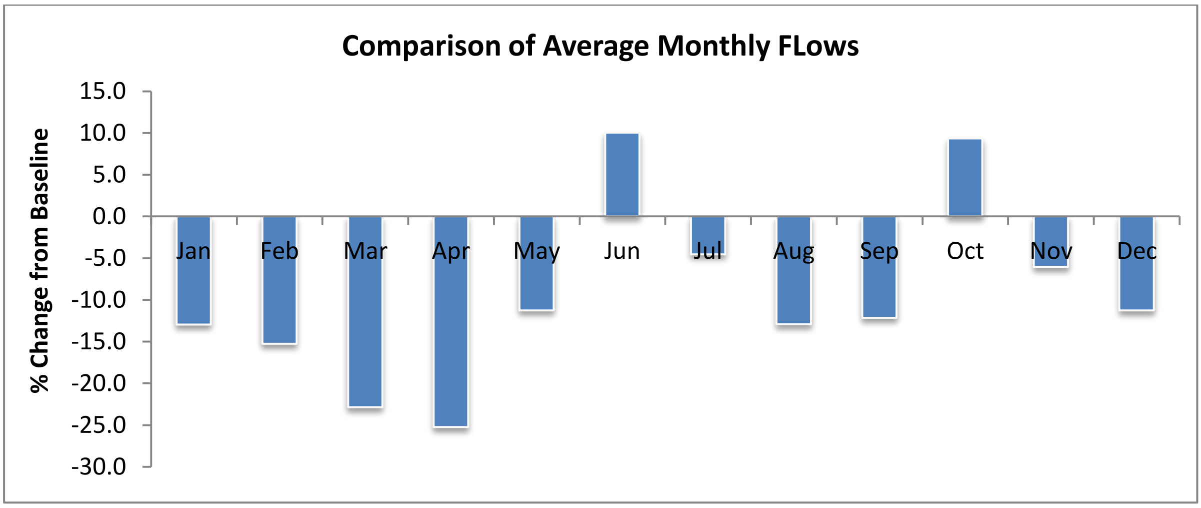



**Figure 7-21: Percentage Change from Historic Series**

The Flow duration curve for the HADCM3 dataset is shown in **Figure 7-22**. Comparing the flows at different probabilities of exceedance for the observed series (**Figure 7-23**), it is evident that there is an increase in 1% Flow duration values by as high as 61% in the later part of the 2050s. The results are in good agreement with those showed by projected flows under ECHAM series. This result suggests a probable increase in extreme flow events in the future. However the 90 and 95% dependable flows are decreasing as compared with the historical case. This indicates decrease of flow during the lean seasons.

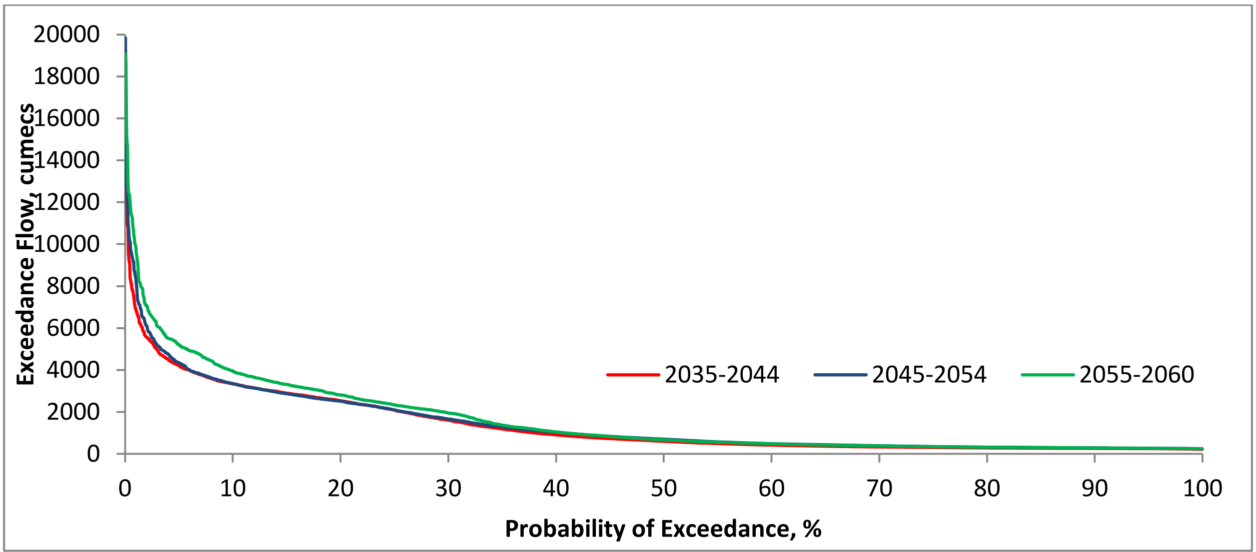



**Figure 7-22: Decadal Flow Duration Curves for Projected Series**

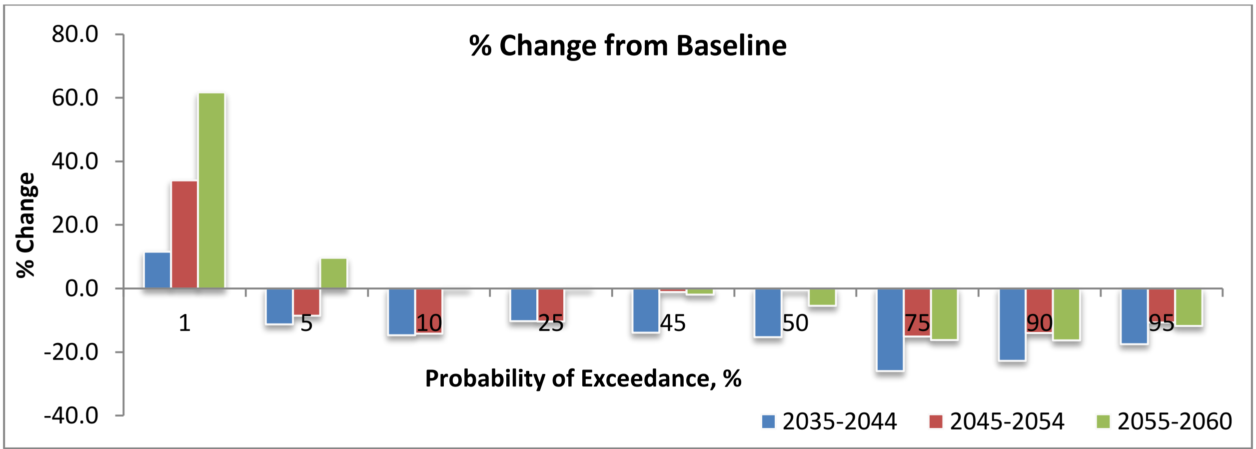



**Figure 7-23: Percentage Change in Flow Duration from Historic Series**

## 7.6.3 Sediment Projections:

With increased frequency of extreme floods, both ECHAM05 and HADCM3 simulations suggest extreme increase in sediment yield by almost 74000 tonnes and 99800 tonnes per year respectively. Refer **Figure 7-24** Average sediment yield during the projection period exceeds the historical simulated average of 2.4 tonnes by almost 107% based on ECHAM05 data as well as 65% according to HADCM3 projections.

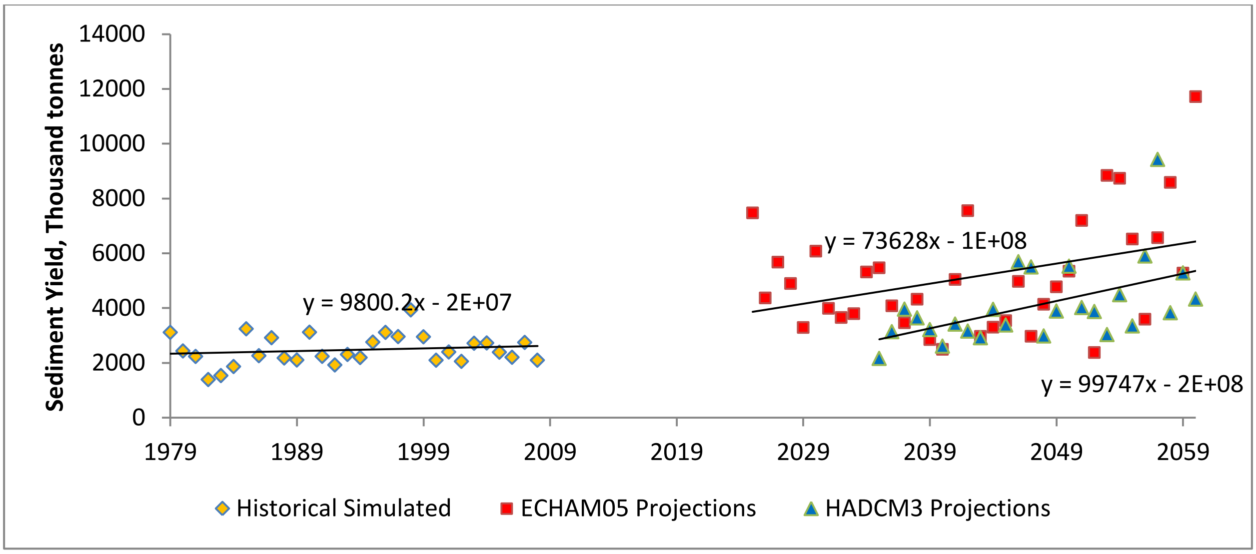



**Figure 7-24: Simulated annual sediment yields for historic and projected conditions**

## 7.7 Impacts Of Climate Change On The Proposed Hydraulic Structures

Regarding the impacts of climate change on the proposed Sapta Koshi High Dam, analysis were carried out focusing on the design values and standards of the dam.

### 7.7.1 Design Flood:

To analyze the impacts of climate change on the design flood for the proposed dam, various return period floods for the historic maximum instantaneous series were considered and were compared with the respective return period floods in the future. To calculate the instantaneous floods during the projected period, the following methodology was adopted.

1) Frequency analysis of annual instantaneous maximum flow for the historic data for different return periods ($\mathbf{Q_{T,i}}$) was calculated using Log-Pearson III distribution.
2) Similarly, frequency analysis of annual maximum daily flows for the historic data for different return periods was also calculated($\mathbf{Q_{T,d}}$)
3) A ratio was then obtained by dividing (a) by (b) for each return period T , $\mathbf{R_T = Q_{T,i} / Q_{T,d}}$
4) Frequency analysis of annual maximum daily flows for the projected flows for different return periods ($Q'_{T,d}$) was done.
5) Finally the instantaneous floods for different return periods in the projected series were thus calculated by multiplying the ratio obtained for each return period in step (c) with the values obtained from step (d) for the respective return periods. $\mathbf{Q'_{T,i} = Q'_{T,d} * R_T}$

The instantaneous floods for various return period floods for historic, projected (ECHAM05 and HADCM3) series are plotted in **Figure 7-25**. To represent the average climate change conditions, an average values of ECHAM05 and HADCM3 floods are also plotted. **Table 7-8** shows the flood values for different return periods.

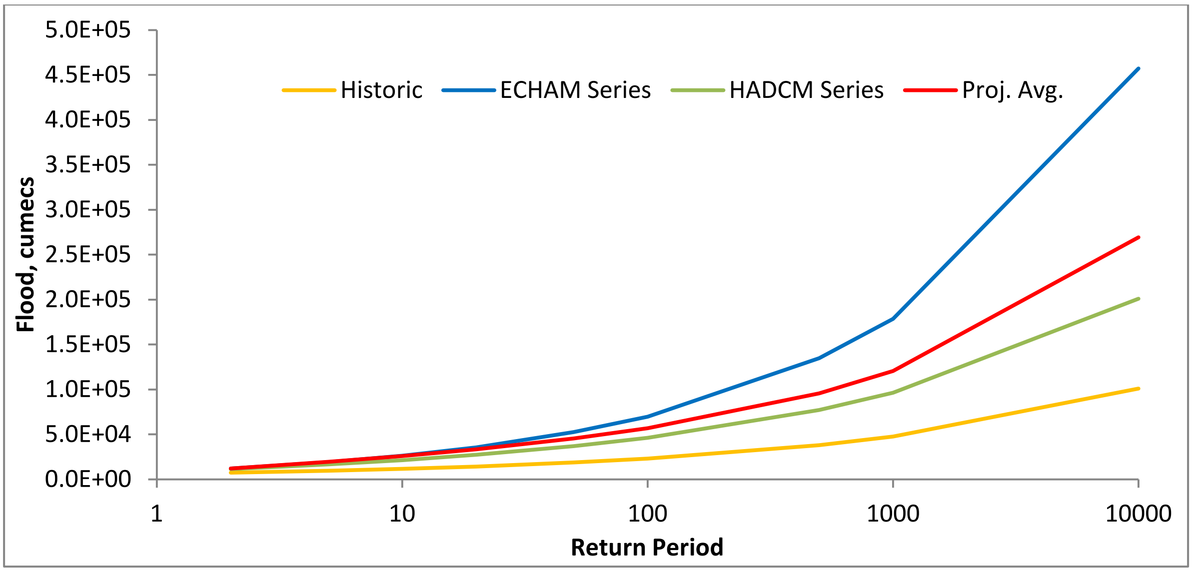



**Figure 7-25: Different Return Period Floods for Historic and Projected Conditions**

**Table 7-8: Return Period Floods for Historic and Projected Conditions**

| Return Period (Year) | Historic | ECHAM Series | HADCM Series | Projected Avg. |
|---|---|---|---|---|
| **2** | 7245.5 | 11878.2 | 11206.8 | 11939.9 |
| **5** | 9463.6 | 19184.3 | 16600.5 | 19547.9 |
| **10** | 11579.1 | 26349.0 | 21387.8 | 25908.2 |
| **20** | 14196.5 | 35617.3 | 27146.9 | 33286.2 |
| **50** | 18665.5 | 52380.8 | 36772.6 | 45303.0 |
| **100** | 23040.9 | 69758.0 | 46042.4 | 56761.7 |
| **500** | 38033.6 | 134647.6 | 77087.8 | 95714.4 |
| **1000** | 47444.5 | 178538.9 | 96165.0 | 120492.0 |
| **10000** | 101079.8 | 457142.6 | 201102.8 | 269294.5 |

Considering a 1000 year return period design flood for the spillway of the proposed high dam, it is evident from the above figures that under average climate change conditions the 1000 year return period flood value for historic conditions could occur within 50 years of the design of the structure. Hence if the design is to be made taking climate change into consideration, the design values for the spillway must be higher than the 10000 year return period flood calculated under historical data.

Similarly **Figure 7-26** shows the correlation obtained between historical and projected instantaneous floods under climate change. As can be observed from the figure, under average climate change conditions, the relationship between the historic and projected floods is shown below in **Equation (7-1).**

$$\boldsymbol{Flood_{projected}} = \mathbf{2.}604 \times \boldsymbol{Flood_{histotic}} \quad \textbf{(7-1)}$$

For instance, a 50000 $m^3/s$ historic flood would be equivalent to a flood of almost 130000 $m^3/s$ under climate change. These results provide an indication that strong reconsiderations in the design values are to be made if climate change is taken into consideration.

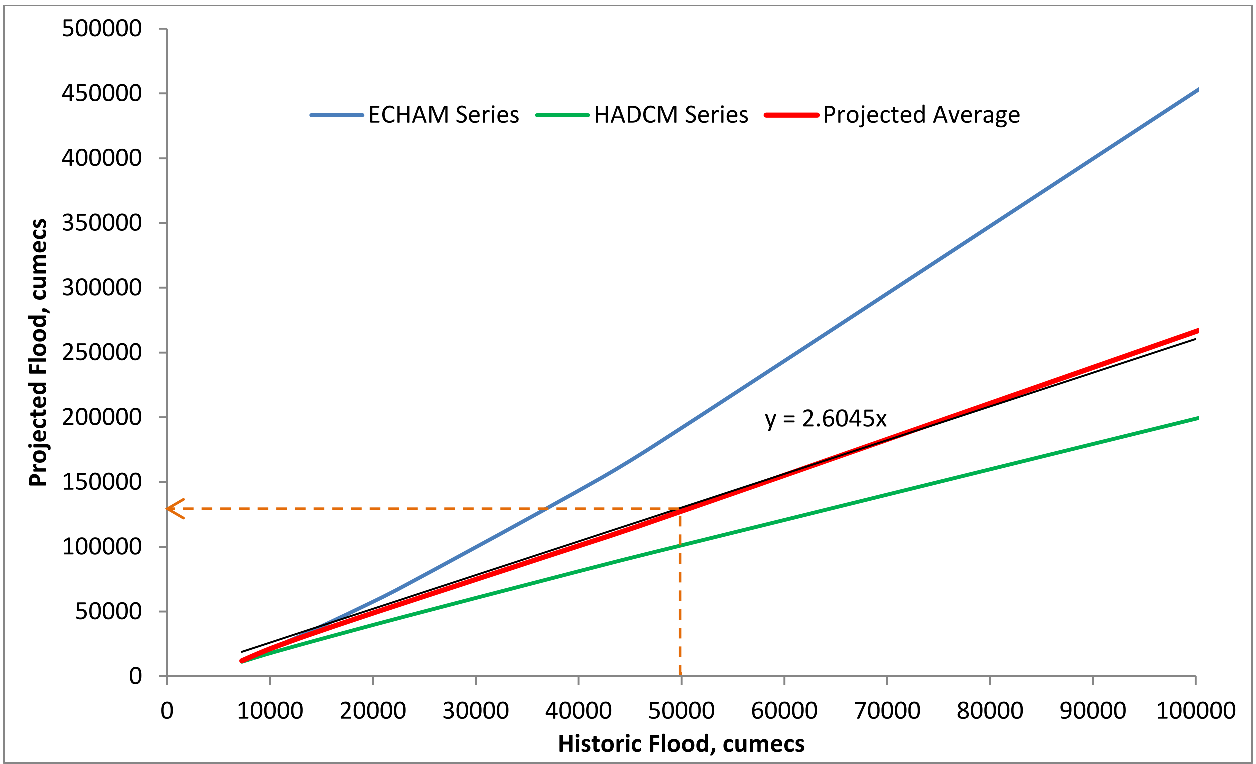



**Figure 7-26: Co-relation between Historical and Projected Floods**

### 7.7.2 Design Dead Storage

After reviewing various literature on the total sediment load of the Koshi River at Chatara, a value of 120 MCM (Million Cubic Meters) (Devkota et. al, 2012) was considered as the average annual total sediment load considered for the design dead storage. The reported proposed dead storage for the high dam i.e. 4087 MCM (Singh, 2013), under our assumption of a historical average total load of 120MCM would give the design life of about 35 years.

Since the SWAT model just calculates the suspended sediment load, it was assumed that the average simulated suspended load for the historic data (2.1 MCM) would be a share of the 120 MCM total sediment load. This proportion (suspended sediment to total load) was assumed to be constant in the future and hence the total loads for both ECHAM05 and HADCM3 simulations were calculated. **Table 7-9** shows the simulated suspended and calculated total sediment loads for the historic, ECHAM05 and HADCM3 projections.

**Table 7-9: Simulated and Estimated sediment loads for different periods**

| Average Simulated Suspended Load (MCM) | | Calculated Average Total Load (MCM) | |
|---|---|---|---|
| **Historic** | 2.1 | Historic | 120 |
| **ECHAM05** | 4.3 | ECHAM05 | 250 |
| **HADCM3** | 3.4 | HADCM3 | 199 |
| **Projected Average** | 3.9 | Projected Average | 224 |

Sediment loads were assumed to be increasing by the same average amounts each year. **Figure 7-27** shows the cumulative sediment loads for different design years.

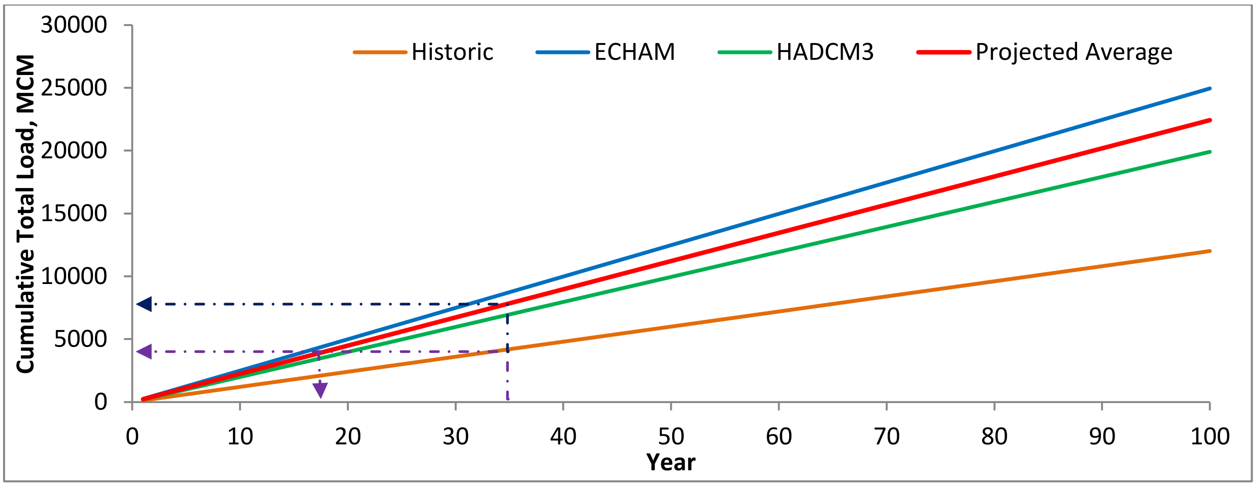



**Figure 7-27: Sediment Load Estimates for different design years**

From the chart, it can be observed that the dead storage designed for 35 years under historical conditions, would be filled in just about 18 years under average climate change conditions. Hence to obtain a design life of 35 years taking climate change into account, the design dead storage should be increased to about 8000 MCM. Hence a reconsideration needs to be done in the design standards and values.

## 7.8 Conclusion

The bias corrected RCM data were used in the calibrated SWAT model to assess the future hydrologic scenarios and sediment fluxes in the basin. Increase in annual flows after 2040 for both ECHAM05 and HADCM3 series was observed, with pronounced increase in the late 2050s. ECHAM05 simulations suggested a shift in average annual peak flow from August under existing conditions to July in the future, with 26% and 3% increase in June and July and a 15% decrease in August flows. However HADCM3 data only showed 10% and 9% increase in June and October flows without any shifts in peak flow. Similarly increase in the extreme flows (1% probability of exceedance) in all the decades was observed for both ECHAM05 and HADCM3 simulations (54 and 61% increase respectively in the 2050s) whereas the dependable flows (80 - 95% probability of exceedance) were found to be on a decreasing trend. Likewise increase in sediment yield was clearly seen from both ECHAM05 and HADCM3 simulations. All the decades unanimously show increasing sediment yields to as high as 215% under ECHAM05 and 124% under HADCM3 data in the 2050s.

With climate change underway, both ECHAM05 and HADCM3 simulations suggest increase in extreme flood events and high sediment load in the future. To incorporate the impact of climate change in the design of hydraulic structures, the design flood values should be increased by 2.6 times the values being adopted under existing climatic condition. Similarly, due to the increase in sediment load in the future, the capacity of the dead storage of the proposed Koshi High Dam should be increased by more than 100% to make it functioning for the envisioned design life. Amidst the uncertainties, these predictions provide reasonable insight for any alterations or re-consideration of design standards and design values of hydraulic structures under climate change conditions.

# Chapter 8: Hydraulic Modeling

Hydrologic Engineering Center's River Analysis System (HEC-RAS) and HEC-GeoRAS, developed by the US Army Corps of Engineers were used in the research to analyze the flood inundation pattern in the Terai plains of the Koshi River Basin downstream of Chatara. Refer **Figure 8-1**. A 1D Steady flow analysis was carried out to study the flood hazard and inundation pattern.

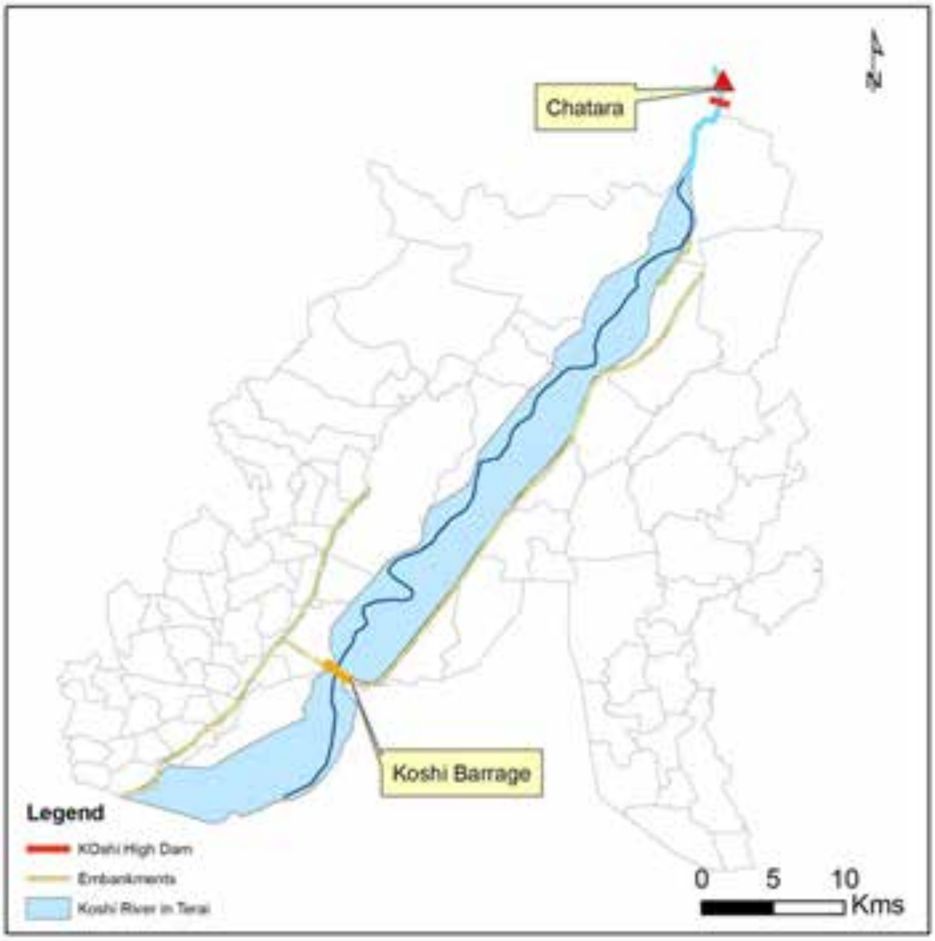



**Figure 8-1: Study Area for Hydraulic Analysis**

**Input data used in the steady flow analysis were:**

**A. Geometric data**: These include the river system schematics, cross-section data, reach lengths, Manning's n, contraction/expansion coefficients, stream junction information and information of hydraulic structures, such as embankments and dams.

**B. Steady flow data**: The steady flow data are required as:

i. Flow regime: subcritical, supercritical, mixed
ii. Boundary conditions
iii. Known water surface elevation
iv. Critical depth
v. Normal
vi. Rating curve
vii. Peak Discharge information

## 8.1 Input Data:

A customized Digital elevation model (DEM) was prepared for the Koshi river stretch emerging after Chatara to the Koshi Barrage using the contour data, GPS measured spot heights and cross section survey data obtained from the Department of Water Induced Disaster Prevention (DWIDP). The river cross-sections were obtained from the surveyed data as well as extracted from the DEM. The river centreline, banklines, and flood plain extents were delineated using Google Earth Imagery. Hydraulic structures such as embankments and barrage were also identified within the reach from the Google Earth Imagery.

Peak instantaneous floods for historical series were calculated using the Log-Pearson Type III distribution for different return periods. However for the projected period, the instantaneous floods for different return periods were obtained from the methodology explained in Chapter **Chapter 7**: **Section 7.7.1. Table 8-1** shows the calculated values of floods for various return periods using the maximum instantaneous flows at Chatara.

**Table 8-1: Flood values at different return periods**

| Return Period | Log-Pearson | Gumbell |
|---|---|---|
| **2** | 7213.0 | 7797.7 |
| **10** | 11636.6 | 13668.7 |
| **25** | 15282.8 | 16623.6 |
| **50** | 18778.7 | 18815.8 |
| **100** | 23074.1 | 20991.7 |
| **200** | 28352.2 | 26020.0 |
| **1000** | 45780.8 | 28181.8 |

### 8.2 Model Setup:

Geometric Data required for the HEC-RAS model such as river cross-section, reach lengths, river schematics, elevation data, levee alignments, etc were prepared using HEC-GeoRAS in the ArcGIS domain. This data was imported into the HEC-RAS and the model was set up for steady flow run, using boundary conditions for mixed flow conditions. The upstream boundary condition was provided as the rating curve with recorded gauge heights at the Chatara station (Refer **Table 8-2**) . Similarly, the downstream boundary condition was set as the normal depth obtained from the surveyed data.

**Table 8-2: Stage-Discharge data at Chatara**

| Stage (m) | Flow ($m^3/s$) | Stage (m) | Flow ($m^3/s$) |
|---|---|---|---|
| **11.5** | 24000 | **6.0** | 6320 |
| **8.35** | 12400 | **5.66** | 5630 |
| **7.65** | 10200 | **1.0** | 387 |
| **7.46** | 9760 | **0.74** | 288 |
| **7.11** | 8860 | **0.6** | 185 |
| **6.42** | 7220 | | |

Since a very high flood is being considered for the study, the Manning's values were set to a constant of 0.025. Also identifying the minimum impact of smaller tributaries during the high floods, the tributaries were not taken into account.

## 8.3 Results

After all the data were prepared and the boundary conditions set, HEC-RAS model was run for different return period floods for historical and projected conditions under different scenarios. The results were exported back to the HEC-GeoRAS environment to visualize the inundation pattern. Results under different scenarios used in the analysis are shown below:

### 8.3.1 Embankment Breach Scenarios

***A. Embankment Breach at Paschim Kusaha***:

In order to reassess the embankment breach at Paschim Kusaha which triggered the devastating flood of Koshi river on 18th August, 2008, a 1km stretch along the left embankment was breached in the model. The reported 4770 cumecs flood was diverted through the breach section and the inundation analysis was carried out. The flood inundation map for this flood is shown in **Figure 8-2**.

