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Changing Climatic Parameters and its Possible Impacts in Hydropower Generation in Nepal (A Case Study on Gandaki River Basin)

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Abstract: The analysis of water resources in Nepal identifies two critical impacts of climate change –GLOFs and variability of river runoff – both of which pose significant impacts not only to hydropower, but also to rural livelihoods and agriculture. Temperature differences are most pronounced during the dry winter season, and least during the height of the monsoon. Impacts on water resources and hydropower rank significantly higher than any other sector for several reasons. First, a number of impacts on water resources and hydropower are directly related to rising temperatures that have already been observed, and are projected to increase further over the coming decades. This includes glacier retreat that in turn causes both greater variability in stream flow and glacial lake outburst floods that pose significant risk to hydropower facilities, other infrastructure, and human settlements. GLOFs are not hypothetical; such events have already had significant impacts in Nepal. In this study over the Gandaki river basin, discharge of the rivers, temperature trends, and rainfall patterns are analyzed using data from meteorological stations of the Department of Hydrology and Meteorology (DHM), Government of Nepal. Similarly the hydrological stations over the major glacier rivers of the basin are examined. In the study area, some hydropower stations and their energy production fluctuations over the seasons reflect the climate change impact to the hydro energy production in Nepal.

Keywords: Climate change, GLOF, hydropower, DHM

1. Introduction

Nepal contains 8 of the 10 highest mountain peaks in the world, including Mount Everest (8850 m), although some of its low lying areas are only about 80m above sea level. Therefor, there is extreme spatial climate variation in Nepal – from a tropical to arctic climate within a span of only about 200 kilometers. Nepal is divided into five geographic regions: Terai plan, Siwalik hills, Middle Mountains, High Mountains (consisting of the Main Himalayas and the Inner Himalayan Valleys), and the High Himalayas.

Nepal has three categories of rivers. The largest river systems-from east to west: *Koshi, Gandaki/Narayani, Karnali/Goghra,* and *Mahakali* all originate in or beyond the high Himalaya and maintain substantial flows from glacial melt through the hot, droughty spring before the summer monsoon. These largest rivers cross the mountains in deep gorges before emerging onto the plains. Koshi is also called Sapta Koshi for its seven Himalayan tributaries: Indrawati, Bhote Koshi, Tama Koshi, Dudh Koshi, Liku*, Arun,* and Tamor. The Arun rises about 150 kilometers inside Tibet. The ***Gandaki/Narayani*** also has seven Himalayan tributaries: *Daraudi*, *Seti Gandaki*, *Madi, Kali gandaki*, *Marsyandi, Budhi Gandaki*, and *Trisuli* also called *Sapta Gandaki*. The *Kali Gandaki* flows between the 8,000 meter *Dhaulagiri* and *Annapurna* ranges in the world's deepest valley. After the seven upper tributaries have joined, the river becomes the *Narayani* inside Nepal; however, it is called the *Gandak* in India.

The Himalaya encompasses the world's third largest glacier systems after Antarctica and Greenland, occupying about 15% of the mountain terrain (Anthwal et al., 2006). The Himalayan range extends from 26 to 41°N in latitude (about 1,700 km) and from 70 to 105°E in longitude (about 3,200 km). The Himalayas lie in the sub-tropical high-pressure belt, where the climate is controlled by the Asian monsoon system, with summer precipitation exceeding winter precipitation (Tartari et al., 1998). Nepalese Himalayas, with altitudes above 3,000m, make up 27% of the country's total area with 5% above 5,000 m, including the highest peak of the world, Mt. Everest (8,850 m), and the world's deepest gorge, 5,791m in the *Kali Gandaki* valley. Out of the 14 eight thousand meter and higher peaks in the world, Nepal Himalayas host eight, namely: *Sagarmatha1, Kanchunjunga, Lhotse, Makalu, Dhaulagiri, Manaslu, Cho-Oyu, and Annapurna-I.* The Himalaya region abounds in glaciers. Nepal Himalayas contain 3,252 glaciers and 2,315 glacier lakes of various sizes above 3,500m, covering an area of 5,323 km^2 with an estimated ice reserve of 481 km^3 (Thomas and Rai, 2005). The area covered by glaciers and estimated ice reserves in the basin of three major river systems in the country are shown in Table 1.

Table 1: Glaciers and Lakes in the Basin Area of Three Major River Systems in Nepal

River System	Basin area, km^2	No. of Lakes	No. of glacier	Area covered by glaciers, km^2	Estimated ice reserves, km^3
Koshi	54100	1062	779	1409.84	152.06
Gandaki	**31100**	**338**	**1025**	**2030.15**	**191.39**
Karnali	42890	907	1361	1740.22	127.72

Source: Mool, 2001a; Bajracharya et al., 2002; Thomas and Rai, 2005

2. Objectives

The main objective of this research is to identify the possible impacts of the climate change and glacier melting on hydropower generation in Nepal. Some of the specific objectives are as follows:

- Collect and compute hydrological and meteorological data for the Gandaki basain.
- Collect and compute the hydrological and energy production data from the major hydropower stations in the study area.
- Study climate change related research and correlate to the study.
- Correlate the data in an overall energy perspective.
- Recommend possible threats/advantages/disadvantages to the hydropower industry.
- Suggest various energy planning measures.

3. Methodology

In the Gandaki basin, secondary meteorological and hydrological data from the DHM was mathematically modeled, graphed, plotted, and analyzed along with the data from the six stations for hydrological data measurement, i.e., Kali Gandaki-Andhi ghat station (30 years), Seti-Damauli Station (7 years), Madhi-Sisaghat Station (32 years), Marsangdhi-Bimal Nagar station (20 years), Budhi Gandaki-Arughat Station (43 years), Trishuli,Betrabati Sataion (30 years). The daily discharge recorded at these stations is the raw data used to analyze the flow patterns of these rivers. For the snow or glacier stations there is only one station in Langtang. Hence the available data for Langtang is also collected from the DHM and used for research.

