Impacts of Climate Changes on Water Resources of Nepal

A CASE STUDY OF TSHO ROLPA GLACIAL LAKE

Submitted by

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Apr	-	April
asl	-	above sea level
Aug	-	August
AWS	-	Automatic Weather Station
BPCH	-	Butwal Power Company Hydroconsult
CCSP	-	Climate Change Study Project
CD	-	Compact Disk
CEN	-	Clean Energy Nepal

Ch	-	Chapter
Dec	-	December
DHM	-	Department of Hydrology and Meteorology
DHM/N	-	Department of Hydrology and Meteorology of Nepal
et al	-	and other people (Latin : et alii/alia)
F/Y	-	Fiscal Year
Feb	-	February
GCM	-	Global Circulation Model
GEF	-	Global Environment Facilities
GHG	-	Green House Gas
GLOF	-	Glacier Lake Outburst Flood
ibid	-	in the same book, article, passage etc as previously mentioned
ICIMOD	-	International Centre for Integrated Mountain Development
IPCC	-	Intergovernmental Panel on Climate Change
ITC	-	International Aerospace Survey and Earth Science, Netherlands
Jan	-	January
Jul	-	July
Jun	-	June
Mar	-	March
MS	-	Micro Soft
NGO	-	Non-Governmental Organization
NMS	-	Nepal Meteorological Society
No	-	Number
no	-	Number
Nov	-	November
NRs	-	Nepalese Rupees
Oct	-	October
P	-	Precipitation
p	-	page
pp	-	pages
PRA	-	Participatory Rural Appraisal
Q	-	River Discharge
REDP	-	Rural Energy Development Programme
Sep	-	September

SPSS	-	Statistical Programme for Social Science
T	-	Temperature
TAR	-	Third Assessment Report
TU	-	Tribhuwan University
UNDP	-	United Nations Development Programme
UNEP	-	United Nations Environment Programm
USCST	-	United States Country Study Project
Vol	-	Volume
WLBM	-	Water Level Bench Mark
^{0}N	-	degree north latitude
%	-	percentage
<	-	less than
>	-	greater than
±	-	plus or minus
^{0}C	-	degree Celsius
^{0}E	-	degree east longitude
^{0}S	-	degree south latitude
cm	-	centimetres
km	-	kilometre
km^2	-	square kilo metre
kW	-	kilo Watt
lps	-	litre per second
m	-	metre
m^2	-	square metre
m^3/s	-	cubic metre per second
mm	-	millimetre
MW	-	Mega Watt
sq km	-	square kilo metre

List of Equations

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EXECUTIVE SUMMARY

Energy is one of the most essential inputs for the economic development of any country, but the per capita energy consumption of Nepal is very low as compared with developed countries. More than 85 % of the energy needs are met by traditional energy sources dominated by fuelwood. As there are still no proven reserves of fossil fuels in Nepal, all the required petroleum and coals are imported from other counties, for which Nepal spends roughly one-third of its total foreign earnings. Hydro-electricity is only available commercial energy source from Nepal's own natural resources but its share in national energy supply is very low. Therefore, the present situation of energy pattern of Nepal is not sustainable and extremely necessary to be improved. Despite the huge hydropower potential of about 83,000 MW only 524.9 MW (0.6 % of total capacity) of hydropower was generated by 2002. So the development of Nepal greatly depends on the development of water resources particularly in the area of hydropower generation.

Nepal is still in its primitive stage of industrial development and main source of its national economy comes from agriculture. More than 80 % of Nepal's population live on subsistence agriculture farming. But still significant section of Nepal's agricultural land does not have modern irrigation facilities and solely depends on precipitation to meet the crop-water requirement. Many of rural people still do not have safe drinking water facilities and they solely rely on local springs and rivers to meet their drinking water demands. Thus, water resources in Nepal are playing a multidimensional role on economy and development.

Nepal has more than 6000 rivers originating at the high mountains and flowing down to the plains and valleys all the year round. As Nepal has monsoon type of precipitation pattern and 70-80 % of its annual precipitation occurs in summer monsoon, making 75 % of the months of the year relatively dry. This unevenly distributed precipitation character has direct relation to the river flow pattern in Nepal. In summer, there is more water in the rivers than really needed, whereas there is water-deficit in winter and dry season. Despite this unbalanced situation, glaciers in the high mountains are providing a sustained flow in the rivers even in non-monsoon dry season. They are acting as a backup of water storage, they collect the precipitation during the summer monsoon as snow and they melt and provide flow to the river in the consequent dry season (i.e. in spring season). Thus the glaciers are making possible of survival of mankind, plants and animals in the mountains, hills, and valleys in Nepal

Himalayas. The glaciers in Nepal Himalayas contribute a substantial part of river-flow not only to the Nepalese river system but also Indian rivers as well. Thus any change in the glaciers position, and consequently in river flow pattern causes significant impacts on the water balance even beyond the national boundary of Nepal. Change in flow pattern has direct impact not only on hydropower generation but also irrigation and drinking water.

So it is extremely important to study the changing pattern of river flow and precipitation in the changed temperature scenario not only for future planning of new water resources projects but also maintaining the well-operation of the existing schemes. Besides glaciers, numerous springs in hills and mountains are also feeding the rivers substantially during the dry seasons. During low flow period, glaciers are feeding the rivers from the surface storage as snow and ice, while the springs are feeding from the ground as ground water. Both of these sources of water are extremely sensitive to the changing precipitation and temperature parameters over the time.

Many studies have shown that the temperature of the earth has increased substantially in a relatively faster rate during the second half of the last century. As in other high- and mid latitude areas, the glaciers in Nepal Himalayas have significantly retreated during this period, resulting in formation of numbers of glacier lakes in Nepal Himalayas. Glaciers in the high mountains are serving as a permanent source of these rivers to provide a sustained flow even in dry non-monsoon season. Such glacier lakes formed at the terminus of mother glaciers and dammed generally by loose unconsolidated moraines are very unstable due to rapid rise in water level inside them. Therefore during the second half of the last century in Nepal Himalayas many glacier lakes not only appeared, but also caused many outburst floods too causing huge damage of lives and properties in the downstream. Recent study has shown that there are altogether more than 2000 glaciers lakes, out which 20 have serious risk of potential outburst flood.

Tsho Rolpa is the biggest glacier lake in Nepal Himalayas, which appeared only about a half century ago and has a potential threat of outburst. It is located in eastern Himalayas at an altitude of 4580 m asl. The lake area increased significantly by more than 7 times from 0.23 km^2 in 1957-59 to 1.65 km^2 in 1997. In 1997, the lake was in the most dangerous situation and more than 3000 families, including cultivated land, forest, and physical infrastructures were under the threat of the glacier lake outburst flood. In order to reduce the risk of outburst flood, the lake water level was lowered by draining out the water from the lake through siphon pipes as an immediate measure. As a permanent measure, the lake level was lowered by 3 m in 2000 by constructing an open channel at the end moraine. Besides that 17 numbers of early warning systems have been installed at 17 villages with high risk of potential outburst flood from Tsho Rolpa.

This research was aimed to assess the hydrological and meteorological trends at Tsho Rolpa and in its vicinity; to determine the people's perception towards the potential threat of outburst flood from Tsho Rolpa and ongoing risk reduction measures; and their information on the changing climatic pattern including its impact on the water resources. The case study was carried out in the villages of northern part of Dolakha district of Nepal to investigate the trend of climate change and its impacts on water resources along with potential threat of outburst flood from Tsho Rolpa Glacier Lake. Due to the lack of long-term climate data at Tsho Rolpa, the climate data of Jiri (the nearest meteorological station) and river flow data of Tamakoshi Busti (the nearest river gauge station), as the nearest possible data sources in the district, were analysed to assess the trends over the past decades.

The results showed that there were significant changes in temperature, precipitation, and river flow for the last 3-4 decades, which corresponded to the rapid growth of Tsho Rolpa Glacier Lake. The information among the people about the real situation of Tsho Rolpa and its potential outburst flood was very gloomy. People's information about climate change was very much in line with the trends shown by the observed data. The average annual temperature was increasing approximately at 0.019 ^{0}C per annum, while the average summer temperature was increasing even at faster rate of about 0.044 ^{0}C per annum. The year 1998 was the warmest year of the whole period of observation, with an annual extreme maximum value of 29.2 ^{0}C. Similarly the total annual precipitation was increasing approximately at 13.62 mm per year (i.e. 0.6% annually), while total numbers of rainy days were decreasing approximately at 0.82 days per annum (0.27% annually). This result showed an increasing trend of intensity of precipitation, the possible cause of increasing landslides and floods in the area for the last 20 years.

Similarly, the annual river flow was found also increasing at about at 1.478 m^3/s (0.9 % annually), which was about 1.5 times higher than the increase rate of precipitation. Increase in summer flow was found even more at about 5.654 m^3/s per year (i.e. 1.5 % annually). Rapidly increasing summer temperature of about 0.044^0C per year (i.e. 0.22 % annually) was contributing significantly to the increased summer river flow (about 55 % of increased flow) by causing the snow and glaciers melt.

Increased precipitation along with rapid melting of snow and glaciers in the mountain valleys were found some of the major responsible factors for the formation of glacier lakes and their potential outburst floods threatening millions of lives and properties in downstream. But due to remoteness of glacier lakes people were found lacking the true information on glacier lake outburst flood (GLOF) phenomenon. Unfortunately, the attitudes of the people, even under the risk of potential outburst flood, were also not so supportive towards the ongoing risk reduction projects and installed early warning systems. But , educated people and those living near to Tsho Rolpa had better understanding of the potential risk of the outburst flood.

Springs and spring fed rivers in mid hills were found drying up leading to possible water scarcity in winter and dry seasons. Snowfalls and frosts in the mid hills were found decreasing in line with the increasing average winter temperature. Weather related extreme events like excessive rainfall, longer draught period, landslides, floods etc. were found increasing both in terms of magnitude and frequency.

Recommendation is that there should be more studies on the impacts of changed climatic parameters on water resources. The analyses of more stations covering larger areas should be carried out in order to minimize the error on estimation. More scientific studies should be carried out to determine the relation of climatic parameters at high mountains (where almost no long term data available) with mid-hills and low lands. People's perception towards extreme climate events is not less important than the instrumental records, especially in the areas like Nepal Himalayas, where the average number of meteorological station per unit land area is considerably low. The conclusion is simply that there are significant impacts of climate change on water resources of Nepal, which should be carefully assessed for the planning of future development and for minimizing the potential risks of these impacts. Massive awareness campaign is extremely necessary to improve the level of people's understanding towards the potential GLOF phenomenon. Similarly, the people's participation in planning and implementation of the risk reduction projects and others related directly to them, should be significantly increased.

ZUSAMMENFASSUNG

Energie ist einer der bestimmenden Faktoren für die wirtschaftliche Entwicklung eines jeden Landes, aber der Pro-Kopf-Verbrauch in Nepal ist, verglichen mit den industrialisierten Ländern, sehr niedrig. Über 85 % des Energiebedarfes werden durch traditionelle Energiequellen gedeckt, vor allem durch Feuerholz. Da es bis heute keine nachgewiesenen Reserven fossiler Energieträger in Nepal gibt, wird alles benötigte Erdöl sowie die Kohle importiert, wofür Nepal ungefähr ein Drittel seiner gesamten Deviseneinnahmen ausgibt. Strom aus Wasserkraft ist die einzige verfügbare kommerzielle Energiequelle aus Nepals eigenen natürlichen Ressourcen, aber sein Anteil an der nationalen Energieversorgung ist sehr gering. Der heutige Umgang mit Energie ist also nicht nachhaltig und muss dringend verbessert werden. Trotz des großen Wasserkraftpotentials von ungefähr 83 000 MW existierten im Jahr 2002 nur 524,9 MW installierte Leistung (0,6 % der gesamten Kapazität). Die Entwicklung Nepals hängt also im hohen Grade vom Ausbau der Ressource Wasser ab, insbesondere von der Stromproduktion aus Wasserkraft. Hinzu kommt, dass 80 % der nepalesischen Bevölkerung von Subsistenzwirtschaft mit Einsatz primitiver Technik und Methoden lebt. Die Ressource Wasser spielt also durch Wasserkraft, Bewässerung und Trinkwasser eine vielschichtige Rolle für die nepalesische Wirtschaft und Entwicklung.

In Nepal gibt es über 6000 Flüsse, die im Hochgebirge entspringen und sogar in den trockenen Monaten Wasser führen. Ungefähr 70 – 80 % des jährlichen Niederschlags findet während dem Sommermonsun statt, wodurch drei Viertel des Jahres verhältnismäßig trocken sind. Dieser ungleichmäßig verteilte Niederschlag führt dazu, dass die Flüsse im Sommer mehr Wasser führen als benötigt wird, während es im Winter und während der Trockenzeit nicht ausreicht. Im Gegensatz dazu verursachen die Gletscher im Hochgebirge, sogar während der Trockenzeit (z. B. im Frühling), einen ununterbrochenen Zulauf zu den Flüssen. So ermöglichen die Gletscher das Überleben von Menschen, Pflanzen und Tieren in den Bergen, Hügeln und Tälern des Himalayagebirges in Nepal. Veränderungen des Wasserzuflusses beeinträchtigen die Nutzung von Wasserkraft, Bewässerung und Trinkwasser in starkem Maße.

Deshalb ist es außerordentlich wichtig, die Änderungen des Wasserflusses und des Niederschlags unter einem anderen Temperaturszenario zu untersuchen, und zwar nicht nur

für die Planung künftiger neuer Wasserprojekte, sondern auch für die bereits bestehende Situation und Wirtschaft. Neben den Gletschern tragen auch zahlreiche Quellen in den Hügeln und Bergen während der Trockenzeit maßgeblich zum Wasserstand der Flüsse bei. Wenn dieser niedrig ist, führen die Gletscher den Flüssen Oberflächenwasser aus Schnee und Eis zu, während die Quellen Grundwasser beitragen. Beide Wasserzuflüsse reagieren sehr sensibel auf sich zeitlich verändernde Niederschlags- und Temperaturparameter.

Die Gletscher im Himalayagebirge Nepals sind während der letzten 50 Jahre deutlich zurückgegangen, möglicherweise verursacht durch die globale Klimaerwärmung; dies hat zur Entstehung zahlreicher Gletscherseen geführt. Solche Gletscherseen, die sich am Ende eines Muttergletschers bilden und gewöhnlich durch einen Damm aus losem Moränenmaterial gehalten werden, sind durch den in ihnen rapide ansteigenden Wasserstand sehr instabil. Deshalb sind während der letzten fünf Jahrzehnte nicht nur viele Gletscherseen im Himalayagebirge Nepals entstanden, sondern sie haben auch mehrere Flutwellen verursacht, die zu hohen Verlusten von Menschenleben und Besitz in den Gebieten flussabwärts führten. Eine neuere Studie hat gezeigt, dass es alles in allem über 2000 Gletscherseen gibt, von denen bei 20 die ernsthafte Gefahr einer potentiellen Flutwelle besteht.

Tsho Rolpa ist der größte Gletschersee im Himalayagebirge Nepals; er ist erst vor ungefähr einem halben Jahrhundert entstanden und von ihm geht die Gefahr einer Flutwelle aus. Er befindet sich im östlichen Himalaya in einer Höhe von 4580 m über dem Meeresspiegel. Der Trakarding-Gletscher, der Muttergletscher des Tsho Rolpa, ist in den 29 Jahren von 1963 bis 1992 um 5 km zurückgegangen. Die Seefläche hat sich bedeutend auf über das siebenfache von 0,23 km² in 1957-59 auf 1,65 km² in 1997 vergrößert. Im Jahre 1997 war die Situation sehr kritisch, über 3000 Familien sowie bebautes Land, Wald und Infrastruktureinrichtungen waren der Gefahr einer Flutwelle aus dem See ausgesetzt. Um das Risiko einer Flutwelle zu reduzieren wurde der Wasserspiegel des Sees zunächst durch das Absaugen von Wasser durch Rohre als unmittelbare Maßnahme abgesenkt. Später, im Juni 2000, wurde der Wasserspiegel durch die Konstruktion eines offenen Kanals an der Endmoräne um 3 m abgesenkt. Außerdem wurde in 17 Dörfern mit einem hohen Risiko einer Flutwelle aus dem Tsho Rolpa zum Opfer zu fallen jeweils ein Frühwarnsystem installiert.