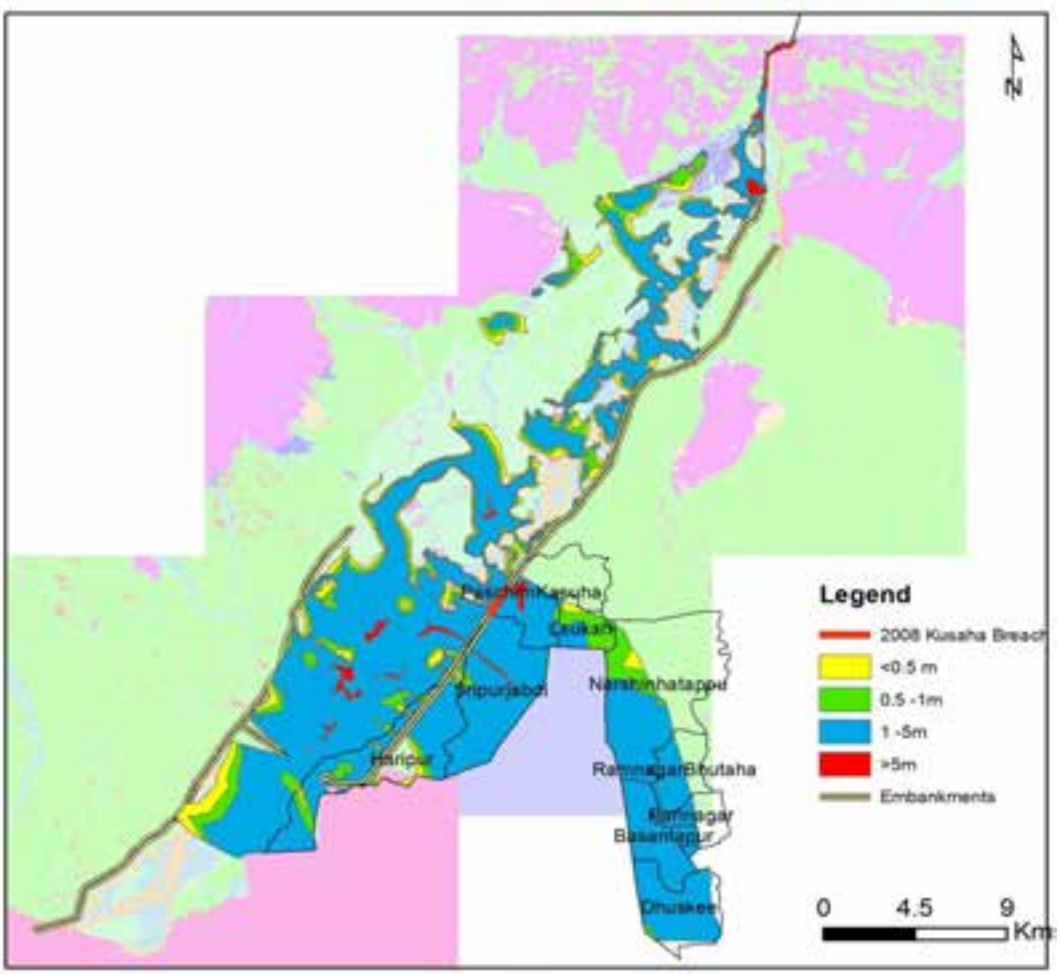



**Figure 8-2: Flood Inundation after Kusaha Breach**

The VDCs directly exposed to the flood are Paschim Kusaha, Sriupurjabdi, Haripur, Basantapur, Ramnagar Bhutaha, Ghuskee, Harinagara, Laukahi, etc. Vast stretches of land are observed to be under 1-5m inundation.

***B. Embankment Breach at Rajabas***

After the simulation of the breach at Kusaha and the resultant flood, another embankment breach analysis was carried out at Rajabas village in the Prakashpur VDC of Sunsari district. As reported by the locals during the field survey, Koshi embankment section along the Rajabas village was found to be a susceptible area for levee breach. To analyze the impacts of this breach (if it were to occur), a 2.5km stretch was breached and the same amount of discharge (4770 $m^3/s$) as the 2008 flood was passed through the breach. Spatial extent of inundation were assessed using the HEC-RAS model. Figure 8-3 shows the inundation pattern after the breach at Rajabas.

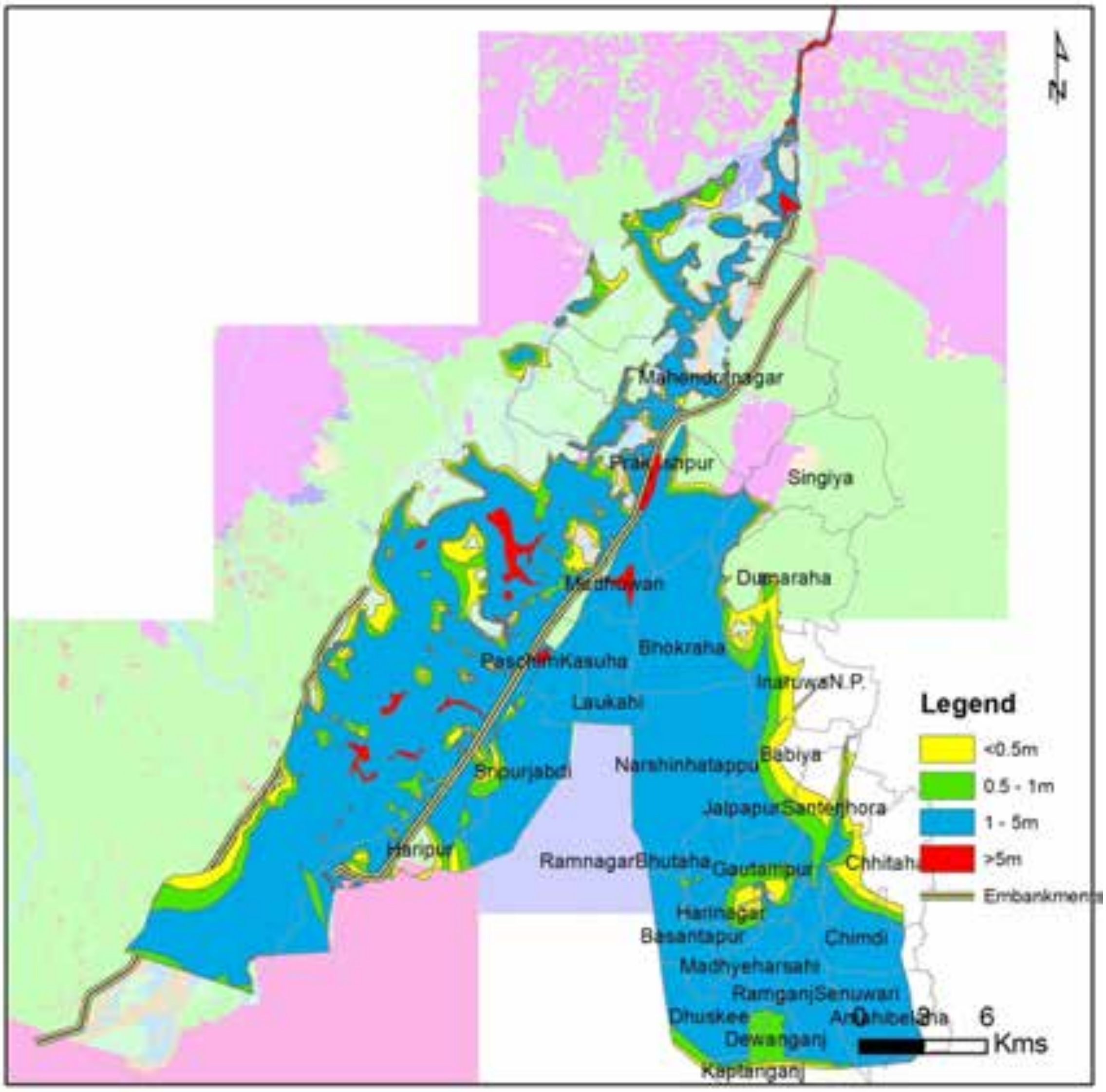



**Figure 8-3: Flood Inundation after Rajabas Breach**

As can be compared from the **Figure 8-2** and **Figure 8-3,** same volume of flood through Rajabas will have a more widespread and devastating inundation within Nepal. Twenty seven VDCs will come under inundation with this flood. The VDCs include Prakashpur, Madhuwan, Bhokraha, P.Kusaha, Laukahi, Narshinhatappu, Sripurjabdi, Babiya, Santerjhora, Dumrah, Gautampur, Harinagar, Haripur, Basantapur, Chimdi, Senuwari, Ramganj, Dewanganj, Kaptanganj, Madhyeharsahi, Ghuski, Chhitaha, Jalpapur, Singhiya, Anuhibelana and Inaruwa Municipality. The figure shows major share of the area inundated will be under 1-5m depth.

### 8.3.2 Flood Inundation Scenarios (With Existing Embankments):

To analyze the flood inundation pattern of the Koshi River with existing embankments in place, various return period floods for historical, ECHAM05 and HADCM3 data were used in the model.

***A. 100yr Return Period Flood:***

A historical 100 year return period flood of 23074 m3/s was first considered for the steady flow analysis to map the extent of flood inundation in the study area. **Figure 8-4** shows the inundation map during 100yr return period flood with embankments. The result indicates that the embankment under normal conditions will contain the 23074 m3/s flood thereby preventing any overtopping. It can be observed that the maximum inundation depth is in the range of 1- 5m.

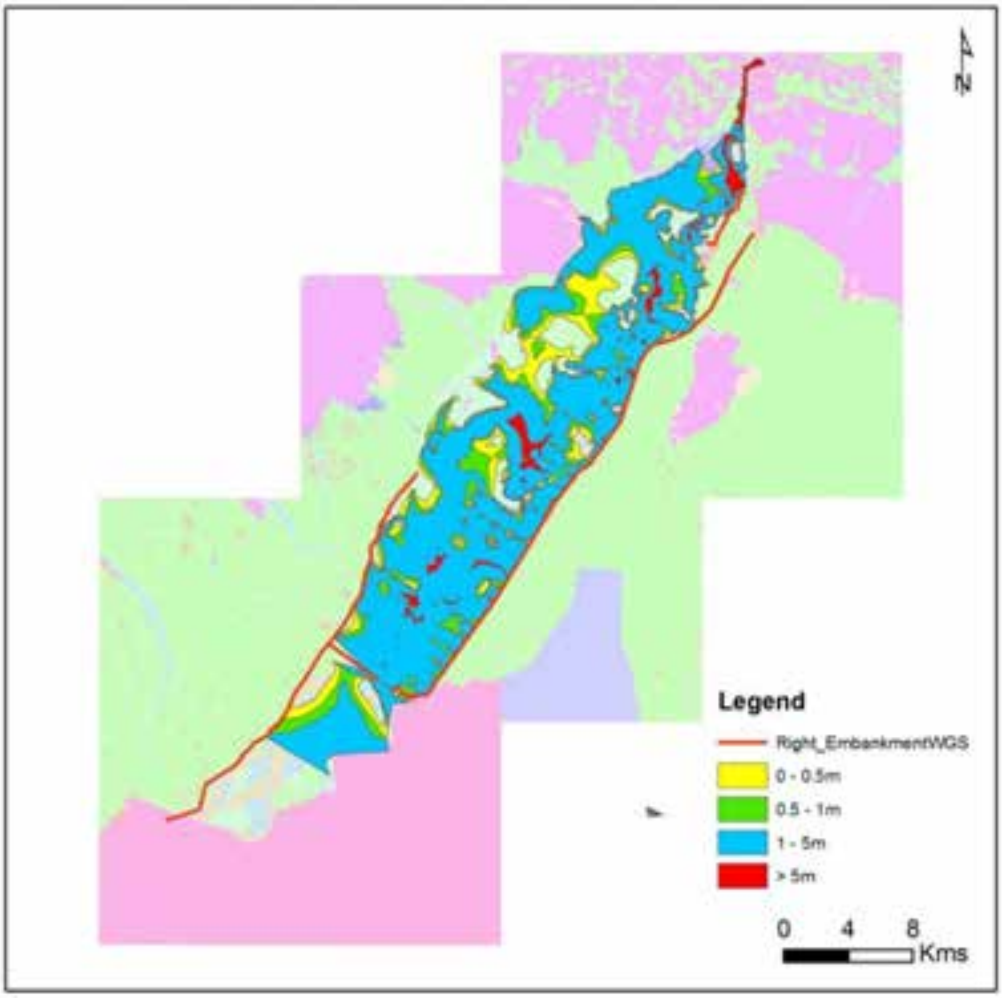
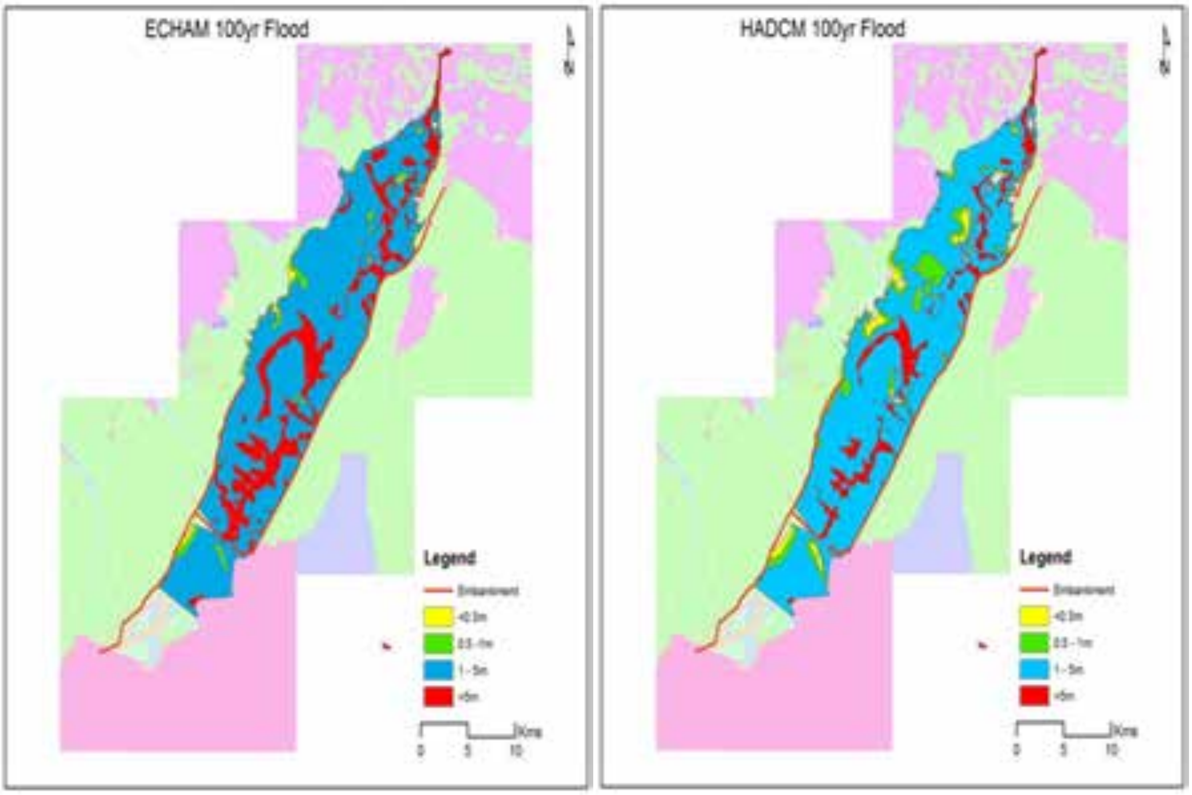



**Figure 8-4:Inundation Pattern under 100 yr Return Period Flood**

To assess the inundation under climate change, 100 year return period floods for ECHAM05 (69700 $m^3/s$) and HADCM3 (46000$m^3/s$) were also used in the model. As can be seen from **Figure 8-5:a and b**, both floods would be contained within the levees. However increased inundation depths have been observed in both cases.



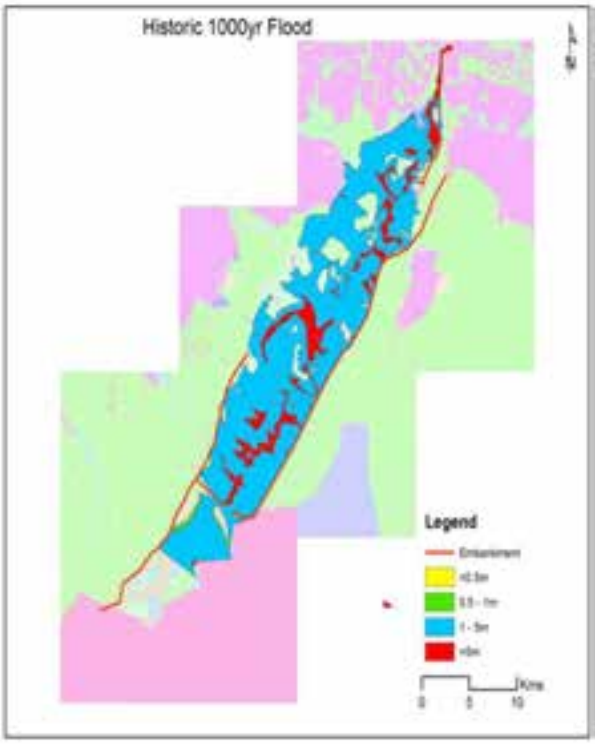

a. ECHAM05 100-yr flood b. HADCM3 100-yr flood

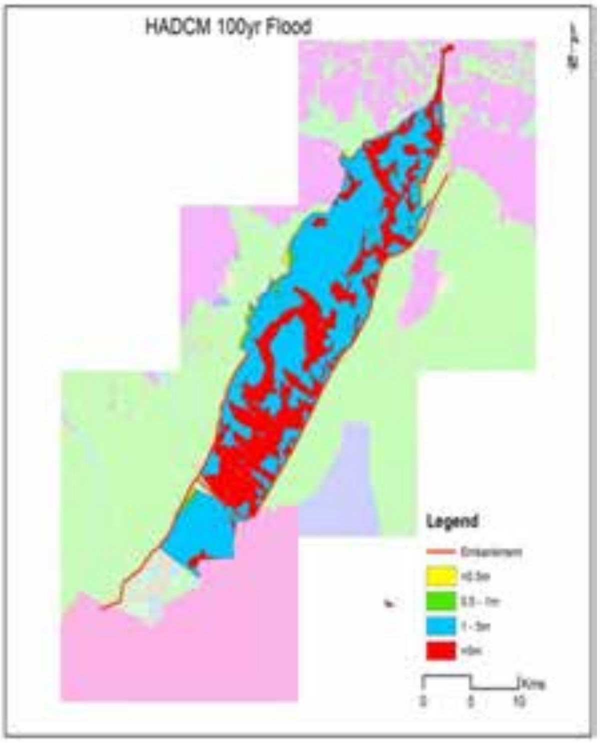
**Figure 8-5: Inundation under 100 year return period floods during the projected conditions**

### *B. 1000yr Return Period Flood:*

Similarly 1000 year return period floods of 47400, 178540 and 96165 $m^3/s$ under historic, ECHAM05 and HADCM3 conditions were used in the model to analyze the inundation under extreme floods. **Figure 8-6: a and b** show that with existing embankments in place, the floods under historic and HADCM3 conditions wouldn't overtop the embankment.

However with the ECHAM05 flood, the embankments wouldn't contain the flood and overtopping is observed at Paschim Kusaha, Sripur Jabdi, Haripur and Portaha. These VDCs are in the risk of extreme inundation (>5m). Refer **Figure 8-7.**




a. Historic 1000-yr flood b. HADCM3 1000-yr flood

**Figure 8-6: Inundation under 1000 year return period historic and HADCM3 floods**

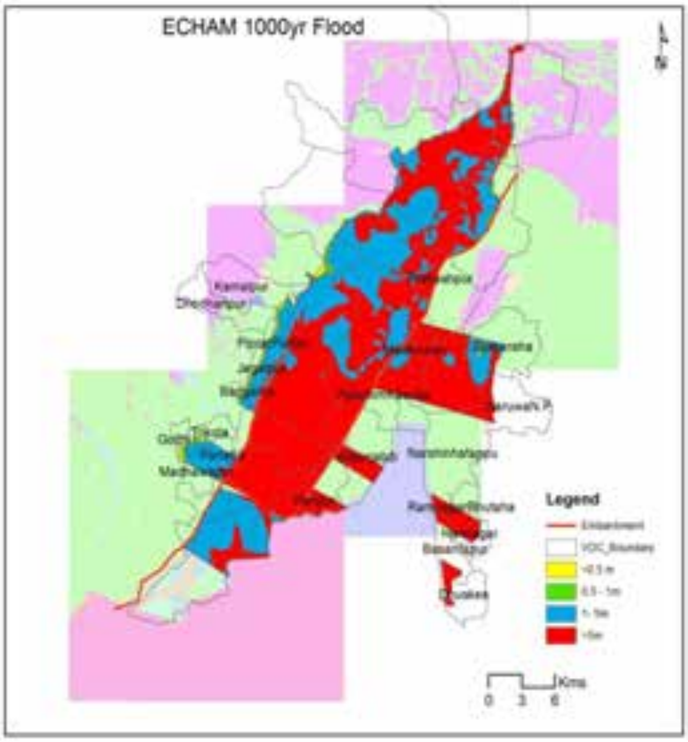



**Figure 8-7: Inundation under 1000 year ECHAM05 flood**

### 8.3.3 Flood Inundation Scenarios (Without Existing Embankments):

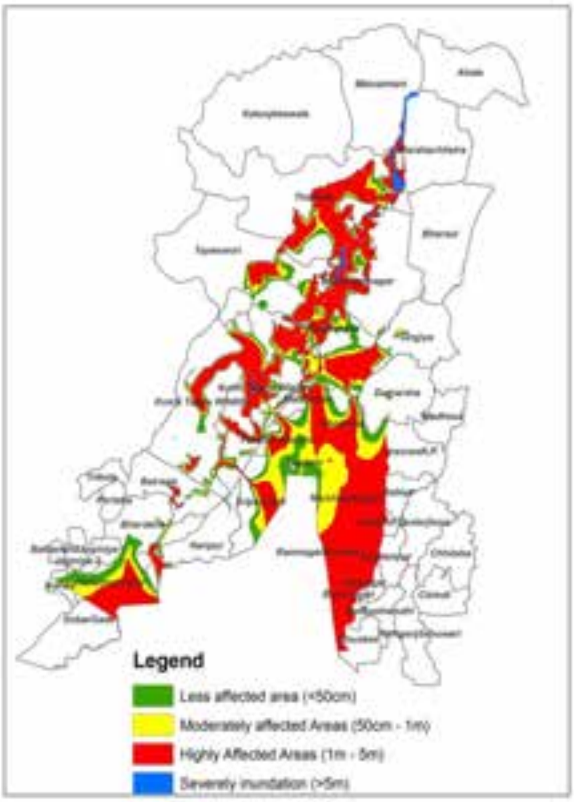
To assess the flood inundation scenario and the extent of hazard in the absence of embankments, a HEC-RAS model was set up without the embankments and was run with different return period floods under historic and projected conditions. Four different inundation depth classes were developed viz. <0.5 m as less affected representing agricultural loss, 0.5 - 1m as moderately affected representing mobility loss, 1m -5m as highly affected (loss of lives) and >5m as extreme inundation.

***A . 100yr Return Period Floods:***

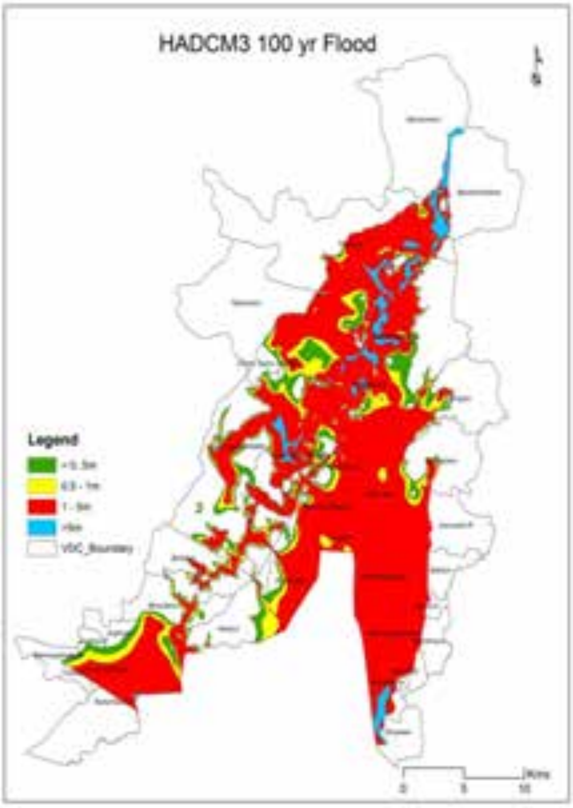
100yr return period historic, ECHAM05 and HADCM3 floods were used to analyze the change in inundation under different magnitudes of floods. It is clear from **Figure 8-8: a, b, c,** that in the absence of embankments, VDCs in Sunsari are more exposed to the flood hazard. Under the historical 100 yr return period flood, 61 $km^2$ area would be inundated under 0.5m depth followed by 69$km^2$ under 0.5 - 1m inundation and 187 $km^2$ under 1 -5m inundation. However for the ECHAM05 flood, inundated areas under 0.5m and 0.5 - 1m depths are converted into higher inundation depths resulting in 100% and 750% increase from historical case for 1-5m and >5m inundation areas. Similarly, HADCM3 floods show 75% and 350% increase in 1-5m and >5m inundated areas as compared with the historical case. Comparison of the inundation depths under different floods are shown below in **Table 8-3**.

**Table 8-3: Comparison of Inundation areas under historic and projected 100yr floods**

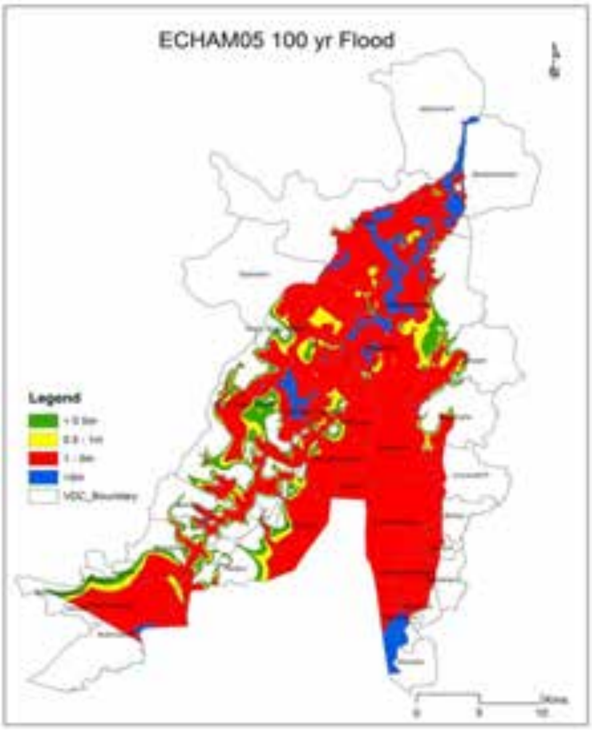
| Depth Classes | Historical flood inundation area, $km^2$ | ECHAM Flood<br>% Change in inundation area | HADCM3 Flood<br>% Change in inundation area |
|---|---|---|---|
| <0.5 m | 61 | -31.1 | -22.3 |
| 0.5 – 1m | 69 | -29.0 | -22.2 |
| 1 – 5m | 187 | 100.5 | 74.8 |
| >5m | 4 | 750.0 | 354.1 |




a. Historical 100yr Flood




b. HADCM3 100yr Flood



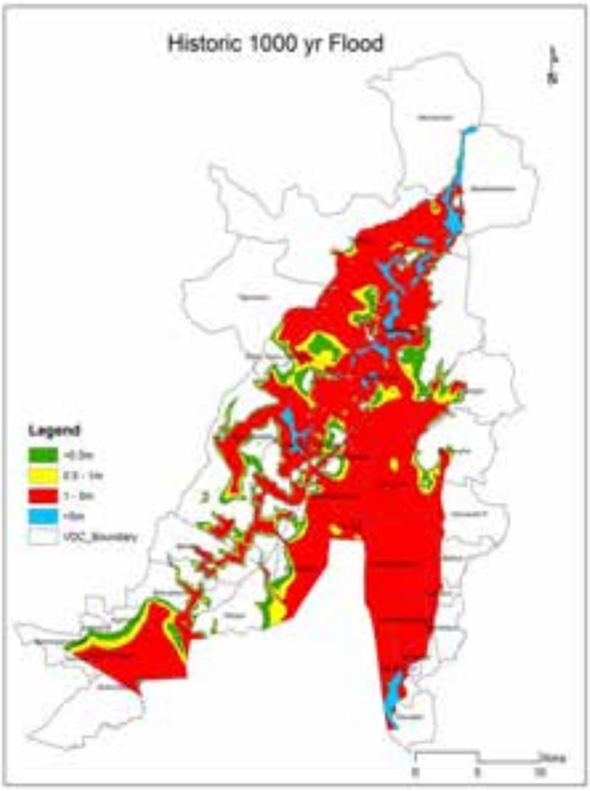

c. ECHAM05 100yr Flood

**Figure 8-8: Inundation Pattern under 100-yr return period floods**

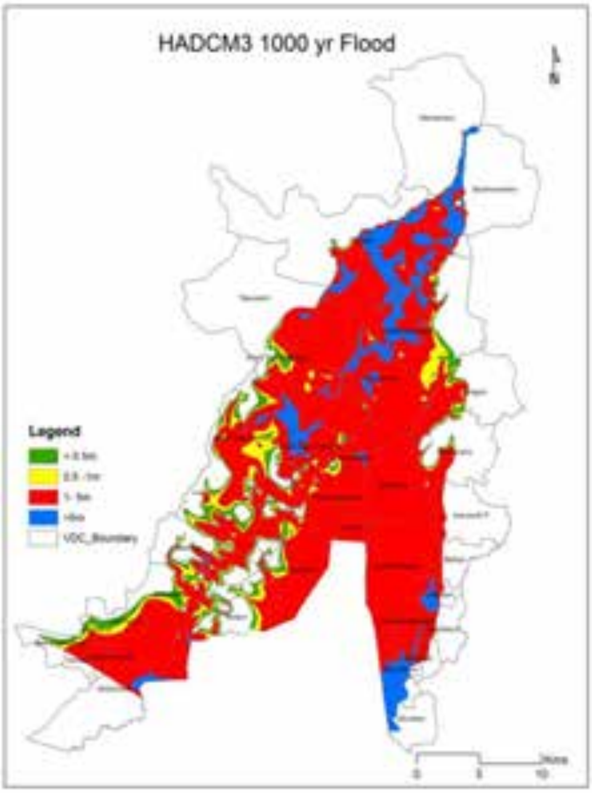
***B. 1000yr Return Period Floods:***

Similarly to assess the flood inundation during the extreme flood events in the future, the model was run with 1000 return period floods for historical and projected cases. **Figure 8-9 a, b, and c** show the inundation pattern under the historic, ECHAM05 and HADCM3 floods. Comparison of the inundation extent for different floods are shown