For the meteorological data of temperature and rainfall, 21 year DHM data is analyzed in the study and we have taken information from seven stations around the Gandaki River basin: Baglung station at Baglung, Chame station at Manang, Khudi Bazar station at Lamjung, Kusma Station at Parbat, Lumle Station at Kaski, and Langtang Station at Rasuwa. Temperature forecasting has been done using the linear regression up to 2030.

Analysis of the previous reports done by experts, scientists, personnel from nongovernmental organizations (NGOs), international nongovernmental organizations (INGOs), and university students are taken into account. The International Centre for Integrated Mountain Development (ICIMOD) is an independent 'Mountain Learning and Knowledge Centre' serving the global community and the eight countries of the Hindu Kush-Himalayas, i.e., Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan. Founded in 1983, ICIMOD is based in Kathmandu, Nepal. It has previously performed significant research in the Himalayan region. The research in our study area (Gandaki basin) has been thoroughly reviewed to relate such valuable previous findings to energy production and vulnerabilities.

Data and reports from the Nepal Electricity Authority (NEA) and the power scenario of the study area are considered and analyzed along with the computed results.

4. Limitations

There are very few meteorological stations in high altitudes. Only six hydrological stations are available for the analysis, hence the result has been inferred from considering these limited stations. Long term temperature, precipitation, and river flow data were available only at the lower levels. Thus, the trends of weather parameters at lower and higher altitudes for the longer period might not be the same. Furthermore, the other weather parameters, such as solar radiation, wind speed, atmospheric pressure, and evaporation and transpiration data were not analyzed due to study limitations and unavailability of relevant data. The is also a lack of glacier data, hence the exact mass balance of the glacier has not been identified.

5. Results and Discussions

Rivers and their Discharge Characteristics

The Gandaki River (also known as the Narayani in southern Nepal and the Gandak in India) is one of the major rivers of Nepal and a left bank tributary of the Ganges in India. In Nepal, the river is known for its deep gorge through the Himalaya and its enormous hydroelectric potential. It has a total catchment area of 46,300 km^2, most of it in Nepal. The Kali Gandaki River originates in Nepal near Tibet, flows southward through the Mustang Basin, crosses the Himalayas in a gorge, and descends to the lowlands of Nepal. Extremely strong diurnal upvalley flow in the gorge and the basin alternates with rather weak drainage flow in the night. The Seti River is a river running down from the Himalaya range in the north-west. It is one of the major tributaries of the Karnali River in Nepal. Among perennial rivers situated in Lamjung, e.g., Midim, Dordi, Khudi, Ngadi; Marshyangdi river is the biggest one and is a major contributor to the Narayani basin. The Marshyangdi river rises on the northern slopes of the Annapurna Himal, flows east through an arid valley around Manang, and then swings south to join the Trisuli river at Mugling. Budhi Gandaki rises wholly in Nepal and drains the Eastern slopes of Manaslu and the Ganesh Himal before flowing south through a steep-sided valley to join the Trisuli River upstream of Mugling.

Kali Gandaki River

Analysis of the available data from 1996 to 2006 shows the average minimum flow is 69.20 m^3/s in March 2006 and the maximum flow is 2420 m^3/s in August 2008. Hence the mean flow fluctuations 1996 to 2006 were 34.97 times. Analyzing the yearly mean flow, 1998 was the maximum with a mean average flow of 568.43 m^3/s and 2006 was the minimum with 297.28 m^3/s

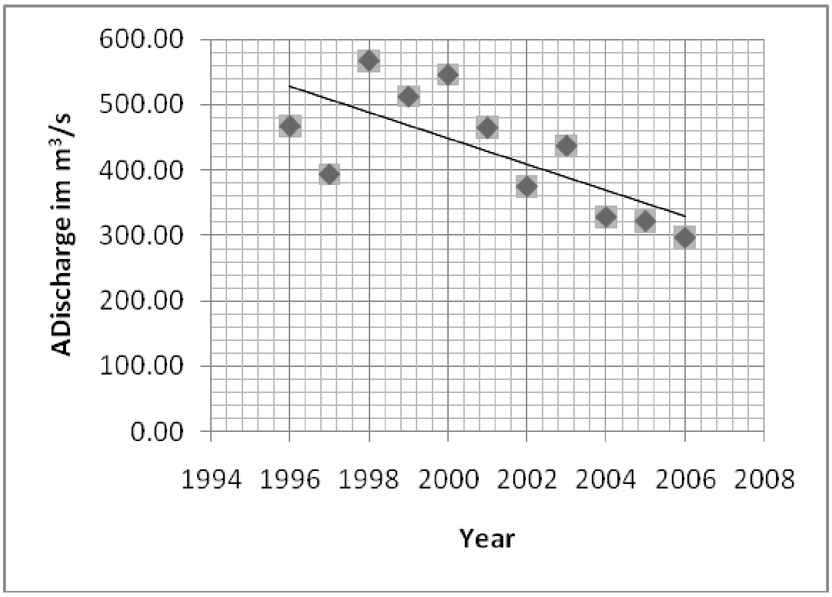

Figure 4.1: Annual average discharge of the Kaligandaki River at Ansigh Andhi Ghat station