Diese Untersuchung soll die hydrologischen und meteorologischen Tendenzen des Tsho Rolpa und in seiner Umgebung näher betrachten, sowie die Wahrnehmung der Menschen von der potentiellen Drohung einer Flutwelle aus dem Tsho Rolpa und laufende Risikominderungsmaßnahmen feststellen. Außerdem sollte der Informationsstand der Menschen hinsichtlich des Klimawandels und seiner Auswirkungen auf die Ressource Wasser in ihrer Umgebung erfasst werden. Die Fallstudie wurde in den Dörfern des nördlichen Teils des Dolakha Distrikts in Nepal durchgeführt, um die Tendenzen des Klimawandels und seine Auswirkungen auf die Ressource Wasser und die Gefahr einer Flutwelle aus dem Tsho Rolpa zu untersuchen. Wegen des Mangels an Langzeit-Klimadaten am Tsho Rolpa wurden die Klimadaten von Jiri (nächste meteorologische Station) und die Wasserflussdaten von Tamakoshi Busti (die nächste Flussstation) als die nächsten möglichen Datenquellen des Distriktes untersucht, um die Trends der letzten 3 Jahrzehnte festzustellen.

Die Ergebnisse haben gezeigt, dass es während der letzen drei bis vier Jahrzehnte wesentliche Veränderungen hinsichtlich Temperatur, Niederschlag und des Wasserstandes der Flüsse gegeben hat, die zu dem rapiden Wachsen des Tsho Rolpa Gletscher Sees passen. Der Informationsstand der Bevölkerung über die tatsächliche Situation des Tsho Rolpa und einer möglichen Flutwelle war schlecht. Die Informationen der Menschen hinsichtlich des Klimawandels passen sehr gut zu den Trends, die die beobachteten Daten anzeigen. Die jährliche Durchschnittstemperatur stieg um ungefähr 0,019 ° C pro Jahr an, während die durchschnittliche Temperatur im Sommer um 0,044°C sogar noch schneller anstieg. Das Jahr 1998 war das wärmste Jahr der ganzen Beobachtungsperiode mit einem Extremwert von 29,2°C. Auf ähnliche Weise stieg der jährliche Gesamtniederschlag um ungefähr 13,62 mm pro Jahr an (das heißt 0,6 % jährlich), während die Anzahl der Regentage um ungefähr 0,8 Tage pro Jahr (0.27% jahrlich) abnahm. Dieses Ergebnis zeigt einen zunehmenden Trend in Richtung starker Niederschläge, eine mögliche Ursache für Erdrutsche und Überflutungen in dem Gebiet während der letzten 20 Jahre, was mit den Informationen der Bevölkerung hinsichtlich von Erdrutschen und Flutwellen übereinstimmt.

Auf ähnliche Weise zeigte sich, dass der Wasserstand der Flüsse über die Jahre um ungefähr 1,478 m^3/s (0,9 % jährlich) zunahm, was einer anderthalbfach höheren Zunahme als der des Niederschlages entspricht. Die Zunahme des Wasserstandes im Sommer lag mit 5,654 m^3/s pro Jahr (das heißt ungefähr 1,5 % jährlich) sogar noch höher. Rapide ansteigende Temperaturen während des Sommers von ungefähr 0,044°C pro Jahr (das heißt 0,22 % jährlich) haben erheblich zu dem höheren Wasserstand im Sommer beigetragen (verantwortlich für ungefähr 55 % der Zunahme des Wasserstandes), da sie zum Abschmelzen

von Schnee und Gletschern führte. Steigende Niederschläge zusammen mit rapidem Abschmelzen von Schnee und Gletschern in den Gebirgstälern stellten sich als die für die Entstehung von Gletscherseen mitverantwortlichen Hauptfaktoren heraus, die wiederum zu Flutwellen und damit zur Gefährdung von Millionen von Menschenleben und viel Besitz im Gebiet flussabwärts führen können. Zudem sind, wie sich herausgestellt hat, viele Menschen nicht ausreichend über die Gefahr von Flutwellen informiert. Leider unterstützen viele Bewohner die laufenden Risikominderungsmaßnahmen nicht, trotz des Risikos einer Flutwelle. Menschen mit einer höheren Schulbildung hingegen und solche, die in der Nähe des Tsho Rolpa Sees leben, haben ein besseres Verständnis für das potentielle Risiko, das von einer Flutwelle ausgeht.
Bäche und aus Bächen gespeiste Flüsse trocknen zunehmend aus, was zu Wasserknappheit während des Winters und der Trockenzeit führen kann. Schneefall und Frost im Hügelland haben zusammen mit der Durchschnittstemperatur im Winter abgenommen. Es stellte sich heraus, dass wetterbezogene Extremereignisse wie exzessive Niederschläge, längere Trockenperioden, Erdrutsche, Flutwellen usw. sowohl hinsichtlich der Heftigkeit als auch der Häufigkeit zunahmen.

Es wird empfohlen, weitere Studien über die Auswirkungen des Klimawandels auf die Ressource Wasser zu erstellen. Untersuchungen von Daten aus mehr Stationen, die ein größeres Gebiet abdecken, sollten durchgeführt werden um Fehler bei Beobachtungen und Schätzungen zu minimieren. Mehr wissenschaftliche Studien sollten erstellt werden um die Beziehung von Klimaparametern im Hochgebirge (wo fast keine Daten vorliegen) mit denen im Hügel- und Flachland zu vergleichen. Die Wahrnehmung der Menschen hinsichtlich extremer Wetterereignisse ist nicht weniger wichtig als die technischen Messungen und sollte mit viel Respekt behandelt werden; besonders in Gebieten wie dem Himalayagebirge Nepals, wo die durchschnittliche Anzahl von meteorologischen Messstationen pro Landeinheit sehr niedrig ist, kommt den Beobachtungen der Bevölkerung hohe Bedeutung bei. Die Schlussfolgerung ist, dass der Klimawandel erhebliche Auswirkungen auf die Ressource Wasser hat, was für die Minimierung sich daraus ergebender Gefahren und für die Planung der weiteren Entwicklung in Nepal gründlich untersucht werden sollte. Für die Verbesserung des Wissensstands in der Bevölkerung in Bezug auf das GLOF – Phänomens, ist eine Aufklärungskampagne dringend notwendig. In ähnlicher Weise sollte auch die Teilnahme der Bevölkerung an der Planung und Durchführung von Projekten zur Risikoverringerung gesteigert werden.

CHAPTER ONE: INTRODUCTION

1.1 Background

Nepal is a mountainous country situated in south Asia in the central part of Himalayan arc, which separates the Gangetic plain of India from the Tibetan plateau of China. The total area of Nepal is 147,181 sq km. Within an average width of only about 150 km, the altitude range varies from 161 meters above sea level (m asl) to 8,848 m asl (CBS, 2002b p.20), which gives favourable conditions for the existence of wide range of climatic characteristics; plant and animal species; and other human activities. Furthermore, huge orographic disparity consisting of hundreds of hills, valleys, mountains, cliffs, and plains makes very complex the study of climatic and geographic characteristics of Nepal. The relative location of Nepal is shown below in the Figure (Fig) 1.1

Fig 1.1 Map of the World and Nepal

Source : http://www.askasia.org/image/maps/nepal1.htm printed on February 14, 2003
http://www.maps.com/explore/atlas/political/ printed on February 14, 2003

Northern part of Nepal consists of the snow-covered Himalayan ranges with altitude variations from 5888 m asl to 8848 m asl. This region constitutes about 38 percent of the total area of Nepal. Because of being extremely cold as polar region, the area is also called as "The Third Pole". The central region of Nepal covers about 36 percent of the total area and consists of middle hills, river basins and valleys. Its altitude varies from 1830 m asl to 5888 m asl. The southern region, which forms about 26 percent of the whole Nepal consists of inner Terai, Chure hills and low plain areas with an altitude range of 161-1830 m asl (Yogacharya, K.S., 1985, p 25). Most of the perennial rivers (i.e. providing relatively sustained flow even in dry season of the year) originate from this region.

Nepal has a monsoon climate and about 80 percent of annual precipitation falls during a very short period of summer months from June to September, which produces a large numbers of small and big rivers in mountains. These rivers fed by rainwater, snow and groundwater make Nepal one of the richest countries in the world in terms of hydropower potentials. Theoretical potential of hydropower generation from more than 6000 Nepalese rivers originated from mountains and hills is estimated to be about 83,000 MW (Shrestha, H.M., 1985, p. 33).

History of the hydropower development in Nepal starts from 1911 A. D., when a 500 kW Pharping Hydropower Plant was constructed to supply electricity to the capital city of Kathmandu (Dixit, A, 2002, p.355). Even after about a century of the first initiation, Nepal has developed only 524.9 MW of hydropower by July 2002, which is only 0.6 percent total capacity (HMG / N, 2002, p. 125). Out of Nepal's total households of about 4.25 million, only 39.39 % enjoy the electricity lighting, and the rest of the population uses kerosene (57 %) and other sources of fuels for lighting their homes (CBS, 2002a, p.46). As Nepal does not have any proven sources of petroleum fuels, it is fully dependent on import from other countries with high prices. In the FY 2000/2001 Nepal paid a total amount of NRs 18,685.7 million for the import of petroleum products, which was about 33.6 % of all commodity exports of the country during the same period (HMG /N, 2002, p. 129). Huge unexploited hydropower potential, large section of population without electricity, and full dependency on fossil fuels to other countries are the main challenges on energy sector of Nepal. This suggests that the proper development of hydropower is a must for fulfilling the increasing energy demand needed for its overall economic development.

Water resources are variable in time and space. Their availability is affected by many natural, environmental, geographical, and meteorological parameters. During summer monsoon, there is plenty of water; and during other seasons, there is significant water deficit. The water availability is dominated basically by monsoon precipitation.

Generally rivers in Nepal are classified into three major groups. The first group of rivers is originated from snow covered high Himalayas and fed by snow, ice and glaciers. The Koshi, Gandaki, Karnali and Mahakali rivers (i.e. the major rivers of the country) fall into this group. These rivers maintain a sustained flow during the dry season, so are very important for the development of Nepal's water resources. The second group of rivers originates in the middle hills of Mahabharat region and are fed by the ground water during dry season, and therefore, generally do not dry up. The rivers originating from Chure hills fall under the third group. They are significantly low during dry season, while some of the smaller rivers may dry up completely during the non-monsoon season. All these rivers are very sensitive to climate as their flow regime is dominantly determined by the climatic parameter of the hills and the mountains. It is very necessary to know the changing climatic parameters and their impact on the water resources of the hills and mountains of Nepal for the initiation of water resource development project; from its planning, design, and construction to operation and management.

As mentioned before the glacier-fed rivers play a vital role on Nepal's economy and development, it is important to have a detailed study on the glaciers, glacier lakes, their formation and changes over time, impacts of climate change on them etc. Due to limited financial and human resources, remoteness of the areas, harsh climatic and topographical characteristics; low level of education and awareness among Nepalese people very limited studies have been done in this sector. A recent study carried out by ICIMOD/UNEP has found out that there are altogether 3, 252 glaciers in Nepal covering an area of 5,322 sq km (about 3.6% of Nepal's total area). Similarly there are 2,323 glacier lakes formed from these glaciers (Mool, P.K. et al., CD, Ch. 9). The fast retreat of world's glaciers including the glaciers in the Nepal Himalayas have been observed in recent decades (Kadota, T. et.al, 1992, p.1) creating a numbers of glacier lakes in this region. Most of the dams, supporting the glacier lakes consist of very loose and unconsolidated moraines. This situation has led to the occurrence of glacier lake outburst floods in the Himalayas, the number and frequency of which is sharply increased during the second half of the last century.

1.2 Theoretical Statement of the Problem

As mentioned earlier, Nepal has a precipitation pattern of unevenly distributed over the year. In the low altitudes, precipitation predominantly occurs as rainfall; whereas, in high altitudes mostly as snowfall. Liquid precipitation i.e. rain water either flows directly as surface runoff or infiltrates into ground as subsurface runoff. The solid precipitation i.e. the snow mass is accumulated on the ground or flows down slowly as glaciers. The surface or subsurface runoff at high altitudes occurs as melt-water or glaciers. The more the portion of solid precipitation, the more sustained flow in the rivers during dry season and the less of probability of rainfall induced flood occurrences. Changing climatic parameters are also causing the changes in the ratio of solid and liquid precipitation. In the recent decades the ratio of solid and liquid precipitation is decreasing due to global warming (McCarthy, J.J. et al, 2001, p.197). The increased liquid precipitation badly affects on the water storage capacity of mountains in two ways. Firstly, it will create a direct runoff and possible flooding and secondly it will accelerate the process of ice/snow melting (personal communication with Dr. A.B. Shrestha, on December 3, 2002). Thus changing climatic parameters have doubled the adverse effects on the water resources of the Nepalese Himalayas- firstly, warmer temperature accelerates the glacier retreat and secondly, the liquid precipitation further accelerates the retreating of glacier.

Global warming and glacier retreat during the recent decades has assisted to create a number of glacier lakes in the mountains (Mool et al, 2002, CD Ch.9). The water level in the glacier lakes rises due to the various reasons such as rapid change in temperature, intensive precipitation, decrease in seepage across the moraine, blocking of outlet, shrinking of glaciers etc (ibid). As already stated, there are more than 2,300 glacier lakes formed in the Nepal Himalayas out of which 347 glacier lakes are the major ones having the area of more than 0.02 sq km. Most of the major glacier lakes are in contact with or at a distance of less than 500 m from the mother glaciers (ibid). Twenty glacier lakes, out of the total major ones have been identified as the most dangerous. The different indicators such as rise in lake water level, activity of supra-glacier lake, position of the lake, dam condition, condition of associated mother glacier, physical conditions of surroundings etc were used for such identification. Three of them do have the past records of outbursts and 17 ones do not. Tsho Rolpa is one of the largest glacier lakes identified as potentially dangerous glacier lake, which do not have the past records of outburst flood.

The Tsho Rolpa glacier lake area was measured as 0.23 sq km in 1957-59, but in 1997 it grew up to 1.65 sq km about 7 times bigger than it was found originally. Now this lake contains about 100 million cubic meters of water behind an unconsolidated natural moraine dam. Many people, settlements, cultivated land, physical infrastructures like bridges, roads and forest are in a high risk of damages by its potential outburst.

1.3 Studies in Nepal

There were not so many studies carried out in Nepal on the glacier lakes and their possible outbursts before 1980s. Scientists started to get concerned after the reported changes in glacier areas in Nepal Himalayas after Nepal-Japan joint expedition programme, whereas the climate change studies over Nepal were initiated for the first time during US Country Studies Programme (USCSP) in 1993 (Sharma, K.P. et. al., 2002, p 5). The USCSP was aimed to work the status of inventory of the greenhouse gases (GHGs) emission and mitigation options in energy sector of Nepal, development of climate change scenarios with reference to Nepal, vulnerability and adaptation assessment of water resources and agriculture sector to climate change in Nepal (Gurung, T.M, 1997, p.33). This programme was completed in 1997 with some of its targeted outputs. In 1999, Climate Change Study Project (CCSP) was started with the support from UNEP /GEF. This programme is being implemented by the government of Nepal, is its final stage of completion. This programme is working on greenhouse gas inventory; vulnerability / impact assessment and adaptation; mitigation option; and national action plan and national communication (personal communication by author with Mr Purna Bahadur Shrestha, DHM on December 12, 2003).