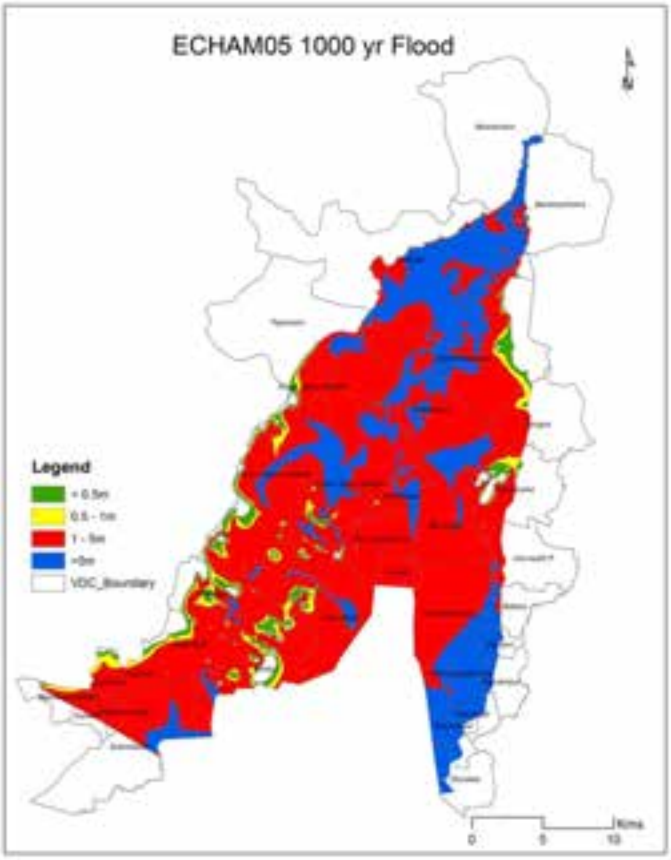
**Table 8-4**. The results indicate that under the historic 1000 yr flood, 48km$^2$ area would be under 0.5m, 53 km$^2$ under 0.5 - 1m, 331km$^2$ under 1-5m and 19km$^2$ under >5m inundation. However for the extreme flood under ECHAM05, 24% and 660% increase in areas inundated under 1-5m and >5m depths were observed as compared with the historical flood. However, for the HADCM3 1000yr flood, these increments are limited to 23% and 187% respectively.




a. Historical 1000yr Flood




b. HADCM3 1000yr Flood




c. ECHAM05 1000yr Flood

**Figure 8-9: Inundation Pattern under 1000-yr return period floods**

**Table 8-4: Comparison of Inundation areas under historic and projected 1000yr floods**

| Depth Classes | Historical flood inundation area, km$^2$ | ECHAM Flood<br>% Change in inundation area | HADCM3 Flood<br>% Change in inundation area |
|---|---|---|---|
| <0.5 m | 48 | -61 | -32 |
| 0.5 – 1m | 53 | -53 | -21 |
| 1 – 5m | 331 | 24 | 23 |
| >5m | 19 | 661 | 187 |

## 8.4 Dam Break Analysis

Dam break analysis was carried out using the HEC-RAS model to simulate the hydraulic processes and inundation pattern in case of breaching of the Koshi High Dam. The objective of this analysis was to evaluate the breach model of HEC-RAS as well as develop an insight into what the scenario would be after the breach. A model dam was constructed in the Koshi River at Chatars where the proposed Koshi High Dam is supposed to be constructed. The model dam has the characteristics resembling the available specifications of the Koshi High Dam along the proposed axis. While doing this analysis, the dam was placed as an inline structure in the HEC-RAS environment and piping was assumed as a trigger mechanism for the breach. **Figure 8-10** and **Table 8-5** below show the specification of dam used in the model

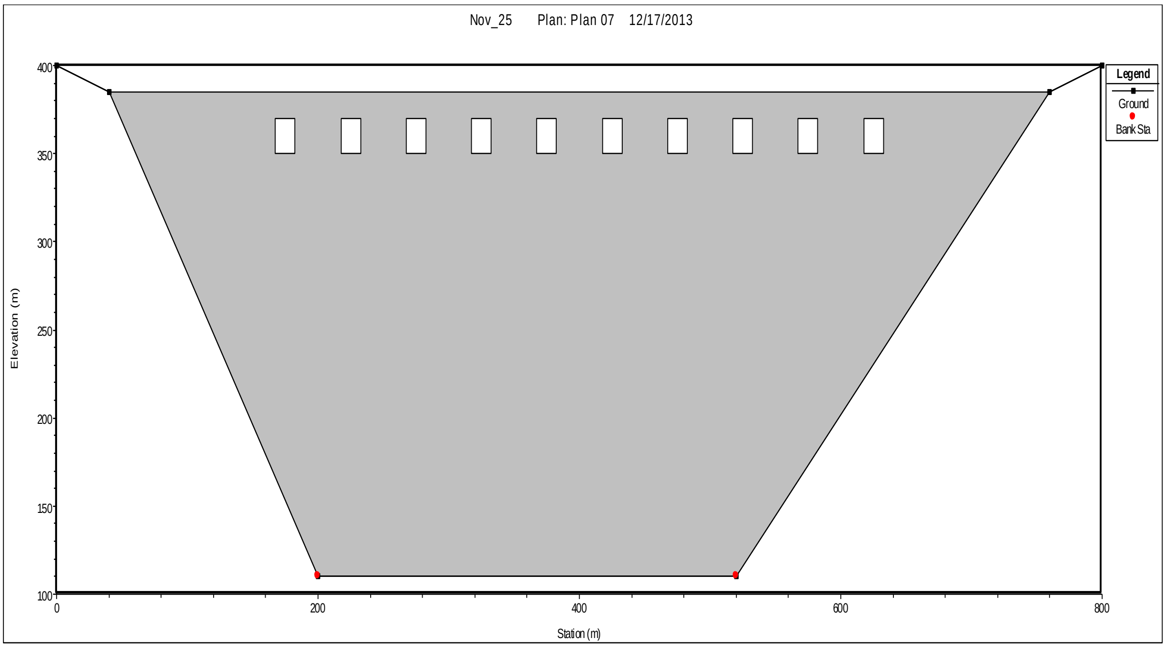



**Figure 8-10: Dam Specification used in the model**

**Table 8-5: Dam Specification used in the model**

| | |
|---|---|
| Dam Specification: | Dam Height: 269m<br>Deck width: 15m<br>Weir Crest shape: Broadcrested<br>US side slope: 0<br>DS Side slope: 2:1<br>Bed Elevation: 116 masl |
| Gate Specification : | Type: Sluice<br>Numbers: 10<br>Size: 20m * 15m<br>Sluice Discharge Coefficient: 0.6<br>Invert: 350m<br>Weir shape: Broad crested weir<br>Weir coefficient: 1.67 |

A storage area of about 8.5 billion cubic meters (equivalent to the proposed Koshi High Dam Gross storage) was assumed for analysis.

### 8.4.1 Breach Specifications:

Piping was considered as the triggering mechanism for the dam breach. Full formation hours for the breach was considered as 10hrs and a half sine wave breach progression was used for the simulation process. **Figure 8-11** and **Figure 8-12** show the breach specification and the breach progression plot respectively.

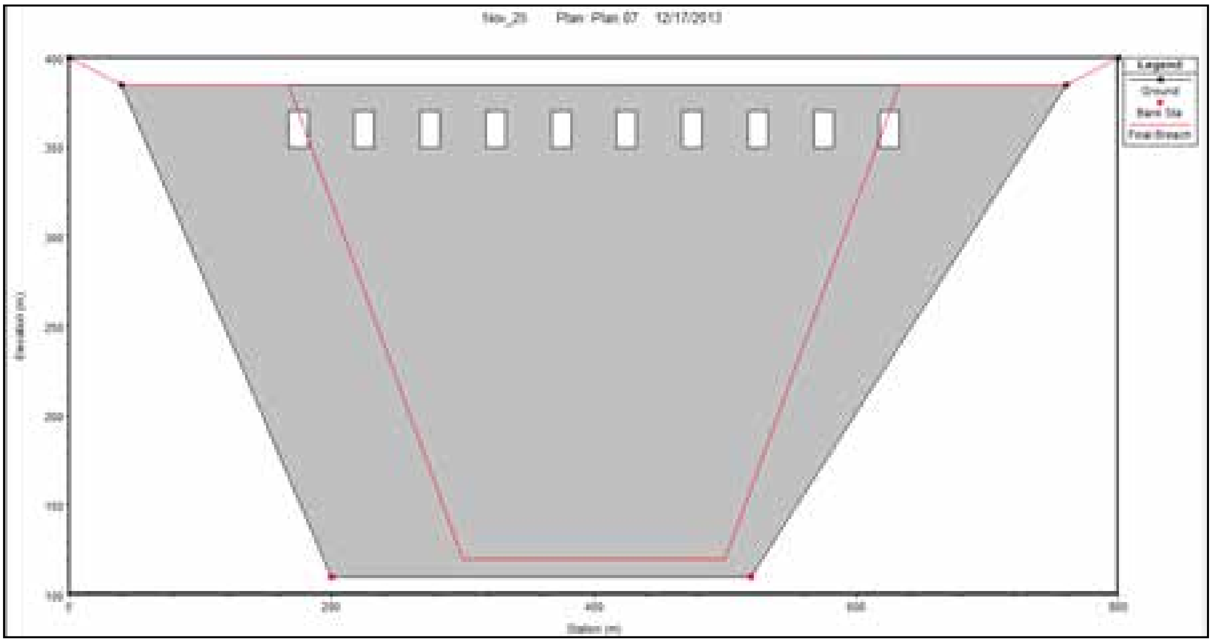


**Figure 8-11: Specification of the Breach**

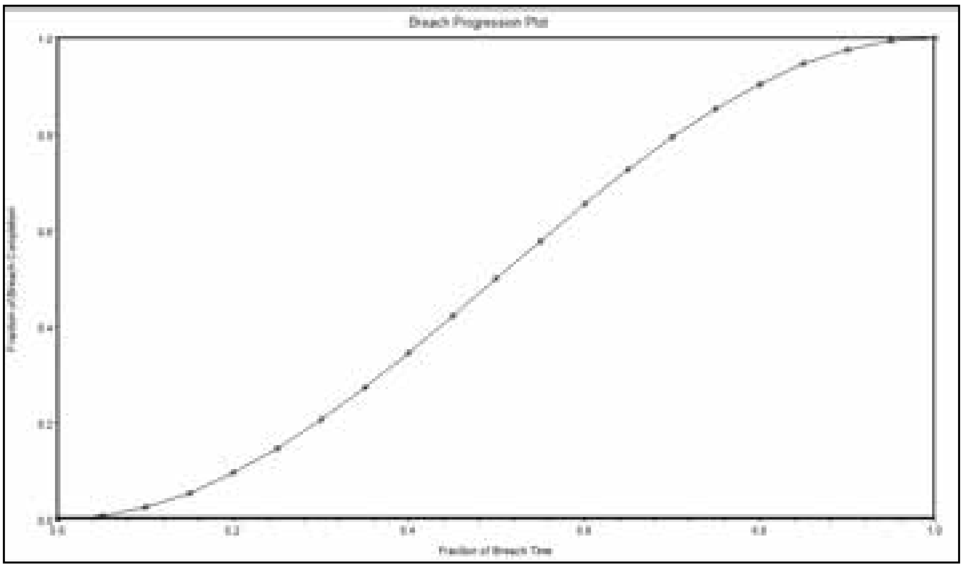


**Figure 8-12: Breach Progression Plot**

**Table 8-6** shows the breach specifications in detail.

**Table 8-6: Specification of the Breach**

| | |
|---|---|
| Center Station | 400m |
| Final bottom width | 200m |
| Final bottom elevation | 120m |
| Left side slope | 0.5 |
| Right side slope | 0.5 |
| Breach weir coefficient | 2.5 |
| Full Formation Time (hrs) | 5 |
| Failure Mode | Piping |
| Piping Coefficient | 0.5 |
| Initial Piping elevation | 250 |
| Trigger failure at | 25th August, 2006 |

Elevation controlled gates were used as the boundary condition for the inline structure (dam). Flow hydrograph for August was used as the upstream boundary condition whereas normal depth was used as the downstream boundary condition. The model was set to breach under the extreme flood of 69758 $m^3/s$ (100yr return period ECHAM05 flood) which is much higher than the 1000 year return period flood under historic data (i.e. 47444 $m^3/s$).

### 8.4.2 Results

Unsteady flow analysis was carried out to evaluate the dam breach scenario in the HEC-RAS model. Results are shown below.

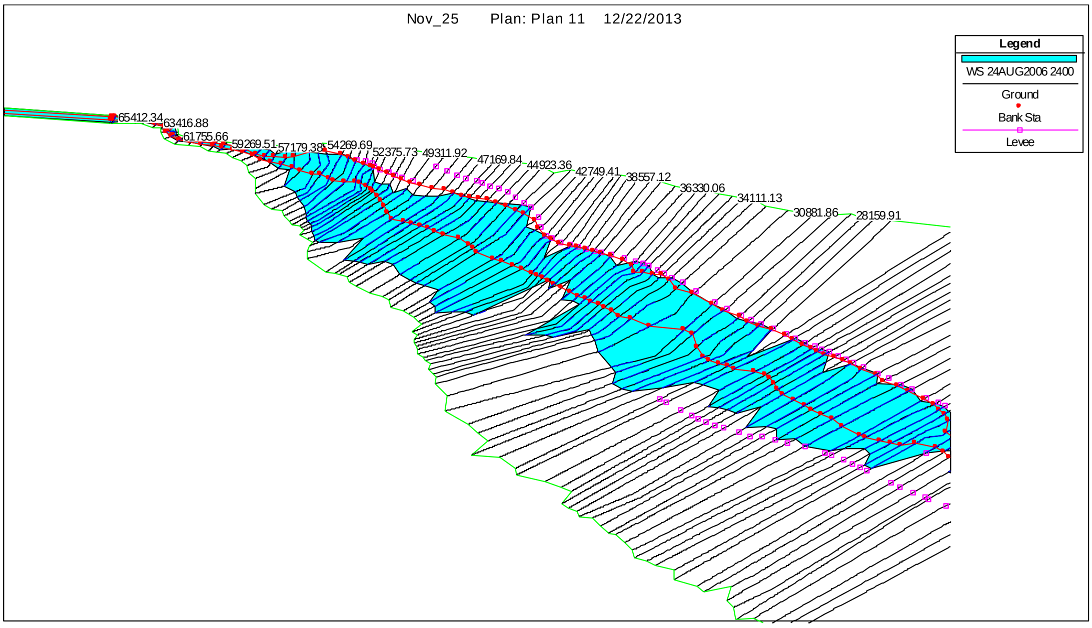



**Figure 8-13: Plan Prior to breach (24th August, 24:00)**

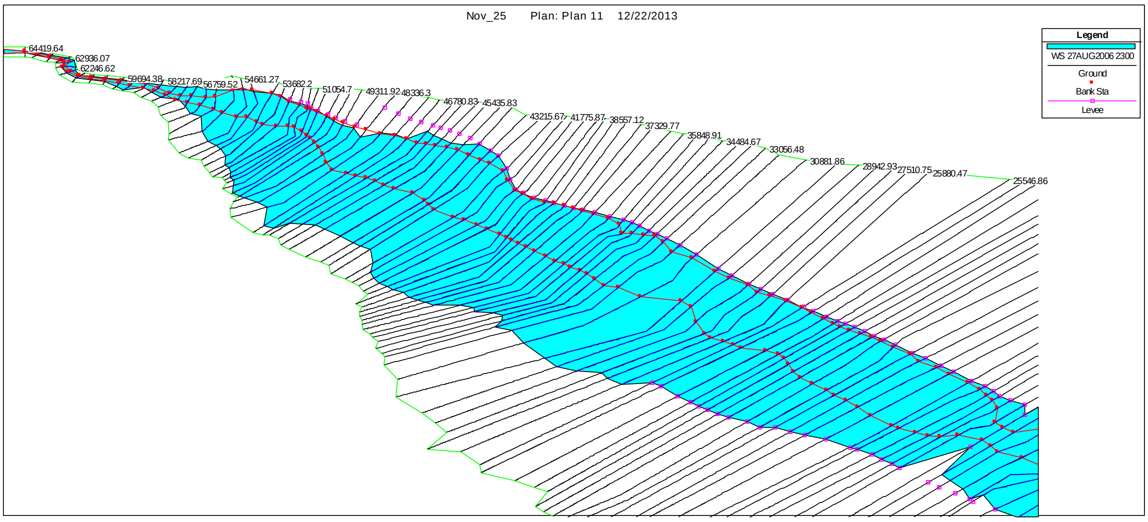
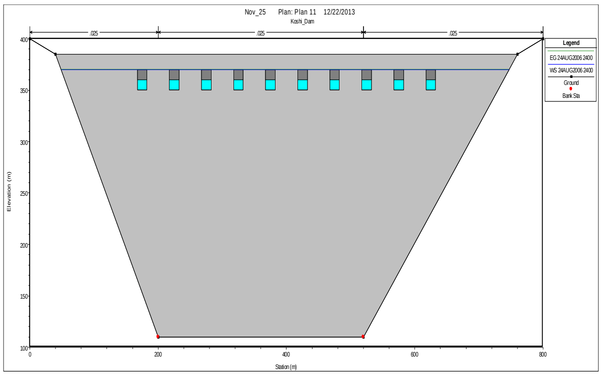
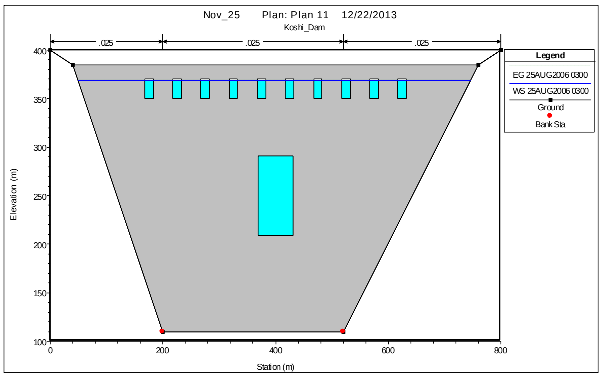



**Figure 8-14: Plan Prior to breach (29th August, 24:00)**

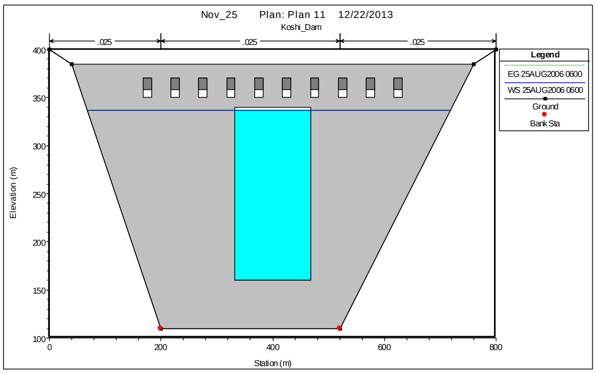
**Figure 8-13** and **Figure 8-14** show the plan of the Koshi River, before and 4 days after the breach. As can be observed from the figures, the inundation area has increased but are contained within the embankments. Similarly the breach formation at the dam can be seen in **Figure 8-15 a-e.**



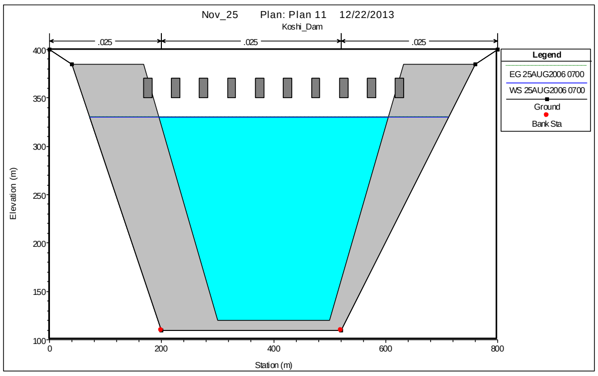
a. Prior to the breach



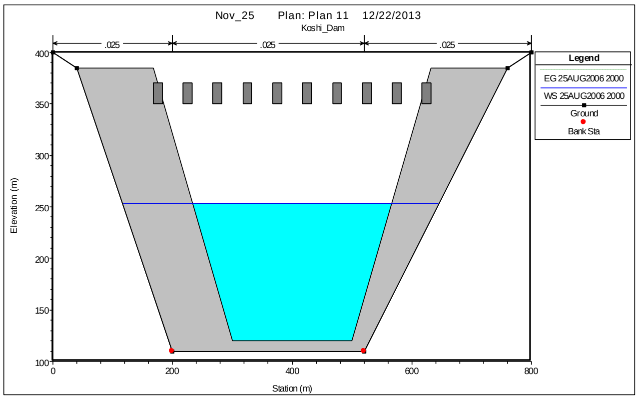

b. During Breach (breach initiation)




c. During Breach (Intermediate)



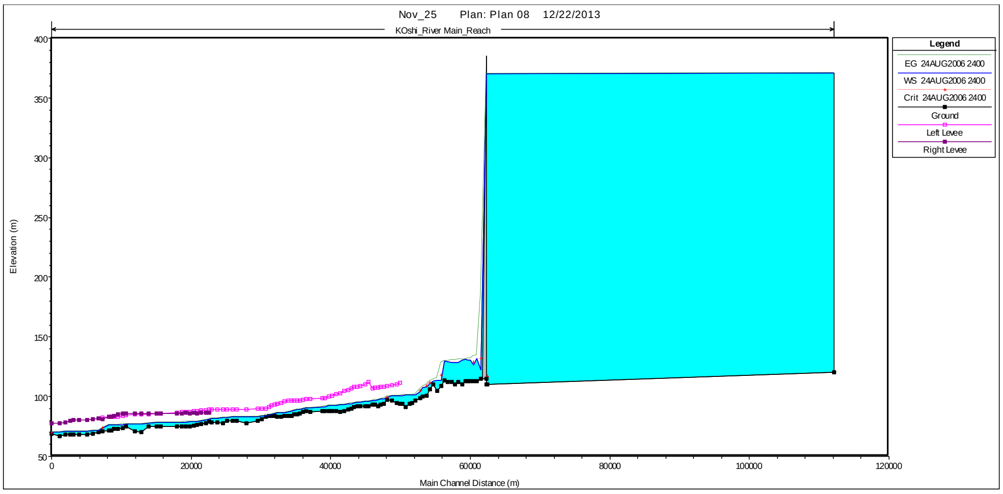

d. During Breach (Full breach)



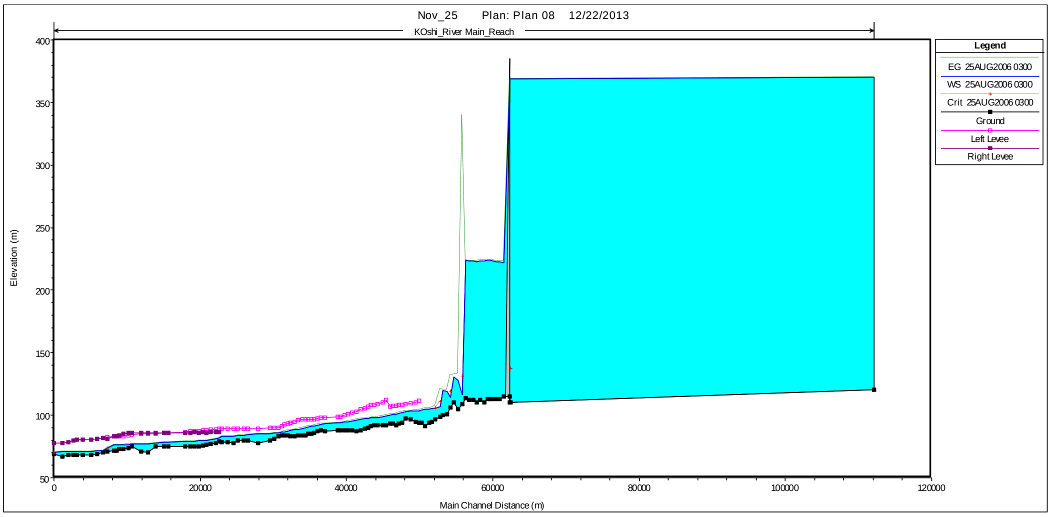

e. After the breach

**Figure 8-15: Cross-section of dam prior to, during and after the breach**

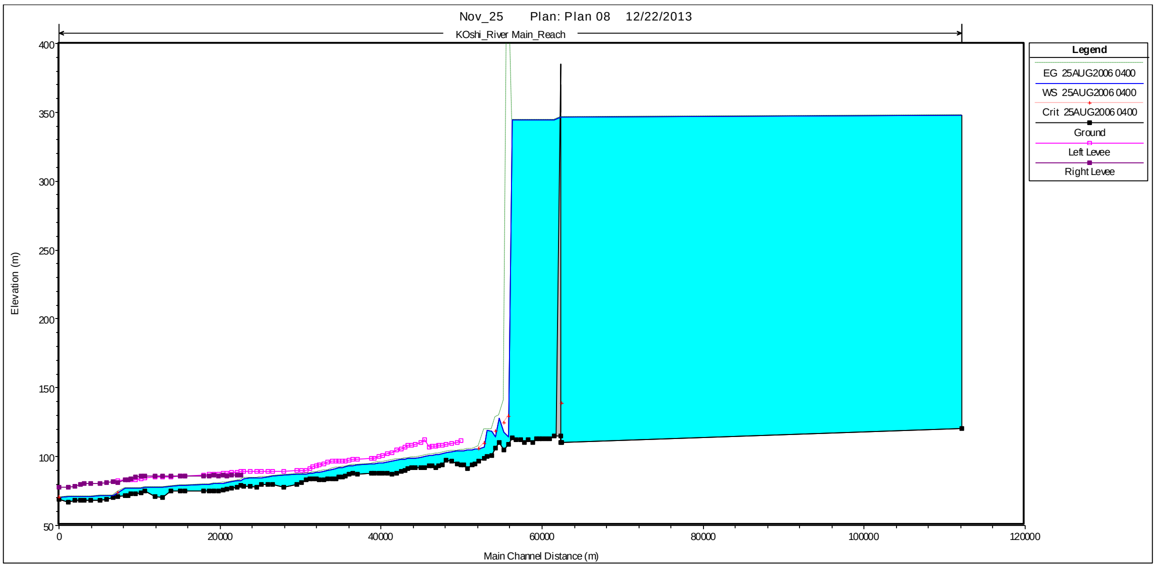
**Figure 8-16** a, b, c and d show the profile before, during and after the breach.



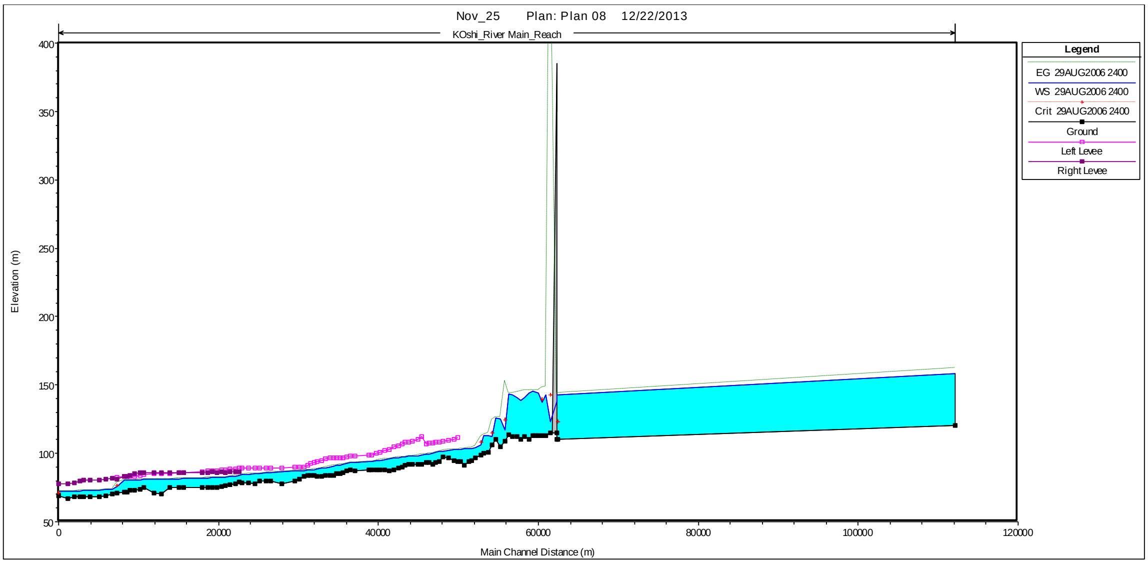

a. Profile prior to breach




b. Profile during the breach (Initial)




c. Profile during the breach (Intermediate)

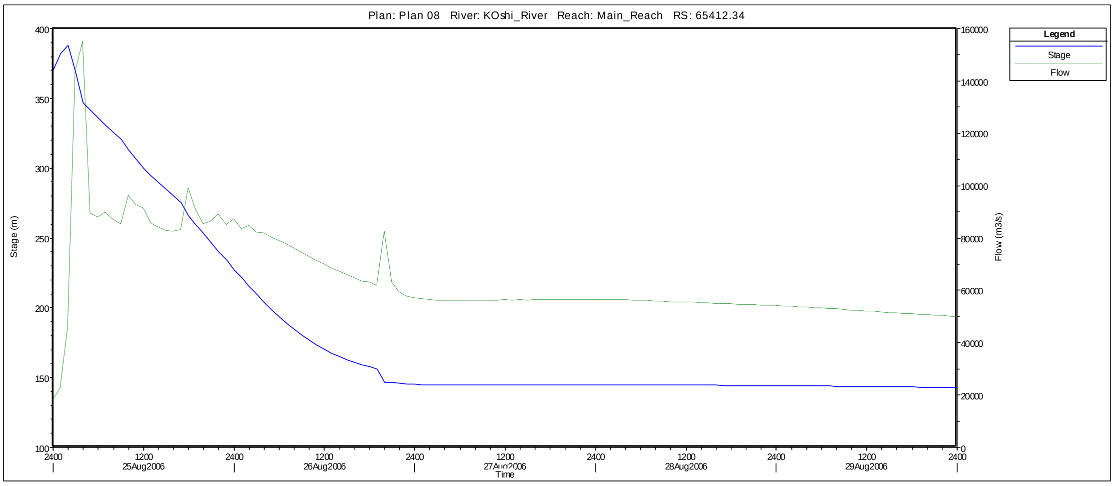



d. Profile after the breach

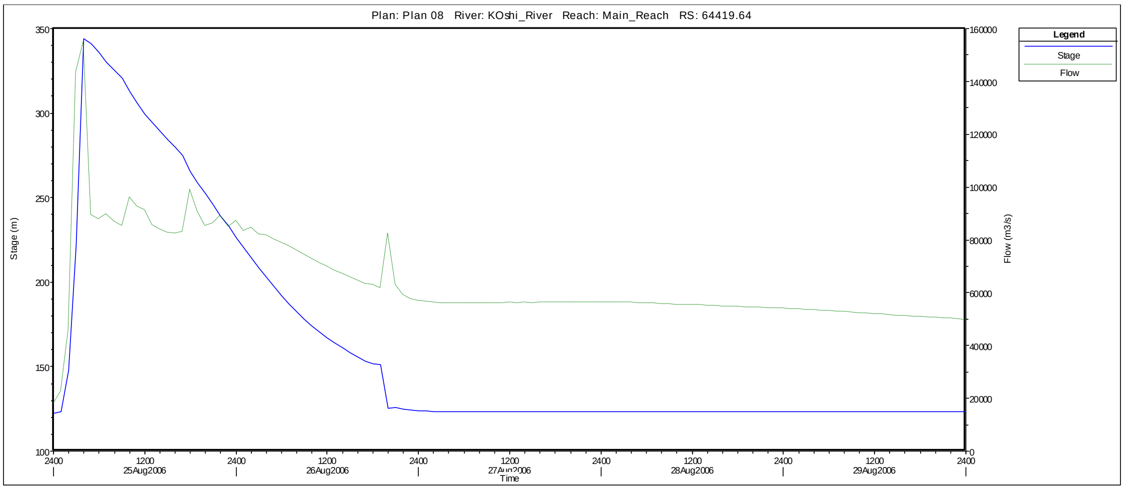
**Figure 8-16: Profile of dam prior to, during and after the breach**

It can be observed from the figures that the volume of water stored behind the dam is flooded within 5 days of breach.