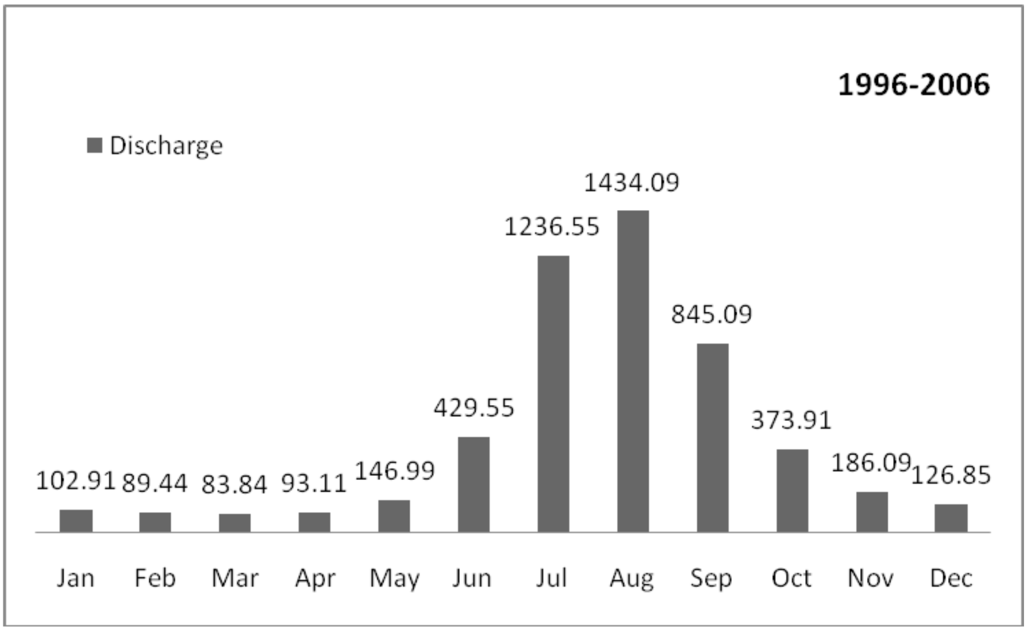

Figure 4.2: Monthly average discharge of the Kaligandaki River (1996-2006)

The monthly average data of Kaligandaki river flow shows that the increase in flow gradually starts from June to August and then decreases gradually, with the minimun flow in the March and April. Additionally, the analysis of availabe data on annual average flow shows a decrease of 19.82m^3/s per year.

Seti River

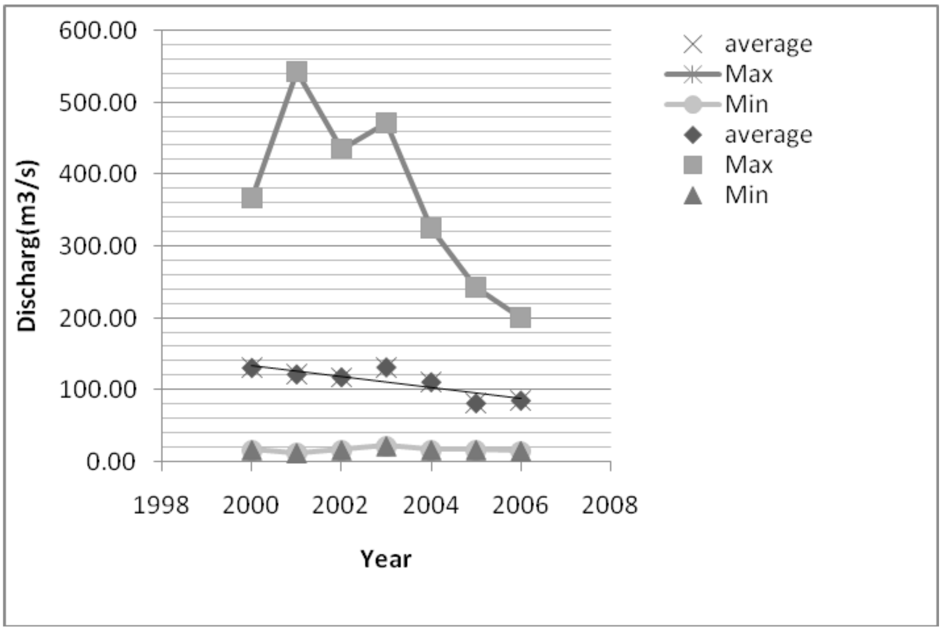

Figure 4.3: Annual average discharge of the Seti River at Damauli station

The average minimum flow was 13 m^3/s in April 2001 and the maximum flow was 543 m^3/s in August 2001. Hence the mean flow fluctuations during 2001 were 41.77 times during the period of 2000 to 2006. Also, the annual average flow of the Seti river has been found to be decreasing by 7.9 m^3/s annually.

Madhi River

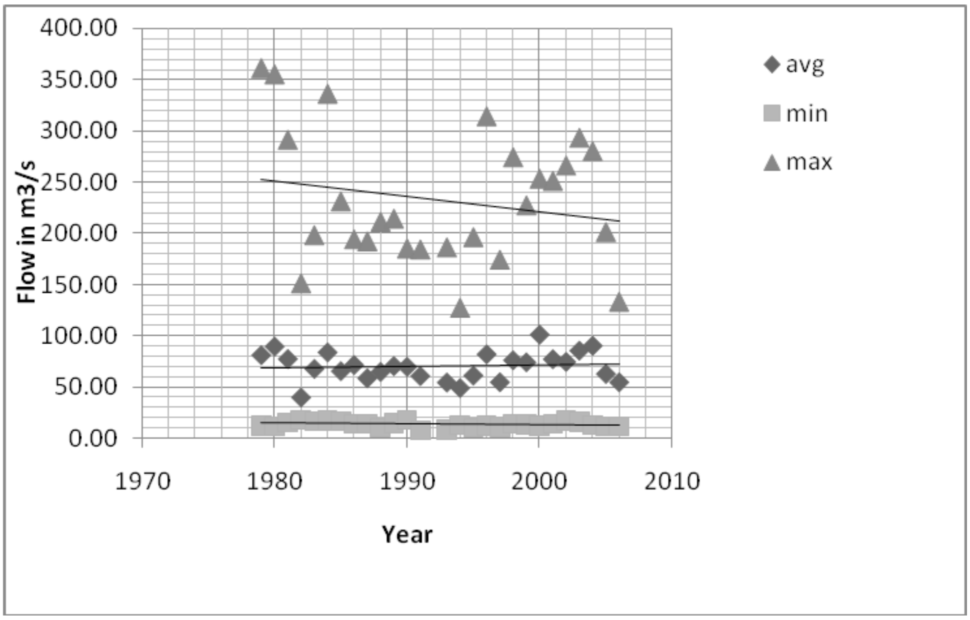

Figure 4.4: Average annula discharge of Madhi River (1979-2006)

From analysis of the Madhi river(1979-2006), annual flow has been found to be increasing by 0.149 annually. In 1979 the average flow was at a maximum and in 2006 the flow was at a minimum (133m^3/s). If we analysis the maximun and minum fluctuations then on the average cycle about four year the maximun and flow has been found to be repeated. The maximun flow of the Madhi river is in August, after which it gradually decreases and the minimum flow occurrs during February and March.