The Tsho Rolpa glacier lake is the subject of ongoing studies by several Nepalese as well as international individuals and organizations. The first article on this lake was published by Robert Thomson in Himal Magazine (Jan-Feb 1992) with the title of “Rolwaling in Danger”, after which a number of scientists and scientific organizations were interested on it. After that many study reports and publication have come out, but still there are some studies to be carried out involving not only technical data of the lake and its surroundings but also the people themselves, which are in direct threat of the potential outburst the lake.

1.4 Objective of the Study

The overall objective of the study was to assess the vulnerability and impacts of climate change on the development paradigm in relation to water resources of Nepal. The specific objectives of this study were:

- To analyze the hydrological information of Tsho Rolpa and its nearby areas to determine the trends of climate change
- To identify the perception of the downstream people towards the outburst and their understanding on the ongoing outburst flood risk reduction project.
- To assess the impacts of potential outburst of Tsho Rolpa Glacier Lake
- To assess the people's understanding about climate change and its impacts on water resources.

1.5 Hypothesis of the Study

The major hypothesis of the study stated: "There are adverse impacts of climate change through the increase in temperature and summer precipitation; and decrease in winter precipitation and snowfall on the water resources of the study area. The specific hypotheses were as followings:

- Glaciers in Nepal Himalayas are retreating very fast resulting in rapid increase in the numbers of glacier lakes
- Rapid rise in water level in glacier lakes is adding the threat of their outburst towards the lives and the properties of the people living in the downstream.
- Temperature in the mountains of Nepal is increasing
- There is increasing trend in summer precipitation and decreasing winter precipitation
- There is decreasing trend in river flows during low flow period and increase in floods during summer monsoons.
- There is decreasing trend in snowfall and snow cover
- The springs and spring fed rivers are drying up.
- There is strong fear from the outburst of the Tsho Rolpa glacier lake among the people living in the downstream of the lake, thus they are applying some measures for

reducing the risk of damage from the possible flooding. Even they are trying to migrate to other places.

- People are facing more extreme weather events related to water resources such as floods, landslides, draught etc.
- There will be more demand for irrigation and drinking water due to increased temperature

1.6 Limitations of the Study

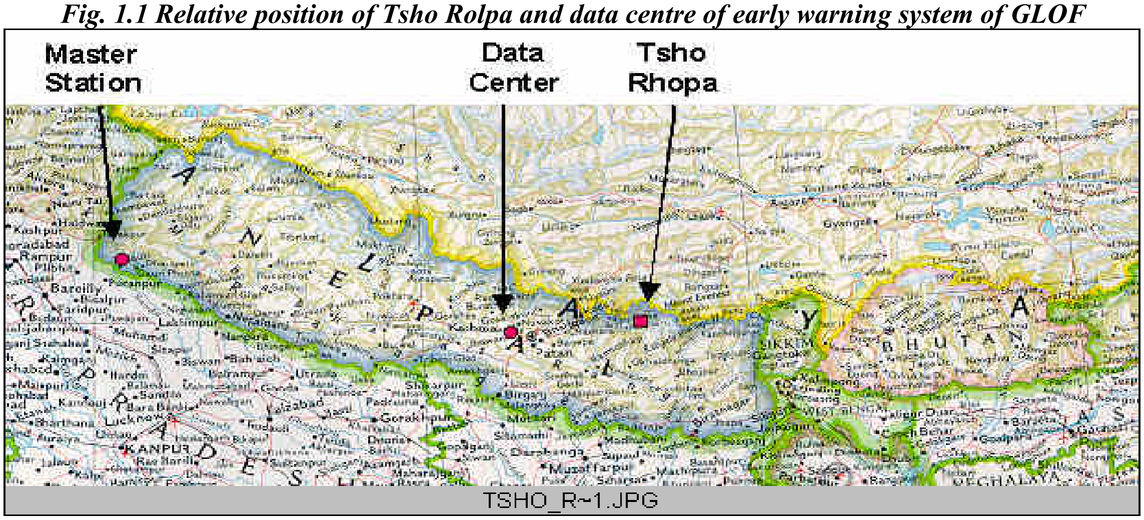
Certainly there were some limitations during the study, which were as followings:

- Tsho Rolpa Glacier Lake is situated in high altitudes far from the residential areas, thus very few people in the downstream are familiar with real condition of the lake and its potential risk of outburst and flooding.
- There are very few meteorological stations in high elevations making difficult long-term trend analysis of climatic parameters. The weather data and hydrological observations were available only after 1993, even not regularly.
- Climatic conditions are largely affected by the orography of the land. Due to huge climatic variations and uneven topography, the available meteorological stations cannot sufficiently represent the whole study area.
- Very limited studies have been carried out due to unavailability of financial and human resources required for such studies
- Very difficult to get information from the local residents about the long term climatic variations because annual variation is more significant than long term variation. Furthermore they were hardly asked before in this issue by other researchers.
- People are more concerned on economic activities having direct economic benefits rather than environmental issues because of the extreme poverty in rural areas.
- Long term temperature, precipitation, and river flow data were available only at the lower levels. So the trends of the weather parameters at the lower and higher altitudes for the longer period might not be the same. Further more the other weather parameters, such as solar radiation, wind speed, atmospheric pressure, and evaporation and transpiration data were not analysed during the analysis due to study limitation and unavailability of the relevant data.

1.7 Area of Study

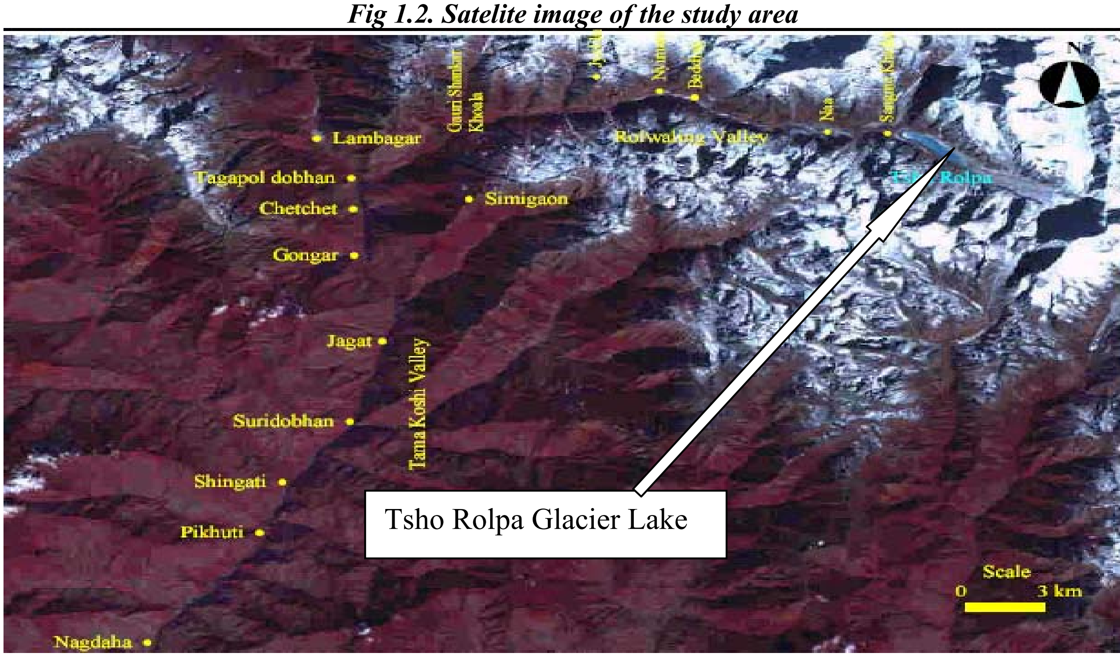
Tsho Rolpa Glacier Lake and the villages in downstream to it in Dolakha district of eastern Nepal Himalaya is taken the study area. Tsho Rolpa is the biggest glacier lake in Nepal, and the risk of the potential Glacier Lake Outburst Flood (GLOF) from that lake to the people and their properties in downstream would be disastrous. The area of study is shown in the fig. 1.1 and 1.2 below.

Fig. 1.1 Relative position of Tsho Rolpa and data centre of early warning system of GLOF



Source :http://www.geologie.at/html/body_introduction.html nepal-tsho rolpa-photo-3, printed on 10.02.03

Fig 1.2. Satelite image of the study area



Source : Mool et al.(2001), p.36

1.8 Definition of Terms

Some of the terms used in this report are as followings:

Glacier: A glacier is a huge flowing ice-mass.

Glacier lake: A glacier lake is formed at the end of glacier lake by glacier retreat and accumulation of the water on the way to downstream.

Glacier lake outburst flood (GLOF): The flood caused by the outburst of the glacier lake by the failure of supporting dam

Climate: Climate is defined as average weather in narrow sense and as the statistical description in terms of mean and variability of temperature, precipitation, and wind over a period of time ranging from months to thousands of years. The classical period is 3 decades, as defined by WMO (McCarthy, J. J. et al, 2001, p.984).

Climate Change: Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity.

Average monthly values: The average values of a particular weather parameter during a particular month.

Average annual values: The average values of a particular weather parameter of all the months in a year during a particular month.

Long-term annual average values: The average of all annual values during a particular study period.

Extreme values: Extreme values are those recorded once in a day, month, or a year as minimum or maximum of the particular period.

Springs: The sources of fresh water, which is generally used for drinking in the hills and mountains.

The four seasons of the year: Summer monsoon (June-August), Post monsoon (September-November), winter (December-February), and pre-monsoon (April-May)

CHAPTER TWO: RESEARCH METHODOLOGY

2.1 Literature Review

In order to find out the present status of the problems related to the present study, numbers of literature were reviewed as followings:

- Reports on the previous study on Tsho Rolpa glacier lake, its formation, development, and the potential threat of its outburst
- Case study of previous glacier lake outbursts
- Country report on climate change of Nepal,
- Seminar /workshop proceedings, published /unpublished papers and articles on glacier lake outburst, impacts of climate change on water resources prepared by the national and international experts / scientists
- Climate Change 2001: Scientific Basis; Impacts, Adaptation, and Vulnerability; Mitigation; and Synthesis Report. Contributions of Working Groups of I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)
- Inventory report on glacier lakes in Nepal
- Field Report of Tsho Rolpa Glacier Lake (digital version)
- News paper cuttings of the news on the panic of potential threat of Tsho Rolpa glacier lake outburst flood

After critically reviewing all the available information from the literature, the following research methods were determined.

2.2 Data Collection

In order to get the required information from primary and secondary sources, three types of data were collected. The data collection procedure consisted of qualitative as well as quantitative methods of surveying. The data collected were as followings:

- Secondary data on meteorological and hydrological information of the study area were collected from Department of Hydrology and Meteorology of Nepal (HMG/N)
- Descriptive interviews with key informants, experts, scientists, personnel from non-governmental organization (NGO), development worker, and politicians having the knowledge on the present study matter.

- Qualitative survey with the local people, which comprised of the descriptive interviews with the local people of Dolakha district living downstream of the Tsho Rolpa Glacier Lake. Direct conversation was made with these people in order to find out their knowledge on the glacier lake outburst flood, its causes, their activities on adaptation / mitigation or preparedness for reducing the risk of damage from the potential flooding, information on climate change and its impacts on their lives through the impacts on water resources etc.

2.2.1 Secondary Data from Department of Hydrology and Meteorology (DHM)

Tsho Rolpa Glacier Lake is situated at 4580 m asl and far from the residential area. The weather data of the area collected only after June 1993 with establishment of an Automatic Weather Station (AWS). Before than that no weather data suitable for analysis were available. Even after its establishment there were certain data gaps from time to time. For the period of 1996 –1998 there were no data available for Tsho Rolpa. The nearest meteorological stations in the district were found at Jiri (temperature, precipitation and relative humidity), and at Tamakoshi Busti (river flow records) since 1971. The Department of Hydrology and Meteorology of Nepal kindly provided all the hydrological and meteorological data of these stations in paper as well as in digital formats.

2.2.2 Descriptive Interviews with Key-informants

Descriptive interviews were made with the national level experts and scientists of Nepal in order to have better information on the present study topics and their views on it. They were the renowned personnel in Nepal as experts working in the field of climate change and water resource sector. A structured interview was taken individually with each expert by the author. The subject of conversation was divided into two subtopics i.e. firstly, the general information about climate change and its impacts on water resources; and secondly, the weather related extreme events including the potential glacier lake outburst flood from Tsho Rolpa.

2.2.3 Descriptive Interviews with Local Residents

As Nepal does not have enough meteorological stations in terms of their numbers to represent sufficiently the areas to be studied, neither it has long term past data, it is difficult to get reliable meteorological data in terms of quality and quantity. Most of the meteorological stations were established after 1964, when Nepal Meteorological Service (NMS) was established with the support of United Nations Development Programme (UNDP) and World Meteorological Organization (WMO) (Mool et al, 2002: CD Ch. 1). So it is important to document the information from the general people about their opinion on climate change, its impact on their life through the impacts on water resources, frequency and magnitude of climate related extreme events, their understanding on the glacier lake outburst phenomenon, their preparedness on reducing the risk from the outburst and possible flooding, their participation and attitude towards the ongoing mitigation project in Tsho Rolpa. Similarly it is also important to know about their contribution into the adaptation and mitigation projects targeted to reduce the vulnerability and risk from the impacts of climate change in relation to water resources and climate related extreme events as well. So structured interviews were taken with the local residents of Dolakha district on the present matter of study in order to determine the people's opinion in the present study. Some of the respondent replied individually whether some of them were answered as a group through participatory rural appraisal (PRA). As the study subject was much more of common character, the people preferred to answer in a group. In most of the cases during field survey, the villagers discussed among their own community members before answering the questions as far as possible.

2.3 Data Analysis

The data analysis procedure comprised of as the followings:

- Analysis of climatological data of Tsho Rolpa, Jiri, and Tamakoshi,
- Analysis of the information collected through the interviews and discussion with local people, and
- Analysis of the information obtained from the descriptive interviews with the key informants

The findings thus obtained from the three level of analysis then summarised and synthesized in order to achieve the targeted goal.

2.3.1 Analysis of Climatological Data

The temperature, precipitation and water discharge data of Tsho Rolpa were analysed independently at first then they were correlated by regression analysis with the data of other stations in order to extrapolate the data of Tsho Rolpa to the past times. The assumption for regression analysis was that the two stations (i.e. Tsho Rolpa and the downstream station) had simple linear relationship, in order to avoid the complex analysis. In fact, there might be many complexities and many unknown information between the two meteorological stations located in two different geographical characteristics.

The precipitation and temperature data of Jiri and river flow data of Tamakoshi Busti were analysed to determine their trends for the last three decades. Minimum, maximum, and average values of them were analysed individually. In case of precipitation, the analysis was made dividing the annual rainfall into four seasons viz. summer, pre-monsoon, post monsoon, and winter precipitation and analysed their trend in the past. MS Excel and SPSS 10.0 were used for graphical presentation and analytical calculation. Data available and tools applied were as follows:

- Daily weather data at Tsho Rolpa were available since June 1993 to December 2000 altogether for 52 months, out of which only 39 months precipitation, temperature, and humidity; and 27 months for outlet water discharge were without missing daily data. Only the months without missing-daily-data were taken for the analysis.
- The other weather parameters like evapo-transpiration, wind speed, solar radiation, and cloudiness were not analysed here because of unavailability of data.
- Daily average data of Tsho Rolpa were first converted into monthly average data, which were then correlated with the data of Jiri and Tamakoshi.
- River flow data of Tamakoshi Busti and temperature, precipitation, and humidity data of Jiri were available in annual and monthly format. Altogether the data of 30 years i.e. of 360 months were taken for analysis. Some missing data of particular months were restored taking average of the data of the same months of previous and consequent years. When more than one year data were missing, the missing data were restored by linear interpolation of the available data of the same months of the previous and consequent years.