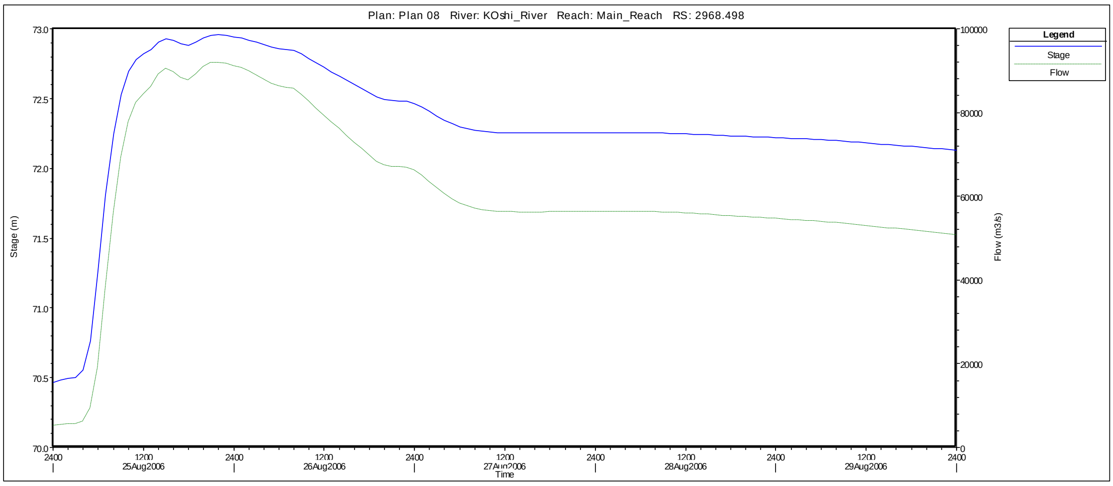
**Figure 8-17** show the stage and flow volumes at different locations within the Koshi River.




a. Just upstream of Dam




b. Just downstream of Dam




b. Most downstream cross-section

**Figure 8-17: Stage and Flow at different locations**

As can be read from the **Figure 8-17**, the maximum flood wave is transferred to the most downstream cross-section (about 62kms downstream) after 20 hours of breach.

# Chapter 9: Socio-economic Vulnerability Assessment

## 9.1 General

Socio-economic vulnerability assessment of the Koshi River basin is one of the important components of this project. It aims to assess flood risks in the context of climate change by combining the different socio-economic vulnerability scenarios along with the degree of preparedness and recovery capacity status at the Koshi River basin. There are growing concerns along the Koshi River basin of Nepal with respect to the risks associated with climate change. Among all the possible impacts of climate change, flood from the Koshi River is one of the key physical threats on livelihood of the basin. Flood is expected to be more common in areas with particular geomorphologic characteristics, such as low-lying and low-sloped areas. There have been numerous assessments and management plans to identify these particular areas with higher susceptibility to flood and other associated hazards, however, the number of disasters and scale of impacts are increasing and causing even larger damage. The flood on August 18, 2008 affected approximately 2 million people as the river broke its embankment at PaschimKusaha(Nepal), thus submerging several districts of Nepal and India. About 95% of the total flow of the River is now flowing through the new course (FM, 2008). During the flood, the Koshi River breached its embankment and displaced 45,000 people from three severely affected villages (Haripur, Shreepur and PacchimKusaha) of the Sunsari District, Nepal (Minute of UN OCHA, 29 March 2009). About 3.065 million residents from 1,704 villages in North Bihar (India) were similarly affected (Mishra, 2008b), and around 4,648 Ha of agricultural land and crops were washed away in Nepal (Minute of UN OCHA, 29 March 2009). The damage caused by the Koshi flood of 2008 is highest in five decades of flood history in Bihar (Kale, 2008) and worst in the entire flood history of Nepal according to a Nepalese senior officer from the Ministry of Home Affairs and member of the Central Disaster Relief Committee, Nepal.

It is therefore now necessary to understand the vulnerabilities and to take the necessary steps to enhance the adaptive capacities of the most exposed populations and sectors in the Koshi River basin. Detailed socio-economic vulnerability assessment of the river basin is essential to provide adequate information for planning and management purposes in the area. The assessment helps to identify the vulnerable areas consequently useful for making flood disaster risk reduction policies/strategies so that risk can be minimized.

### 9.1.1 Climate Change and Vulnerability

Climate change will have various effects on water resources and water management in Nepal. Climate-induced disasters such as floods, landslides and drought have killed more than 4,000 people in Nepal over the last 10 years. The large variability in projected climate scenarios over Nepal’s most vulnerable river basin system, the Koshi River basin, makes any policy reformulation in anticipation of climate change difficult. However, improved efficiency in irrigation systems and water use are strongly recommended modes of action because they will benefit the region despite the degree and direction of climate change.

The ordinary use of the word vulnerability refers to the possibility to have wounds, i.e., the degree to which a system is likely to experience harm due to exposure to a hazard (Turner II et al., 2003 cited by Fussel, 2007). Various scholars have defined vulnerability towards natural resources in different ways. The IPCC defines vulnerability as a function of character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and adaptive capacity

(IPCC 2001). In this case exposure is the magnitude and duration of the climate related exposure such as flood or change in precipitation. Sensitivity in this case is the degree to which the system is affected by the exposure. And adaptive capacity is the system's ability to withstand or recover from the exposure. Vulnerability (V) = f (exposure, sensitivity, adaptive capacity). Similarly, the definition of vulnerability used in the Second Assessment Report of IPCC (1996) is as the extent to which climate change may damage or harm a system; it is a function of both the "sensitivity" of a system or structure to climate and the opportunities for "adaptation" to new conditions. Sensitivity in this case is defined as the degree to which a system will respond to a change in climatic conditions (e.g., the extent of change in ecosystem composition, structure, and functioning, including primary productivity, resulting from a given change in temperature or precipitation).

According to Eldsvig et. al (2011), vulnerability is considered to be dependent upon the demographic and socio-economic characteristics as well as the degree of preparedness and recovery capacity. These factors are taken into account under demographic, socio-economic, the degree of preparedness and recovery capacity indicators respectively. The vulnerability index is estimated as weighted average of these indicators. It is noted here that Vulnerability Index will be estimated semi-quantitatively, with additive aggregation of the indicators similar to proposed by Eidsvig et. al. (2011) as explained in the methodology section of Chapter 3.

## 9.2 Analysis and Results

### 9.2.1 Demography

***A. Population, family size and age group***

In order to assess socio-economic vulnerability of the study area, it is important to analyze demographic feature of that area. Two key demographic indicators were considered for this study i. e. age distribution and house type based on construction materials of wall. Among the total sampled households surveyed in the study area, the total number of male and female surveyed are 1338 (52%) and 1219 (48%) respectively which is just opposite comparing to district level data (male 49%, female 51%) as well as national level data (male 48%, female 52%). The average family size in the surveyed area is 7 whereas the highest family size (10) was found in the moderately affected area and lowest (4) in the less affected area **Table 9-1.** This implies that moderately affected area is more vulnerable to flood in terms of family size.

**Table 9-1: Population distribution and family size of the sampled households**

| Category | Male | Female | Total | Average family size |
|---|---|---|---|---|
| **Highly affected (n=241)** | 853 (52%) | 786 (46%) | 1639 | 7 |
| **Moderately affected (n=91)** | 298 (51%) | 283 (49%) | 581 | 10 |
| **Less affected (n=60)** | 187 (55%) | 150 (45%) | 337 | 4 |
| **Total** | 1,338 (52%) | 1,219 (48%) | 2,557 (100%) | 7 |
| **District** | 371,229 (49%) | 392,258 (51%) | 763,487 (100%) | |
| **Nepal** | 12,849,041 (48%) | 13,645,463 (52%) | 26,494,504(100 %) | |

Source: Field survey, 2012

**Table 9-2: Age group of household members of the sampled households**

| Age group | Highly affected | % | Moderately affected | % | Less affected | % | Total | % |
|---|---|---|---|---|---|---|---|---|
| **<10** | 355 | 22 | 126 | 22 | 71 | 21 | 552 | 22 |
| **10-37** | 913 | 56 | 295 | 51 | 172 | 51 | 1380 | 54 |
| **38-65** | 305 | 19 | 130 | 22 | 75 | 22 | 510 | 20 |
| **>65** | 66 | 4 | 30 | 5 | 19 | 6 | 115 | 4 |
| **Total** | 1639 | 100 | 581 | 100 | 337 | 100 | 2557 | 100 |

Source: Field survey, 2012

The **Table 9-2** shows that the majority (54%) of the household members fall in the age group of 10-37 years followed by less than 10 years (22%) with the least from the senior age group (above 65 years). We could not find disabled population in the study area. People with less than 10 years and greater than 65 years, falling on vulnerability level rank 2 (**Table 3-3**), accounts to a total of 26% of total sample population. This implies that all the affected areas are moderately vulnerable while considering only age group of the population of those areas.

### 9.2.2 House type

The type of houses is one of the socio-demographic indicators of adoptive capacity (system's ability to withstand). The type of construction materials of wall is considered for this study, assuming that strong resistance house i. e. concrete/cement with burnt brick wall has minimum risk towards flood. Out of 392 households surveyed, it was found that 68.6% households have wall made up of grass/ leaves/ reeds/ bamboo having the highest percentage (75%) in the less affected area followed by 68.5% in the highly affected area and 64.8% in the moderately affected area. This implies less affected area has one of the lower adaptive capacity house type compared to other two affected areas as it has high number of households made up of grass/leaves/reeds/bamboo/ wood/branches (**Table 9-3).**

**Table 9-3: House types based on construction materials of the wall**

| Category | | Grass/ leaves/ reeds/ bamboo/ Wood/ branches | Un-burnt bricks with Mud | Burnt bricks | Concrete/ Cement |
|---|---|---|---|---|---|
| **Highly affected** | N | 165.0 | 28.0 | 31.0 | 8.0 |
| | % | 68.5 | 12.4 | 12.9 | 3.3 |
| **Moderately affected** | N | 59.0 | 17.0 | 9.0 | 5.0 |
| | % | 64.8 | 18.7 | 9.9 | 5.5 |
| **Less affected** | N | 45.0 | 7.0 | 5.0 | 3.0 |
| | % | 75.0 | 11.7 | 8.3 | 5.0 |
| **Total** | N | 269.0 | 54.0 | 45.0 | 16.0 |
| | % | 68.6 | 13.8 | 11.5 | 4.1 |

Source: Field survey, 2012

### 9.2.3 Economic Characteristics of the sampled household

Economic characteristic of the household is another important indicator for this study which measures the adaptive capacity of households. Here economic indicator is divided into two sub indicators i.e. main income sources and income status which are discussed hereafter.

### *A. Main income sources*

Different trends in the diversity of income sources between highly affected area, moderately affected area and less affected area were found. In all three areas the households have found similar range of income sources for income generation. The majority of household in the study area have agriculture as the main source of income to sustain their livelihood as in other parts of the country. It provides income to more than 50% of households in all the three affected areas, which is followed by waged/skilled labor (24%) and business (9%) (**Table 9-4).** That means more than 50% of the households were dependent on agricultural land for primary source of income, which implies those households are more vulnerable to flood. On the other hand Nepalese agriculture is subsistence in nature and highly dependent on weather consequently more vulnerable to climate change.

**Table 9-4: Income sources of the sampled households and dependency in land for their livelihood**

| Occupation | Highly affected (n=241) | | Moderately affected(n=91) | | Less affected (n=60) | | Total (N=392) | |
|---|---|---|---|---|---|---|---|---|
| | N | % | N | % | N | % | N | % |
| **Agriculture** | 114 | 47.3 | 55 | 60.4 | 35 | 58.3 | 204 | 52.0 |
| **Govt. service** | 8 | 3.3 | 2 | 2.2 | 1 | 1.7 | 11 | 2.8 |
| **Business** | 23 | 9.5 | 7 | 7.7 | 7 | 11.7 | 37 | 9.4 |
| **Waged /skilled labor** | 66 | 27.4 | 20 | 22 | 8 | 13.3 | 94 | 24.0 |
| **Foreign employment** | 6 | 2.5 | 2 | 2.2 | 1 | 1.7 | 9 | 2.3 |
| **Public service** | 4 | 1.7 | 2 | 2.2 | 1 | 1.7 | 7 | 1.8 |
| **Total** | 221 | 100 | 88 | 100 | 53 | 100 | 362 | 100 |

Source: Field survey, 2012

Note: Students and unemployment population are excluded.

### *B. Income Status*

Total earning from different income sources was considered to estimate their income. **Table 9-5** shows income status of the sampled households in the study area. It shows the majority (47%) of household have income less than $ 0.5 per capita per day. Only 4% households have income greater than $ 2 per capita per day. This implies that the vulnerability level of those households is very high as the majority of households fall on vulnerability rank 4.

**Table 9-5: Income status of the sampled households**

| Vulnerability Rank | Income | HH | % |
|---|---|---|---|
| **1** | Less than $ o.5per capita per day | 184 | 47 |
| **2** | $ 0.5 to $ 1per capita per day | 114 | 29 |
| **3** | $ 1 to $ 2per capita per day | 77 | 20 |
| **4** | Greater than $ 2per capita per day | 17 | 4 |
| **Total** | | 392 | 100 |

Source: Field survey, 2012

### *C. Landholding*

Land ownership within the agrarian economy of the study area provides a major source of income, which is an important natural asset that people have. Only agricultural land is presented, as people mostly depend on agricultural land to sustain their livelihood in all the three affected areas. The average agricultural land holding of the households is 0.57 Ha having the highest landholding size of 0.88 Ha in the less affected area followed by 0.63 Ha in the highly affected area. Households from moderately affected area have very low landholding compared to other two affected areas.

**Table 9-6: Landholding (agricultural land) status of the sampled households**

| Category | Agriculture land-irrigated Land (Kattha) | | Agriculture land-Un-irrigated Land (Kattha) | | Total | | Average landholding (Kattha) | Average landholding (Ha.) |
|---|---|---|---|---|---|---|---|---|
| | | Area | N | Area | N | Area | | |
| **Highly affected** | 64.0 | 2037.5 | 131.0 | 2489.8 | 241.0 | 4527.3 | 18.8 | 0.63 |
| **Moderately affected** | 25.0 | 194.0 | 34.0 | 362.0 | 91.0 | 556.0 | 6.1 | 0.21 |
| **Less affected** | 32.0 | 558.5 | 52.0 | 1004.5 | 60.0 | 1563.0 | 26.1 | 0.88 |
| **Total** | 121.0 | 2790.0 | 217.0 | 3856.3 | 392.0 | 6646.3 | 17.0 | 0.57 |

*(Unit conversion: 1 Ha. = 29.585 Kattha)* Source: Field survey, 2012

## 9.2.4 Social characteristics of the sampled household

### *A. Education status*

Education sector plays a key role in providing awareness towards flood hazard to the people. The education of the population of the study area does not show the satisfactory status. As shown in Table 6.7, the highest percentage (32%) of the population in the study areas is illiterate. Only 9% of the population attended SLC level education. However, literacy rate in the two affected areas is higher than the national literacy rate where as in the moderately affected area it is 61%, which is lower than the national literacy rate. The average literacy rate of the study areas is 68% which falls on the vulnerability level 1 as defined in **Table 9-7** which means that if more than 50% of the population is literate, then the area is less vulnerable. This implies that considering literacy, all the three affected areas are less vulnerable to flood.

**Table 9-7: Educational status of households according to three affected areas**

| Category | Highly affected | | Moderately affected | | Less affected | | Total | |
|---|---|---|---|---|---|---|---|---|
| | N | % | N | % | N | % | N | % |
| **Illiterate** | 410 | 28 | 191 | 39 | 107 | 36 | 708 | 32 |
| **Primary (class 1-5)** | 471 | 33 | 106 | 22 | 72 | 24 | 649 | 29 |
| **Secondary (class 6-10)** | 314 | 22 | 104 | 21 | 73 | 25 | 491 | 22 |
| **SLC** | 125 | 9 | 45 | 9 | 38 | 13 | 208 | 9 |
| **Intermediate** | 83 | 6 | 27 | 6 | 4 | 1 | 114 | 5 |
| **Bachelor & above** | 36 | 3 | 14 | 3 | 2 | 1 | 52 | 2 |
| **Total** | 1,439 | 100 | 487 | 100 | 296 | 100 | 2,222 | 100 |
| **Literacy rate (study area)** | | 71 | | 61 | | 69 | | 68 |
| **National Literacy rate *** | | | | | | | | 66 |

*Source: Field survey, 2012** CBS, 2011; Under 6 population are excluded

### *B. Access to communication*

The ownership of communication facilities measures a level of access to information about flood hazard, which consequently minimizes flood risk. Access to more than one unit of telephone set/mobile set is considered to be least vulnerable to flood for this study. **Figure 9-1** shows that at least one mobile set is found to be owned by 90% households, 82% households and 85% households in highly affected, moderately affected and less affected area respectively. This implies that more than 80% of the population in all the three affected areas is less vulnerable to flood in terms of quick access to information about flood.

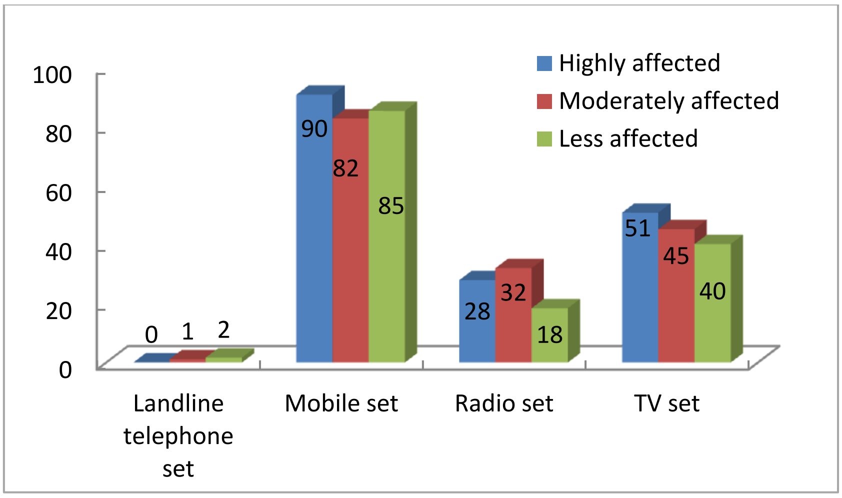



**Figure 9-1: Access to communication facilities according to three affected areas (%)**

### *B. Mobility*

Households having private car is assumed to be least vulnerable to flood for this study. The **Figure 9-2** shows household having private car is minimal. The highest proportion of households in all three affected areas found to be owned at least a bicycle in their house. Thus in terms of mobility people in all three affected areas are considered to be highly vulnerable to flood.

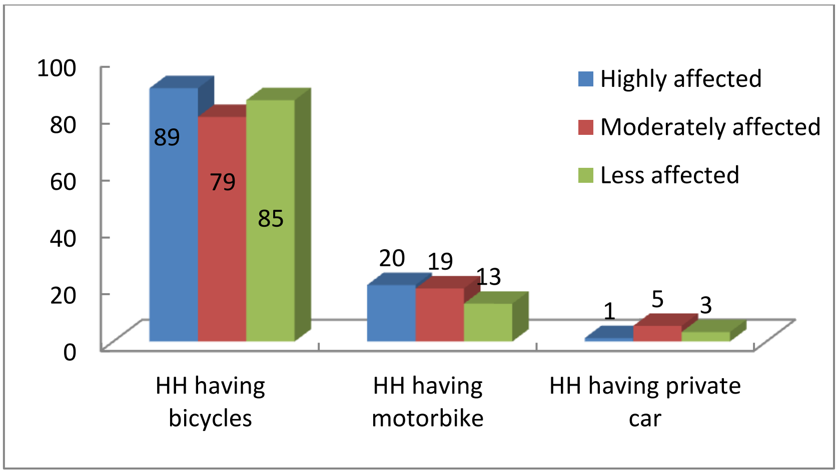



**Figure 9-2: Percentage of transportation facilities owned by households**

### *C. Access to market facility*

One of the important vulnerability status measures considered for this study is access to market facility. Those households having less than 1 km distance from a market centre are considered to be least vulnerable to flood in terms of access to market facility. **Table 9-8** reveals that only 17% households were found to be situated in less than 1 km distance from a market centre, which means, these households are highly vulnerable to flood in terms of access to market facility.

**Table 9-8: Distance to market centre from the surveyed households**

| Market facility | Market Centre | |
|---|---|---|
| | HH | % |
| **<1km** | 67 | 17 |
| **1km - 2km** | 94 | 24 |
| **2km - 3km** | 49 | 13 |
| **3km - 4km** | 57 | 15 |
| **>4km** | 125 | 32 |

*Source: Field survey, 2012*

### *D. Access to drinking water facility*

The majority (60.5%) of the households depends on tube-well for drinking water. It was found that most of the households do not treat tube well water before using it for drinking purpose. About 37% of the households in highly affected and moderately affected areas have access to drinking water facility in their own house whereas it is only 23% in less affected areas (**Figure 9-3**). This implies that in terms of access to drinking water, households from less affected area are more vulnerable than other two affected areas. However, all the three affected areas can be considered as highly vulnerable as people of those areas, who have very little access to drinking water in their own house.

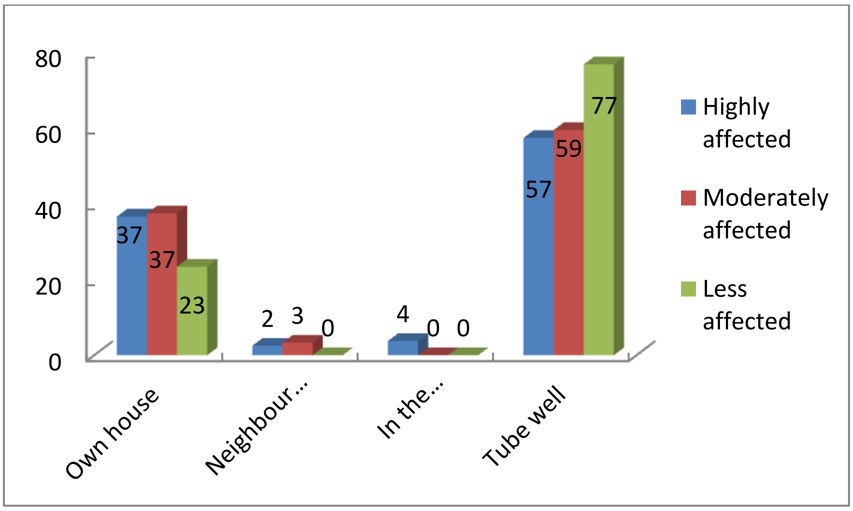



**Figure 9-3: Access to drinking water by surveyed households (%)**

### 9.2.5 Degree of Preparedness

#### *A. Awareness of Hazard Evaluation Map*

Awareness of hazard evaluation map is one of the important sub-indicators of preparedness. When asked if people have heard about hazard evaluation map, only 18.4% of the respondents mentioned positively. The majority of the respondents (81.6%) do not know anything about the hazard evaluation map (**Table 9-9).**

**Table 9-9: Awareness of hazard evaluation map**

| Awareness of hazard evaluation map | Highly affected | | Moderately affected | | Less affected | | Total | |
|---|---|---|---|---|---|---|---|---|
| | N | % | N | % | N | % | N | % |
| **Yes** | 35 | 14.5 | 22 | 24.2 | 15 | 25.0 | 72 | 18.4 |
| **No** | 206 | 85.5 | 69 | 75.8 | 45 | 75.0 | 320 | 81.6 |
| **Total** | 241 | 100.0 | 91 | 100.0 | 60 | 100.0 | 392 | 100.0 |

*Source: Field survey, 2012*

#### *B. Emergency response*

**Table9-10** shows that the existence of emergency response facilities in all the three affected areas is very poor as the majority of the respondents mentioned that they have no emergence response facility in their community. However, about 15% of the respondents from moderately affected area mentioned that they have good transportation which means, an organized response group exists in their community, which is working actively.

**Table9-10: Flood emergency response facility in the study area**

| Category | Highly affected (n=241) | Moderately affected (n=91) | Less affected (n=60) | Total (N=392) | % |
|---|---|---|---|---|---|
| **Good transportation and organized response group in place** | 3 | 1 | 0 | 4 | 1 |
| **Good transportation or organized response group in place** | 5 | 53 | 2 | 58 | 15 |
| **Self-organized local group only** | 5 | 2 | 3 | 7 | 2 |
| **None** | 228 | 35 | 55 | 263 | 67 |

*Source: Field survey, 2012*

#### *C. Early warning system (EWS)*

Early warning system is another key sub-indicator of preparedness and it plays significant role in minimizing the damage through flood in any area. Respondents were asked if they were aware of flood early warning system and about 36% of the respondents replied positively. When further asked what kinds of EWS exist in their communities, about 15% of the respondents mentioned basic system i.e. telephone and microphone. About 98% of the respondents mentioned that there were none of the EWS in the less affected areas followed by 83% in highly affected area and 62.6% in moderately affected area. This shows that the access to EMS in all the three affected areas is very low (**Table 9-11).**

**Table 9-11: Types of existing EWS in the study areas**

| Types of EWS | Highly affected (n=241) | | Moderately affected (n=91) | | Less affected (n=60) | | Total (N=392) | |
|---|---|---|---|---|---|---|---|---|
| | N | % | N | % | N | % | N | % |
| **Advanced (24 hrs radio, TV, Automatic Siren, 1 day ahead)** | 9 | 3.7 | 1 | 1.1 | 0 | .0 | 10 | 2.6 |
| **Average (24 hrs radio, TV, Manual Siren, same day)** | 6 | 2.5 | 2 | 2.2 | 0 | .0 | 8 | 2.0 |
| **Basic (Telephone, Microphone)** | 26 | 10.4 | 31 | 34.1 | 2 | 3.3 | 59 | 14.8 |
| **None** | 200 | 83.0 | 57 | 62.6 | 58 | 96.7 | 315 | 80.4 |
| **Total** | 241 | 100 | 91 | 100 | 60 | 100 | 392 | 100 |

*Source: Field survey, 2012*

### *D. Evacuation place*

When asked if they were aware of evacuation place, 44% of the respondents replied positively. When further asked if they have evacuation place in their community, 97% of the respondents replied they do not have particular evacuation place in their community. They mentioned that they used to go to nearby school or river embankment or any high altitude place during flood.

### *E. Insurance (life/property/any kind of insurance)*

Households having life insurance of all family members as well as all property are considered low vulnerable to flood as those households can be resettled soon even if they are impacted by flood. But in the study area high percentage (88%) of households does not have any kind of insurance. About 3% of the households has life insurance of more than 50% family members and about 7% of the households have life insurance of less than 50% family members.

## 9.2.6 Recovery capacity

### *A. First aid services*

Households having adequate first aid service in their own home are considered less vulnerable. **Table 9-12** shows that about 68% of the respondents mentioned that they have very limited access to first aid services in their own home as well as in the community. About 24.5% respondents mentioned that first aid service is adequate only at the community level. Only about 7% respondents mentioned that they have adequate first aid service in their homes, which shows that the situation of first aid services is very poor in all the three areas.

**Table 9-12: Access to first aid services in the study areas**

| Status | Highly affected (n=241) | Moderately affected (n=91) | Less affected (n=60) | Total (N=392) | Total % |
|---|---|---|---|---|---|
| **Adequate and in own home** | 16 | 9 | 1 | 26 | 6.6 |
| **Adequate and in community level** | 55 | 27 | 14 | 96 | 24.5 |
| **Limited** | 168 | 54 | 45 | 267 | 68.1 |
| **None** | 2 | 1 | 0 | 2 | 0.5 |

*Source: Field survey, 2012*

### *B. Health institution-Hospital*

**Table 9-13** shows people have very less access to health institutions particularly hospitals in all the affected areas as there is very less percentage (only 5%) of households situated in less than 1 km distance to hospital. Majority of households lie more than 4 km far from hospital. This implies the recovery status in terms of access to hospitals is weak in all the three affected areas.

**Table 9-13: Distance between households and hospital**

| Hospital distance (km) | Highly affected (n=241) | Moderately affected (n=91) | Less affected (n=60) | Total (N=392) | Total (%) |
|---|---|---|---|---|---|
| **Less than 1 Km** | 20 | 0 | 1 | 21 | 5 |
| **1-2 km** | 57 | 17 | 3 | 77 | 20 |
| **2-4 km** | 38 | 2 | 0 | 40 | 10 |
| **More than 4 km** | 126 | 72 | 56 | 254 | 65 |

*Source: Field survey, 2012*

### *C. Disaster fund*

When asked if they were aware of disaster fund, all of the respondents replied positively. When further asked about access to disaster fund at different levels- local level, government level and non- government level, about 42% of the total respondents strongly agreed that the community people have access to disaster fund at local level whereas about 47% of respondents moderately agreed on access to disaster fund at government level and 36% at non-government level (**Table 9-14**). This shows that people have access to disaster fund in some extent in all the affected areas.

**Table 9-14: Access to disaster fund at different level**

| Category | Local level | | Government level | | Non-government level | |
|---|---|---|---|---|---|---|
| | N | % | N | % | N | % |
| **Least agreed** | 1 | 5.3 | 2 | 10.5 | 2 | 10.5 |
| **Less agreed** | 1 | 5.3 | 3 | 15.8 | 1 | 5.3 |
| **Moderately agreed** | 6 | 31.6 | 9 | 47.4 | 7 | 36.8 |
| **strongly agreed** | 8 | 42.1 | 3 | 15.8 | 5 | 26.3 |
| **Total** | 19 | 100.0 | 19 | 100.0 | 15 | 78.9 |

*Source: Field survey, 2012*

## 9.3 Socio-economic Vulnerability Indices (SVI) and maps

The livelihood of a household is comprised of diverse aspects of demographic and socio-economic aspects. These data have been analyzed to assess socio-economic status/vulnerability of the local communities and to prepare SVI. The data were then analyzed to prepare vulnerability map. A Composite Socio-economic Index (CSI) comprising of five different parameters namely; demographic, social, economic, degree of preparedness and recovery capacity was calculated based on the survey data and information.

The findings on five different indicators i.e. demographic, economic, social, preparedness and recovery capacity clearly indicated that the regular livelihood of the household of surveyed areas on Koshi River basin are difficult. Moreover, frequent occurrence of flood in those areas further worsens the life of people and trigger to become more vulnerable. To encompass the situation Socio-economic Vulnerability Index (SVI) is estimated for all the three affected areas (thirteen VDCs of Koshi River basin).Under the five indicators relevant sub-indicators were selected with vulnerability ranking from 1: low vulnerability to 4: high vulnerability. The **Table 9-15** shows the SVI of the surveyed VDCs, which were calculated on the basis of field survey information by using **equations 3.8 and 3.9** given in section 3.