Marshyangdi River

Analyzing the monthly mean of the Marshyangdhi River, the flow has been found to be slightly increased by 0.3149, but examining the dry season flow (November to April) reveals that the flow has been remarkably decreasing by 0.338. The flow is minimum during February and March, after which it gradually increases and becomes maximum during July and August.

Budi Gandaki River

Analyzing the monthly mean of the Budi Gandaki River, the flow has increased by 0.5076, but the dry season flow (November to April) shows that the flow has decreased by 0.1627

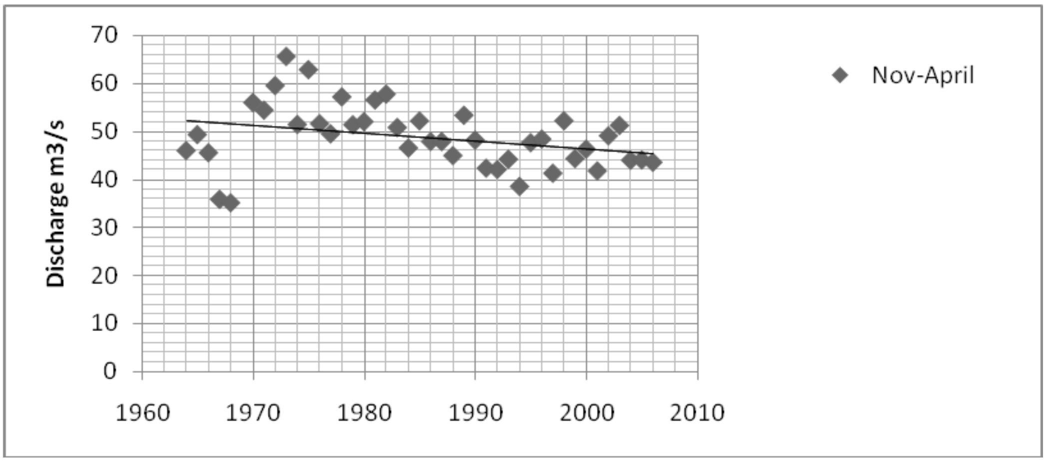

Figure 4.4: Average discharge of the Budigandaki, Arughat station during dry season (Nov – April, 1964-2006)

Trishuli River

The daily discharge data from 1977 to 2006 has been analyzed and a corresponding standard deviation, minimum, and maximum flow has been calculated. The average minimum flow was 36.6m^3/s on March 2001 and the maximum was 904 m^3/sec on July 1990. Hence the mean flow fluctuations during 1977 to 2006 were 26.13 times.

The analysis of monthly mean flow reveals that 2003 was the maximum, having mean average flow of 273.5 m^3/sec and the minimum was in 1985, with 151.43 m^3/s.

With the analysis of the available data on the annual average flow of Trishuli river, it has been found to be increasing by 2.7366 m^3/s per year. However, during the dry season (Nov-April) it has been found to be decreasing by 0.2206 m^3/year.

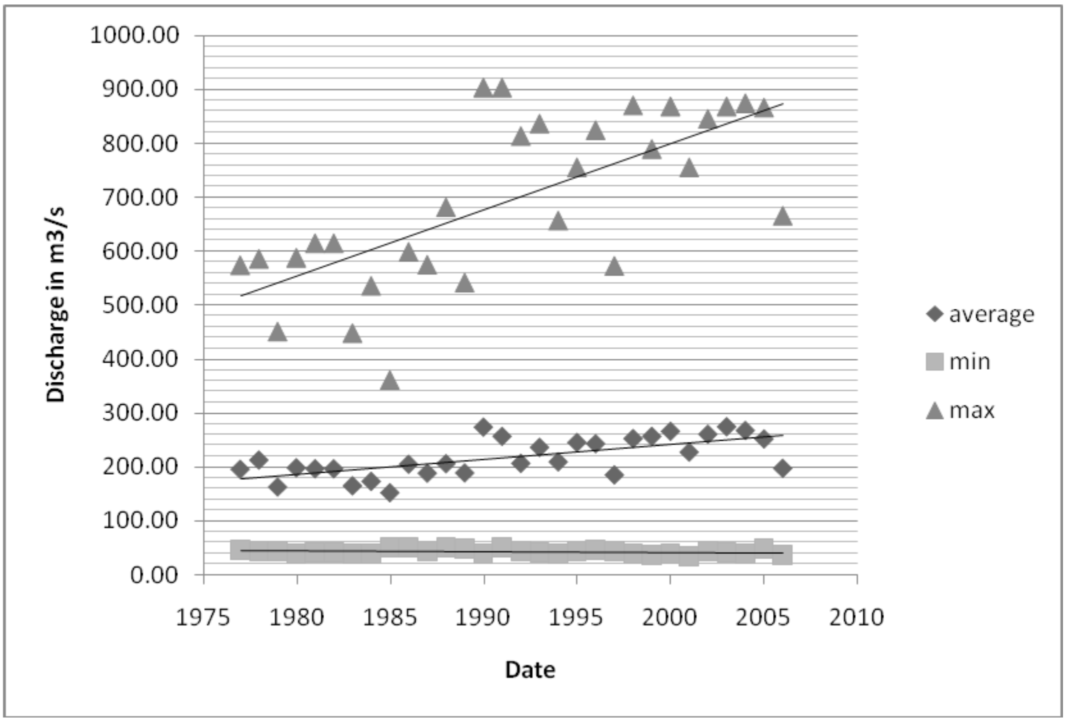

Figure 4.5: Annual average discharge (Trishuli, Betrabati Station) with minimum and maximum flow (1976-2006)