- The monthly average values of temperature, precipitation, relative humidity, and river flow at Tsho Rolpa were correlated with the monthly average values of temperature, precipitation, and relative humidity at Jiri and river flow at Tamakoshi Busti. For example average monthly temperature of Tsho Rolpa in June 1993 was correlated with the monthly temperature of Jiri in June 1993 using simple linear regression analysis.
- Within the whole period of 30 years (i.e. 360 months), the weather data of Jiri for the following months with missing data were restored by aforementioned methods:
    - Temperature data for 23 months (i.e. 6.4 % of total months)
    - Precipitation data for 22 months (i.e. 6.2 % of total months)
    - Relative Humidity data for 13 months (i.e. 3.6 % of total months)
- Similarly out of 360 months of the whole period of study, the river flow data of Tamakoshi Busti were missing for 39 months. They were restored by simple linear interpolation of the same months of previous and consequent years.
- The trends of temperature, precipitation, relative humidity, and river flow were calculated as a slope of linear-trend line of the observed values with the help of MS Excel Chart for the period of 1971-2000.

2.3.2 Analysis of Surveyed Data from Local People

As the nature of the survey was qualitative, it was difficult to get them in quantitative form to make them easier for analysis. But the information collected during interviews was tabulated according to the answers obtained. As the data were tabulated and converted into to-some-extent quantitative form after the interviews took place, there might be some biasness from author's side, though it was tried to avoid such biasness. All the information got from the interview about their responses on climate change and Tsho Rolpa including the impacts of climate change and potential GLOF on their lives through the impacts on water resources was analysed by using SPSS 10.0 for Windows. Their responses were summarised by making regression analysis, correlation, cross tabulation, and frequency analysis with respect to their age, place of living, education, ethnic group, profession etc.

In spite of frequency analysis of each variable, the responses of the local people on the study topic were analysed based on their ages, ethnic group, geographical location of their residence, and educational level by using Cross Tabulation and Chi-square test.

During the analysis the following assumptions were made (Wesley, 2001, p.156):

- The two variables are very strongly related, when the significance is less than 0.001
- The two variables are strongly related, when the significance is less than 0.01
- The two variables have good relationship, when the significance is less than 0.05
- The two variables have weak relationship, when the significance is more than 0.05

2.3.3 Analysis of Information from Key Informants

The descriptive interviews for assessing the vulnerability of water resources of Nepal to climate change and potential outburst flood of Tsho Rolpa glacier lake were taken with the renowned national level experts, meteorologists, glaciologists, hydrologists, professors, and water resource engineers working in the field of climate change and water resources of Nepal.

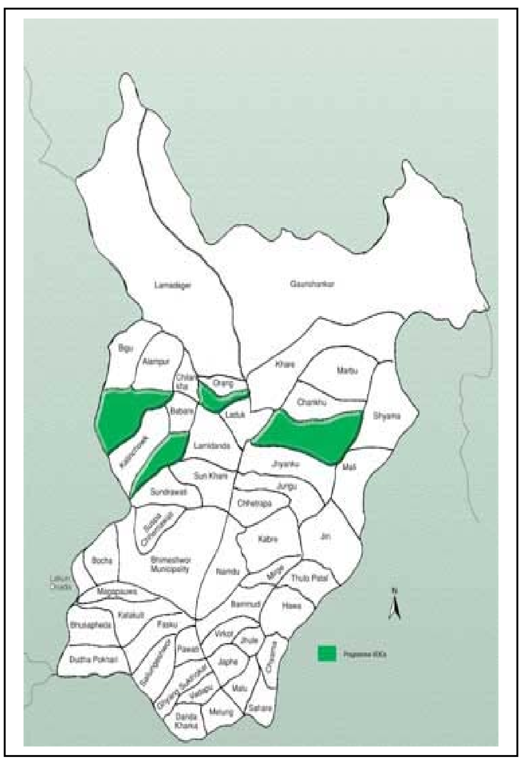
CHAPTER THREE: DESCRIPTIONS OF RESEARCH OBJECTS

3 General

3.1 Study Area

The study area was taken mainly in the downstream of Tsho Rolpa Glacier Lake. As the lake found located at a remote and mountainous area with poor accessibility, not so many people were living very near to the lake. But when the possible outburst of the lake would occur, many people and their properties in the downstream along the Rolwaling and Tamakoshi valleys of Dolakha and Ramechhap districts of Nepal would be affected. But due to time and resource limitation, the study was basically limited to Dolakha district only.

3.1.1 Dolakha District



Dolakha is one of 75 districts of Nepal. It is located in the eastern Himalayas. The total area of the district is 2,191 sq km (about 1.49 % of Nepal). The altitude of the district varies from 762 m asl to 7,183 m asl. Geographically the district is subdivided into three major parts viz. Himalayan range (35 %), high mountain range (40%), and mild mountain range (25 %)(REDP, 1998, p.5). There are 51 Village Development Committees and 1 Municipality within this district. As per the census of 2001, the total population and the household of the district are 204,229 and 43,165 with an average household size of 4.73 (CBS, 2002b, pp.20 &170). The district map of Dolakha is given in Fig. 3.1.

Fig. 3.1: District Map of Dolakha;

Source: REDP, 2001

Out of the total population, only about 11 % live in urban areas. The population density of the district is only 93 persons per sq km in compared with the average Nepal's figure of 157 persons per sq km. The literacy rate is only 50.6 % (the average figure for Nepal is 53.7 %) (ibid).

As the altitude of the district varies in a wide range, the climate also varies accordingly from tropical, subtropical, temperate to alpine. Average annual temperature of the district is 14.6 degree Celsius, whereas the average annual precipitation and average annual relative humidity are about 2175 mm and about 78 % respectively (REDP, 1998, p.16). About 44 % of the total is covered by forest, whereas only 21 % of the land is arable. Rest of the land is pasture, barren land, rivers, lakes and others (REDP, 1998, p.18).

3.1.2 Tsho Rolpa

Tsho Rolpa is the largest glacier lake situated in eastern Himalayas of Nepal (DHM, 2001 p. 2). It is located at about 110 km northeast of Kathmandu at an altitude of 4580 m asl in the Rolwaling Valley, at Gaurishankar Village Development Committee of Dolakha district of Janakpur zone. The lake is shown in the Fig 3.2 below

Fig 3.2 Tsho Rolpa Glacier Lake looking towards west to the outlet from upstream

Source: http://www.namche.net/bridges/tsho-rolpa-05.html printed on 10.02.2003

The risk of the potential outburst flood of Tsho Rolpa Glacier Lake is very high, as many people and property in the downstream of the lake would be affected in case of such flood.

3.2 Global Temperature and Precipitation Trends

The climate of the earth has changed significantly over the last century. The global average surface temperature has increased by 0.6±0.2 ^{0}C over the last century (Houghton et al., 2001, p.2). The 1990s was, most probably, the warmest decade and 1998 the warmest year in the instrumental record since 1861. In addition to that, for the period 1950-1993, average night time daily minimum air temperature over the land has increased by about 0.2 ^{0}C per decade, while daytime daily maximum air by about 0.1 ^{0}C per decade. This has elongated the freeze-free season in many mid- and high latitude regions. The land surface has increased twice than the sea surface during the period of 1950-1993 (ibid).

Increasing global surface temperature causes the changes in precipitation and atmospheric moisture. Global land precipitation has increased by 2% for the last century (Houghton et al., 2001, p.142). The increase in precipitation is not even over the globe. Over the last century, the average precipitation for mid- and high latitudes has increased by about 7 to 12 % for the zones 30^0 N to 38^0 N, while by about 2% for 0^0 to 55^0 S (ibid). Over the past 50 years, the annual precipitation in China has decreased slightly with decrease in the number of rainy days by 3.9 % per decade, but there is little evidence for a long-term trend in Indian monsoon rainfall (Houghton et al., 2001, p.143).

3.3 Temperature and Precipitation Variations in Nepal

Within a relatively small area, Nepal has large varieties of climates and microclimates, from subtropical in the plains of south to artic in high mountains of the north. The other climatological zones are warm temperate, cool temperate, and alpine in middle hills, high hills, and mid-mountains in the middle zone from east to west of Nepal. Likewise there are four seasons in Nepal viz. summer monsoon (June-August), post-monsoon (September-November), winter (December-February), and pre-monsoon (March-May). The mean annual precipitation of Nepal is about 1530 mm, about 80 % of which occurs during summer season (Yogacharya, 1998, p.185). Large altitudinal variations in a relatively short horizontal distances creates complexities for the study and understanding of different microclimates and climatic zones in Nepal.

Mountainous environments are very sensitive to climate change due to their physiographic characteristics (Barry, 1990, p.168; Shrestha at al, 1999, p.2775). Significant retreat of several glaciers, and formation /growth of numbers of glacier lakes in the last two decades in Nepal Himalayas may be considered as some of the indicators of global warming (Shrestha et al, 1999, p.2775). A study carried out by Shrestha et al (1999) by using the maximum temperatures of more than 49 stations over Nepal for the period of 1971-94, showed a warming trend after 1977 from 0.06 ^{0}C to 0.12 ^{0}C annually in most of middle mountain and high Himalayan regions. The warming trend in low hills and southern plains was found relatively low less than 0.03 ^{0}C per year (ibid). Very limited stations over Nepal have the temperature records before 1970s.The longest temperature data for Nepal is available for Kathmandu since 1921.The analysis of Kathmandu temperature records had shown a warming trend before 1934 and cooling trend from 1934 to 1975 (ibid). The same study had found that the maximum temperature of Kathmandu had decreased by 0.6 ^{0}C for 1934-1975 and increased by 1 ^{0}C for 1975-1994.

Most of the high mountainous regions in Nepal Himalayas are still untouched by the modern industrialization, which generally do not have direct significant anthropogenic influences. So, on this warming effect in the mountain, the urbanization or land-use change at local level may not play a significant role as compared to the regional-scale-effect caused by increased concentration of greenhouse gases (Shrestha et al, 1999, p.2784). Such high warming trends in high elevation mountainous regions are resulting in high all-Nepal warming trend, as the majority of Nepal's land consists of hills and high mountains (ibid).

Precipitation in Nepal greatly varies with place and time, and it is dominated by monsoon from Indian Ocean. Even in the time scale, there is large inter-annual and decadal variability in the all-Nepal and regional (within Nepal) precipitation records. The summer monsoon precipitation (which is dominant precipitation for Nepal) is relatively higher in the east and southeast parts of Nepal than west and northwest parts (Shrestha et al, 2000, p.317). A study carried out by Shrestha et al (2000) using the precipitation records of past three decades showed a lack of distinct long-term increasing trend in the precipitation records, even though climate models showed an increase in monsoon precipitation because of greenhouse gas-induced warming (Shrestha et al, 2000, p.325). Though there was not an overall increasing trend for the whole period for all-Nepal, an increasing trend was significant for 1967-1990 for all-Nepal and for western regions. There were distinct peaks of annual precipitation records in 1962, 1973, and 1984; whereas 1992 was the driest year of the whole record (Shrestha et al, 2000, p.320).

3.4 Climate Change and Himalayan Hydrology

Recent studies on glaciers and Himalayan hydrology showed that there might be some relationship, if not direct, between the fast retreat of glaciers in Nepal Himalayas and global warming during the past two decades (Sharma et al., 2000b, p.118). The hydrology itself is closely related with temperature and precipitation. Temperature change causes the change in precipitation because the land and sea heats up differently (the land heats up faster than the sea). In other words, the more the temperature rise is, the steeper will be the thermal gradient between sea and land (ibid). . So for the countries like Nepal, the temperature fluctuations highly influence on river flow and hydrology, though river discharge is not dependent only on precipitation and temperature. In addition to that, river discharge is an integrated measure of land cover, and human activities that influence the hydrologic cycle over a drainage basin (Sharma et al, 2000a, p.157). The study carried out by Sharma et al (2000a) showed decreasing trends of river flows particularly during the low-flow season. The possible causes for this might be one or more of factors, such as decreasing snow covered areas, a negative annual mass balance of glacierized areas, increasing evaporation/transpiration losses, and decreasing winter precipitation in the high mountains (Sharma et al., 2000a, p.163).

3.5 Glaciers and Glacier Lakes in Nepal Himalayas

The climate of Nepal Himalayas is largely influenced by the summer monsoon. About 70-80 % of annual precipitation occurs in the summer season, from June to September, and the accumulation and ablation (melting) of glaciers occur in the same season; thus mass exchange in other seasons is quite small (Ikegami et al, 1991, p.17). The warmer conditions may cause drastic melting of snow /ice but the colder temperatures do not always bring a positive mass balance because the precipitation is significantly low during cold seasons (Fujita et al, 2000, p.162). The response of glacier mass balance to increased-mean air temperature is more complicated, and non-linear. Furthermore, this non-linearity increases very sharply at high elevations, generally above 3500 m (Oerlemans, 1989, p.403). During the second half of the last century the mass balance of glaciers in Nepal Himalayas might have been reduced dramatically resulting in the formation of several glacier lakes in this area.

A study on an eastern Himalayan glacier (Kadota et al, 1992, p.1) has shown a relationship between the mass balance of glaciers and mean temperature / precipitation based on observational data of 1978, 1979, and 1983 at Glacier AX010 in the Nepal Himalaya. The study found out empirical formulas for calculating summer accumulation and summer ablation having mean summer temperature (June-September) and mean summer precipitation of the glacier. The glacier AX010 in Shorong Himal in eastern Nepal retreated about 30 m from 1978 to 1989. Some studies are pointing out the possibilities that the temperature in the glacierized areas increases at faster rate than in non-glacierized areas below (Kadota et al, 1992, p.2).

3.5.1 Glacier Lakes

Several glacier lakes have developed in the Nepal Himalayas during the second half of the last century. They are formed on the glacier terminus due to the fast retreating process of glaciers. Most of these lakes are dammed by unstable moraines, which were created by glaciations of the Little Ice Age (Mool et al, 2002, CD: Ch.9). Recent study carried out jointly by International Centre for Integrated Mountain Development (ICIMOD) and United Nations Environment Programme (UNEP) has prepared an inventory of glaciers and glacier lakes in Nepal Himalayas, which has found that there are 3252 glaciers and 2323 glacier lakes (ibid). This inventory consists of numbering of each glacier with its snow line, registration of snow and ice masses, mean glacier thickness and ice reserves, length, width, elevation, latitude, and longitude.

Besides the glacier retreat, it is also necessary to be other favourable conditions such as suitable geological and topographical conditions to form a lake, continuous accumulation of water (i.e. outflow is lower than inflow), blocking of outlet by landslides or so, inter-basin subsurface flow from another lake/s, and so on. Among the glacier lakes, the moraine dammed ones, generally, have a potential for outburst. The moraines were formed during Little Ice Age about 300 years ago with very loose and unstable materials. Usually these moraines are 20-250 m high and often contain dead ice layers beneath them (Mool et al, 2002, CD: Ch.3).

Based on some criteria such as rise in water level, activity of other lakes located upper side, position of lake, dam condition, condition of associated mother glacier, physical conditions of surroundings, etc. twenty numbers of glacier lakes in Nepal Himalayas have been identified as potentially dangerous. Some of these lakes have already past records of outburst flood events (Mool et al, 2002, CD: Ch 13). Potentially dangerous lakes identified by the study of ICIMOD /UNEP in Nepal Himalaya are given in the Table 3.1 and fig 3.3 below.

Table 3.1 Potentially Dangerous Glacier Lakes in Nepal

Type of Glacier Lakes	Name of Glacier Lakes	
	Koshi River Basin	Gandaki River Basin
Lakes without a record of past GLOF events	Ktr_gl 146, Lower Barun, Kdu_gl 28 (Lumding Tsho), Kdu_gl 350 (Imja Tsho), Kdu_gl 422 (Dudh Pokhari), Kdu_gl 442, Kdu_gl 444, Kdu_gl 449 (Hungu Lake), Kdu_gl 459 (East Hungu 1), Kdu_gl 462 (East Hungu 2), Kdu_gl 464, Kdu_gl 466 (West Chamjang), and Tsho Rolpa	Gbu_gl 9, Gmar_gl 70 (Thulagi), Gka_gl 38, and Gka_gl 67
Lakes with past GLOG events	Ktr_gl 191 (Nagma Pokhari), Kdu_gl 55 (Dig Tsho), and Kdu_gl 399 (Tam Pokhari)	
Total	16	4

Source : Mool et al., 2002 : CD Ch. 13

The table and figure show that most of the potential glacier lakes are located in the eastern Himalayas within Koshi River Basin. Tsho Rolpa is the biggest of all the potentially dangerous glacier lakes threatening to outburst flood in Nepal Himalayas.