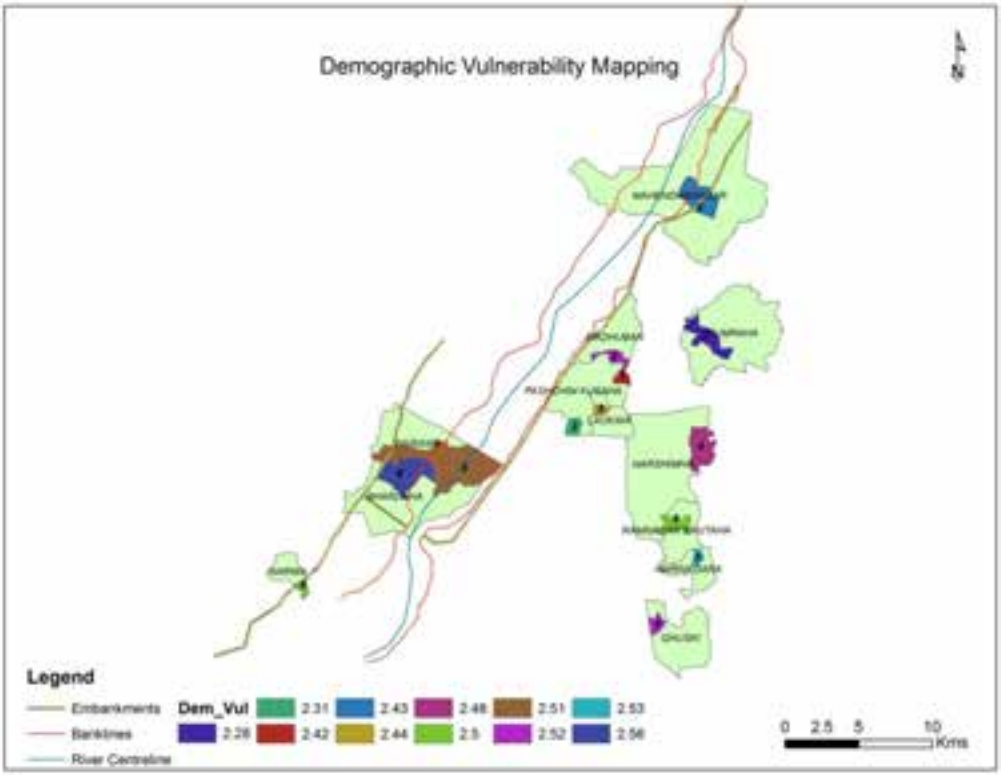
**Table 9-15: Socio-economic Vulnerability estimation**

| Wards | Vulnerability Index of selected indicators | | | | | Average | Average SVI value |
|---|---|---|---|---|---|---|---|
| | Demographic | Economic | Social | Preparedness | Recovery | | |
| **Laukahi** | 2.8 | 2.9 | 1.7 | 3.5 | 3.2 | 2.83 | 2.80 |
| **Bairawa** | 2.5 | 2.9 | 1.9 | 3.7 | 2.8 | 2.77 | |
| **Inarwa** | 2.9 | 2.8 | 2.0 | 3.7 | 2.9 | 2.86 | 2.71 |
| **PaschimKusaha-3** | 2.9 | 3.1 | 1.6 | 3.5 | 2.7 | 2.78 | |
| **Dumraha** | 2.3 | 2.7 | 1.7 | 3.7 | 2.1 | 2.49 | |
| **Bhardaha** | 2.6 | 2.8 | 1.9 | 3.7 | 2.8 | 2.76 | 2.77 |
| **Narshimha** | 2.8 | 2.9 | 1.8 | 3.7 | 2.7 | 2.77 | |
| **RamnagarBhutaha** | 2.9 | 3.1 | 1.8 | 3.7 | 2.9 | 2.89 | |
| **Harinagara** | 2.7 | 2.7 | 1.8 | 3.5 | 3.0 | 2.74 | |
| **Madhuwan** | 2.9 | 2.8 | 1.7 | 3.6 | 3.1 | 2.83 | |
| **Ghuski** | 2.9 | 3.0 | 1.8 | 3.6 | 2.9 | 2.84 | |
| **Mahendranagar** | 2.8 | 2.7 | 1.8 | 3.7 | 2.0 | 2.60 | |
| **PaschimKusaha-1** | 2.8 | 2.8 | 1.7 | 3.7 | 1.9 | 2.75 | |
| **Average SVI** | 2.8 | 2.9 | 1.8 | 3.6 | 2.7 | 2.76 | |
| **Gross Average** | | | | | | | |

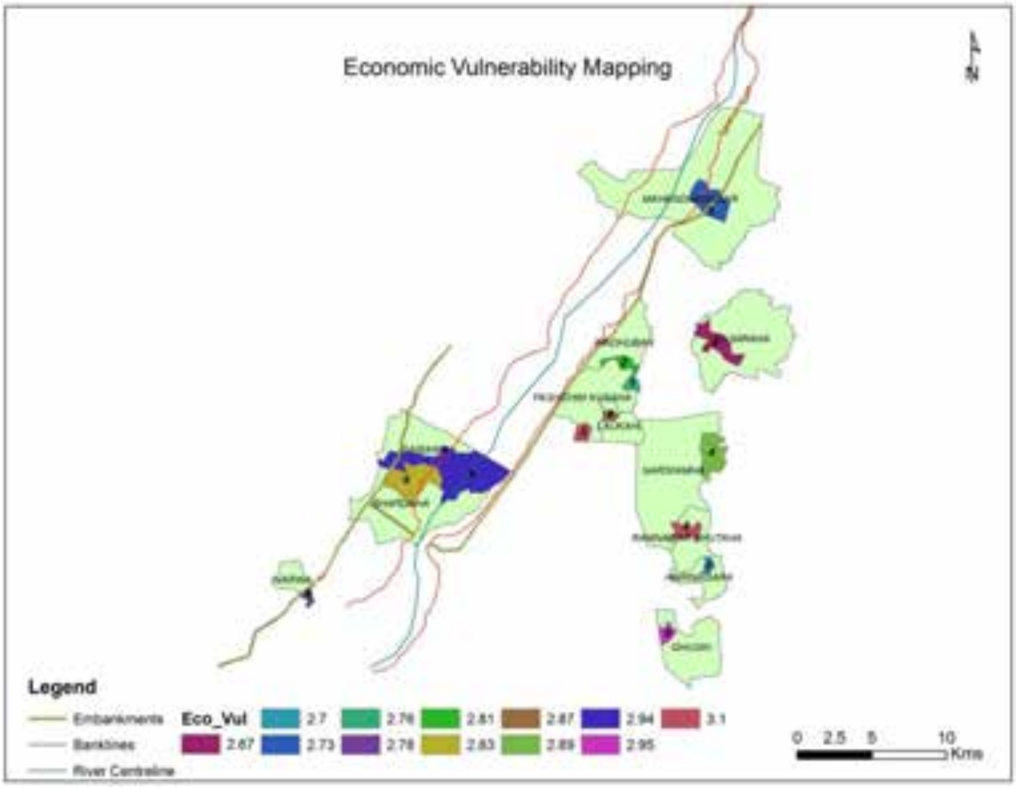
*Note: 1-2: Less vulnerable, 2-3: Moderately vulnerable, 3-4: Highly vulnerable*

It was observed that the gross average SVI is 2.76 (in a scale of 1: low vulnerability to 4: high vulnerability). The spatial variation of SVI was found to be very small (with minimum value 2.49 at Dumraha and maximum value of 2.89 at Ramnagar Bhutaha). Among the five indicators, the preparedness for flood disaster was found to be very weak (with vulnerability index value of 3.6) followed by economic one (with vulnerability index= 2.9). The social indicator was observed to be quite strong among them with vulnerability index of 1.8. The result predicted very low access to preparedness facility and with a good social bond in all study area.

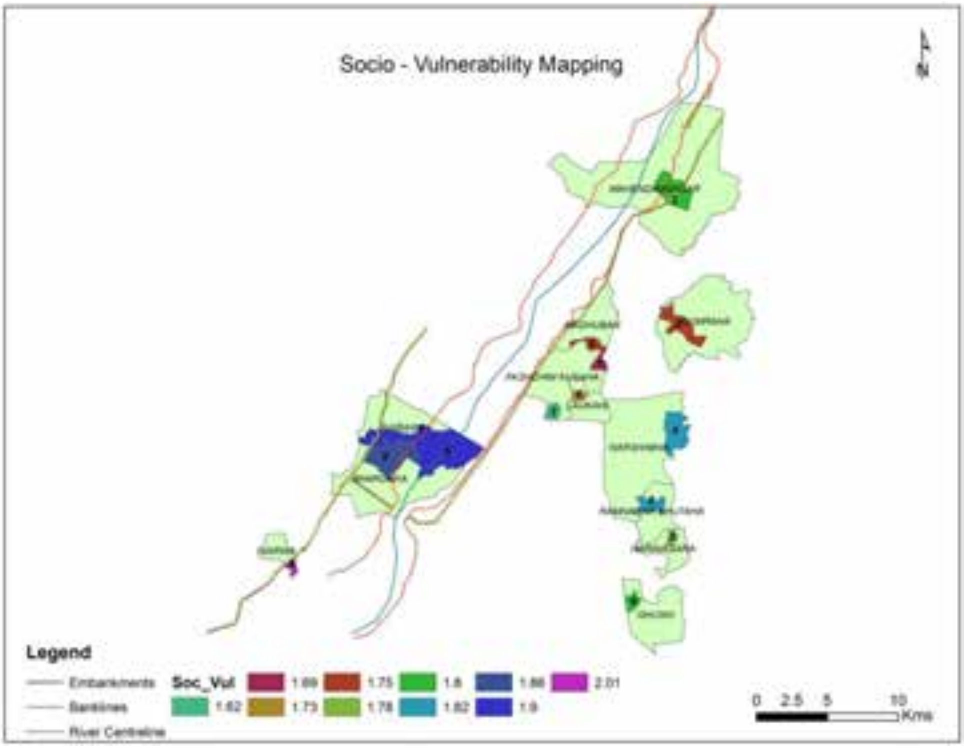
Based on the result of SV Index for study areas, different vulnerability maps were prepared. **Figure 9-4 (a - f)** show these maps**.**



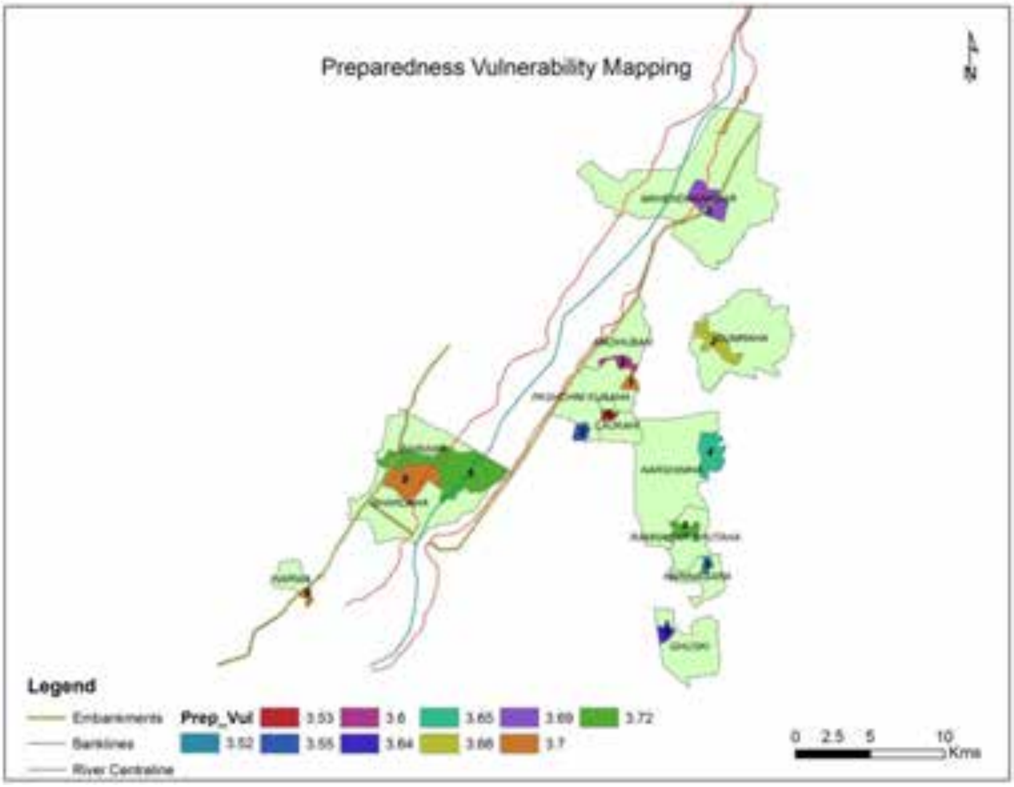

a. Vulnerability Map (Demographic)



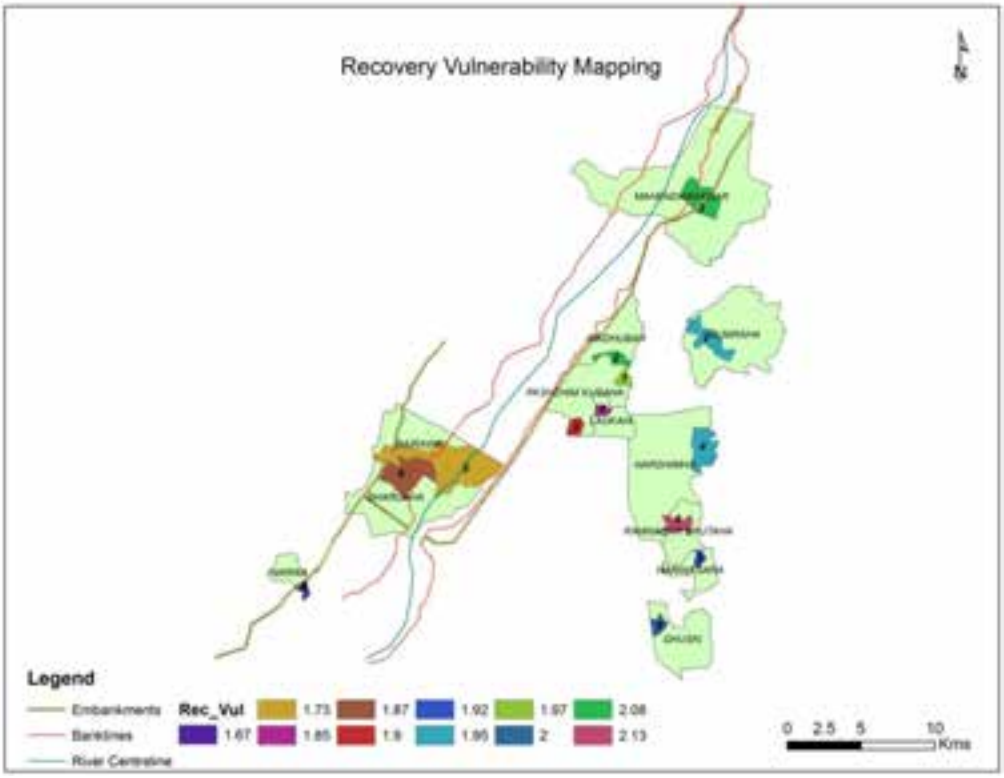

a. Vulnerability Map (Economic)



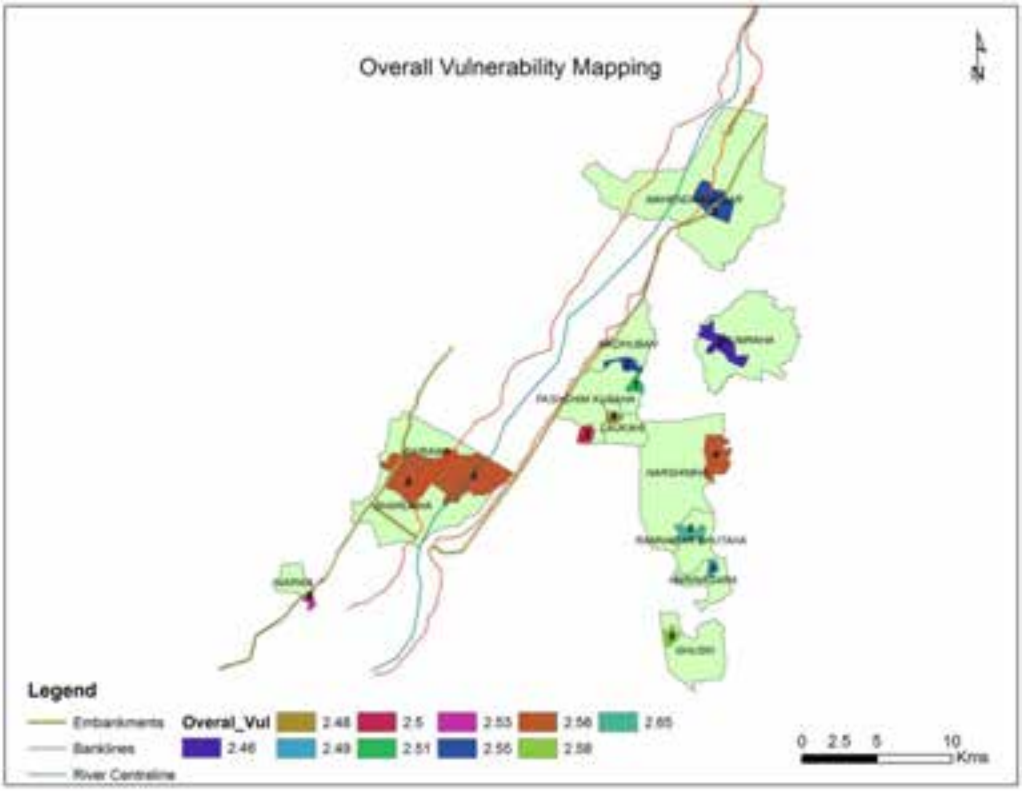

c. Vulnerability Map (Socio-economic)




d. Vulnerability Map (Preparedness)




e. Vulnerability Map (Recovery)




f. Vulnerability Map (Overall)

**Figure 9-4: Vulnerability Maps based on indicators**

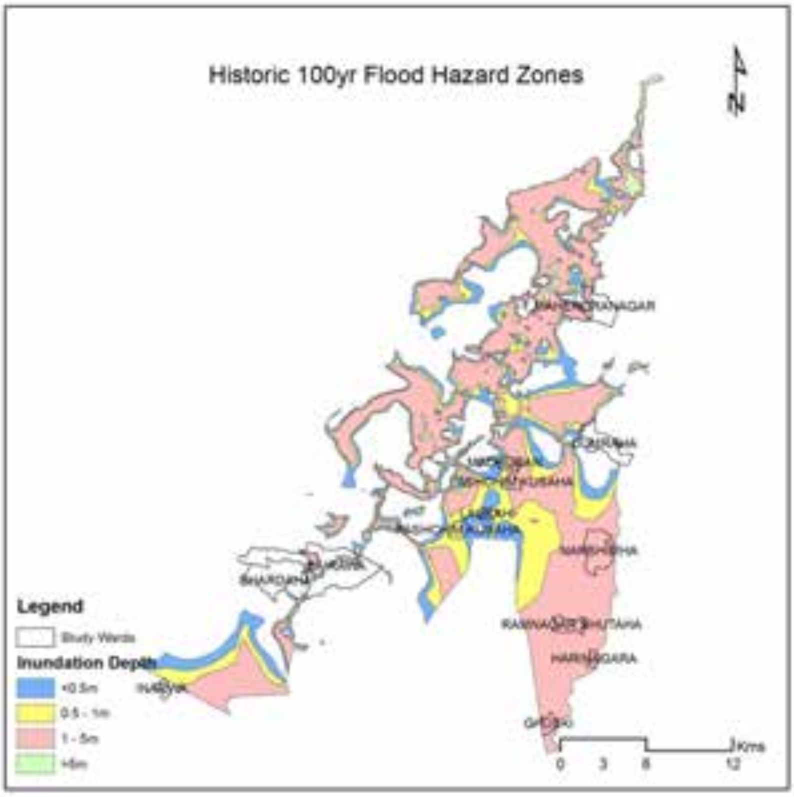
## 9.4 Risk Assessment and Mapping

Based on the flood hazard, vulnerability and exposure of the population in the study area to potential flood risks, composite risk maps were prepared for existing historic as well as climate change conditions. The composite risk index was obtained as the product of vulnerability, hazard and exposure indices as shown below.

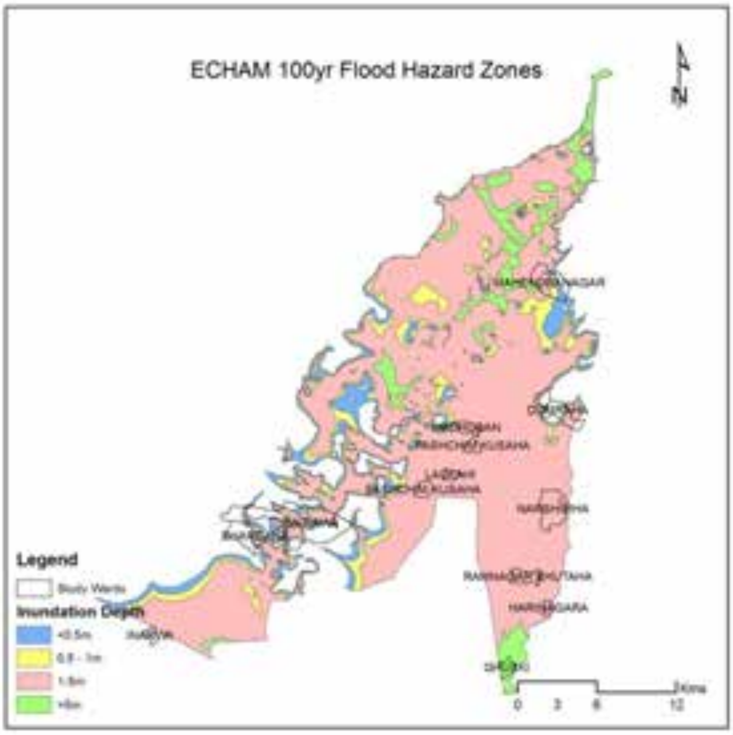
***Risk = Hazard * Vulnerability* Exposure*** **( 9-1)**

### 9.4.1 Hazard:

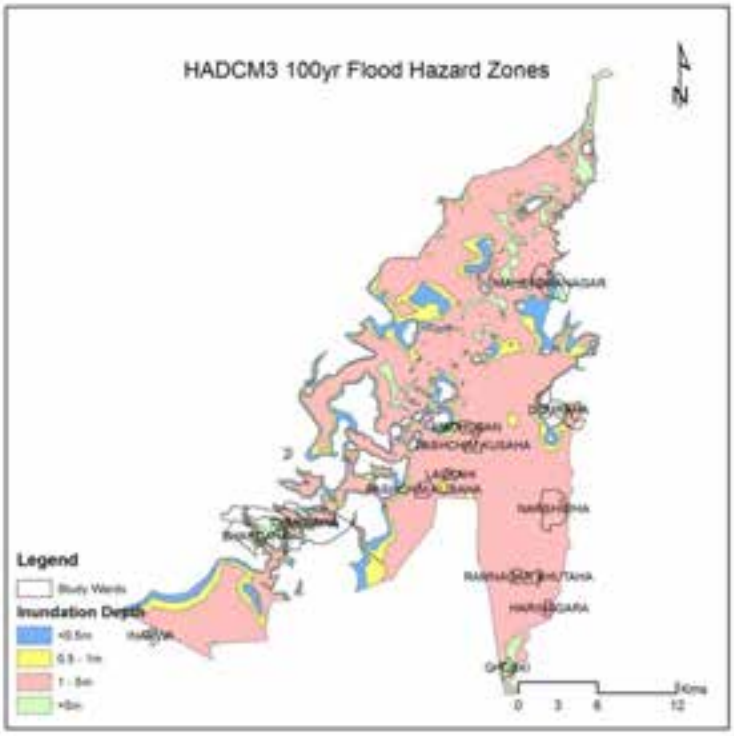
As discussed earlier in Chapter 8, flood inundation mapping for 100-yr return period floods for historic as well as climate change scenarios (HADCM3 and ECHAM05) was done. The inundation depths were classified into four hazard zones viz. <0.5m as less hazardous zone, 0.5 - 1m as moderate hazardous zone, 1-5m as high hazardous zone and >5m as severe hazardous zone. These four classes were assigned with the values of 1 to 4 (1 being the less to 4 being the severely affected). **Figure 9-5** show the hazard zones for historic as well as ECHAM05 and HADCM3 conditions.




**a. Historical 100-yr flood**




**b. ECHAM05 100-yr flood**




**c. HADCM3 100-yr flood**

**Figure 9-5: Hazard zones under different floods (with and without climate change)**

The hazard values of 1-4 were then normalized to values from 0 to 1 keeping the highest hazard value of 4 as 1.

Table 9-16 below shows the index values adopted for different hazard conditions.

**Table 9-16: Hazard values for different conditions**

| Wards | Hazard Values (1-4) | | | Normalized Hazard Values (0-1) | | |
|---|---|---|---|---|---|---|
| | Historic | ECHAM | HADCM | Historic | ECHAM | HADCM |
| **Bairawa-5** | 1 | 3 | 3 | 0.25 | 0.75 | 0.75 |
| **Bhardaha-9** | 3 | 3 | 3 | 0.75 | 0.75 | 0.75 |
| **Dumraha-2** | 1 | 3 | 3 | 0.25 | 0.75 | 0.75 |
| **Ghuski-9** | 3 | 4 | 4 | 0.75 | 1.00 | 1.00 |
| **Harinagara-5** | 3 | 3 | 3 | 0.75 | 0.75 | 0.75 |
| **Inarwa-9** | 2 | 3 | 3 | 0.50 | 0.75 | 0.75 |
| **Laukahi-8** | 1 | 3 | 3 | 0.25 | 0.75 | 0.75 |
| **Madhuban-2** | 3 | 3 | 3 | 0.75 | 0.75 | 0.75 |
| **Mahendranagar-3** | 3 | 3 | 3 | 0.75 | 0.75 | 0.75 |
| **Narshimha-4** | 3 | 3 | 3 | 0.75 | 0.75 | 0.75 |
| **Pashchim Kusaha-1** | 3 | 3 | 3 | 0.75 | 0.75 | 0.75 |
| **Pashchim Kusaha-3** | 2 | 3 | 3 | 0.50 | 0.75 | 0.75 |
| **Ramnagar Bhutaha-8** | 3 | 3 | 3 | 0.75 | 0.75 | 0.75 |

### 9.4.2 Vulnerability:

The vulnerability indices calculated for different locations were considered for vulnerability value. The calculated values were adopted for the existing conditions whereas since there were no means to calculate the same indices for the future conditions, it was assumed that the vulnerability of the study population would remain the same. Hence, the same values were adopted for the calculation of risks in the future. **Table 9-17** below shows the overall vulnerability for different study wards. The vulnerability values were also normalized to values from 0 to 1 keeping the highest 2.89 as 1.

**Table 9-17: Overall vulnerability for different wards**

| Wards | Vulnerability | Normalized |
|---|---|---|
| Bairawa-5 | 2.77 | 0.96 |
| Bhardaha-9 | 2.76 | 0.96 |
| Dumraha-2 | 2.49 | 0.86 |
| Ghuski-9 | 2.84 | 0.98 |
| Harinagara-5 | 2.74 | 0.95 |
| Inarwa-9 | 2.86 | 0.99 |
| Laukahi-8 | 2.83 | 0.98 |
| Madhuban-2 | 2.83 | 0.98 |
| Mahendranagar-3 | 2.6 | 0.90 |
| Narshimha-4 | 2.77 | 0.96 |
| Pashchim Kusaha-1 | 2.75 | 0.95 |
| Pashchim Kusaha-3 | 2.78 | 0.96 |
| Ramnagar Bhutaha-8 | 2.89 | 1.00 |

## 9.5 Exposure:

Population of the surveyed wards was considered as the indicator for exposure. Latest census data and VDC profile of 2011 were used for the ward population in this approach (Refer **Table 9-18**). For the future conditions, different growth rates between 2001 and 2011 census for each VDCs were calculated. These growth rates were used to project the population at 2060. The calculated population along with the growth rates and population density are shown in **Table 9-19.** Assuming that the maximum population during 2060 has the highest exposure value of 1, all the population data were normalized between 0 and 1.

**Table 9-18: Population and growth rates according to 2001 and 2011 census**

| VDC Names | 2001 Census | 2011 Census | Growth Rate/decade | Growth Rate per annum |
|---|---|---|---|---|
| Bairawa | 570282 | 639284 | 12.1 | 1.2 |
| Bhardaha | 570282 | 639284 | 12.1 | 1.2 |
| Dumraha | 15662 | 16528 | 5.5 | 0.6 |
| Ghuski | 9580 | 10531 | 9.9 | 1.0 |
| Harinagara | 7038 | 7820 | 11.1 | 1.1 |
| Inarwa | 570282 | 639284 | 12.1 | 1.2 |
| Laukahi | 4615 | 5038 | 9.2 | 0.9 |
| Madhuban | 7409 | 7706 | 4.0 | 0.4 |
| Mahendranagar | 22195 | 23631 | 6.5 | 0.6 |
| Narshimha | 17369 | 21094 | 21.4 | 2.1 |
| Pashchim Kusaha | 9954 | 11496 | 15.5 | 1.5 |
| Ramnagar Bhutaha | 11087 | 12337 | 11.3 | 1.1 |
| | | | | ***Source:** ***CBS 2001, 2011*** |

**Table 9-19: Projected Population and Exposure Indices**

| WARDS | Area, $km^2$ | Population | Growth rate per yr (1991-2001) | Population at 2060 | Exposure (Current) | Exposure (Future) |
|---|---|---|---|---|---|---|
| **Bairawa-5** | 14.49 | 2656 | 1.21 | 4787 | 0.40 | 0.72 |
| **Bhardaha-9** | 6.19 | 1574 | 1.21 | 2838 | 0.24 | 0.43 |
| **Dumraha-2** | 3.62 | 1954 | 0.55 | 2561 | 0.29 | 0.38 |
| **Ghuski-9** | 1.09 | 808 | 0.99 | 1311 | 0.12 | 0.20 |
| **Harinagara-5** | 0.70 | 841 | 1.11 | 1445 | 0.13 | 0.22 |
| **Inarwa-9** | 0.71 | 656 | 1.21 | 1182 | 0.10 | 0.18 |
| **Laukahi-8** | 0.70 | 566 | 0.92 | 886 | 0.08 | 0.13 |
| **Madhuban-2** | 1.30 | 930 | 0.40 | 1131 | 0.14 | 0.17 |
| **Mahendranagar-3** | 4.43 | 1594 | 0.65 | 2187 | 0.24 | 0.33 |
| **Narshimha-4** | 4.21 | 2359 | 2.14 | 6674 | 0.35 | 1.00 |
| **Pashchim Kusaha-3** | 1.14 | 761 | 1.55 | 1616 | 0.11 | 0.24 |
| **Pashchim Kusaha-1** | 0.98 | 655 | 1.55 | 1392 | 0.10 | 0.21 |
| **Ramnagar Bhutaha-8** | 1.72 | 2404 | 1.13 | 4164 | 0.36 | 0.62 |

## 9.6 Risk:

Similarly composite risks were calculated using the equation ( 9-2). **Table 9-20** below shows the various risk values under current and climate change conditions.