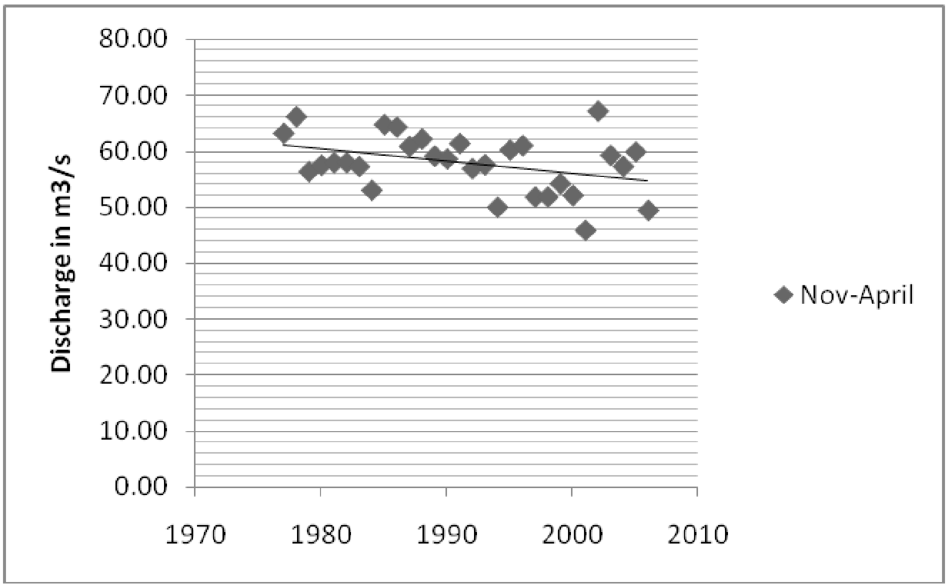

Figure.4.6: Average discharge during the dry season (Nov- April)

Overall, Dry season flow is decreasing at a very slow rate, whereas the wet season flow has been either increasing at higher rate or decreasing in similar pattern. This reflects that the glacier contribution at the dry season is becoming less over time while the rain contribution during the wet season is not uniform.

6. Temperature Analysis at Different Stations

In Nepal, the temperature is reported to be increasing and the impacts of warming have already been observed in the Himalayan glaciers. Annual maximum, minimum, and mean temperature trends are therefore important to study.

At the Baglung station, data from 1987 to 2007 is available. The minimums and maximums are computed seperately. Monthly averages of the daily data are averaged into yearly data. From 2007 onward linear regression has been used to forecast future values. The forcasted maxminum temperature of 2030 is 24.57 ^{0}C and the minimun forcasted temperature is 15.67 ^{0}C. The maximun temperatiure in this station, is decreasing by a rate of 0.1123 while the minimum temperature is increasing by a rate of 0.0228.

At the Chame station, the computation of availabe data from 1987 to 2007 shows an increasing trend in the temperature. The forcasted maxminum temperature of 2030 is 22.88 ^{0}C and the minimun forcasted temperature is 0.94 ^{0}C.

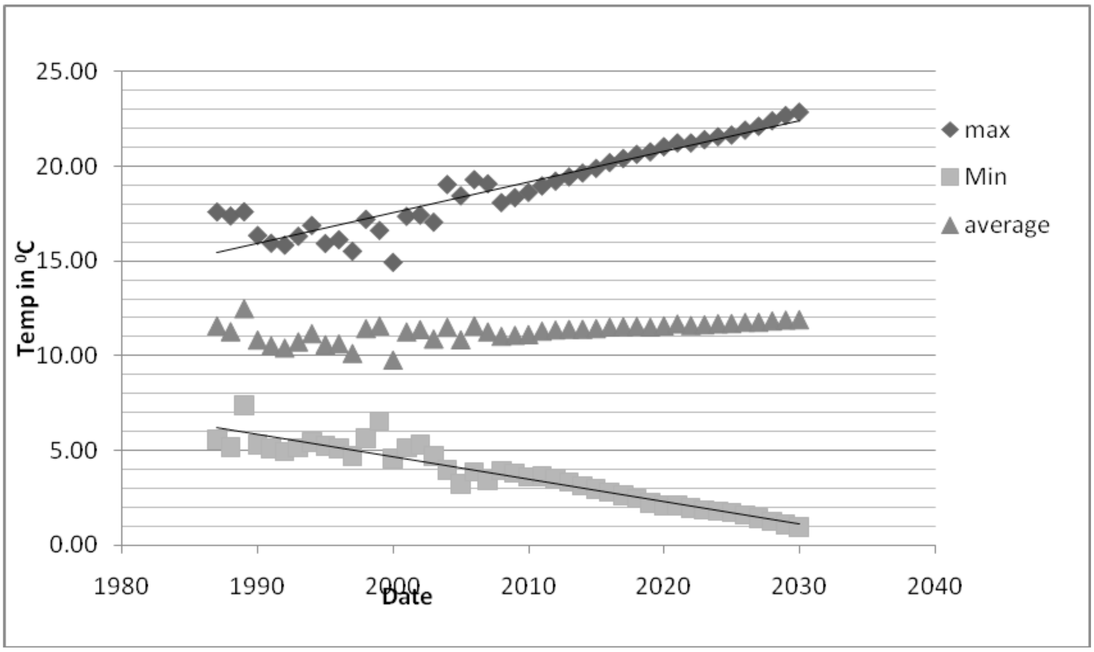

Figure 5.1: Temperature trend of the Chame, Manang

From the analysis, the maximun temperature is increasing by 0.1621 while the minimun tepmperature is decreasing by 0.1182 and the average temperature shows an increasing trend. This is a very serious indiction of increasing temperature, if the forcasted trend continues it will be a serious problem.