Fig 3.3: Glaciers and Glacier Lakes in Nepal

Source: http://www.un.org/Pubs/chronicle/2002/issue3/0302p48_glacial_lakes_flood_threat.html printed on 14.02.03

3.5.2 Glacier Lake Outburst Flood (GLOF)

Increasing level of lake water from fast retreat of glacier may overtop the moraine dam of the glacier lake and break the dam easily. The huge amount of stored water, when released instantaneously, may damage the whole things on the way of river at the downstream of the glacier lake. These phenomena are generally called Glacier Lake Outburst Floods (GLOF) and have caused serious damage to the people of Nepal and their properties in the recent past decades. Even though there were many glacier lake outburst floods in Nepal in the past, very few such GLOFs were well investigated due to their occurrence in the remote areas (Yamada, 1998, p.11). In Nepal, GLOF explicitly appeared only about four decades ago at a time when water resource development had been expanding up to the deep Himalayas (WECS/JICA, 1996, p.1). Only very few such floods by the outburst of the glacier lakes in Nepal have been studied in details. Some of them are as given below.

3.5.2.1 Zhangzangbo Glacier Lake Outburst Flood

Zhangzangbo glacier lake located in Tibet in the headwater of Sunkoshi caused GLOF on 11 July 1981 damaging existing Sunkoshi hydropower station, Arniko highway, the friendship bridge, farmland etc and modifying the river channel for 30 km downstream into Nepal (DHM/BPCH, 1996, p.2). The cause of the failure of the moraine dam of the lake was glacier falling into the lake and creating high waves. The dam breach was about 50 m deep and 40-60 m wide. The maximum discharge was estimated to be 1600 m^3/s and the about 19 million cubic meters of water was released (ibid).

3.5.2.2 Dig Tsho Glacier Lake Outburst Flood

The Dig Tsho GLOF occurred on 4 August 1985 in Khumbu region of east Nepal created a strong shock among the government officials, engineers, and planners of Nepal. It was the most disastrous GLOF occurred inside Nepal with huge damage in the infrastructure including the nearly completed Namche hydro plant and some people's lives too (Yamada, 1998, p.11). This made the people think deeply about the water resource development, which had been expanding gradually up to the deep Himalayas by the time.

The lake was formed somewhere from 1963 to 1973 (Ives, 1986, p.26). Before the outburst on 4 August 1985, the lake water was close to overtopping the moraine dam and the lake was potentially unstable for several years (ibid). No heavy rain had fallen on previous days and the weather throughout the much of July and early August of 1985 before the GLOF, was warm and clear, which resulted in some melting of large mass of ice high on the rock above the

Langmoche glacier (mother glacier of Dig Tsho). The sudden fall into the lake of large mass of avalanche ice (and possibly rockfall debris) created a surge wave across the moraine dam. As the water level in the lake was close to overtopping, the surge assisted the water to overtop the dam and destroyed it releasing about 6-10 million cubic meters of water within about four hours (Ives, 1986, p.27). The maximum discharge was estimated to be 1600 m^3/s at a point 2 km downstream of the lake (Yamada, 1998, p.11). The surge including heavy debris caused a serious damage along the rivers of the Langmoche Khola, Bhote Koshi and Dudh Koshi within a distance of 40 km from the flood source. The nearly completed Namche hydropower plant at 12 km downstream, 30 houses, 14 bridges, trails, and cultivation lands were washed away as well as three human lives and several livestock were lost (ibid). The flood excavated the river banks by lateral erosion and undercutting, which destabilized the steep slopes on both sides of the river. Slope collapses and landslides were generated damaging also the adjoining forest.

The surge movement was of a rolling type, dragged trees and large boulders with it, emitting a loud noise, " like many helicopters" and a foul mud smell. The valley bottom of the river full of water vapour, the river banks trembled, houses shook and the sky was cloudless (Ives, 1986, p.27).

3.5.3 Tsho Rolpa Glacier Lake

Tsho Rolpa is located at about 110 km north-east of the capital city of Kathmandu at an altitude of 4580 m asl in the Rolwaling Valley, at Gaurishankar Village Development Committee of Dolakha district of Janakpur zone. As already mentioned, Tsho Rolpa Glacier Lake is one of the most potentially dangerous glacier lakes in the Nepal Himalayas, which has taken into serious consideration only after the outburst flood of a very small glacier lake called Chhubung near Tsho Rolpa Glacier Lake (about three hundred times smaller than Tsho Rolpa) in the Rolwaling valley near to Tsho Rolpa in July 1991 (Damen, 1992, p.1). This small glacier lake outburst flood destroyed the river banks, potato fields, some houses, forest, and grazing land of the villages of Na and Beding at the same Village Development Committee, where Tsho Rolpa is located. This outburst created a strong fear of potential outburst flood from Tsho Rolpa among the villagers of Na and Beding.

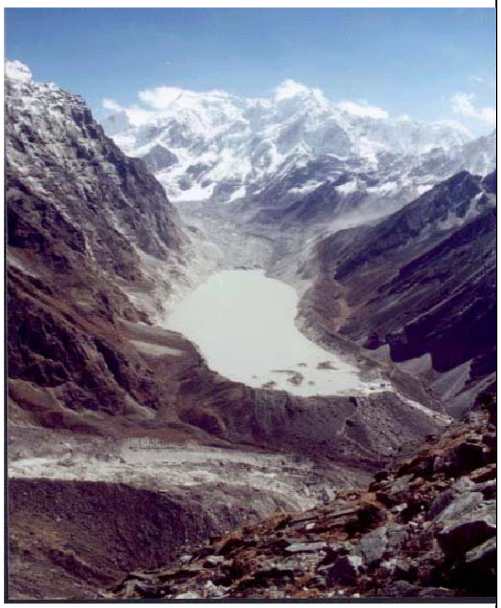


Fig. 3.4 Aerial View of Tsho Rolpa
Source : Mool, P.K. et al, 2001b, p.52

Tsho Rolpa Glacier Lake was formed over the last 45 years by retreat of Trakarding Glacier and is supported by an unconsolidated dam of moraine debris. Geographically it is located at 27^0 50' N latitude and 86^0 28' E longitudes at the headwater of Rolwaling Khola, a tributary of Tamakoshi River in Dolakha district of Nepal. This lake is situated at an elevation of 4580 m asl at the terminus of Trakarding Glacier, elongated northwest to southeast, and bounded by the moraine by three sides and by the Trakarding Glacier in one side (Mool, et al, 2001, p.1). The aerial view of the lake is given in fig 3.4.

The deepest point of the lake is not located at the centre of the lake but near to the glacier terminus, which is a clear reflection of the expansion mechanism of the lake (Yamada, 1998, p.35). The deepest point of the lake in 1993 belonged to the Trakarding Glacier in the early 1970s. The average deepening rate in the lake bottom and elongation rate in the longitudinal direction of the lake is estimated to be at least 2.9 m /year and 71 m /year respectively (Yamada, 1998, p.38).

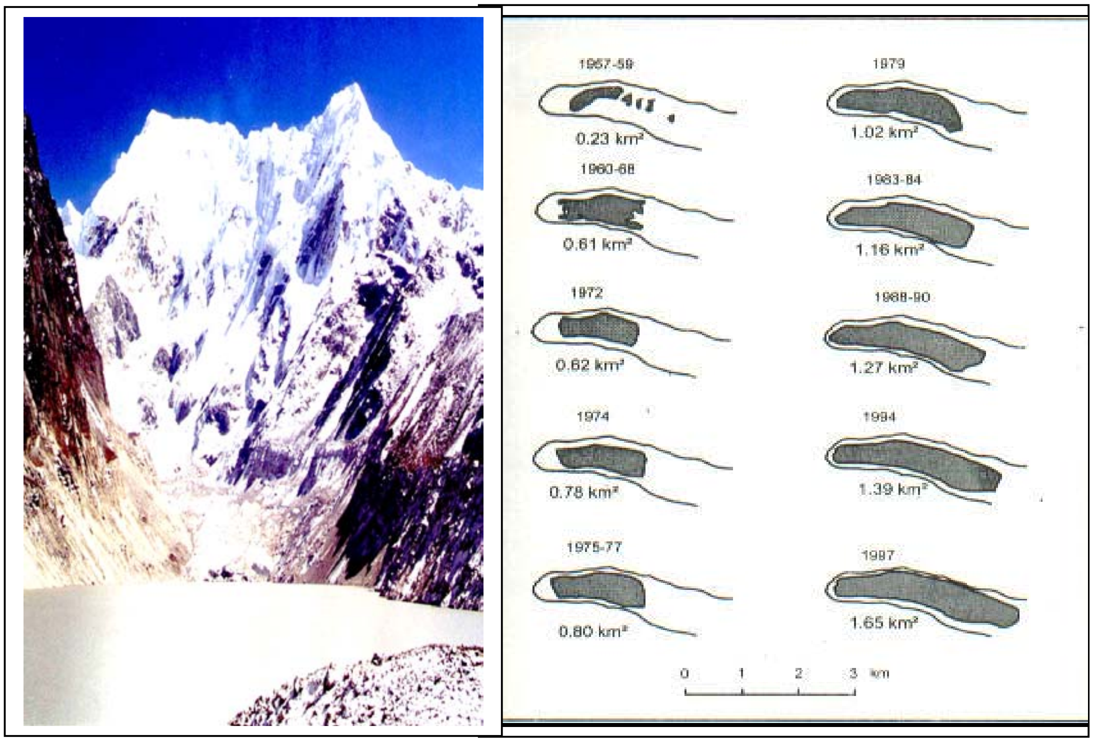
Box 3.1: General features of Tsho Rolpa Glacier Lake

Length, m (in 1999)	3300
Breadth, m (in 1994)	500
Maximum depth, m (in 1994)	132
Average depth, m (in 1994)	55
Lake area, km^2 (in 1996 map)	1.65
Basin area, km^2	77.6
Moraine dam height, m	150
Volume,million m^3	100

Source: DHM/N, 2000: Tsho Rolpa Glacier Lake: Brief Introduction, p 2

The size of the lake was firstly taken in 1957-59 from vertical aerial photos (for the map by survey of India) when the lake area was found to be 0.23 sq. km. But the lake itself was not monitored before 1993. The lake is growing bigger every year due to intensive melting of Trakarding glacier terminus (DHM, 2001, p.2). Lake areas of Tsho Rolpa estimated by means of various data sources for the different time period are given in fig. 3.5 below.

Fig. 3.5: Development of Tsho Rolpa Glacier Lake



Source: Photo from Mool, et al., 2001,p.49; and graph from DHM, 2000, p.3, combined by author

3.5.3.1 Drainage Basin of Tsho Rolpa

According to the topographical map(HMG/N, 1996a, Sheet nos 278602, 278603), the drainage basin of Tsho Rolpa lies between 4577 m als and 6938 m asl. The lowest level is the lake level of Tsho Rolpa glacier lake after lowering the level by 3 m in June 2000 and the highest is the top of Mt Tengi Ragi Tau, the highest peak of the area. The drainage basin is distinctively decorated with snow and glaciers. The total catchment area of the basin is 77.6 sq km, of which 55.3 % and 16.5 % are covered with debris free glaciers and debris covered glaciers respectively and only 26.5 % is covered by the rock surface (Yamada, 1998, p. 46). The area of Tsho Rolpa Glacier Lake, 1.40 sq km (after lowering the lake level in June, 2000) occupies 1.7 % of the basin area (Yamada, 1998, p.46; Mool et al, 2001, p.3). The large ratio of the glacier area to the basin area indicates that melt-water of snow and ice is essentially important for the source of water supplied into the lake. About 85 % of the total drainage basin lies above 5000 m asl. The drainage basin and area altitude distribution of Tsho Rolpa drainage basin are given below in the Figures 3.6 and 3.7 respectively.

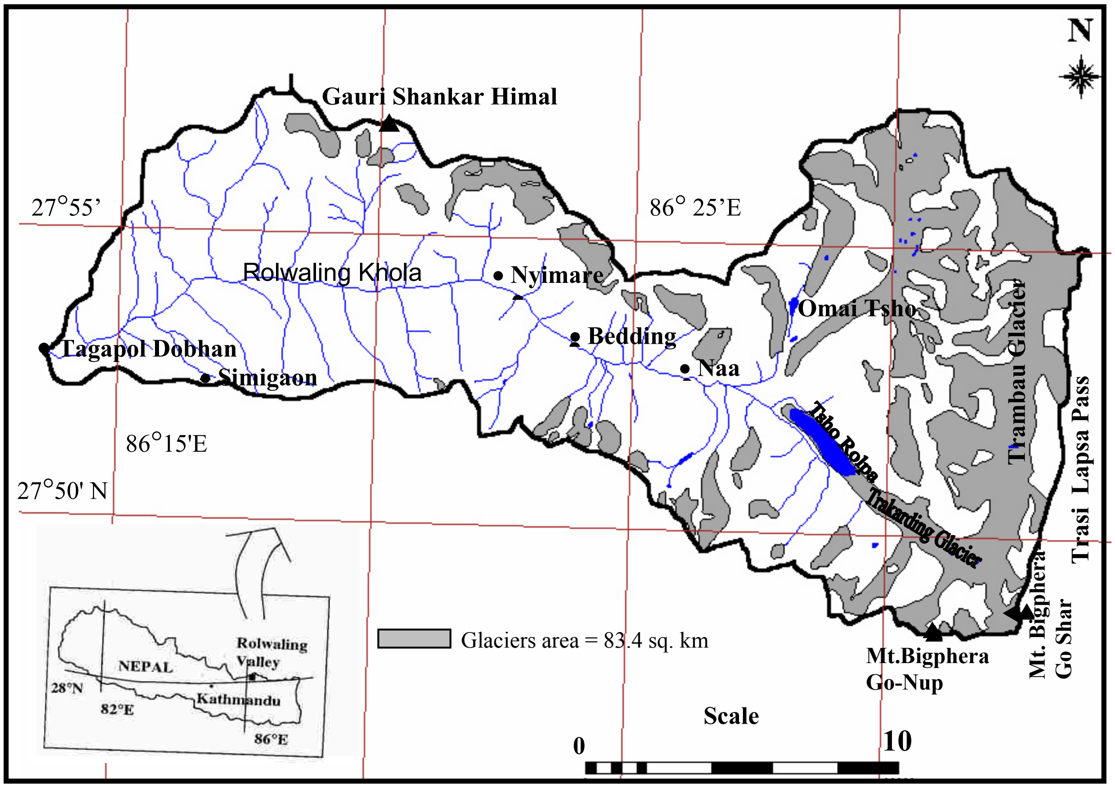
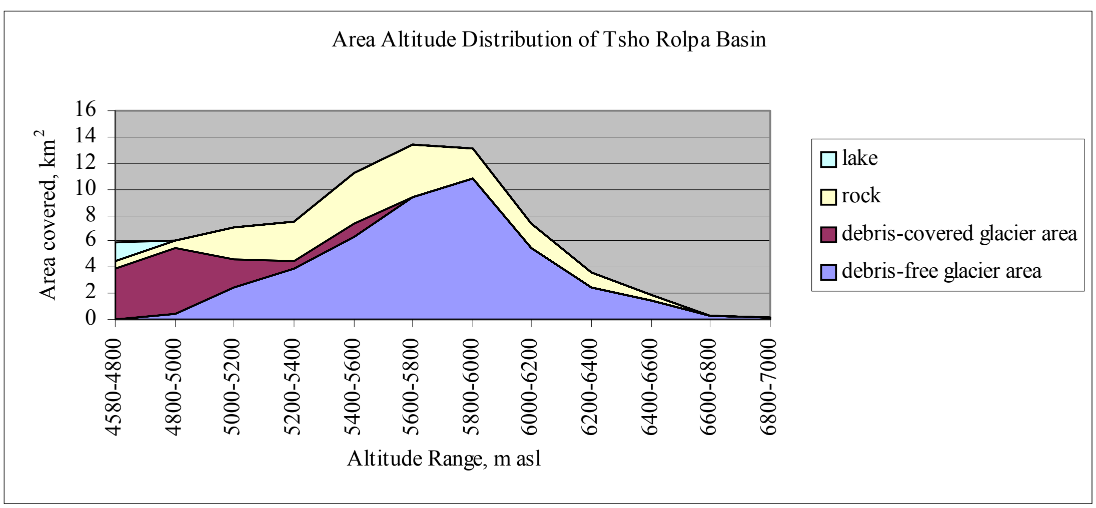


Figure 3.6 Drainage Basin of Rolwaling Valley and Tsho Rolpa, *Source: Mool et al, 2001, p. 1*

Fig 3.7: Area altitude distribution of Tsho Rolpa drainage basin



Source: Graph by author, data from Yamada, T, 1998, p.46

3.5.3.2 End Moraine Dam of Tsho Rolpa

As stated earlier, Tsho Rolpa has been formed on the tongue of Trakarding Glacier, one of the typical debris covered glaciers in the Nepal Himalayas. The lake is dammed by the end moraine consisted of very loose debris carried by the glacier. The moraine was formed about 300 years ago, when the Trakarding Glacier actively flowed down to the end moraine position (Yamada, 1998, pp.7, 46). The height of the moraine dam is 150 m from the riverbed of Rolwaling Khola. The moraine dam, to some extent, is like a poorly constructed rock-fill dam composed of unconsolidated debris. So such dam is very unstable. Besides that, dead ice mass is contained in the end of moraine and beneath the lake and the moraine is possibly frozen except for a few meters in the surface layer (ibid). The ice masses of the moraine are facing great hydrostatic pressure of the lake water.