**Table 9-20: Risks for current and climate change conditions**

| Wards | Current Scenario | | | | ECHAM05 | | | | HADCM3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | H | V | E | Risk | H | V | E | Risk | H | V | E | Risk |
| **Bairawa-5** | 0.25 | 0.96 | 0.40 | **0.10** | 0.75 | 0.96 | 0.72 | **0.52** | 0.75 | 0.96 | 0.72 | **0.52** |
| **Bhardaha-9** | 0.75 | 0.96 | 0.24 | **0.17** | 0.75 | 0.96 | 0.43 | **0.31** | 0.75 | 0.96 | 0.43 | **0.31** |
| **Dumraha-2** | 0.25 | 0.86 | 0.29 | **0.06** | 0.75 | 0.86 | 0.38 | **0.25** | 0.75 | 0.86 | 0.38 | **0.25** |
| **Ghuski-9** | 0.75 | 0.98 | 0.12 | **0.09** | 1.00 | 0.98 | 0.20 | **0.20** | 1.00 | 0.98 | 0.20 | **0.20** |
| **Harinagara-5** | 0.75 | 0.95 | 0.13 | **0.09** | 0.75 | 0.95 | 0.22 | **0.16** | 0.75 | 0.95 | 0.22 | **0.16** |
| **Inarwa-9** | 0.50 | 0.99 | 0.10 | **0.05** | 0.75 | 0.99 | 0.18 | **0.13** | 0.75 | 0.99 | 0.18 | **0.13** |
| **Laukahi-8** | 0.25 | 0.98 | 0.08 | **0.02** | 0.75 | 0.98 | 0.13 | **0.10** | 0.75 | 0.98 | 0.13 | **0.10** |
| **Madhuban-2** | 0.75 | 0.98 | 0.14 | **0.10** | 0.75 | 0.98 | 0.17 | **0.12** | 0.75 | 0.98 | 0.17 | **0.12** |
| **Mahendranagar-3** | 0.75 | 0.90 | 0.24 | **0.16** | 0.75 | 0.90 | 0.33 | **0.22** | 0.75 | 0.90 | 0.33 | **0.22** |
| **Narshimha-4** | 0.75 | 0.96 | 0.35 | **0.25** | 0.75 | 0.96 | 1.00 | **0.72** | 0.75 | 0.96 | 1.00 | **0.72** |
| **Pashchim Kusaha-1** | 0.75 | 0.95 | 0.11 | **0.08** | 0.75 | 0.95 | 0.24 | **0.17** | 0.75 | 0.95 | 0.24 | **0.17** |
| **Pashchim Kusaha-3** | 0.50 | 0.96 | 0.10 | **0.05** | 0.75 | 0.96 | 0.21 | **0.15** | 0.75 | 0.96 | 0.21 | **0.15** |
| **Ramnagar Bhutaha-8** | 0.75 | 1.00 | 0.36 | **0.27** | 0.75 | 1.00 | 0.62 | **0.47** | 0.75 | 1.00 | 0.62 | **0.47** |

Four risk classes were then defined to demarcate risk zones in the study area. Risk values of 0 - 0.2 was considered as very low risk zone, 0.2 - 0.4 as low risk zone, 04 - 0.6 as moderate risk zone, 0.6 - 0.8 as high risk zone and 0.8 - 1.0 as very high risk zones. **Figure 9-6** shows the risk zones for current climatic conditions. As can be seen from the figure, only Narsimha and Ramnagar Bhutaha lie in the low risk zones whereas all the other wards are found to be in the very low risk zone for current condition.

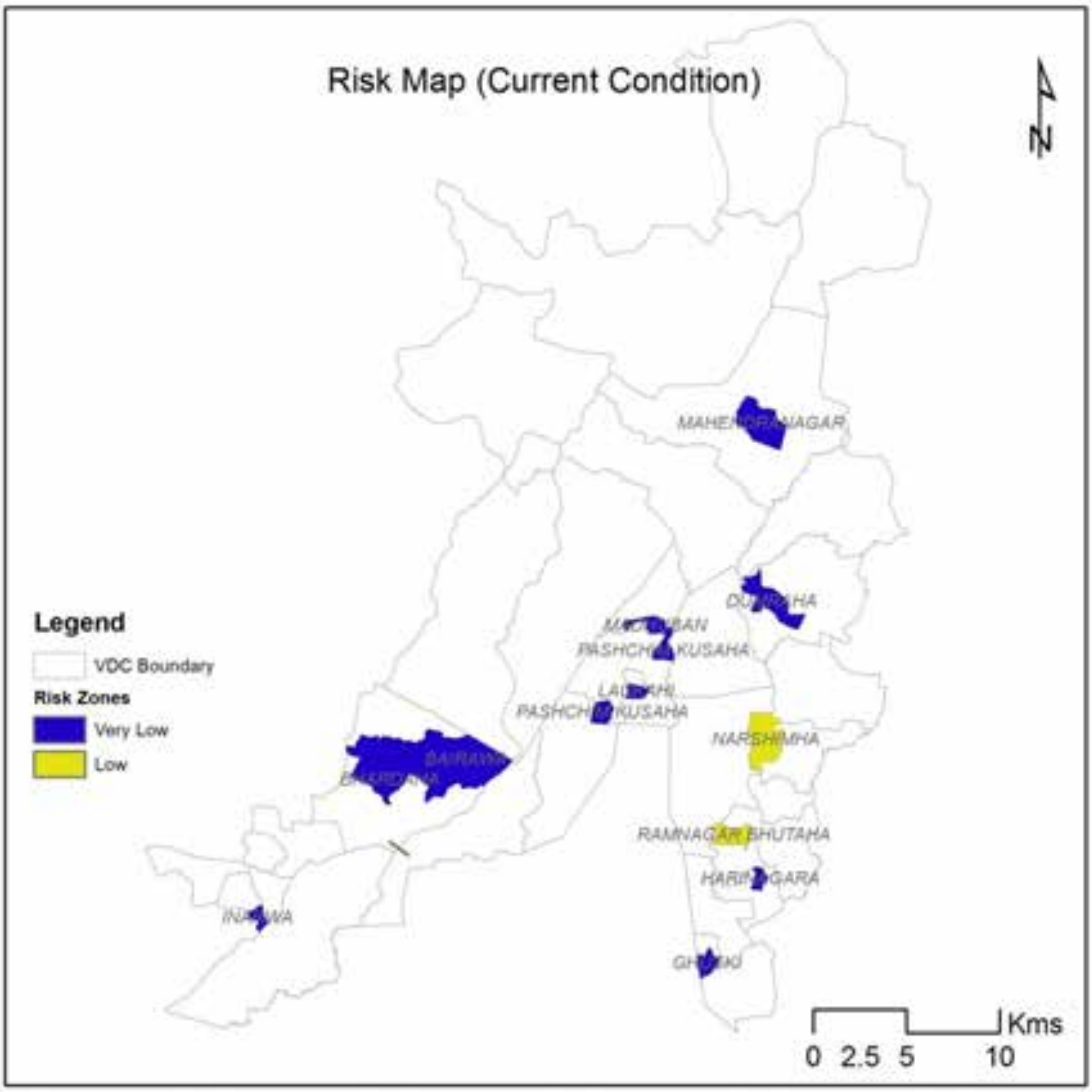



**Figure 9-6: Risk zones under current climatic conditions**

Similarly the risk zones under climate change conditions are shown in **Figure 9-7**. The figure clearly suggests that the very low risk conditions in Mahendranagar, Dumraha, Bhardaha and Ghuski have increased to low risk conditions. Likewise very low risk condition in Bairawa and low risk in Ramnagar Bhutaha are changed to Medium risk conditions under climate change. High risk zone is observed in Narsimha. All the other wards remain under the same risk zones.

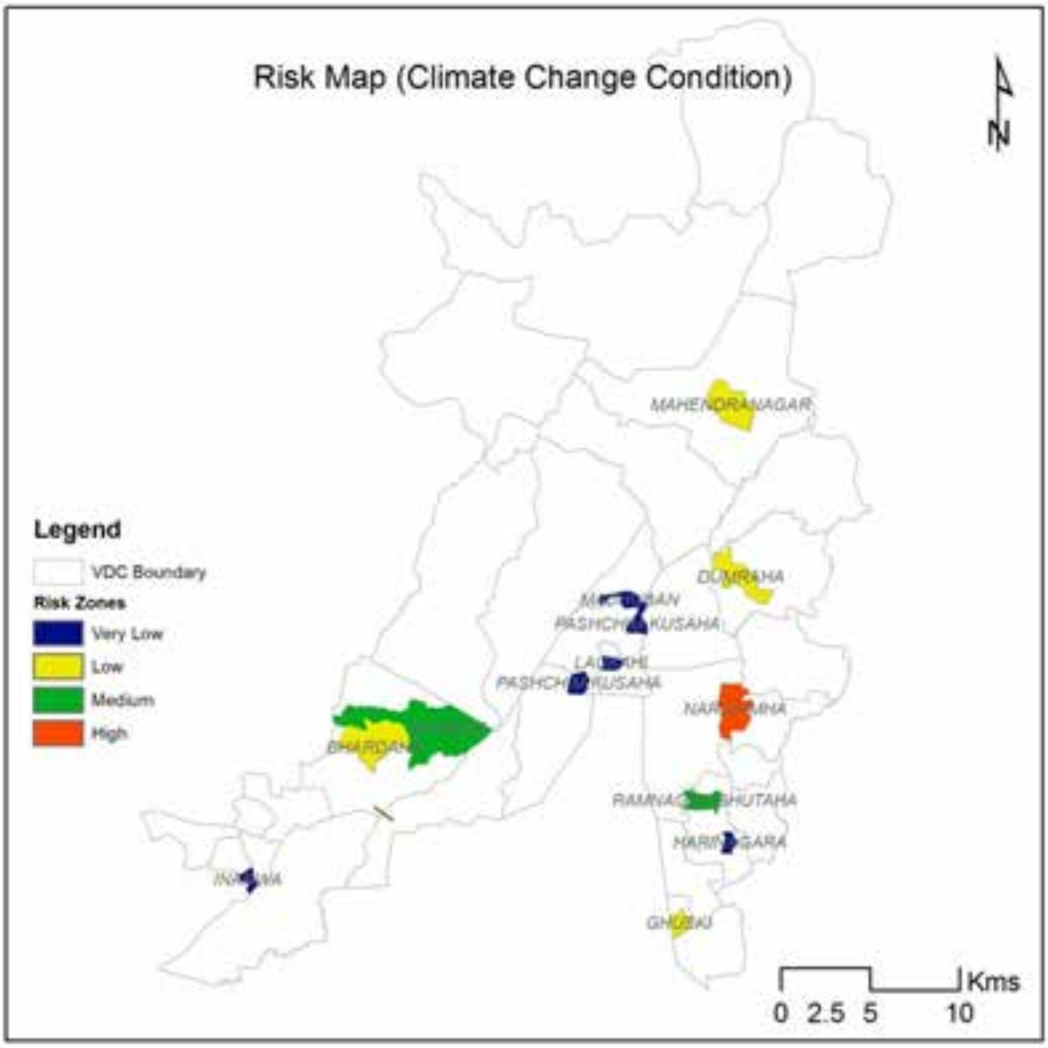



**Figure 9-7: Risk zones under climate change conditions**

## 9.7 Conclusion

Flood from the Koshi River is a growing concern along Koshi River basin of Nepal. The study area is often inundated by the flood annually, which has higher degree of impact on the livelihood of the people. Analysis of demographic, socio-economic, degree of preparedness and recovery capacity indicators clearly indicated that vulnerability of households is very high while considering, house type, income status, access to market, access to early warning system, access to emergency response facilities and access to health institution particularly hospitals. Whereas the vulnerability level is very low while considering education status and access to communication facilities.

Similarly, the result of socio-economic vulnerability index estimation shows that the gross average value of SVI is 2.7, which implies that the vulnerability level of the households from all the three areas is moderate, however, if we consider the value of preparedness and the economic, and demographic indicators, the vulnerability seems very high. Therefore, all these factors worsen the life of people and trigger more vulnerability. This needs to be highly considered while preparing policy on Disaster Risk Reduction.

# Chapter 10: Policies and Strategies

## 10.1 General

Climate Change Adaptation (CCA) is concerned with actions to moderate climate change impacts in the long term, as well as to take advantage of any potential beneficial consequences. And Disaster risk Reduction (DRR) is a broad concept aims to reduce the adverse impacts of hazards on people, property and the environments through activities and measures for prevention, mitigation and preparedness (ADPC, 2013). Therefore, the policies and strategies to address CCA and DRR needs a comprehensive and integrated study background.

Based on the review of existing policies and strategies of Nepal regarding climate change adaptation, and the outputs from this research, relevant policies and strategies are recommended in this chapter.

## 10.2 Research Methodology

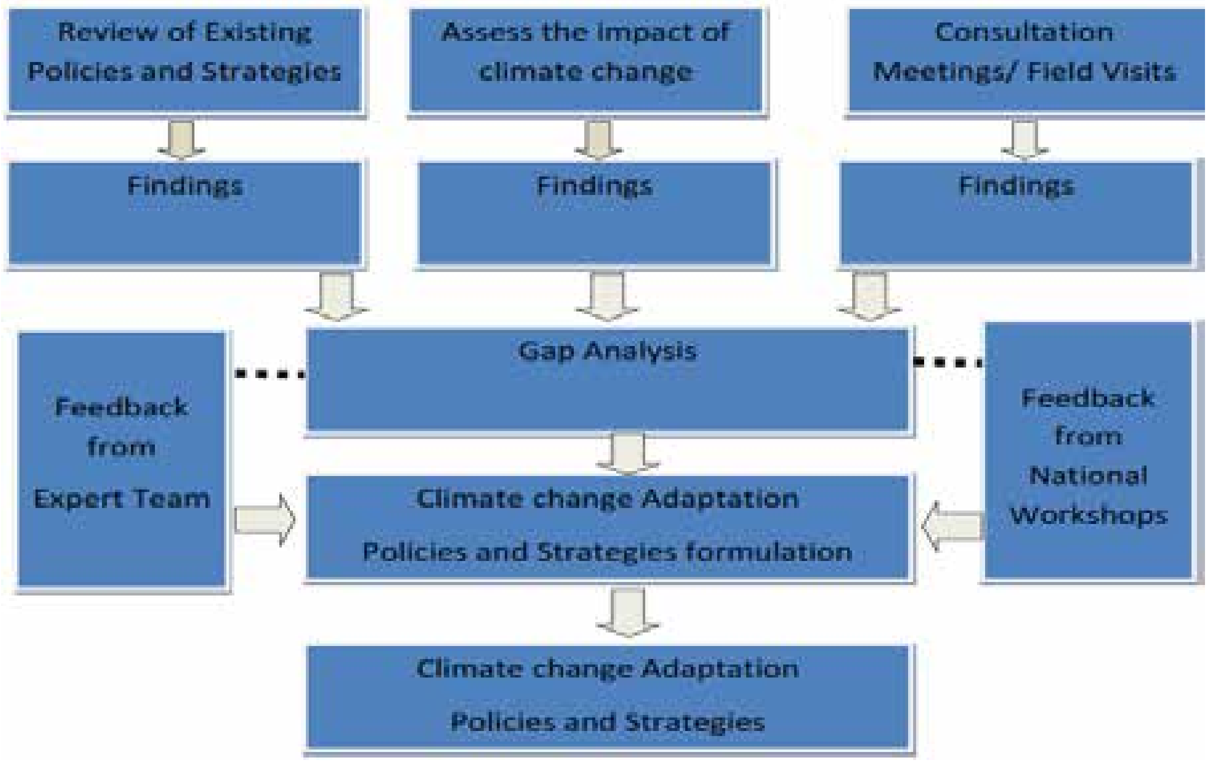



**Figure 10-1: Research Methodology**

## 10.3 Review of Policies and Strategies and Its findings

To formulate the policies and strategies to address the CCA and DRR, it is necessary to review the existing policies and strategies related to climate change, disaster, water resources and other relevant acts, policies and strategies. Therefore, following legal, policies and Strategies documents were reviewed.

- **The Interim Constitution of Nepal, 2007:**

The Interim Constitution of Nepal, 2007 states that the state shall have the responsibilities of raising the standard of living of the general public by fulfilling the basic needs of the people of all regions, and by protecting the forest, vegetation and biodiversity and ensuring their sustainable use and equitable distribution of the benefits derived from them.

- **Sustainable Development Agenda, 2003:**

Sustainable Development Agenda, 2003 envisages integrating environment and development in the national policy making and planning framework by stressing public participation in ecosystem conservation at the landscape level in order to protect valuable biological diversity and agro-diversity and the sustained harvesting of non-timber forest products.

- **Millennium Development Goals:**

Nepal endorsed Millennium Development Goal of the UN in 2002. It has committed itself to the global call for reversing the loss of environmental resources by integrating principles of sustainable development into policies and program.

- **The Action Plan for Disaster Management, 1996:**

The Action Plan for Disaster Management, 1996 prescribes measures for preparedness, response, reconstruction and rehabilitation to minimize disaster impacts. A new bill providing for the establishment of a national disaster Management Council is in the process. To honor its commitment under the Hyogo Framework of Action (HFA 2005), the government developed the National Strategy for Disaster Risk Management in 2009.

- **The Approach Paper:**

The National Planning Commission (NPC)'s approach paper (NPC 2010) to the government's three year national development plan for 2010-2013 recognizes the potential threats posed by climate change to the sustainability to the sustainability of development activities and emphasize the need to make all proposed development plans climate resilient by incorporating measures to reduce the risk. ( Climate Resilient Planning, 2011)

- Water Resources and Energy Sector
- ***Rural Energy Policy 2006***

GON has brought the Rural Energy Policy in 2006 with the overall goal to contribute to rural poverty reduction and environmental conservation by ensuring access to clean, reliable and appropriate energy in the rural areas. For the promotion of various types of alternative energy technologies, the policy has specific working policies on eight different alternative energy technologies. These include: micro and small hydro power; biogas; fuel wood, charcoal, briquette, biomass energy, biomass gasification; solar energy technology; wind energy technology; improved cook-stove technology; improved water mill technology; and rural electrification. This policy also gives special focus on human resources development and institutional strengthening both at public and private sector. Alternative Energy Promotion Centre under the auspices of MoEST is made the key institution for the promotion of alternative energy in the country.

- ***Water Resources Strategy, 2002 and National Water Plan, 2005***

The GON prepared and endorsed the Water Resources Strategy (WRS) in 2002 with the objectives of strengthening water resources development in Nepal. The National Water Plan has been prepared to operationalize the WRS. The Plan has envisaged the overall goal of maximizing sustainable benefits of water use in the country. Although Nepal became party to the UNFCCC in

1994, the National Water Plan has not categorically touched upon the issues of climate change, however, it has many inherent policy initiatives and targeted action plans that are, one way or the other, supposed to address the climate change, and adaptation measures.

The Plan intends to develop and manage water resources: a) relying on principles of Integrated Water Resources Management (IWRM), b) ensuring resource conservation and environment protection, c) holistic river basin management, c) through decentralized water service delivery, and d) through equitable resource and its benefit sharing amongst the riparian countries. The plan covers different sectors of water usages, some of which are – Water Induced Disaster, Management of Watersheds and Sustainable Ecosystems, Drinking Water Supply and Sanitation, Irrigation, Hydropower, Water Resources Information System, and the other usages of water. Th e plan has set some targets to be achieved in short term (by 2007), medium term (by 2017), and long term (by 2027); and has also identified Action Programs to achieve them. The plan has also come up with the suggestions for legal, institutional mechanisms, and investment plan to achieve the policy objectives. The Plan has proposed the need for establishing the Himalayan Climate Change Study Centre by 2007 (in the proposal development stage now) to monitor and deal with climate change related matter in the country.

- ***Water Induced Disaster Management Policy, 2003***

GON has adopted this policy with the objectives of: (i) minimizing the loss of public and property related to water induced disaster; (ii) conserving watershed and aquatic ecosystem for the sustainable use of water related infrastructures, (iii) controlling water induced disaster and management of flood affected areas, and (iv) clarifying the role of government and non-government organizations involved in river management activities. The policy has identified fi ve strategic areas for its implementation: (a) emergency protection measures, (b) abatement of water induced disaster, (c) natural resource conservation, (d) utilization of river banks and fl ood plains, and (e) institutional development. Still the policy has not realized the water induced disaster resulting from climate change; however, it seems to have considered all the disaster, climate change or otherwise, irrespective of the causes. This policy can be suitably adjusted to address the impact of climate change phenomenon and adaptation measures that Nepal has to follow.

- ***Irrigation Policy, 2003***

Government of Nepal has formulated this policy with the objectives of expanding year-roundirrigation services, developing user group's institutional development for sustainable management of irrigation systems, and strengthening required institutional capabilities to achieve the said objectives. Th is Policy has neither realized the impact of climate change on the water availability and damages to the system due to extreme precipitation events, nor envisaged the need of adaptation measures to overcome them with a particular emphasis on maintaining and managing the required data base. Nevertheless, the policy has identified some measures to overcome the water scarcity in terms of trans-basin water transfer, use of ground water, rain water harvesting, and development of storage projects. For emergency management of natural disaster, the policy envisaged to set up an emergency maintenance and rehabilitation fund.

- ***Hydropower Development Policy, 2001***

This policy is an improvement of the previous policy adopted by government in 1992 by building upon the experience gained in the course of implementing the principles and emerging new concepts and trends. The policy deals with the development and use of hydroelectricity for both domestic and international markets with a particular emphasis on rural electrification tied-up with rural development. With the realization of supplying rural energy need through hydro-electricity, the policy seems to have been helping in the mitigation of climate change impacts. The policy has realized that by developing hydropower as an alternative to biomass and thermal energy, a contribution can be made to environment protection. Importance of energy conservation has been realized in the policy and it felt that consumers shall be encouraged for it. In addition, the policy also has provisions for export of electricity to neighboring countries which might replace the use of fossil fuels used for energy generation and consumption. In this way, the policy will also be helping to reduce greenhouse gas emissions from the region. Thus, the policy seems to have many features that are indirectly addressing the climate change.

- ***Water Resources Act, 1992***

This Act has provisions for the rational utilization, conservation, management and development of the water resources that are available in the country and legal arrangement for determining beneficial uses of water resources, preventing environmental and other hazardous effects for keeping water resources free from pollution. The Act has identified two types of water resources utilization, one that needs to acquire a license and the other that does not need to acquire a license. The act has a provision allowing Government, by a notification published in the Gazette, fix the necessary quality standard of water resources for various uses and prescribes the pollution tolerance limit. The Act also has empowered the government, in order to fulfill the objectives of this act, to set rules.

Some of them are related to:

- Conservation of water resources and the control of fl ood and soil erosion;
- Conservation of the environment;
- Fee, charges, etc. payable to Government of Nepal for the utilization of any service related to water resources; and
- Pollution prevention of water resources

- ***National Conservation Strategy, 1988***

In 1988, GON has approved the National Conservation Strategy having the following objectives:

- To satisfy the basic material, spiritual, and cultural needs of the people, both present and future generations;
- To ensure sustainable use of land and renewable resources;
- To preserve biodiversity in order to maintain and improve the variety of yields and quality of crops and livestock, and to maintain the variety of wild species of plants and animals; and
- To maintain essential ecological and life-support systems, such as soil regeneration, nutrient cycling and protection and cleansing of water and air

This strategy has suggested a number of policy, institutional, organizational, research, and conservation awareness activities to achieve these objectives. Although more focused on conservation of natural resources and biodiversity, NCS realized the need of the establishment of air and water quality monitoring and evaluation system and also guided the government to enforce industrial effluent standards, and correlative mitigation and preventive measures.

➢ ***Environment Protection Act, 1996 and Environment Protection Regulation, 1997***

Environment Protection Act enacted in 1996 is the umbrella Act for the environment protection in Nepal. This Act aims to ensure the sustainable development through integration of environment and development, sustainable use of natural resources, minimizing the adverse impacts on human and other living beings, and creating a clean and healthy environment for all. Some of the key legal provisions are summed up as follows:

- Requires major development projects to carry out Initial Environmental Examination (IEE) or Environmental Impact Assessment to ensure that environmental concerns are properly addressed;
- Makes creation of pollution a punishable act and authorizes MoEST to bring environmental standards for the prevention and control of pollution as well as ensuring the compliance of such standards;
- Special provisions on conservation of national heritage, environment conservation area, and creation and use of environmental protection fund;
- Special provisions to provide additional incentives to environment-friendly technologies;
- Creation of Environmental Protection Council to provide advice to the government for the formulation of policies, plans and programs for environmental conservation and protection; and
- Authorizes GON to introduce specific rules and regulations to address specific environmental problems including air pollution and waste management.

Similarly other existing related policies and strategies of Nepal are:

**Forestry Sector**

- *Nepal Biodiversity Strategy (NBS), 2002*
- *Revised Forest Policy, 2000*
- *Master Plan for Forestry Sector, 1989*
- *Forest Act, 1993 and Regulation, 1995*
- *Soil and Water Conservation Act, 1982*
- Industry Sector *Industrial Development Perspective Plan: Vision 2020 (draft)*

**Transport Sector**

- *Transport Policy, 2001*
- *Vehicle and Transport Management Act, 2049 & its Regulation, 2054 (first amendment 2061)*

**Agriculture Sector**

- *National Agriculture Policy, 2061*
- *Agriculture Perspective Plan*

***Housing Sector***

- *Housing Policy*

**Health Sector**

- *Health Sector*
- *National Health Policy 1991*

**Disaster Sector**

- *National Strategy for Disaster Risk Management 2009*
- *Natural Calamity Act 1982*

- **Climate Change Sector**
- *Climate Change Policy, 2011.*

Nepal signed the UN Framework Convention for Climate Change (UNFCCC) in June 1992. UNFCCC entered into force in Nepal in July 1994. The Kyoto Protocol entered into force in Nepal in December 2005. The Ministry of Environment, Science and Technology (MoEST) is responsible for the overall coordination of climate change adaptation and mitigation. The Climate Change Policy was formulated by Government of Nepal (GON), MoEST in 2011 in order to face the challenges and solve the problems due to climate change and maximize the benefits from the climate change convention. The policy envisions a country spared from the adverse impact os climate change, by considering climate justice, through the pursuit of environmental conservation, human development, and sustainable development- all contributing toward a prosperous society. The mission of this policy is to address the adverse impacts of climate change utilize the opportunities created from it to improve the livelihoods achieve climate-friendly physical and social and economic development.

- *National Adaptation Programme of Action (NAPA) to Climate Change, 2010.*

Nepal is one of the last countries to develop its NAPA, and as such has been able to learn lessons from NAPA processes in other countries. Recent evaluations of other NAPAs have shown that there is a need to take a more strategic approach to national adaptation planning with better linkages to both other climate change planning processes at the national level, and also to mainstreaming adaptation across scales right down to the local level. The NAPA in Nepal also follows a growing realization among academics, government and civil society that in order to achieve mainstreaming, institutional mechanisms need to be developed to forge links between climate change activities initiated under the NAPA processes and risk management and development activities of national, sectoral and local planners. This requires inputs into adaptation policy making from a wide range of stakeholders, to integrate climate change expertise into development policy and planning, whilst maintaining a participatory approach to understanding what vulnerability means in a development context. The overall structure of the NAPA has three components:

**Component 1**: Preparation and dissemination of a NAPA document

**Component 2:** Development and maintenance of a Climate Change Knowledge Management and Learning Platform for Nepal; and

**Component 3**: Development of a multi-stakeholder Framework of Action for Climate Change in Nepal.

Further, the NAPA in Nepal has adopted an innovative approach to multi-stakeholder engagement and vulnerability analysis, moving beyond the regional and national consultation meeting approach adopted under other NAPAs, towards a framework that generates and incorporates meaningful inputs from a wide range of stakeholders including vulnerable communities themselves.

- *Local Adaptation Plan of Action (LAPA), 2011.*

Part of NAPA's approach for multi-stakeholder engagement involving vulnerable communities involves the generation of "LAPAs", or *Local* Adaptation Plans of Action. The vision for LAPAs is to develop a system of adaptation planning that:

- Enable communities to understand the changing uncertain future climatic conditions and engage effectively in the process of developing adaptation priorities
- Implement climate resilient plans, that are flexible enough to respond to changing climate and vulnerability conditions
- Inform sectoral programme and catalyze integrated approaches between sectors

The Local Adaptation Plant of Action (LAPA) is a plan prepared at local level by involving multi-stakeholder team including the vulnerable communities. It involves decentralized and bottom up planning process. The proposed LAPA would identify adaptation needs at the local level that focuses on reducing local-level climate risk and vulnerabilities and ways of increasing resilience. It would also focus on strengthening mechanisms for ensuring consolidated and coordinated adaptation responses at local levels through the existing planning process

Following are the findings from the review of existing policies and strategies of Nepal in relation with Climate Change Adaptation and Disaster Risk Reduction:

1. The policies that Nepal currently adopts do not directly address the issue of adaptation to climate change because this idea of adaptive policies in general had not emerged as an issue of discourse at the time of formulation of that policy. The Climate Change Policy was recently adopted only in 2011.
2. The existing policies need to be harmonizes with Climate Change adaptation and mitigations.
3. Although there is climate change policy, NAPA and LAPA documents including other water infrastructure and other development policies, there is no Laws and regulations which have a bearing on adaptation to climate change. So, there is need of Climate Change Law, 2009 as in Phillipine to enforce the climate change adaptation measures in the big development projects and water infrastructure project like Koshi High Dam.
4. Climate Change Impact Assessment and Its findings

To analyze the impact of climate change on the hydrology and sediment yield in the hilly region of the Koshi River Basin in Nepal, ECHAM05 and HadCM3 data downscaled using the PRECIS Model was used and following are the findings from the Climate Change Impact Assessment:

1. The annual average precipitation of basin seems to be increases from about 6mm/year (present scenario) to 11mm/year (Climate change projection).
2. The annual average temperature of basin seems to be increases from about $0.05^0$ c/year (present scenario) to $0.06^0$c/year (Climate change projection). The rate of evaporation process in the reservoir for irrigation, water supply and hydropower generation will therefore seems affecting the respective design parameters .
3. The Design discharge for a 1000yr return period flood ($Q_{1000}$) over the spillway seems to be increases from about 47444 m3 /s (present scenario) to 137351 m3 /s ( Climate change projection). To safely pass the Q1000 flood, the spillway design standard should be revisited.
4. The annual average sediments yields in basin seems to be increases from about 2158395 Tons/year (present scenario) to 4627936 Tons/year ( Climate change projection). So it is observed to be increased in the future (2020-2060). Hence the dead storage is to be increased to accommodate the increased sediment yield.

Following are the findings from the Socio-Economic Vulnerability Assessment carried out in Koshi river basin Nepal:

- From SVA, it was observed that degrees of preparedness and economic indicators have shown very high indices value of 3.6 in the cases of less affected and moderately affected and 4 in highly affected area which implies that the affected areas are very less access to preparedness facility. Frequent occurrence of flood and less access to preparedness facility further worsens the life of people and trigger to become more vulnerable so that it seems to have higher degree of impact on the livelihood of the people.