At the Khudi Lamjung, The forcasted maxminum temperature in 2030 is 18.06^{0}C and minimun forcasted temperature is 8.18^{0}C. In this case the maximun temperature is decreasing at the rate of 0.11205 while the minimun temperature is increasing by 0.0292. The temperature difference of the minimun and maximun is becoming smaller. Similar conditions have been seen at the Kusma Station, Parbat, but it is quite different at the Lumle station at Kaski which has the mean maximun temperature increasing at rate of 0.1028^{0}C and the minimun mean temperature is only slightly increasing (0.0548^{0}C).

The only high altitude station availabe in the Gandaki Basin is the Langtang station at Rasuwa, where data from 1988 to 2009 is available. From 2009 onward linear regression has been used to forecast future values to see the temperature trend. The forcasted maxminum temperature of 2030 is 12.51^{0}C, the minimun forcasted temperature is 12.18^{0}C, and the forecasted average temp is 1.64 ^{0}C and the average temperature forecasted will be 7.08 ^{0}C

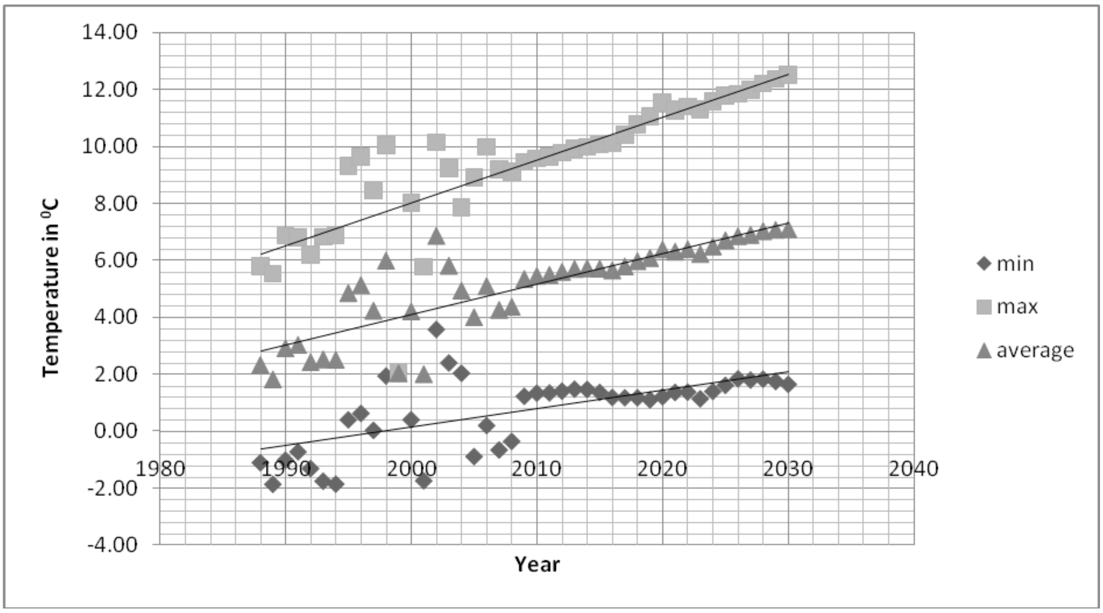

Figure 5.2: Temperature trend of Langtang, Rasuwa

In Langtang both the maximum and minimum temperature are increasing at a similar rate. Maximun temperature is increasing by 0.1489^{0}C and minimum temperature is increasing at a rate of 0.0643^{0}C . Hence we can see that the mean temperature in Langtang is increasing. The warming rate at the higher altitude is most prominent, which indictes that glacier melting is occurring at a higher rate and the glacier mass reserve is becoming less and less.

7. Rain Fall Patterns

The monsoon (rainy season) normally starts in the second week of June and continues until the fourth week of September. Monsoon is the wettest season and is the main source of rainfall in Nepal. Monsoon season contributes an average 79.58% of the total annual rainfall in the country. The large amount of rainfall within a short period causes flash floods, massive landslides, soil erosion and sedimentation in hilly and mountainous regions, and inundation of the plains areas. The study of the rainfall pattern is very important for the hydrological study and climate change impacts on water resources.

Rainfall data at Baglung, Choser at Mustang, Khudi at Lamjung, Kusma-Parbat, Kaski, and Timure at Rasuwa were selected and analyzed, resulting in the identification of a slight shift of the rain fall patterns. Additionally, rain fall in the hilly reasons has been increasing; there is rainfall in the high altitudes of Rasuwa, Jomson, and Manang, which was not common in the past.