3.5.3.3 Upstream-end of Tsho Rolpa and Shape of its Basin

The upstream end of the lake is connected with the terminus of Trakarding Glacier. The surface area and volume of stored water in 1994 was 1.39 sq km and 76.6 million cubic meters respectively (WECS /JICA, 1996, pp.6-7). The glacier is retreating year after year by calving, thus the lake is expanding upstream. Mostly the glacier is covered by debris. The basin shape of the lake is rather complex in comparison with the basin shape of the main lake. Within the upper 20 m of the lake depth, about one third of its water volume is contained. There are some islands at the end part of the lake, which are cored with dead glacier ice. With melting of the cored ice, the islands are decreasing in height and will disappear into the lake in future (Yamada, 1998, p.51).

3.5.3.4 Outlet and Inlet of the Lake

Water supplied from the catchment area of 77.6 sq km into the lake was drained out through the outlet on the lowest part of the end moraine throughout the year before lowering the lake in June 2000. An artificial channel with sluice gate structure has been constructed by cutting the end moraine to the left of the natural outlet to lower the water level by 3 m. The lined canal has a capacity of designed flow of 14 m^3/s and maximum flow of 35 m^3/s.

Besides the Trakarding Glacier itself, only one visible small stream of 20-40 litre per second (lps) flow in summer can be seen as the source of water into the lake. No other water inflow were found there besides this surface stream, which meant that almost all of water in Tsho Rolpa drainage basin must be absorbed and concentrate in the drainage systems of the Trakarding Glacier (Yamada, 1998, p.52). Potential Risks for the Outburst Flood from Tsho Rolpa

3.5.3.5 Potential Risks for the Outburst Flood from Tsho Rolpa

The several study reports on Tsho Rolpa Glacier Lake stressed the likelihood of its outburst flood due to huge amount of water stored in the lake, seepage in the lake composed of unconsolidated natural moraine dam having small width and free-board (DHM, 2001, p 3). There is strong possibility of falling the ice-mass from the north-western and southern areas into the lake creating a high wave of the lake water capable of overtopping the free-board and causing the failure of the dam. If the moraine dam fails, about 26.08 million cubic meters of water could be released and the resulting flood could put in a serious threat of damage to the numbers of people's lives, their properties including cultivated land, forest, and physical infrastructure (BPCH/DHM, 2000, p.12).

3.5.4 Dolakha district and its area under threat of Tsho Rolpa outburst

Dolakha is one 75 districts of Nepal located in the eastern Himalayas. The total area of the district is 2,191 sq km (about 1.49 % of Nepal). The altitude of the district varies from 762 m asl to 7,183 m asl. Geographically the district is subdivided into three major parts viz. Himalayan range (35 %), high mountain range (40%), and mild mountain range (25 %) (REDP, 1998, p.5). There are 51 Village Development Committees and 1 Municipality within this district. As per the census of 2001, the total population and the household of the district are 204,229 and 43,165 with an average household size of 4.73 (CBS, 2002b, pp.20 &170). Out of the total population, only about 11 % live in urban areas. The population density of the district is only 93 persons per sq km in compared with the average Nepal's figure of 157 persons per sq km, whereas the literacy rate is 50.6 % (the literacy rate of Nepal is 53.7 %) (ibid).

As the altitude the district varies in wide range, the climate also varies accordingly from tropical, subtropical, temperate to alpine. Average annual temperature of the district is 14.6 degree Celsius whereas the average annual precipitation and average annual relative humidity are about 2175 mm and about 78 % respectively (REDP, 1998, p.16). Out of the total land area about 44 % of the land covered by forest whereas only 21 % of the land is arable. Rest of the land is pasture, barren land, rivers, lakes and others (REDP, 1998, p.18).

After the outburst flood of small glacier lake Chhubung at the end of Ripimo Shar glacier in Rolwaling Valley in July 1991, when the river valley with potato field, track near to river bank and some other infrastructures of Beding village of Gaurishankar VDC in Dolakha district were damaged by the flood, a immediate investigation on the Tsho Rolpa glacier was felt to be necessary (Damen, 1992, p.1). The people of Beding and Na at Gaurishankar VDC were afraid of the fact that the very small lake outburst flood could damage so much, what would happen if the Tsho Rolpa glacier lake would break, which is almost three hundred times larger and located higher not very far from their village. Then the study of the lake was started on the demand of the villagers.

3.5.5 Risk Assessment of Potential Outburst Flood of Tsho Rolpa Glacier Lake

The Tsho Rolpa Glacier Lake is dammed by loose unconsolidated end moraine with no vegetation on it. The lake is situated at the terminus of Trakarding Glacier. The dam looks quite fresh and was formed a few hundred years ago, when the Trakarding Glacier actively flowed down to the present end moraine position (Damen, 1992, p.46). There is dead ice mass contained in the end moraine, which is more sensitive to exposure and melting. Excavation of a breach in the end moraine dam may expose the interior ice body in the moraine, which might melt due to strong solar radiation. This might weaken the end moraine structurally and cause its spontaneous break (Damen, 1992, p.55). Increased temperature might increase the risk of dead-ice melting and breach in the moraine. Several studies on Tsho Rolpa Outburst Flood have shown that the outburst of the lake is very likely due to the fast growing size of it caused by the fast melting of Trakarding glacier and due to unconsolidated moraine dam holding about 100 million cubic meter of water (DHM, 2001, p.2). Studies had shown that the potential GLOF of the lake would cause an instantaneous release of about 26.08 m^3 of the upper 20 m depth of the present lake water level.. This will create a peak flow of about , this is about 5000 m^3/s, which is about 190 times higher than the observed maximum flow at Tsho Rolpa (BPCH/DHM, 2000, p.18; Yamada, 1998, p.68). The flood water level in many places along the river course may rise up to 20 m from the original water level in case of outburst flood (ibid). The name of villages and number of families under the risk of potential outburst flood are given below in Table 3.2.

Table 3.2. Description of possible damage by potential Tsho Rolpa GLOF in Dolakha district

SN	Name of VDC	Name of villages	No of affected family	No of affected houses	Distance from Tsho Rolpa, km

1	Gaurishankar	Na, Beding	279	54	3.3-10.6
2	Lamabagar	Chetchet, Jagat,	219	26	26.15
3	Orang	Jagat,Masmarang	125	24	37
4	Khare	Manthale,Totlabari	144	25	39
5	Suri	Bhorle, Jhyalkhet,	108	21	44
6	Laduk	Singati	186	51	48
7	Lamidanda	Chapleti, Singati	114	44	49
8	Jhyanku	Jhangreli, Pikhuti	100	26	52
9	Jugu	Pikhuti	55	10	53
10	Sunkhani	Gumakhola, Ratmate	280	45	55
11	Namdu	Kande	36	4	60
12	Bhimeshwar Municipal	Nagdaha, Nayapul	384	105	60-63
13	Bhedpu	Baguwabesi	89	14	71
14	Malu	Malukhola bazaar	46	20	73
15	Melung	Miltikhola, Sitali	310	64	77
16	Bhedpu	Baguwabesi	89	14	71
		Total	2564	547	

Source: Information provided by DHM, by Mr Jagadish Ghimere (01.12.2002), author's personal communication with local people, and political leaders in Dolakha district.

The other possible major damages are as the followings:

- About 2100 people from the aforementioned 547 houses along Rolwaling and Tamakoshi valleys not considering the people living in the areas further downstream in Ramechhap district.
- Forest, cultivated land, and other physical properties of 3408 families.
- Three numbers of concrete bridges, 18 numbers of suspension bridges.
- Lamusangu – Jiri Road near Nayapul
- Airport near Manthali of Ramecchap
- Khimti Hydropower plant , 63 MW
- Six temples, 4 agro-processing mills, 1 police station, and 4 government offices

Source : Budhathoki, K.P. et al, 1996, pp.31-36; BPCH/DHM, 1996, pp.3-4; BPCH/DHM, 2000, p.20; Mool, P.K. et al, 2001, pp37-42

In case of outburst flood of the Tsho Rolpa Glacier Lake, the flood will reach within 10 minutes to the nearest village of Na and to Manthali about 94 km downstream from Tsho Rolpa within about 2-3 hours (BPCH/DHM, 2000, p.20; BPCH/DHM, 1996, p.4).

3.5.6 Risk Reduction Measures of Potential Outburst Flood of Tsho Rolpa Glacier Lake

As the water level of Tsho Rolpa Glacier Lake was rapidly increasing for the last decades, the lowering of water level was considered as the immediate and temporary measures for the reduction of risk from potential GLOF. The study conducted by JM Reynolds in 1996 showed that the water level in the lake should be reduced by 20 m over a period of 3-5 years for the lake to be safe, as the dam of the lake consists of relatively stable material below the depth of 20 m (BPCH/DHM, 2000, p.13). In 1995, one trial siphons and then in 1997 other five siphons were installed to lower the water level (DHM, 2001, p.4). As the siphon pipes required frequent maintenance especially during winters, a permanent open channel was constructed by cutting the end moraine and water level was lowered by 3 m in June 2000. The open channel regulated by a sluice gate was designed to cater 14 m^3/s of flow with a maximum capacity of 35 m^3/s, after which the volume of water in the lake has been reduced by about 4.8 million m^3 (ibid). As per the study, still more water level lowering is necessary to be safe. The applied lake lowering measures are given in Fig 3.8 and 3.9.

Figure 3.8: Siphon pipes used for lake water lowering before the construction of open channel

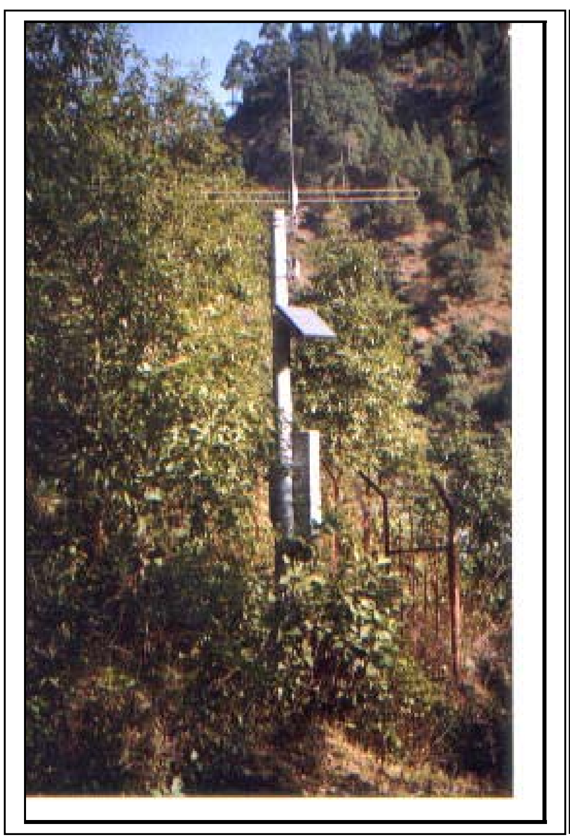
Source : Photographs from DHM, 2001, p.4

Figure 3.9: Synoptic view of mitigation construction activity at the end moraine of Tsho Rolpa Glacial Lake to reduce the lake water level

Photo source: Dr. Arun Bhakta Shrestha, DHM /N

Besides that, early warning systems have been installed in 17 villages in the downstream of Tsho Rolpa along Rolwaling valley and Tamakoshi Basin in order to warn the people about the outburst and to reduce the risk. The early warning systems are shown below in Fig 3.10.

Figure 3.10:Early warning system at Gumkhola (left), and Singati (right)



Source: Photographs by author (December 2002)

3.5.7 Growth Rate of Tsho Rolpa Glacier Lake

Tsho Rolpa is continuously growing for about 45 years. The lake is expanding in the longitudinal direction by retreat of glacier and also in vertical direction by dead ice melting. The lake has no space to expand for lateral direction, as both of the sides of the lake are confined by the lateral moraines (Yamada, 1998, p.82).

The longitudinal growth of the lake is not due to melting of cliff-shaped terminus but rather due to the collapse of the cliff. The collapse results in the upstream growth of the lake. The lake expanded upward at about 200 m for nearly 2 years from November 19,1993 to October 4, 1995 (Yamada, 1998, p.82). As the lake length of 3.2 km reached within about 45 years giving an average growth rate of about 71 m per year, but the observed average value was 100 m per year, so that the present growth rate may be rather accelerated (Yamada, 1998, p.85). The ice at the glacier terminus is in direct contact with lake water (Damen, 1992, p.44) and the surface current of wind driven warm water of the lake might have caused active melting of the ice.

While talking about the retreat of Trakarding Glacier, the mother glacier of Tsho Rolpa, the glacier front has retreated 3500 m from 1963 to 1975 (average retreat of 290 m per year) and another 1500 m from 1975 to 1992 (average annual retreat of 88 m) giving a total shrinking of Trakarding Glacier in 5 km within about 30 years (Damen, 1992, p.6).

3.5.8 Existing Hydrological and Meteorological Stations in Study Area

As the lake is situated at remote areas in high mountains, the observation of meteorological conditions in regular basis was just started in 1993. As the classical period for the analysis of climate is three decades (McCarthy et al, 2001, p.984), the nearest possible such stations could be found at Tamakoshi Busti for river discharge, and at Jiri for meteorological data. Both of these stations are located in Dolakha district. The hydrological and meteorological observation data of the stations for the period of 1971-2000 were taken for analysis purpose.

3.5.9 Aanderaa Automatic Weather Station

Aanderaa Automatic Weather Station (AWS-2700) is regularly recording the meteorological data of Tsho Rolpa Glacier Lake except sometimes since its establishment in June 1993 (Yamada, 1998, p.58). The weather data could not be recorded from October 1996 to May 1999. Even during the period when the station was functioning, the data for some days and sometimes even months were missing. After June 1999, again the station started functioning and regular data recording..