**Table 10-1: Potential Risk Sectors of Climate Change**

| Risk Sectors | Heavy Rainfalls | Decreased rainfall/drought | Increased Temperature |
|---|---|---|---|
| **Socio- economic activities** | • Uncomfortable for movement and work<br>• Loss of employment<br>• Less work and less income | • Decrease of crop harvest | • Uncomfortable for movement and work |
| **Social Infrastructures** | • Damage to the social infrastructures like schools and hospitals | | • Uncomfortable living |
| **Human Health** | • Higher rate of Mosquito borne diseases<br>• Snakes biting problems | • More dust<br>• Epidemic<br>• Scarcity of Water | • More dust<br>• Higher rate of Asthma<br>• Uncomfortable living<br>• High stress<br>• Epidemic |
| **Agriculture** | • Flooding of agricultural areas<br>• Flooding and damages of roads | • Destruction of crops<br>• Food Shortage for people and Animals | • Crop damage and destruction<br>• High rage of evaporation<br>• Increased breeding of insects<br>• Food shortage |
| **Housing and Infrastructure** | • Flooding and damages to houses<br>• Flooding and damages of roads | | |
| **Dam and Water reservoir** | • Risk of Damage to dam and its associated structures<br>• Higher Siltation | • Death of Trees | • Uncomfortable living of the wild animals |
| **Forestry** | • Flooding of forest<br>• Loss of forest and wild animals | • Death of Trees | • Uncomfortable living of the wild animals |
| **Animals** | • Flooding<br>• Loss of animals | | • Uncomfortable living |

## 10.4 Policies and Strategies Gap Analysis

Based on the findings of different types of study mentioned above, gap analysis was made to address the climate change adaptation and disaster risk reduction in the Koshi Basin , which is tabulated in the **Table 10-2** below.

**Table 10-2: Gap Analysis**

| Category | Gaps |
|---|---|
| **1. Existing policies** | 1. The policies related to development that Nepal currently espouse do not directly address the issue of adaptation to climate change because this idea of adaptive policies in general had not yet emerged as an issue of discourse when they were framed. So, these policies including Climate Change policy have to be revisited in the context of CCA. |
| **2. Climate Change Law** | 2. Even there is Climate change policy 2011, there is no climate change related Laws and regulations which have a bearing on adaptation to climate change in broadly categorized governing three systems: the natural resource management, the social and economic, and the financial systems. |
| **3. Awareness on CCA** | 3. People have lack of education and training on CCA. |
| **4. Preparedness for disaster ( like flood)** | 4. Lack of Hazard Evaluation Map, Emergency Response, Early warning system, Evacuation space, alternative route for safe place and risk sensitive planning. |
| **5. Insurance** | 5. Lacking of insurance of life and property. |
| **6. Alternative Employment Opportunities** | 6. Lack of capacity development for alternative employment opportunities besides agriculture like vocational trainings, vegetable farming on sandy land etc. |
| **7. Resource allocation for DRR** | 7. In-sufficient resource allocation for DRR and post disaster management at local level. |
| **8. Knowledge Management** | 8. The lack of data and scale down climate change information and no system of knowledge management. |
| **9. CC Consideration in Design** | 9. No consideration of CC in the design of water resource infrastructures like dam, reservoir for irrigation etc. |
| **10. Gender Equity** | 10. Mostly leadership participation of women are lacking and their problems have been integrated for Disaster Risk Reduction into CCA. Women are deprived to access the disaster relief opportunity and facilities |
| **11. Institutional Arrangement for DRR** | 11. The existing institutional arrangement should be restructured including community people and has to be extended up to community level. |
| **12. Information and Communication System** | 12. Pre-information in the early phase of disaster and instructive information during disaster and post disaster phase has to be strengthened up to the community level and educated about the community people about it. |

## 10.5 Recommended Policies and Strategies

Against the findings like less education and awareness, flood preparedness and recovery of the local people, increased sediments flow, flood value and temperature due to climate change; this research formulated the policies and strategies like need of revisiting the design standard/ values of the infrastructures (proposed Koshi High Dam, storage capacity for irrigation and spillway etc) and risk sensitive land use plan, post disaster plan, early warning system, alternative job opportunities, education and awareness among the people. The details of suggested climate change adaptation policies and strategies in National perspectives to reduce disaster risks as follows:

- **Policy 1.** Formulation of new laws (Climate change law) and revise existing development policies in the context of climate change for the implementation of climate change related policies, conventions and protocols.

**Strategies**

a) Prepare a joint committee for formulation of new law – Climate Change law under coordination of Ministry of Science, Technology and Environment involving other ministries.

b) Revise the existing policies of Nepal in the context of climate change in harmony with climate change policy, NAPA and LAPA documents of GON.

- **Policy 2.** Establishment of Climate Change and Disaster Risk Reduction Centre for conducting climate change research, monitoring, maintaining knowledge management system and regularly providing technical advice for the disaster risk reduction.

**Strategies**

a) Developing and utilizing technologies through necessary research for conducting climate resilient structures and infrastructures.

b) Develop system of real time data acquisition system in vulnerable areas and prepare appropriate Climate Forecasting models for Nepal and regularly updating it based on regional climate model.

- **Policy 3.** Minimize the disaster risks through coordinated efforts of government, NGOs and local community.

**Strategies**

a) Introduce disaster insurance in climate change affected areas for different sectors.

b) Develop early warning system of possible flood or disaster to minimize the adverse impacts.

c) Train each household to rescue during flood and ensure first aid materials kept in each household in the flood affected areas.

d) Develop proper compensation mechanism by the government for the loss and damage of property.

e) Conduct Vulnerability assessment of public buildings where it is planned to accommodate large no of people during emergency

f) Develop a integrated action plan for disaster risk management and climate change adaption coordinating the inter-governmental ministry and development agency including donor organizations.

g) Establishment of a District level Climate Change Advisory Committee involving stakeholders and experts to guide and implement the climate change adaptation process, sustain the activities and mainstream the development projects in practices for Disaster Risk Reduction

h) Assess, protect and strengthen critical public facilities and physical infrastructures

i) Develop and implement, on a priority basis, special DRR programmes for the most vulnerable segments of the society – the marginalized groups, women, handicapped; disadvantaged groups, children and the elderly.

j) Establish and/or strengthen warehousing and prepositioning capacities at strategic locations (centre, district, municipality and villages) for storing food, medicines, other relief supplies and rescue tools and equipment.

- **Policy 4.** Develop a basin approach for water utilization and management through regular monitoring of water resource availability.

**Strategies**

a) Develop integrated plan of action for water utilization and management in the whole Koshi Basin.

b) Develop coordination and cooperation mechanism among the development organizations including donor agency, local people and NGOs for water utilization and management with regulation consultations and transparent environment.

e) Conduct the regular monitoring system of water resources availability in the basin.

- **Policy 5.** Formulating and implementing design standards for climate resilient construction of bridges, dams, river flood control and other infrastructure.

**Strategies**

a) Design of major projects based on the Climate Change Impact Assessment (CCIA).

b) Revisit the design standard and parameters in the water related infrastructures like Dam, Water Storage Capacity for Dead storage, water for hydropower production, drinking water supply and irrigation etc considering climate change variability.

- **Policy 6.** Develop and Practice Climate Change friendly Agriculture methods.

**Strategies**

a) Identify, develop and utilize agriculture varieties /species that can tolerate floods (too much water) and sands.

b) Provide skill trainings to the community people of the affected areas for alternative job opportunity other than farming or doing farming using new skills in the changed context after flooding. For example- practicing vegetables (eg. Parbar) growing in the agriculture lands that turns into sand.

c) Develop, recommend and provide the crops seeds and varieties suitable for agriculture against extreme climate condition with providing mechanism for sufficient consultation and information about the new technology like drip irrigation and improved varieties of seeds and crops.

- **Policy 7.** Empower the women of the affected areas through education and training, skill enhancement programs and ensuring women participation in the climate change adaptation and disaster risk reduction related government incentive programs.

**Strategies**

a) Enforcing effective monitoring and evaluation system of Government and International Agency Disaster Relief Programme ensuring that local people specially women, children and more vulnerable people are receiving the benefits of the Programme.

b) Give high priority to the women as a beneficiaries in the Climate Change Adaptation Incentives Programme like Skill Enhancement Training and Education, Income Generating Opportunities and Exposure Visits.

- **Policy 8.** Prepare Risk Sensitive land use maps and adopt accordingly.

**Strategies**

a) Identify the flood prone areas preparing Risk Sensitive Maps and prohibit the development of human settlement in those areas based on Risk Sensitive Planning.

b) Enforcing appropriate Building Codes (like raised plinth level, sufficient windows etc) and recommend typical flood resistive house in risk sensitive areas incorporating climate change dimension.

c) Identify and establish evacuation spaces and emergency shelters and prepare post disaster plan in partnership of all stakeholders including line agencies, local government, NGOs and private sector)

d) Make Plantation of trees near house and vacant places locally suitable multiple use trees like Shisau, Bakaina, Bamboo, Dale ghans, Mango, lichhi, Coconut, banana, Masala, Kadam etc.

e) Provide better care to Children, elderly, women and disabled persons with high priority to bring them at secured place during disaster keeping the records of the potential affecting community in advance.

f) Arrange basic facilities like food, medicine, water, lighting system at secured place in house and in the community.

g) Manage properly for extracting stones and sands from the rivers and control deforestation.

h) Develop multi-purpose Parks in the community so that these can be helpful during the flood and in other time it can be used for the open space, playing and relaxing purposes.

i) Make pre-plan arrangement for escaping to the high elevated spaces (Evacuation spaces) during flood. Such places should have the temporary arrangement for basic facilities.

- **Policy 9.** Conduct regular mass public awareness and school children awareness about climate change and CO2 emission reduction.

**Strategies**

a) Emphasize on implementing regular public awareness about climate change and CO2 emission reduction and capacity building programmes through multi stakeholder participation about CCA and DRR.

b) Include the climate change course in the curriculum of the high school education.

c) Encourage and support NGOs, CBOs and other stakeholders for developing and implementing awareness- raising programmes on disaster risk reduction and preparedness.

d) Develop/strengthen and encourage awareness raising programmes on DRM at the local level

e) Develop and implement a comprehensive national programme for disaster awareness

- **Policy 10.** Develop a proper communication and information system among local people and climate change adaptation and disaster risk reduction related organizations

**Strategies**

a) Establish Climate Change and Disaster Risk Reduction Information Center for providing related information including service to the people at the time of disaster ( eg. Steps to be followed)

b) Develop a proper communication system linking between upstream and downstream community people for sharing about the expected flood related information.

c) Develop plans, programmes and facilitate for use of mass communication media for dissemination of information on disaster risk and risk reduction

- **Policy 11**. Capacity development of government and non government organization, local people and community towards climate change adaptations and lunching the disaster relief packages in the affected areas for quick recovery.

**Strategies**

a) Coordinated action plans should be made in advance about the roles of governmental, non- governmental organizations and local people to reduce then disaster risks regarding flood under the coordination of DRR Committee in each community.

b) Identify the possible alternative employment and promote non farming sector.

c) Government should lunch Disaster Recovery Programme. The package of the programme should include capacity building of the community people, Provision of Housing and Agriculture loans to recover from damage of houses and agriculture, Provision of basic facilities

d) Allocate the maximum available fund ( about 75%) for field level climate change activities and emphasize for improving the living standard of people by maximum utilization of the opportunities created from the climate related funds and agreements.

e) Educate and aware the local people about climate change, CO2 emission and how to locally adapt climate change

f) Make exposure visits at the places where local people and related organization people can learn how people are adapting climate change to minimize its disaster risks and to know how adaptation policies and strategies adopted to cope it.

g) Make trainings to the Government and NGO organizations people about the effective disaster risk reduction tools like IT, GIS, communication and information, rescue services.

h) Develop curricula on DRR training for different target groups and implement training programmes for all stakeholders.

i) Enhance emergency response capacities of communities at the VDC level.

- **Policy 12.** Develop fair international negotiation and coordination among the neighbor countries for mutual benefits, sharing information and join initiations for climate change adaptation and disaster risk reduction.

**Strategies**

a) Prepare a joint plan of action between China, Nepal and India fighting against the climate change induced disaster risks and climate change adaptation and disaster risk management in the Koshi River Basin under mutual understanding and cooperation.

b) Develop a mechanism of regular consultation meetings, cooperation and coordination among the neighbor countries (Specially between India and Nepal) to address the common interest of climate change adaptation and disaster risk management.

## 10.6 Conclusion:

Based on the existing policies and strategies review, assessment of impact of climate change, field visit Field survey, consultation meetings with community/local people and related organizations, this study has revealed the fact that the study area is more vulnerable to disaster due to climate change if some interventions are not made in time. With participatory approach of this research analysis for community perception of climate change, its impact, the coping strategies adopted by the communities and modeling result, the findings from the study direct that climate change adaptation requires an integrated approach, including socio-economic development, education and awareness, planning and regulations and disaster risk reduction with implementable climate change adaptation policies and strategies. Therefore, some of the Climate Change Adaptation Policies and Strategies have been recommended here which seems to be helpful for reducing climate change induced disaster risks in Koshi River Basin and for improving livelihood of the local people.

# Chapter 12: Conclusions and Way Forward

## 12.1 General Conclusion

The conclusions drawn from this study are as under.

1. Better understanding of magnitude of climate change impact on hydro-meteorology of the Koshi River is of foremost importance to assess disaster risk reduction and climate change adaptation innovation. The Hydro-meteorological Diagnostics and Modeling were carried out to enhance the knowledge on the impact of climate change on basin hydrology by assessing the trend and the change in the major design statistics of hydro-climatic variable those are required for water resources development works. Successful preparation of future climate data from RCM to apply in modeling purpose and to use in comparing of future hydro-climate variables with the historic data is one of the major achievement of this study.
2. Customized SRM and SWAT models to assess the impacts of expected climate change on the hydrological cycle including extreme events are now in place for the Koshi river Basin. These models are in ready state to use for other climate change scenarios envisioned in IPCC which will enhance the level of confidence on the impact of climate change in basin hydrology. development and use of these models to simulate the snow melt phenomena, flow and sediment yield assessment for this basin augmented the confidence level for the use of these models in other basins too. Similar is the case regarding the development and use of hydraulic model HEC-RAS to simulate the probable flood inundations in the basin that may be either natural flow or embankment/dam breaching.
3. Given the contemporary state of art, the method of estimation of flood flow for a given return period in future from historical data and climate change induced flow hydrographs is another major contribution of this study.
4. The magnitude of flood and its relationship with year of recurrence (return period) with and without climate change has clearly showed the need of the day to revisit the design standard/values for proposed infrastructures: the Koshi High Dam in this case. The increased sediment flow resulted from climate change also demanded the change in the design capacity of the infrastructure to have optimum utilization of the water resources.
5. Vulnerability assessment method applied in this study can be replicated in other places with needed modification as per the specialty of the location. This method is useful not only to quantify the composite vulnerability index but also to identify the more vulnerable sector e.g. economic or social, preparedness or recovery, of a given area.
6. Flood hazard maps, vulnerability and flood risks maps are useful to prioritize the flood disaster risk reduction and climate change adaptation. It gives the policy maker and community people to evaluate the areas of intervention.
7. The policy recommendations for disaster risk reduction and climate change adaptation, that may include the revisit of design standard for the safety of the structure to watershed management to lessen the climate change stresses on water resources development works, measures to be taken to reduce the vulnerability of the people living in the study area is one of the major contribution of this research. Its attempts to link the research and development is another aspect to be noted.

8. Integration of modern techniques (hydrological and hydraulic models) to simulate hydrologic and hydraulic process occurring in the basin with the socio-economic survey to assess the vulnerability of the people living in the flood prone area; integration of snowmelt phenomena of the Himalayan region, rainfall and runoff process of Hilly region and consequent flood flow and inundation of the Terai region of Nepal as well as involvement of practically experienced personnel as steering committee members, experts of different faculties as investigators and young generation as research associates in one study is the real beauty of this project. Further providing research grants to the university students is another new aspects of this project. It has attempted to link research organization with academic institutes and to train the new generation modern scientific techniques and to provide platform for exposure to them.
9. Similarly awareness building of stakeholders including local communities on climate change impacts in water resources development works, water related disaster risks reduction and climate change adaptation through workshops and seminars is another useful output of the study. Feedback workshops and focus group discussion/KII/HH survey provided the opportunity to know the concern of the people and assess the indigenous knowledge of flood adaptation that has been practicing from generation.

## 12.2 Way Forward

From the knowledge it acquired, skill it gained and confidence it built from this research project, NDRI will do the following activities relating to disaster risk reductions and climate change adaptation in the coming days.

1. Publish at least 5 peer reviewed paper from this research work:
   i. Application of the regional climate model data set for analysis of flow in Koshi river in Nepal
   ii. Hydro-meteorological diagnostics with and without climate change scenarios in Koshi River Basin of Nepal
   iii. Application of Snowmelt Runoff Model (SRM) to assess the snowmelt contribution to river flow in response to climate change in Koshi River Basin of Nepal
   iv. Impacts of climate change on the hydrology of the Koshi River basin of Nepal
   v. Revisits of design standard or design values of water resources structures in the face of climate change
   vi. Comparison of flood inundation in the Terai Region of the Koshi River basin with and without climate change scenarios
   vii. Socio-economic vulnerability assessment of Koshi River Basin
   viii. Climate change adaptation policy and strategies for disaster risk reduction in Koshi River Basin, Nepal
2. Assessment of impact of climate change in agricultural and energy sectors considering land use change in the basin with different GCM and RCM model data and IPCC scenarios in Koshi Basin, Nepal
3. Carry out similar researches in other river basins of Nepal
4. Performing collaborative research by extending this research up to Ganga River
5. Conducting researches on the impact of climate change in groundwater system
6. Establishing NDRI as a hub of "Regional Climate Change and Water Research Center" (RCCWRC)

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# Appendix A: Available Meteorological Data

## Appendix A-1: Available Rainfall Data

| S.No. | INDEX | Station | Latitude (D) | Longitude | Elevation (m) | Data available |
|---|---|---|---|---|---|---|
| 1 | 1006 | Gumthang | 27.87 | 85.87 | 2000.00 | 1971-2008 |
| 2 | 1008 | Nawalpur | 27.80 | 85.62 | 1592.00 | 1959-2008 |
| 3 | 1009 | Chautara | 27.78 | 85.72 | 1660.00 | 1947-2008 |
| 4 | 1016 | Sarmathang | 27.95 | 85.60 | 2625.00 | 1971-2008 |
| 5 | 1017 | Dubachaur | 27.87 | 85.57 | 1550.00 | 1971-2008 |
| 6 | 1018 | Baunepati | 27.78 | 85.57 | 845.00 | 1971-2008 |
| 7 | 1020 | Mandan | 27.70 | 85.65 | 1365.00 | 1971-2008 |
| 8 | 1023 | Dolalghat | 27.63 | 85.72 | 710.00 | 1947-2008 |
| 9 | 1024 | Dhulikhel | 27.62 | 85.55 | 1552.00 | 1947-2008 |
| 10 | 1025 | Dhap | 27.92 | 85.63 | 1240.00 | 1971-2008 |
| 11 | 1027 | Bahrabise | 27.78 | 85.90 | 1220.00 | 1971-2008 |
| 12 | 1028 | Pachuwarghat | 27.57 | 85.75 | 633.00 | 1966-2008 |
| 13 | 1036 | Panchkhal | 27.68 | 85.63 | 865.00 | 1975-2008 |
| 14 | 1049 | Khopasi | 27.58 | 85.52 | 1517.00 | 1971-2008 |
| 15 | 1058 | Tarkeghyang | 28.00 | 85.55 | 2480.00 | 1974-2008 |
| 16 | 1062 | Sangachok | 27.70 | 85.72 | 1327.00 | 1981-2008 |
| 17 | 1063 | Thokarpa | 27.70 | 85.78 | 1750.00 | 1983-2008 |
| 18 | 1078 | Dhap | 27.90 | 85.63 | 1310.00 | 1998-2008 |
| 19 | 1101 | Nagdaha | 27.68 | 86.10 | 850.00 | 1977-2008 |
| 20 | 1102 | Charikot | 27.67 | 86.05 | 1940.00 | 1959-2008 |
| 21 | 1103 | Jiri | 27.63 | 86.23 | 2003.00 | 1961-2008 |
| 22 | 1104 | Melung | 27.52 | 86.05 | 1536.00 | 1959-2008 |
| 23 | 1107 | Sindhuligadhi | 27.28 | 85.97 | 1463.00 | 1955-2008 |
| 24 | 1108 | Bahuntilpung | 27.18 | 86.17 | 1417.00 | 1958-2008 |
| 25 | 1115 | Nepalthok | 27.45 | 85.82 | 1098.00 | 1950-2008 |
| 26 | 1123 | Manthali | 27.47 | 86.08 | 495.00 | 1992-2008 |
| 27 | 1124 | Kabre | 27.63 | 86.13 | 1755.00 | 2007-2008 |
| 28 | 1202 | Chaurikharka | 27.70 | 86.72 | 2619.00 | 1950-2008 |
| 29 | 1203 | Pakarnas | 27.43 | 86.57 | 1982.00 | 1948-2008 |
| 30 | 1204 | Aisealukhark | 27.35 | 86.75 | 2143.00 | 1948-2008 |

| S.No. | INDEX | Station | Latitude (D) | Longitude | Elevation (m) | Data available |
|---|---|---|---|---|---|---|
| 31 | 1206 | Okhaldhunga | 27.32 | 86.50 | 1720.00 | 1948-2008 |
| 32 | 1207 | Manebhanjyang | 27.48 | 86.42 | 1576.00 | 1948-2008 |
| 33 | 1210 | Kurule Ghat | 27.13 | 86.42 | 497.00 | 1948-2008 |
| 34 | 1211 | Khotang | 27.03 | 86.83 | 1295.00 | 1959-2008 |
| 35 | 1212 | Saptari | 26.73 | 86.93 | 100.00 | 1976-2008 |
| 36 | 1219 | Salleri | 27.50 | 86.58 | 2378.00 | 1948-2008 |
| 37 | 1220 | Chialsa | 27.48 | 86.62 | 2770.00 | 1966-1998 |
| 38 | 1222 | Diktel | 27.22 | 86.80 | 1623.00 | 1971-2008 |
| 39 | 1224 | Sirwa | 27.55 | 86.38 | 1662.00 | 1959-2008 |
| 40 | 1226 | Barmajhiya | 26.60 | 86.90 | 85.00 | 1970-2008 |
| 41 | 1301 | Num | 27.55 | 87.28 | 1497.00 | 1959-2008 |
| 42 | 1303 | Chainpur | 27.28 | 87.33 | 1329.00 | 1947-2008 |
| 43 | 1304 | Pakhribas | 27.05 | 87.28 | 1680.00 | 1976-2008 |
| 44 | 1305 | Leguwaghat | 27.13 | 87.28 | 410.00 | 1947-2008 |
| 45 | 1306 | Munga | 27.03 | 87.23 | 1317.00 | 1947-2008 |
| 46 | 1307 | Dhankuta | 26.98 | 87.35 | 1445.00 | 1947-2008 |
| 47 | 1308 | Mulghat | 26.93 | 87.33 | 365.00 | 1947-2008 |
| 48 | 1309 | Tribeni | 26.93 | 87.15 | 143.00 | 1948-2008 |
| 49 | 1314 | Terhathum | 27.13 | 87.55 | 1633.00 | 1966-2008 |
| 50 | 1316 | Chatara | 26.82 | 87.17 | 183.00 | 1948-2008 |
| 51 | 1317 | Chepuwa | 27.77 | 87.42 | 2590.00 | 1958-2008 |
| 52 | 1321 | Tumlingtar | 27.28 | 87.22 | 303.00 | 1977-2008 |
| 53 | 1322 | Machuwaghat | 26.97 | 87.17 | 158.00 | 1949-2008 |
| 54 | 1324 | Bhojpur | 27.18 | 87.05 | 1595.00 | 1954-2003 |
| 55 | 1325 | Dingla | 27.37 | 87.15 | 1190.00 | 1950-2008 |
| 56 | 1403 | Lungthung | 27.55 | 87.78 | 1780.00 | 1947-2008 |
| 57 | 1404 | Taplethok | 27.48 | 87.78 | 1383.00 | 1947-2008 |
| 58 | 1405 | Taplejung | 27.35 | 87.67 | 1732.00 | 1947-2008 |
| 59 | 1406 | Memengjagat | 27.20 | 87.93 | 1830.00 | 1950-2008 |
| 60 | 1419 | Phidim | 27.15 | 87.75 | 1205.00 | 1978-2008 |
| 61 | 1420 | Dovan | 27.35 | 87.60 | 763.00 | 1950-2008 |

# Appendix A-2: Available Temperature Data

| S.No | Index | Station | Latitude | Longitude | Elevation (m) | Estd | Type | Data Available Upto |
|---|---|---|---|---|---|---|---|---|
| 1 | 1024 | Dhulikhel | 27.62 | 85.55 | 1552 | 6/1/1947 | Climatology | 2009 |
| 2 | 1036 | Panchkhal | 27.68 | 85.63 | 865 | 11/1/1970 | Climatology | 2009 |
| 3 | 1103 | Jiri | 27.63 | 86.23 | 2003 | 8/1/1961 | Agrometeorology | 2009 |
| 4 | 1107 | Sindhuligadhi | 27.28 | 85.97 | 1463 | 6/1/1955 | Climatology | 2009 |
| 5 | 1124 | Kabre | 27.63 | 86.13 | 1755 | 5/15/2007 | Agrometeorology | 2009 |
| 6 | 1206 | Okhaldhunga | 27.32 | 86.50 | 1720 | 12/1/1947 | Synoptic | 2009 |
| 7 | 1212 | Saptari | 26.73 | 86.93 | 100 | 1/7/1976 | Climatology | 2009 |
| 8 | 1223 | Rajbiraj | 26.55 | 86.75 | 91 | 12/1/1971 | Climatology | 2009 |
| 9 | 1303 | Chainpur | 27.28 | 87.33 | 1329 | 7/1/1947 | Climatology | 2009 |
| 10 | 1304 | Pakhribas | 27.05 | 87.28 | 1680 | 1/1/1976 | Agrometeorology | 2009 |
| 11 | 1307 | Dhankuta | 26.98 | 87.35 | 1445 | 6/1/1947 | Synoptic | 2009 |
| 12 | 1311 | Dharanbazar | 26.82 | 87.28 | 444 | 6/1/1947 | Climatology | 2009 |
| 13 | 1314 | Terhathum | 27.13 | 87.55 | 1633 | 5/1/1966 | Climatology | 2009 |
| 14 | 1319 | BiratnagarAP | 26.48 | 87.27 | 72 | 7/1/1968 | Agrometeorology | 2009 |
| 15 | 1320 | Tarahara | 26.70 | 87.27 | 200 | 7/1/1968 | Agrometeorology | 2009 |
| 16 | 1405 | Taplejung | 27.35 | 87.67 | 1732 | 7/1/1947 | Synoptic | 2009 |
| 17 | 1419 | Phidim | 27.15 | 87.75 | 1205 | 7/1/1978 | Climatology | 2009 |

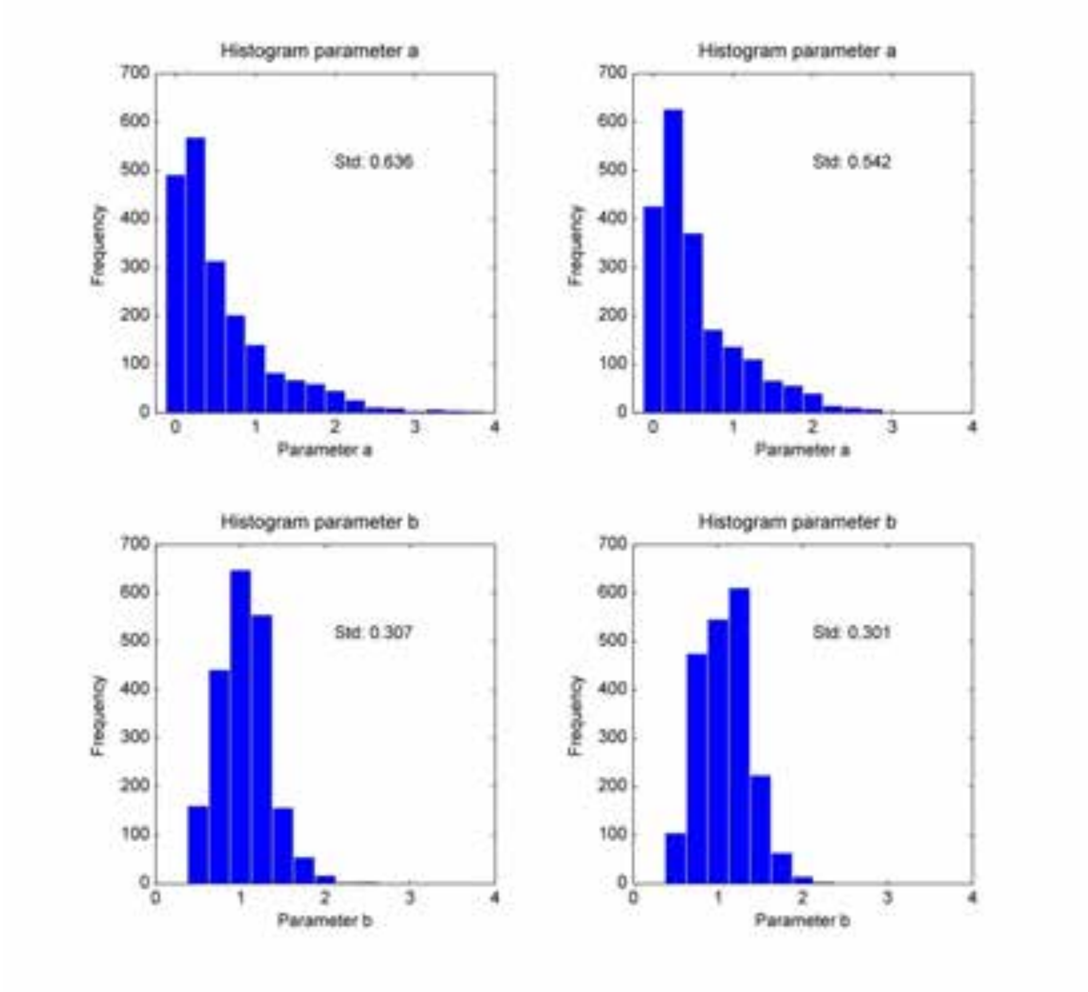
# Appendix B: Available Flow Data

| SN | Station INDEX | RIVER | LOCATION | Longitude | | | Latitude | | | Elevation (m) | Drainage Area (sq.km.) | Data available * |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | ° | ′ | ″ | ° | ′ | ″ | | | |
| 1 | 600.1 | Arun | Uwa Gaon | 87 | 20 | 22 | 27 | 35 | 21 | 1294 | 26750 | 1985-2008 |
| 2 | 602 | Sabhaya Khola | Tumlingtar | 87 | 12 | 45 | 27 | 18 | 36 | 305 | 375 | 1974-2008 |
| 3 | 602.5 | Hinwa Khola | Pipletar | 87 | 13 | 30 | 27 | 17 | 45 | 300 | 110 | 1974-2008 |
| 4 | 604.5 | Arun | Turkeghat | 87 | 11 | 30 | 27 | 20 | 0 | 414 | 28200 | 1975-2008 |
| 5 | 606.0 | Arun | Simle | 87 | 9 | 16 | 26 | 55 | 42 | 152 | 30380 | 1986-2008 |
| 6 | 610 | Bhote Kosi | Barabise | 85 | 53 | 55 | 27 | 47 | 18 | 840 | 2410 | 1965-2008 |
| 7 | 620.0 | Balephi Khola | Jalbire | 85 | 46 | 10 | 27 | 48 | 20 | 793 | 629 | 1964-2008 |
| 8 | 627.5 | Melamchi Khola | Helambu | 85 | 32 | 7 | 28 | 2 | 21 | 2134 | 84 | 1990-2008 |
| 9 | 630 | Sun Kosi | Pachuwar Ghat | 85 | 45 | 10 | 27 | 33 | 30 | 602 | 4920 | 1964-2008 |
| 10 | 640 | Rosi K. | Panauti | 85 | 30 | 50 | 27 | 34 | 50 | 1480 | 87 | 1964-1987 |
| 11 | 647 | Tamakosi | Busti | 86 | 5 | 12 | 27 | 38 | 5 | 849 | 2753 | 1971-2008 |
| 12 | 650 | Khimti Khola | Rasnalu Village | 86 | 11 | 50 | 27 | 34 | 30 | 1120 | 313 | 1964-2008 |
| 13 | 652 | Sunkosi | Khurkot | 86 | 0 | 1 | 27 | 20 | 11 | 455 | 10000 | 1968-2008 |
| 14 | 660 | Likhu Khola | Sangutar | 86 | 13 | 10 | 27 | 20 | 10 | 543 | 823 | 1964-2008 |
| 15 | 668.4 | Taktor Khola | Beni | 86 | 33 | 28 | 27 | 33 | 46 | 2400 | 73 | 1986-1991 |
| 16 | 668.5 | Solu Khola | Salme | 86 | 34 | 52 | 27 | 30 | 3 | 1800 | 246 | 1987-2008 |
| 17 | 670 | Dudh Kosi | Rabuwa Bazar | 86 | 40 | 2 | 27 | 16 | 14 | 460 | 4100 | 1964-2008 |
| 18 | 680 | Sunkosi | Kampughat | 86 | 49 | 10 | 26 | 52 | 28 | 200 | 17600 | 1966-1985 |
| 19 | 681 | Sun Kosi | Hampuachuwar | 87 | 8 | 45 | 26 | 55 | 15 | 150 | 18700 | 1991-2008 |
| 20 | 684 | Tamur | Majhitar | 87 | 42 | 45 | 27 | 9 | 30 | 533 | 4050 | 1996-2008 |
| 21 | 690 | Tamur | Mulghat | 87 | 19 | 45 | 26 | 55 | 30 | 276 | 5640 | 1965-2008 |
| 22 | 695 | Saptakosi | Chatara | 87 | 9 | 30 | 26 | 52 | 0 | 140 | 54100 | 1977-2008 |