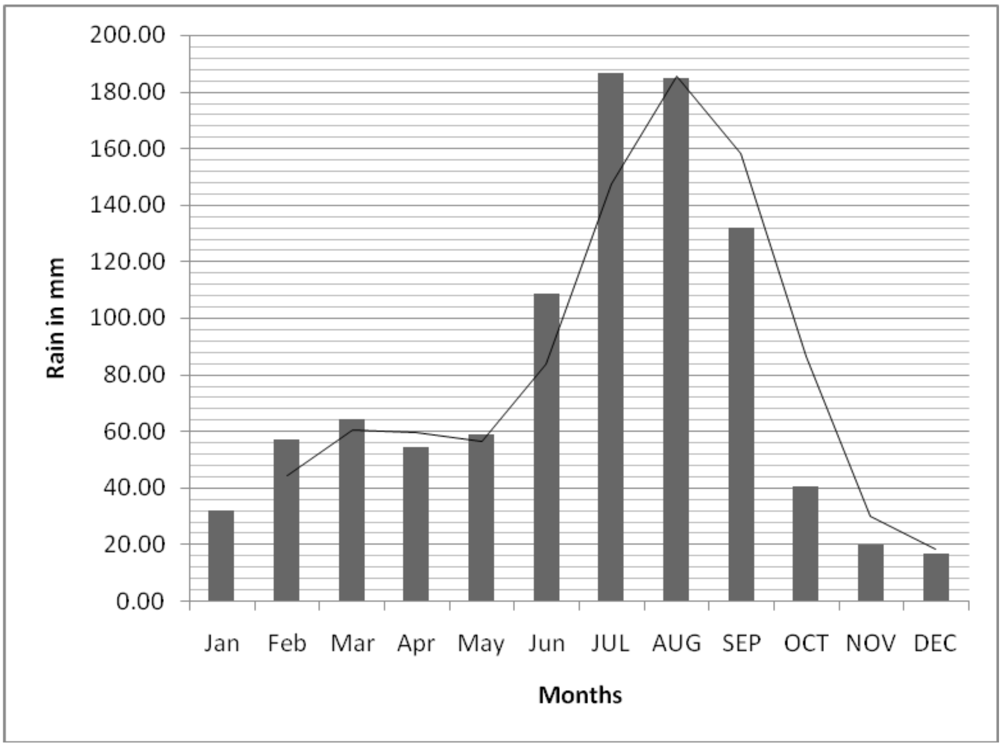

Figure 7.1: Monthly average rainfall pattern at Chame, Manang

8. Impacts in Hydropower Generation

The Gandaki River basin consists of 1,025 glaciers and 338 lakes. The glaciers in the basin cover an area of 2,030.15 km^2 with an estimated ice reserve of 191.39 km^3. Rika Samba Glacier (28°50' N 83°30' E) is the most studied glacier in the Hidden Valley, Kali Gandaki basin. The terminus position was surveyed initially in 1974 (Nakawo et al. 1976) and thereafter intermittently in 1994 (Fujita et al. 1997), 1998 and 1999 (Fujita et al. 2001). According to a study by ICIMOD, Moraine-dammed lake (Gbu_gl 9) in Budhi Gandaki River Sub-basin, Gmar_gl 70 (Thulagi) in Marsyangdi River Sub-basin, and the lakes Gka_gl 38, Gka_gl 41, Gka_gl 42, and Gka_gl 67 in Kali Gandaki River were found to be potentionally dangerous (Mool, P.K. Bajracharya, S.R.; Joshi, et al,2002).

Increasing temperature and shifting rainfall patterns directly affect hydropower generation as most of the rivers in the Gandaki basin are snow feed rivers.

The Chilime hydropower generation is very constant (i.e. variation is in a pattern relative to others) but in other downstream hydropower stations, the production is not so constant (see the Trishuli power production figure) which is due to the flow fluctuations of the river, rain water contribution, and temperature fluctuations.