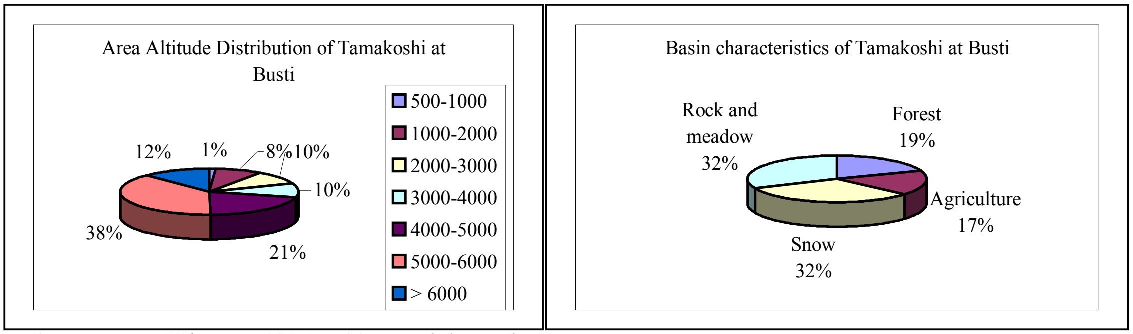
3.5.10 Outlet Discharge

The water discharge values at the outlet of Tsho Rolpa were calculated based on the water level in the lake with respect to the established standard benchmark called Water Level Bench Mark (WLBM) (4580 m asl) by using the empirical formula derived by Tamori Yamada from his field observation in July-November 1994 (Yamada, 1998, p.67). According the measurements done by Yamada (1998), the maximum outlet discharge values were from 16.2 m3/s to 25.9 m3/s in the summers of three consequent years from 1993 to 1995, while the annual average values were between 2.9 m3/s to 4.1 m3/s (Yamada, 1998, p.68). Annual amount of lake discharge was found as 92.6 million m3 in 1994 and 128.9 million m3 in 1995 (ibid). The observed amount of lake discharge corresponded to annual equivalent runoff of 1193 mm and 1661 mm in 1994 and 1995 respectively, whereas the measured precipitation values were 424 mm and 697 mm during the same period (Yamada, 1998, p.69). The observed discharge values were found much higher than the annual observed precipitation values leading to the strong possibilities of more precipitation at higher altitudes and accelerated glacier melt (ibid).

3.6 Hydrological Station at Tamakoshi Busti

The nearest hydrological station from Tsho Rolpa Glacier Lake is situated at about 849 m asl (WECS/DHM, 1996, p. 30) at Tamakoshi Busti nearly about 45 km to the southwest from the lake. This station has river flow measurement data since 1971. The geographical coordination of the station (numbered as 647 of DHM/N) is 27 ^{0} 38' N and 86^{0} 15' E. The river at the station at has a basin area of 2753 km^{2}, out of which about 32 % of snow area. About 50 % of the total basin area was found to be at the elevations of higher than 5000 m asl (ibid). The basin characteristics of Tamakoshi at Busti are given in fig.3.11.

Figure 3.11 Basin Characteristics of Tamakoshi at Busti



Source : WECS/DHM, 1996, p.30, graph by author

3.7 Meteorological Station at Jiri

Jiri Meteorological Station is located at about 35 km southwest from Tsho Rolpa at an elevation of 2003 m asl. The geographical coordinates of the station are $27^0$38’ N, and $86^0$14’E (DHM, 1995, p.2). Temperature, precipitation, and humidity records for 1971-2000 were taken from the station.

CHAPTER FOUR: ANALYSIS AND FINDINGS

4.1 General

There were two levels of data collection, firstly, meteorological and hydrological data from Department of Hydrology and Meteorology of Nepal (DHM/N); and secondly, people's knowledge and information on the study subject from direct interviews with the local people, politicians, journalists, key informants, and experts both at local and national level. The information obtained from key informants and experts was just summarised, but that obtained from the local people was analysed from different angles and perspectives using cross tabulation analysis in order to find the interrelationship between different variables. The data obtained from DHM/N regarding hydrological and meteorological observations were analysed separately for individual parameters of Tsho Rolpa, Jiri, and Tamakoshi. The available data of Tsho Rolpa were not enough to make a trend analysis. So the nearest available stations Jiri (for meteorological data) and Tamakoshi Busti (for hydrological data) were used as data sources. The available data of Tsho Rolpa and those of the stations then correlated to find their interrelationship. After the regression and correlation analyses, the strength and direction of their interrelationship were determined.

The average weather parameters of Tsho Rolpa were found from the simple linear regression analysis. But the trend analyses of these parameters were made for the observed data at downstream stations themselves.

4.2 Analysis of Information Obtained from the Interviews with People

4.2.1 Analysis of Information Obtained from Local People

4.2.1.1General information about the interviewees

Out of the total people contacted during the visit of the study area, most of them agreed to give descriptive interviews to the author, though there were some other people, who provided hands-on information about the study area, current situation on social and safety environment, field visit plan, logistic support and so on. But only the opinions of those, who gave detailed descriptive interview, are mentioned here for analysis.

There were altogether 74 people included into face-to-face interview for this research. Some of them gave information as single person, while others as a group. As the research matter was open to all and required to recall the past memories on the subject, the interviewees preferred to discuss with their family members and even village members while answering. So there was an indirect participation of tens of unnamed people, rather than included in the analysis, who assisted and/or supported to the interviewees in one or other ways during the conversation.

The respondents included in the survey were from 26 different villages of 15 Village Development Committees (VDCs) and one Municipality of Dolakha district. Majority of the respondents were from Singati (16 %) following Charikot (12 %), Jiri (10 %), Beding (8 %), Dolakha (8 %) and rest from other villages. As per the ethnic group, 26 % of them belonged to Brahmin following Sherpa (23 %), Chhetri (19 %), Newar (18%) and others (14 %). Out of the total interviewees, 40 people (54 %) were from the villages, which have been formally identified as the villages having potential risk of flooding from the possible outburst of Tsho Rolpa Glacier Lake (Budhathoki et al, 1996, p.35). According to sex category, most of them were male, as females were not willing to put their names into the survey in front of their male counterparts. Though it was tried to involve the female as well for the face-to-face interview, only 4 % of the interviewees were females.

The respondents were from 25 to 92 years age group. Only 10 % of the respondents were below 30 and about 45 % of them were from the age group of 40-60 years. About 23 % of the interviewees were the age of more than 60 years. Average year of the respondents was 48.2 years.

As per the education level, the biggest group was of just literate (37%), following having school education (32 %) and totally illiterate (16%). The persons having higher education were only about 15 %. Agriculture was the main source of income among the 50 % of interviewed people following teaching (15%), trekking (8%), business (5%), and others. Almost all of them (91 %) were living at the village of present residence since the birth and only 9 % were migrated from elsewhere.

4.2.1.2Methodology and Limitations

It was tried to make conversation with the local people as informal as possible because they were not used to talk in formal manner. The conversation consisted of two major parts. Firstly, their feelings on climate change, its impacts on their lives, economy, environment, water resources etc. Secondly, they were asked about their information level, understanding on Tsho Rolpa Glacier lake, their fear of its possible outburst, possible damage by the flood etc. Therefore it was tried to understand them, to minimise the gap between the respondent and the author and to create a friendly environment. Also it was tried to explain them the objective of the study and the importance of the outcomes of the study to their lives and economy as well. Gradually they became open and frank to the subject matter. As per the research design, the study required to recall the past events for 20-30 years, not all the respondents felt easy to do so. Apart from that, inter-annual variations (i.e. variations within a year) in weather parameters in the study area were more significant than the variations over the years, so it was very difficult for them to compare the weather parameters of the same period of past years to the present ones. Still most of the villagers do not have access to the modern tools and methods for measuring the weather parameters. So they think that it is not their job to know all these things as well. In the past the villagers were hardly asked about such things. Moreover, they think that these things are familiar only for the educated people and experts. After creating a favourable environment for conversation, they were very enthusiastic to share their experience, past remembrance, and knowledge about the natural events to someone else from outside of their village.

As mentioned above, the main research questions for the survey were: firstly, what had been changed in the climate from the past, and what were the impacts on it, focusing on water resources, and secondly, what did the people know about the possible outburst flood of Tsho Rolpa glacier lake. In the study the word “past “ was used to denote the time period of 20-30 years earlier from now. As the structured interview consisted of qualitative character and there was a checklist for the conversation, the information collected from them was compiled into tabular form to make the analysis process easier. The conversion of qualitative data into quantitative was done by the author himself after returning from the interview. So still there might be some places for biasness during this process, though it was made huge effort to be as neutral as possible.

The conversation was basically focussed on five sectors, viz. weather / climate, spring and river flow, biodiversity, weather-related extreme events, and Tsho Rolpa Glacier Lake. As the water resources are closely related to these sectors, the impacts of climate change on water resources was tried to find out through the impacts on these sectors.

4.2.2 Weather / Climate

It was tried to find out whether there were some changes about the seasons, their timings, pattern, and duration over 20-30 years based on the information that the interviewees could remember.

According to the information obtained from the interviews, about 72 % of them told that the summer monsoon started in June. But about end of that season there were divided views on it. About 51 % of the total interviewees told that it ended in September and about 45 % - in October. About the changing of timing of summer monsoon, only a few people (11 %) said that there was a change in timing of monsoon, but about 45 % of the people told that there was no change. Similarly almost the same numbers of respondents did not know whether there were changes or not. Moreover, about the winter season, about 61 % of the people told that it stated in November. There was divided opinion about the ending month of winter. About 47 % of the interviewees told that the winter ended in February whereas the same fraction (47 %) told that it ended in March. In contrary with this about 85 % of the people told that the extreme cold feeling was decreasing.

All of the respondents agreed on the changes in climate and the answers varied from 10 to 40 years. Among them, about 53% told that the climate changes were felt for the last 20 years. About 83 % of answers expressed that the climate was changing for 15-25 years. But a very tiny fraction (about 3 % and the ages of 64 and 76 years) said that the climate was changing for the last 40 year.

It was found that the rainfall character had been changed drastically from the past; from drizzle type of rain (rainfall with low intensity for a long time) to cloudburst type (a sudden and violent fall of rain). About 69 % of the respondent told that monsoon rainfall in the past was drizzle type and about 53 % of them told that now the monsoon rainfall is cloudburst type with frequent shadow rainfall. On the inquiry about the amount of rainfall, 78 % of the opinions were for increased monsoon rainfall while 91 % of them were for decreased winter rainfall. About 55 % of them told that hailstone is decreasing while 88 % of the answers supported the view of decreasing frost in terms of its quantity and numbers of days it occurred.

As in other districts of Nepal Himalayas, the population density in Dolakha and especially in the Himalayan part of the district is very low. Basically the settlements are located at low altitudes, where the climate is not so severe and the agricultural land is available. About 51 % the total respondents were from the place, where there was no snow for a long (15-30 years). The rest of the respondents were basically from the places, where there was still snowfalls reported that the snowfall was decreasing. In that places where there was snowfall in the past (5-10 years ago), remained for more than 2 days, now there is either no snow at all or snow disappears after a few hours of snowfall.

While it was tried to find out whether there is relationship between the age group of the respondent and his/her extreme cold feeling, a positive and strong relationship was found between them (significance of 0.01), similarly a very strong positive relationship was found between their age group and the period for which the respondent is feeling the climate change (significance of 0.007). On the same way, it was found that there is no relationship between increase / decrease of cold feeling and the altitude of the place of their residents (significance > 0.05). The responses on the cold feeling were found to be independent on their ethnic groups (significance of 0.13). The majority of the answers (82 %) said that the predictability about weather phenomena is decreasing.

Box 4.1: Predictability on Weather Events has Decreased Drastically

Rice farming is very important in the Nepalese agriculture. Still significant areas of agricultural land don't have sufficient irrigation facilities, either there is no irrigation at all or there might be insufficient irrigation water. So only the way to fill this gap is to use rainwater. The farmers in Nepal are cultivating crops according to the seasons and rainfall availability. Rice farming needs plenty of water not only for its growth, but also at the time of sowing. About 20-30 years ago, to make a plan, when to plant rice, the people used to make some general prediction based on the natural phenomenon. During the survey, it was found that they used to record the day in the month of Magh (mid January –mid February), when there had been plenty of dew occurred. On the same day of the month of Ashadh (mid June to mid July), there used to be heavy rain giving enough surface flow required for rice plantation. This was the general rule, how they made prediction on rainfall for rice plantation. This rule worked for generations without any major error. But for the last 20-30 years, this predictability lost its strength drastically.

Source : Mr Hari Prasad Gautam, 67; Mr Hari Prasad Adhikari, 64, Charikot, Dolakha in interview on 13.12.2002 at Charikot

4.2.3 Spring Water and River Flow in Dry season

There was a clear view on the water resources available for dry season that the numbers and amount of spring water sources, both were decreasing. About 84% of the respondents reported that the numbers of spring sources were decreasing, while about 82 % of them expressed that the amount of spring water flow was also decreasing. They were feeling the significant water shortage for drinking and agriculture purposes. They needed more water now than earlier to irrigate the same land by the same source of water, almost all agreed on it. But on the other hand, there were divided opinions on the reasons for such decreasing of water sources such as due to more people, due to deforestation, due to landslides, due to human disturbances during the construction work, etc. When it was tried to analyze the relationship of age group, education and profession of the respondents with the decrease in springs, it was found that the responses were strongly dependent on their profession, but independent on age group and education level. The people with the profession of agriculture were more sensitive to the decrease on springs as water sources.

Some Remarkable Notes from the local people how the spring water was decreasing are given below in Box 4.2.

Box 4.2: Springs are drying up

Tirtha Bahadur Siwakoti, 49, Sunkhani-4, Gumkhola :

- Three numbers of springs sources dried up in Gumkhola
- In Riththe spring source, water even dry season was surplus. Water remained surplus from 2.5 cm diameter pipe about 5/6 years ago, now it is just half in the pipe.

Dil Krishna Malla, 37, Laduk-8, Singati:

- About 25 % of water volume in springs sources has decreased and about 10 % of all springs in the village have dried up

Tilak Bahadur Khadka, 76, Laduk-8, Singati:

- About 1/3 of all the springs have disappeared during the last 50 years.
- About 50 years ago, during the wintertime, there used to be heavy snowfall, and all the spring water had frozen. Then the water for drinking was made by melting snow and ice using cook-stoves.

Tirtha Narayan Joshi, 42, Dolakha Bazaar:

- Nowadays, there is too much rainfall, when it is not required; and too less rainfall, when it is required. Rainfall is occurring just opposite to our needs.
- Spring source in Narayan Deu Chhopati Dhara near Dolakha bazaar disappeared.
- The water source from Charikot to Dolakha bazaar has decreased by 60%.

- Now it requires more time to irrigate the same land from the same source of water than 10-15 years ago. It took 1-2 hours to irrigate the land from the same spring source 10 years ago, now it takes 3-4 hours for that.

Krishna Shrestha, 47; Dambar Bahadur Shrestha, 47; Dolakha Bazaar:

- Nowadays, Tindhara spring source dries up in April, which used to sustain for all the time of the year 8-10 years ago
- The dry season flow of Chotebari spring source has decreased by about half of that available 15 years ago.
- Devisthan spring source was full of 7.5 cm diameter pipe during dry season 10-15 years ago, now it is only half of it.

Hari Prasad Gautam, 67; Charikot:

- There was heavy snowfall even down to Tamakoshi in 1944. The rainwater falling from the roofs of the houses converted into ice pillar; the trails and tracks remained fully covered by snow for 3-4 days and it was very difficult to pass through.
- In January 1974, there was again heavy snowfall down to Tamakoshi, where snow remained for 2-3 days.
- Okhreni spring source at Charikot disappeared about 10 years ago.

Pradeep Manadhar, 49 ; Charikot:

- Sim, Silkhan, and Darpe spring sources near Charikot are drying up, especially in spring season

Tara Nath Chaulagain, 58, Jilu:

- Aange spring source at Jilu disappeared 8-10 years ago
- Chharchhare spring source at Jilu has dried up by about 50 % of the previous spring water.
- In Bharyang Khola, the water mill used to run all the days of the year about 15 years ago, now it cannot run from January to April.