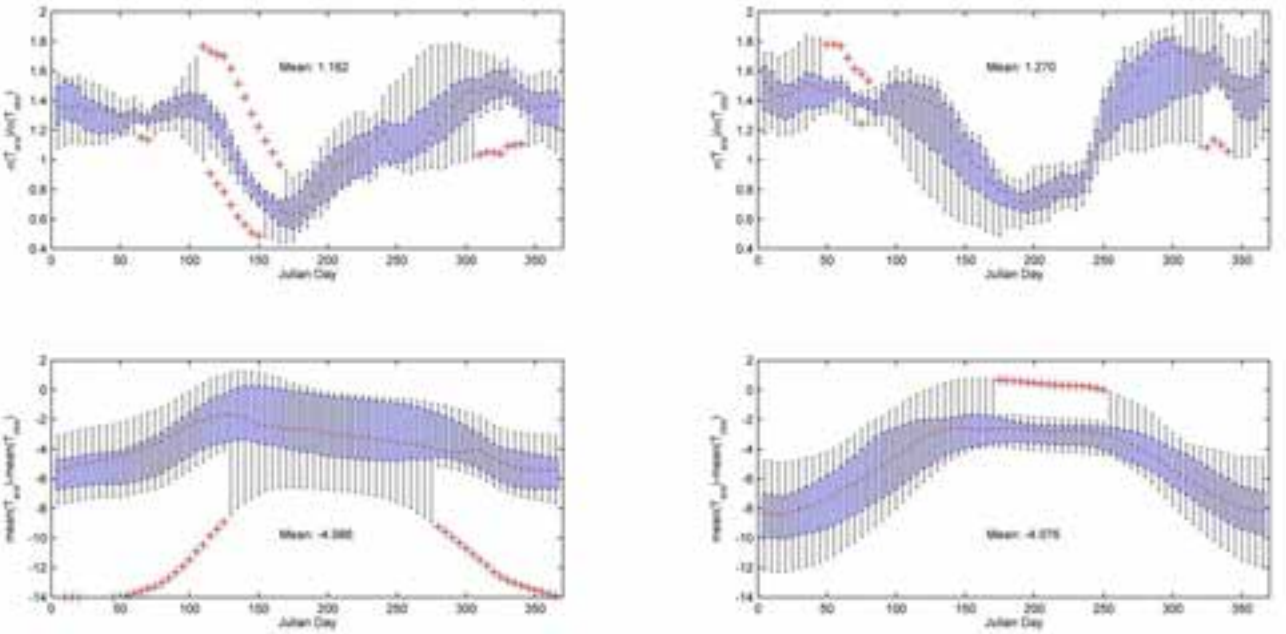
* Data type = Mean Daily Discharge and Instantaneous discharge (Max and Min) in cumecs

# Appendix C: Application of Regional Climate Model data for Koshi River Basin

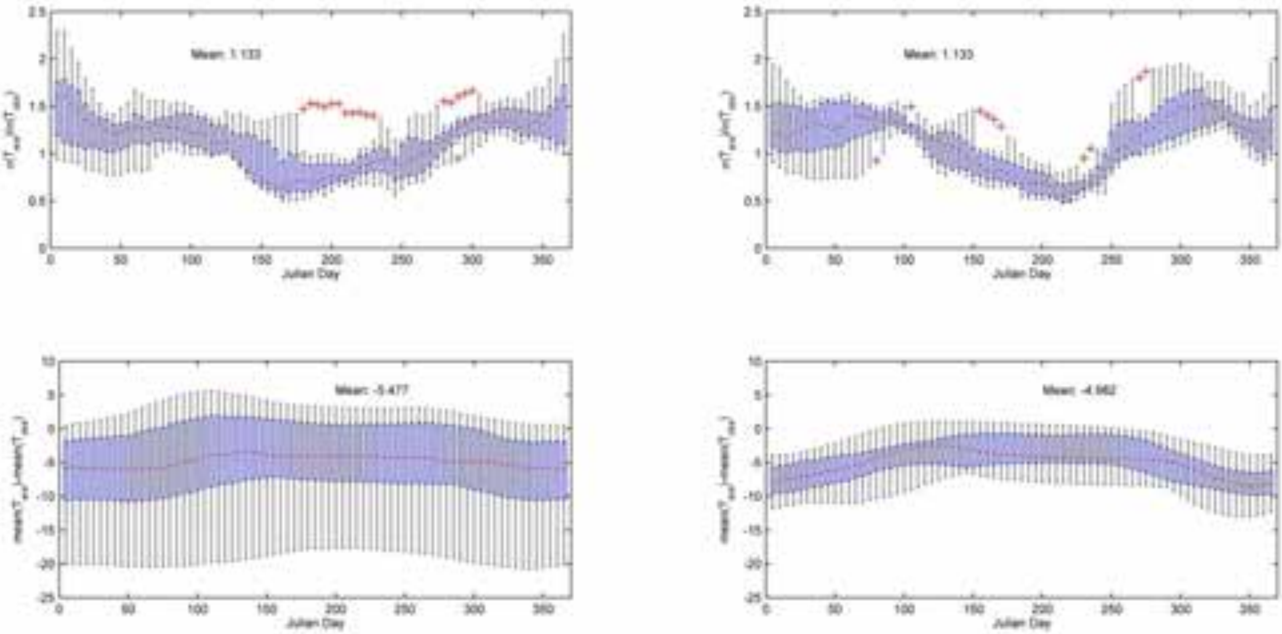
## Appendix C-1: Histograms with corresponding standard deviation of parameters a and b for the SRM model area (Left – ECHAM05, Right – HadCM3)



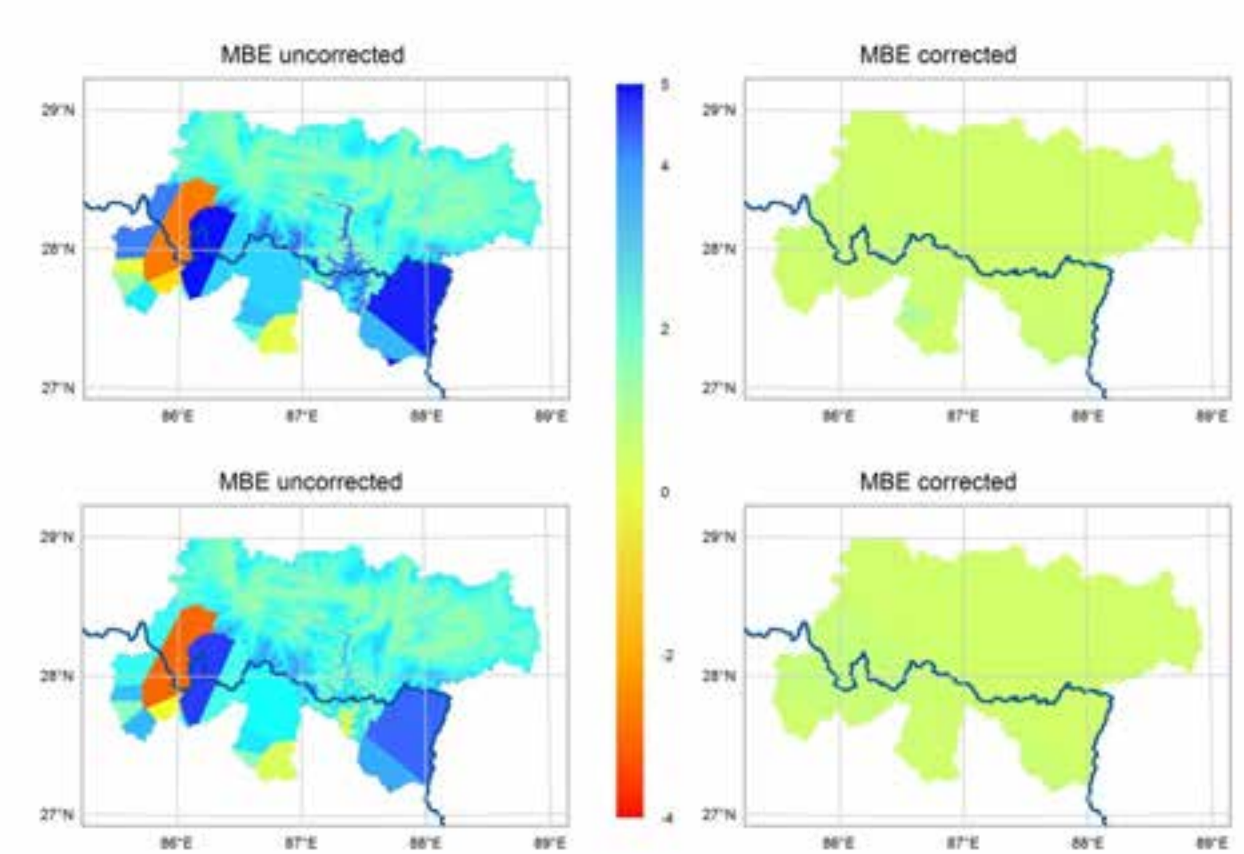
**Appendix C-2: Top: Boxplot for the ratios of the RCM data standard deviations over the observed standard deviations. Bottom: Boxplot for the differences between the RCM data average minimum temperatures and observed average minimum temperatures (SWAT model area; Left – ECHAM05, Right – HadCM3)**



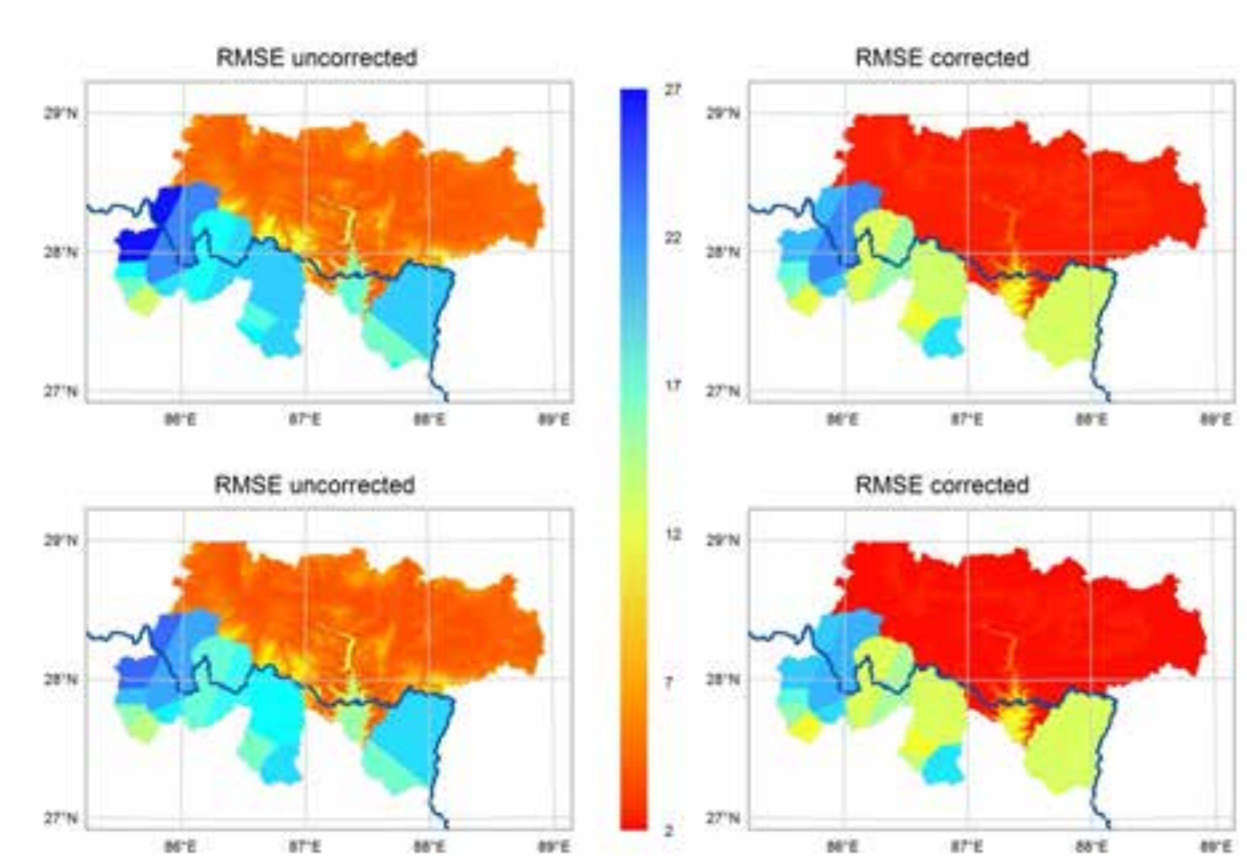
## Appendix C-3: Top: Boxplot for the ratios of the RCM data standard deviations over the observed standard deviations. Bottom: Boxplot for the differences between the RCM data average temperatures and observed average temperatures (SRM model area; Left – ECHAM05, Right – HadCM3)



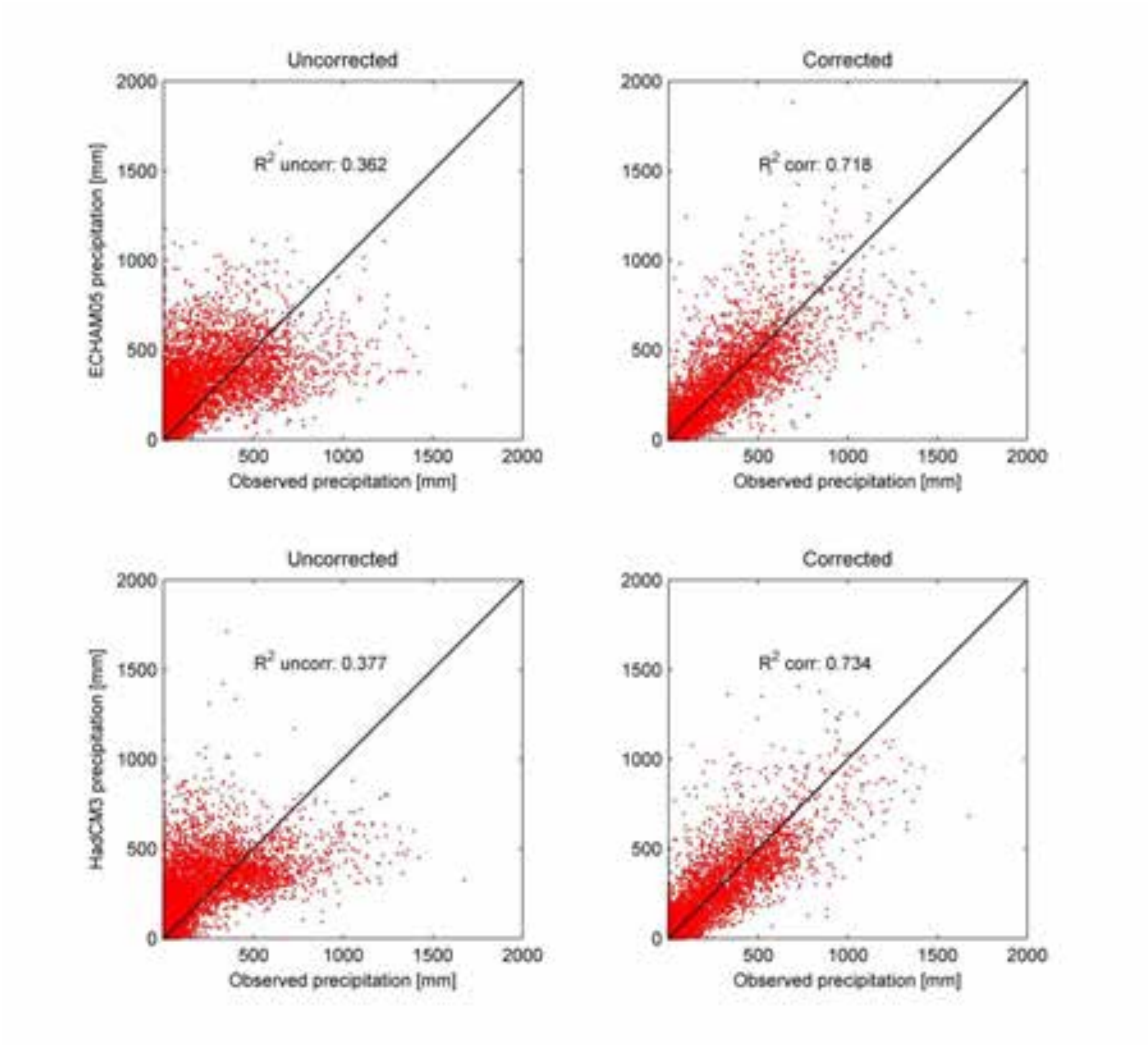
## Appendix C-4: MBE for the uncorrected and corrected RCM precipitation [mm] per sub-basin of the SRM model area for the period 1976-2000 (Top – ECHAM05, Bottom – HadCM3)



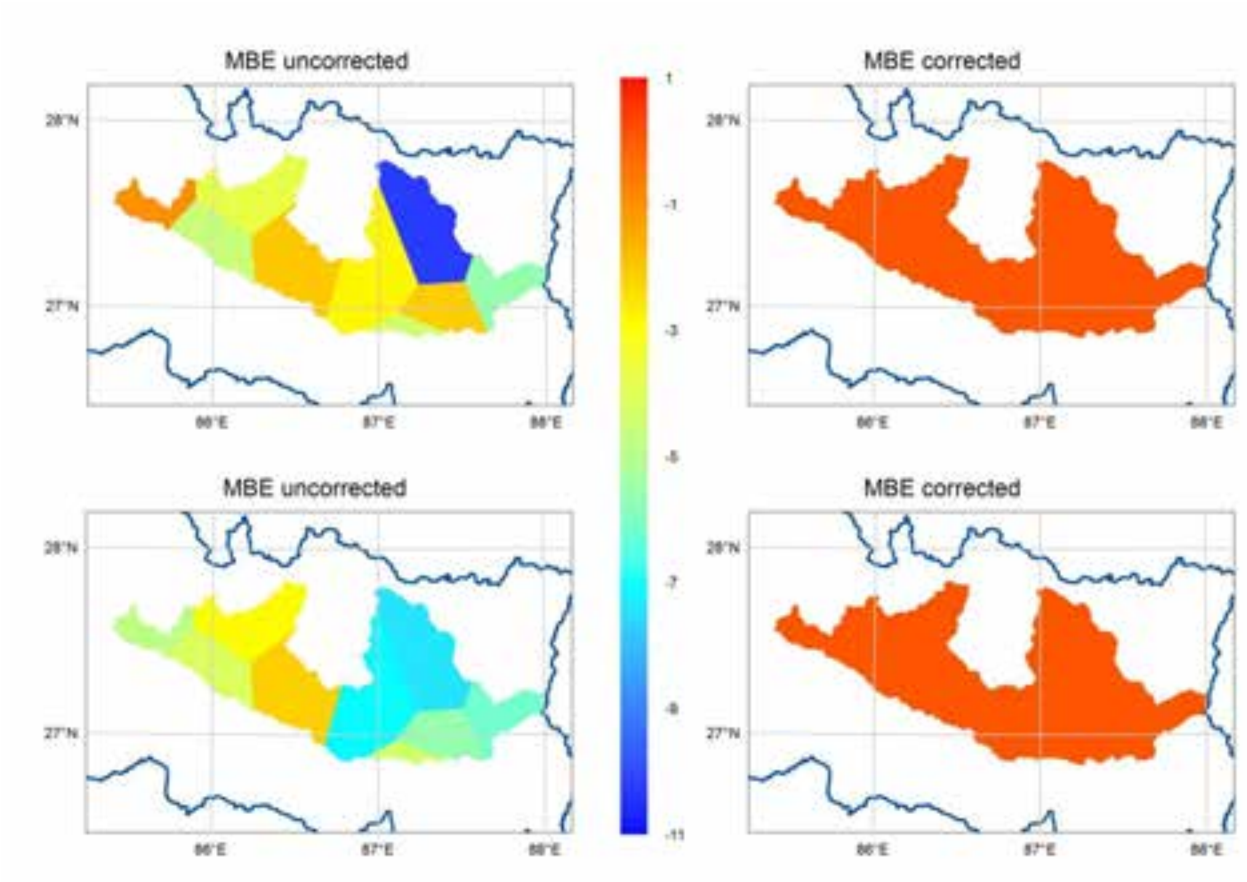
**Appendix C-5: RMSE for the uncorrected and corrected RCM precipitation [mm] per sub-basin of the SRM model area for the period 1976-2000 (Top – ECHAM05, Bottom – HadCM3)**



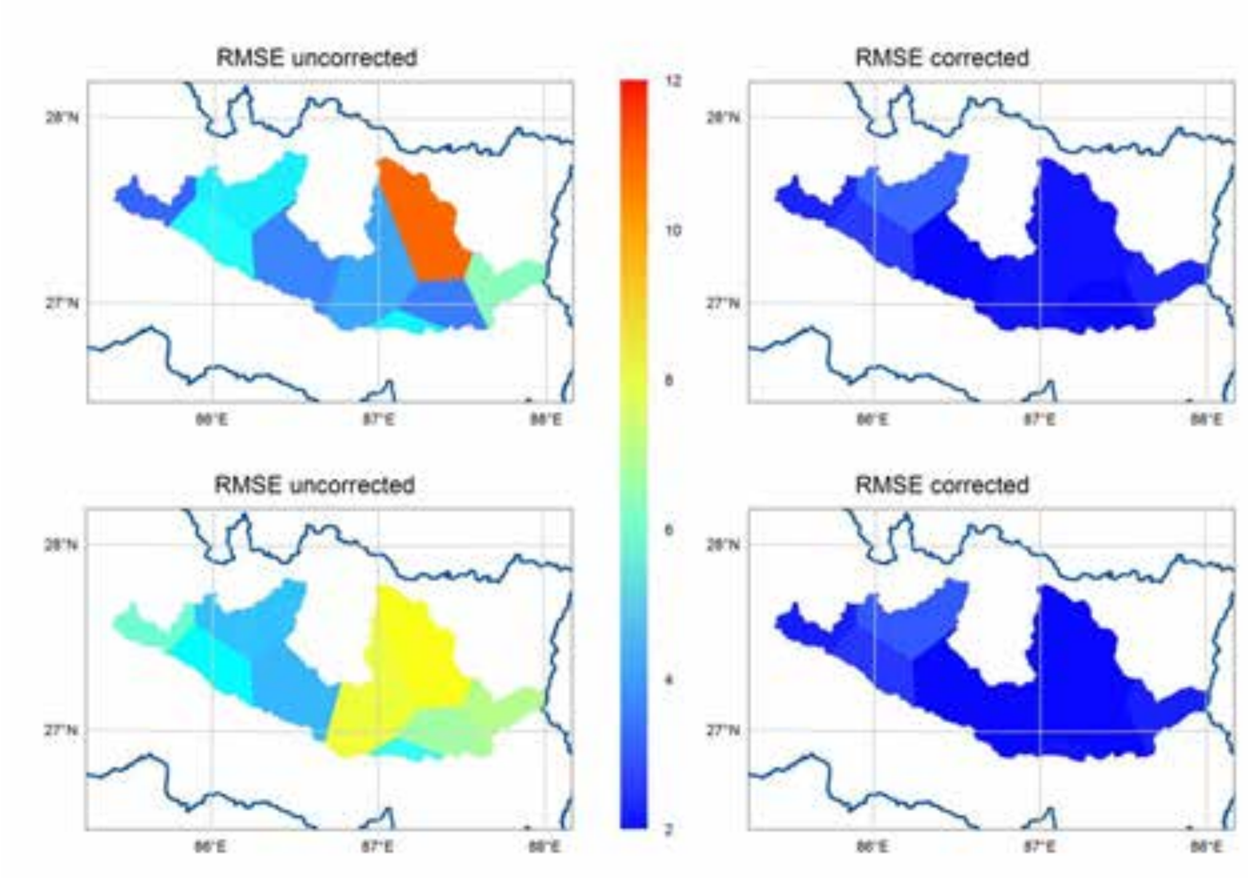
## Appendix C-6: Scatter plots for the uncorrected and corrected RCM data and observed monthly precipitation sums for each year per sub-basin for the SRM model area (Top – ECHAM05, Bottom – HadCM3)



## Appendix C-7: MBE for the uncorrected and corrected RCM minimum temperature [0C] per sub-basin of the SWAT model area for the period 1976-2000 (Top – ECHAM05, Bottom – HadCM3)



## Appendix C-8: RMSE for the uncorrected and corrected RCM minimum temperature [0C] per sub-basin of the SWAT model area for the period 1976-2000 (Top – ECHAM05, Bottom – HadCM3)



# Appendix D: List of Definitions

### Adaptation

The adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities

### Capacity

The combination of all the strengths, attributes and resources available within a community, society or organization that can be used to achieve agreed goals

### Capacity development

The process by which people, organizations and society systematically stimulate and develop their capacities over time to achieve social and economic goals, including through improvement of knowledge, skills, systems, and institutions.

### Climate change

(a) The Inter-governmental Panel on Climate Change (IPCC) defines climate change as: “a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use”.

(b) The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods”.

### Coping capacity

The ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters.

### Disaster

A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources.

### Disaster risk

The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period.

### Disaster risk management

The systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster.

**Disaster risk reduction**

The concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events.

**Disaster risk reduction plan**

A document prepared by an authority, sector, organization or enterprise that sets out goals and specific objectives for reducing disaster risks together with related actions to accomplish these objectives.

**Early warning system**

The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss.

**Emergency management**

The organization and management of resources and responsibilities for addressing all aspects of emergencies, in particular preparedness, response and initial recovery steps.

**Environmental degradation**

The reduction of the capacity of the environment to meet social and ecological objectives and needs.

**Environmental impact assessment**

Process by which the environmental consequences of a proposed project or programme are evaluated, undertaken as an integral part of planning and decision-making processes with a view to limiting or reducing the adverse impacts of the project or programme.

**Exposure**

People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.

**Forecast**

Definite statement or statistical estimate of the likely occurrence of a future event or conditions for a specific area.

**Greenhouse gases**

Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation of thermal infrared radiation emitted by the Earth’s surface, the atmosphere itself, and by clouds.

**Hazard**

A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

**Hydrometeorological hazard**

Process or phenomenon of atmospheric, hydrological or oceanographic nature that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

**Land-use planning**

The process undertaken by public authorities to identify, evaluate and decide on different options for the use of land, including consideration of long term economic, social and environmental objectives and the implications for different communities and interest groups, and the subsequent formulation and promulgation of plans that describe the permitted or acceptable uses.

**Mitigation**

The lessening or limitation of the adverse impacts of hazards and related disasters.

**Natural hazard**

Natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

**Preparedness**

The knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions.

**Prevention**

The outright avoidance of adverse impacts of hazards and related disasters.

**Prospective disaster risk management**

Management activities that address and seek to avoid the development of new or increased disaster risks.

**Public awareness**

The extent of common knowledge about disaster risks, the factors that lead to disasters and the actions that can be taken individually and collectively to reduce exposure and vulnerability to hazards.

**Recovery**

The restoration, and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors.

**Residual risk**

The risk that remains in unmanaged form, even when effective disaster risk reduction measures are in place, and for which emergency response and recovery capacities must be maintained.

**Resilience**

The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

**Response**

The provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected.

**Retrofitting**

Reinforcement or upgrading of existing structures to become more resistant and resilient to the damaging effects of hazards

**Risk**

The combination of the probability of an event and its negative consequences

**Risk assessment**

A methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend.

**Risk management**

The systematic approach and practice of managing uncertainty to minimize potential harm and loss

**Risk transfer**

The process of formally or informally shifting the financial consequences of particular risks from one party to another whereby a household, community, enterprise or state authority will obtain resources from the other party after a disaster occurs, in exchange for ongoing or compensatory social or financial benefits provided to that other party.

**Socio-natural hazard**

The phenomenon of increased occurrence of certain geophysical and hydrometeorological hazard events, such as landslides, flooding, land subsidence and drought, that arise from the interaction of natural hazards with overexploited or degraded land and environmental resources.

**Structural and non-structural measures**

Structural measures: Any physical construction to reduce or avoid possible impacts of hazards, or application of engineering techniques to achieve hazard-resistance and resilience in structures or systems;

Non-structural measures: Any measure not involving physical construction that uses knowledge, practice or agreement to reduce risks and impacts, in particular through policies and laws, public awareness raising, training and education.

**Sustainable development**

Development that meets the needs of the present without compromising the ability of future generations to meet their own needs

**Vulnerability**

The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard

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**Cover Plate:**

Proposed Koshi High Dam Site at Chatara / Koshi Barrage

Locals fishing for livelihood

Household survey for vulnerability assessment / Adaptive farming on the flooded area

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