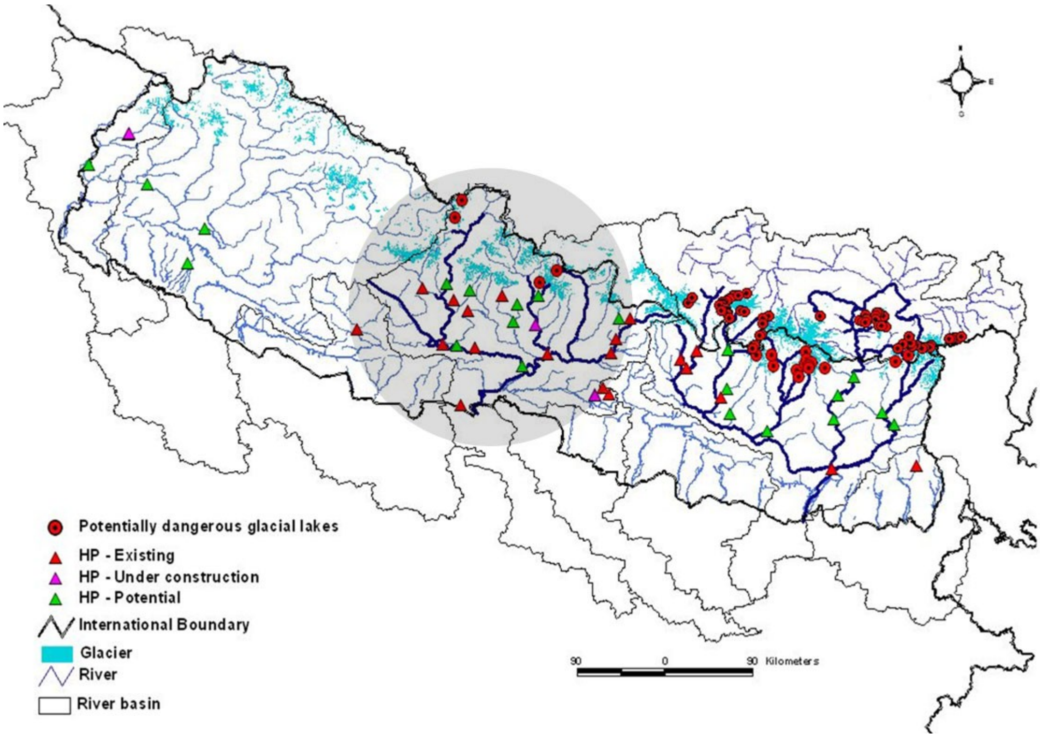

Figure 8.1: Lakes and hydropower stations

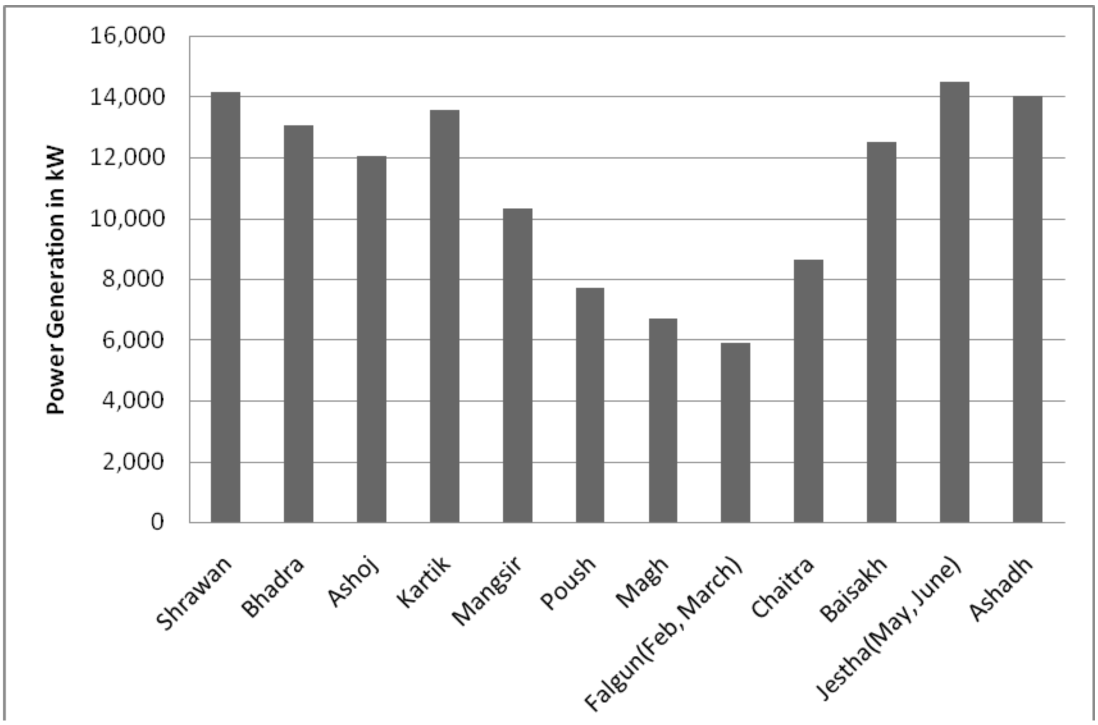

Figure 8.2: Monthly Average of the energy variation (2060 to2066 BS) of Chilime hydropower station

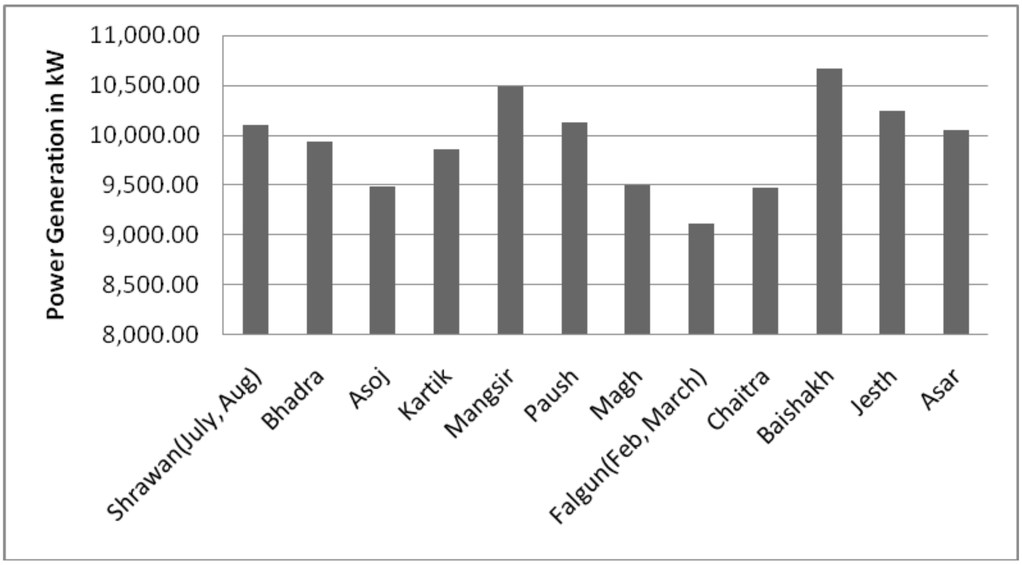

Figure 8.3: Monthly Average of the energy variation (2044 to2066 BS) of Trishuli hydropower station

In particular, greater unreliability of dry season flows poses potentially serious risks to water supplies in the lean season. Hydroelectric plants are highly dependent on predictable runoff patterns. Therefore, increased climate variability, which can affect frequency and intensity of flooding and droughts, could affect Nepal severely in hydroelectric production.

9. Conclusions and Recommendation

One of the major impacts of climate change is the change in hydrology of the rivers resulting in anomalies in hydro resources. Hydro has a significant effect on hydropower development, especially in the dry season. This condition will affect the dependability of flow and assurance in the long run and hence the changing climatic parameters results in an unavoidable factor in the forecasting system of hydropower projects.

Some generalizations are drawn from this study.

- An increasing trend of temperature, hence Glacier melting and formations of glacier lakes in the high Himalaya has increased the vulnerabilities to hydropower stations and hydro energy generation.
- Shift of the rain fall seasons has also increased the hydrological impacts and challenges. Dry season flow in most of the rivers is decreasing and one of the reasons behind this is changing climatic parameters. The implications of climate change are greater in systems that currently are highly stressed, where power generation in dry seasons from run of river plants and water availability may be proportionally smaller than changes in river flows.
- The flow curve of the analyzed period and rivers shows the flow is decreasing, not in a pattern. This will result in the decrease in the full capacity power generation of the plant, which is seen from the power production fluctuations.
- One of the major impacts of climate change is the change in river hydrology. Since the hydrology is changing, the design capacity of corresponding hydropower stations should be revised. In the long run, sufficient water may not be available; water storage in damp should be a good method to control the flow of the river.

The inclusion of impact of climate change or glacier melt on water resource systems has become a necessary aspect for the effective planning and management of the power systems in this country. The following are the recommendations for hydropower projects, government policy makers, and various other concerned agencies for coping with climate change and planing accordingly for the management of the ongoing power crisis.

- Proper data logging and documentation of observed facts are important since such data is lacking in various places. Hydro-power plants are not properly adjusting to the glacier related flow fluctuations although they are directly related with the glacier melting and flow fluctuations.
- Design discharge of the hydropower plants should be revised in accordance with the decrease in river flow fluctuations.
- Damp based hydropower plants are necessary for constant energy production. Damp integration (if possible) with the existing hydropower can be done with a proper study.
- Monitoring of glaciers and glacier lakes is necessary to assess the potential risks of glacier lake outburst floods (GLOFs).
- Water balance in glaciers should be assessed properly. The hydropower generators should cooperate in such research and development.

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