Source: Personal interview with author on 6-15 December, 2003

4.2.4 Bio-diversity

It was tried to analyse the changing pattern of agriculture with respect to cropping and harvesting time, agriculture species, newly started or disappeared agriculture and forest species, animals and birds etc. through the eyes of climate change and its impact on water resources. Almost all of the respondents agreed on that the traditional local species in agriculture are being replaced gradually by the hybrid species, and some forest species are disappearing.

About 93 % of answers told that traditional agriculture species are being replaced by hybrid and new species. They are growing now many new varieties of agricultural species, which they have never seen before in the village, e.g. green vegetables (cauliflower, onions, cabbage, etc.), rice, sugarcane etc. About 51 % of the respondents are growing rice as traditional farming, about 24 % of the respondents have started rice farming as new crop and about 4 % of them have extended the rice farming area. Out of the total respondents, 45 % said that the cropping and harvesting time has been changed against 32 % saying no change. Among them saying changed cropping and harvesting time, opinion was not clear rather divided, 27 % said that cropping / harvesting time at present was earlier than before and 18 % said that the present was later than before. Earlier and later was counted with respect to date and month. The agricultural production in the area was found to be decreasing (66 % of responses) but majority of them (82 % answers) do not know the reason for that. Only about 8 % of them replied climate change as the reason for decrease in agricultural production.

Forest species (plants and animals) were also disappearing (74 % of answers), but the numbers and type of disappeared species from the forest were different for each village. Most of the people replied that the main reason for such disappearances was high encroachment and high pressure into the forest by over-increasing population. There was no mosquito at all in most of the villages of the respondents' residence 20 years ago, but many of them complained mosquito bites in summer months of the recent years.

4.2.5 Socio-cultural effects

It was tried to find out whether there were some impacts of climate change on housing pattern, clothing pattern, and migration. The results from the survey did not give the anticipated output. There were significant changes in housing and clothing pattern but due to modernization and external influences rather than due to climate changes. The hypothesis behind asking these questions was that the people would use less warm clothes, build houses with larger window areas and less wall thickness. The same result came out, while they were asked about the reasons for such changes almost all replied that it is due to fashion and modernization governed by external influences. So in order to define how much the share in influence was by climate change; it required further research and more detailed studies.

Migration might be desired or forced. Desired migration, in general case, is driven by the economic reasons. Such migration might be within the area or outside the area. But when we talk about the forced migration, it is related to some extreme events, natural disaster, fire or so on. Weather related forced migration in the study area was basically caused by landslides and flooding. Such migration had an adverse effect not only on economic situation but also on cultural and social cohesion.

About 60 % of the respondents replied that there was no migration as such. But about 14 % the interviewees replied that there was forced migration due to landslides in their villages. These people were among them, who had lost their properties and even loved ones during the landslides and floods of the past years. Even the people from the area, where early warning systems were installed to warn them in case of outburst of Tsho Rolpa Glacier Lake, did not migrated out to other areas and they were not planning to do so in the near future. This was because of the fact that the people were living there for a very long, and some of them for generations, and most of the sources of their subsistence were integrated with the place and limited within that. Therefore the people were not planning to leave the place, though they were informed about the risk of flooding from the Tsho Rolpa GLOF. This might also be so because of that, most of them (about 68 % of the respondent from risk prone areas) replied that the possibility of outburst flood of Tsho Rolpa was unlikely.

4.2.6 Weather-related disasters

Landslides and floods were mainly found as weather-related disasters in the study area. From the flood, till now there was not so huge damage by river floods compared with that by landslides because the settlements were located a little bit higher than river level; and the river could not come up to their properties yet. Furthermore most of them (about 91 % of the respondents) do not have any real knowledge on the mechanism of GLOF and its disastrous effect and they have not seen such floods yet anywhere else.

Newly born market places on the bank of river are found to be more vulnerable to flooding than traditionally built residential areas. The Tamakoshi River has a deep cross section with nearly vertical gorge in most of the places. The connecting foot trails and tracks generally follow the river course, parallel to it. The market places were born on the way of these tracks / trails on a very limited areas and, some times, very near to riverbed. So a significant numbers of houses are located on the riverbank and are very much vulnerable to flooding, especially in case of GLOF.

As mentioned earlier, the people in the study areas were already suffered very much by the landslides with huge loss of properties and lives. So it was tried during this study to determine the changes, if any, in magnitudes and frequencies of landslides and floods. About 92 % of the respondents expressed that both the landslides and floods were increasing in terms of magnitudes and frequencies. After 1979, the flood and landslides events increased significantly. Some landslides and floods records in Dolakha obtained during the survey are given in Box 4.3 below.

Box 4.3: Floods and Landslides are increasing in Dolakha

May 1979:

- A postman on-duty lost his life under the landslide at Magapauwa VDC. Some agriculture fields and forests were also destroyed there.

July 1982:

- Landslides at Dandakharka VDC affected around 40-42 families.
- About 14-15 families were affected by landslides at Aahale of Magapauwa VDC

July 1985:

- About 10 people were washed away by the landslide even in Dolakha Bazaar
- Landslides at Phalante killed 19 people and washed away their 12 houses including cattle and cattle sheds
- Altogether 17 people and 7 houses were washed away at Jhyanku including agriculture fields, cattle, cattle sheds and forests

August 1987:

- Three houses were completely washed away at Boch, where 3 people were killed

August 1996:

- Newly completed water supply system was destroyed, which was designed for 8-10 villages at Sunkhani VDC. One person lost his life.
- Houses of 7 families with their members, more than 100 cattle and their cattle sheds were completely washed away and 17 people lost lives at Jhyanku. A large area of agricultural fields was also washed away. Many people were washed away, when they were sleeping.
- The landslides destroyed water supply scheme at Jugu VDC.

August 1997:

- Landslides and floods destroyed the rice field of about 20 hectare at Makaibari VDC

August 2002:

- Three people lost their lives at Babare VDC
- Some people were killed at Khare by the landslide..
- About 16 families were displaced at Sailungeshwar VDC
- Agricultural fields were destroyed at Magapauwa VDC
- One house collapsed and 2 children were killed at Makaibari

Source: Dibakar Dahal and victims of Jhyanku landslides in interview with author on 13.12.02.

4.2.7 Potential Risk of Possible Tsho Rolpa GLOF

As already mentioned, about 54 % of the respondents were from the place, which was officially listed as the place having potential risk of flooding from the outburst of Tsho Rolpa lake, it was tried to find out their understanding and views on the lake itself, its nature, and potential threat of its outburst. Almost all of the respondents (about 99 % of them) knew the name of Tsho Rolpa and the information about its potential outburst. In the summer of 1997, the lake was in most dangerous situation and there was massive campaign over the whole district and even over the neighbouring district of Ramechhap (downstream along the Tamakoshi river) on the potential risk of outburst flood and the measures to minimize the losses from it. Most of them were known about the ongoing remedial activities such as installing siphon pipes to drain out the water from the lake in order to minimize the rise in water level in the lake. On the same way they had very weak information on the lake lowering process.

Though about 41 % of the respondents had personally visited the lake and had seen its condition, not all of the visited persons could understand the nature of the problem. Not all, who visited the lake, were interested to know the condition of the lake because they had gone there for other reasons. Out of the total visiting the lake, only about 26 % had been there as a tourist, 23 % were living near to the lake and remaining 51 % had been there as a worker or porter. Out of the total 31 persons visiting the lake, 38 % were just literate, 29 % of them were with school education, and only 19 % with higher education. About 13 % of them were totally illiterate.

On the other hand, those, who had not visited the lake, knew about it from other sources like from their villagers (47 %), and from media (11 %). When it was tried to find out their views on the potential threat of possible outburst of the lake, the result was shocking and amazing. About 50 % of the respondent told that they considered the potential outburst of the lake unlikely, in contrary with only 38 % respondent saying the possibility of outburst flood was likely. Only 58 % of the total respondents visiting the lake reported its outburst likely. All of the respondents living near to the lake believed its outburst. Majority of the respondents visiting the lake as a worker / porter did not believe its outburst. The analysis of the relationship between the distance from Tsho Rolpa and their attitude towards the outburst flood showed a strong relationship between them. The nearer they were, the better they knew the problem, and the more they were aware of GLOF disaster.

Then an attempt was made to find out the relationship between education level and understanding about the GLOF. This analysis showed a strong direct relationship (a higher linear association with significance of 0.021) between them. About 73% of the respondents with higher education believed on possible GLOF, whether 83 % of the illiterate respondents considered such GLOF events as unlikely. Furthermore only about 53 % of the literate respondents up to school education did not considered the outburst flood of Tsho Rolpa as likely. The more educated they were, the more they considered the risk of potential GLOF as likely.

Similarly a strong relationship was found between the understanding of Tsho Rolpa GLOF and the altitude of their residence. The higher the altitude (i.e. the closer to the Himalayan climate) of their residence was, the better understanding of GLOF events they had. About 89 % of the respondents from the altitude below 1500 m asl did not believe on outburst of Tsho Rolpa, whether 44 % of the respondents from 1600-2000 m asl believed on such events. Furthermore, all of the respondents from the places above 3100 m asl considered possible Tsho Rolpa GLOF as a potential threat to their lives and properties.

Nearly the same results came out from the analysis of the responses on the information about the past GLOF events as well. Only about 37 % of the respondent living below 1500 m asl had information about the past GLOF events, while 53 % of the respondent living at 1600-2000 m asl had such information, and furthermore all of the respondents living above 3100 m knew such GLOF events in the past in Nepal Himalayas and/or in China.

On the same way, it was tried to find out the relationship between the distance of Tsho Rolpa and information on past GLOF events, a very strong and direct relationship was found between them (significance of 0.001). All of the respondents within 20 km from Tsho Rolpa knew the past GLOF events including the outburst of Dudhpokhari Glacier Lake (a glacier lake formed at the terminus of Chhubung glacier) in July 1991. About 65 % of the respondents up to the distance of 60 km from Tsho Rolpa had some information on past GLOF events, while only 50 % of the respondents up to 80 km did so.

Again a direct and strong relationship between the ethnic group of the respondents and their attitude towards the outburst of Tsho Rolpa was found. About 62 % of the Newar respondents reported that the outburst was likely. Similarly 42 % of Brahmins and 41 % of Sherpas expressed the same view. But the respondents from other ethnic groups, rather than aforementioned three ethnic groups, none of the respondents told that the outburst was likely.

Box 4.4 Minister's helicopter flight and panic among the people

In summer 1997, Tsho Rolpa Glacier Lake was in the most dangerous situation and had the size of 1.65 km^2, the largest in the history of the lake. Early warning systems were installed in 17 villages in the downstream, which were identified as the most risk-prone. The early warning system was connected to the capital city as well to inform the government on the potential disaster as soon as possible. The villagers were informed about the possibility of glacier lake outburst flood and its disastrous effect. The people were asked to leave their houses as soon as possible after siren blowing (like ambulance) and go to the upper heights of at least 20 m from the riverbed. At every village, the facilitators from the risk reduction projects were providing safety instructions to the villagers. At every village, some special point was fixed as the lowest safe place during flood, so the people should have gone above that point immediately after hearing the siren.

Furthermore, the people were asked not to keep any valuable things, and important documents at their home near to riverbank and to keep them somewhere else in the upper safe places. Similarly they were asked to make temporary sheds at the higher level than the marked point. National level media were full of the news on potential outburst flood of the lake and the people in the area could not sleep at their home and used to sleep at their huts during the "terrible" period. The government of Nepal at that time was in huge pressure from the national and international organizations to act adequately to save the life of people and their property in case of outburst-flood. Likewise, the people were asked to leave their home and go upwards even they would see the helicopters flying over the sky of the areas. They were told that when the lake outburst flood would occur, the high level officials would go immediately to the lake and start monitoring and immediate help even by the helicopter. So the people were afraid of not only hearing the sound of siren, but also of the helicopter nearby to the areas.

Once, in one of the villages, a lizard, by chance entered into the siren systems and something went wrong inside the siren. Then the siren started to blow. The villagers thought that, the outburst occurred and ran away to higher places, but later when there was no flood, they found that it was due to the lizard, rather the outburst flood. This event hurt the people of that village very badly.

Besides that, the then deputy prime minister, wanted to visit the lake and to know the real situation directly. Then he took a helicopter and flew to the area without informing people that it was the simple flight of minister's visit to the lake. When the people saw the helicopter flying over their sky, the thought that the outburst occurred. Then the people of the all villages ran to the higher place immediately. Even the people, who were performing funeral ritual at the riverbank, ran up to higher places leaving the dead body there. In reality it was not an outburst flood, but just a minister's visit. Then that event hurt the whole people in the downstream very badly. Such kinds of events sharply reduced the people's believe on the risk reduction projects, and gave places for the growth of unwanted misunderstandings and numerous rumours about the glacier lake outburst flood. During the time of survey, many people just told that, the outburst flood did not happen because it was unlikely to happen. According to their opinion, the high level officials including national and international donors had vested interest to create such havoc of flood.

Source: Information based on personal conversation with Mr Rajendra Manandhar at Charikot on 15.12.2002.

4.3 Information Obtained from the Interviews with Key Informants

Nepal being a developing country, most of its economic and social systems are based on natural resources rather than modern technological achievements. The minor change in the naturally balanced system faster than the rate required to adapt with the change does much more serious impacts on the life support systems of the economy of the rural people. Marginalized and the poorest of the poor section of the population will be impacted more due to low capability to cope with the changes. Still Nepal has traditional subsistence farming practices supporting nearly 83 percent of the total population of Nepal (CBS, 1998, p.24). Out of the total agricultural land of 3,052,700 ha (CBS, 1998, p.332), which is about 21 percent of Nepal's total area, only a part of it i.e. 908,854 ha, which is about 30 percent of the total agricultural land, is under modern irrigation facilities (CBS, 2002a, p. 62). The rest of the cultivated lands has to rely on rainfall to meet their crop water requirement. The water resources related systems such as drinking water supply, irrigation, and hydropower are facing the water shortage during dry seasons, as their sources are very much vulnerable to climate change. Due to changing climate, there will less rainfall in winter resulting in less ground water recharge in this period, which ultimately will reduce the spring flow in the hilly rivers. This process has doubled the negative effects on irrigation-water-deficit - in one side more water demand due to less rainfall and in the other side less water available in the river sources (Upadhyaya, B.P.). As the more precipitation will be in summer, there will be more floods, landslides and soil erosion (ibid).

As the temperature increases, the less precipitation will be in the form of snow and more in the form of rainfall. This result in less water storage in the mountains, thus smaller dry season river flows, and larger summer monsoon flows in the river. Further more the liquid precipitation accelerates the melting of ice in the mountains. Thus, the more the share of liquid precipitation, the more unbalanced the river flow will be (i.e. the ratio of maximum flow to minimum flow will be more) (Shrestha A.B.).

As already stated, water resources are playing very important roles on each and every sector of national economy in one or other ways, the impacts of climate change on them are very significant for Nepal, specially low flows in the rivers will be very critical due to the change in temperature and precipitation pattern (Sharma, K.P.). Smaller the water systems are, the more vulnerable they are to the climate change and the more random variations they have(Shrestha , PB; Dahal, N; Shrestha AB; Dixit , A) . People in the hills and mountains are mostly using the smaller sources of water because they are easy to manage, which are more sensitive to climate change than the bigger ones. The smaller springs and rivers will dry up first, the smaller glaciers will retreat and disappear first. So the dry period is more critical to the climate change because there will be more demand and but less water is available (Sharma, K.P.; Shrestha, A.B.).

The major vulnerability of water resources to the climate change in context of Nepal exists in the form of hydrological extremes. Water resources are being affected by climate change through hydrological extremes and hydrological variability (Sharma, K.P.). By universally established study, it is known that the greenhouse gas (GHG) emission, mainly from the energy consumption, is the main cause of global warming. Though Nepal's per capita energy consumption is not so high, Nepal is facing the problem of global climate change. So the impacts of climate change on the water resources is much more due to global or regional effects than local (Shrestha, A.B.). Nepal's high altitude variation in small horizontal distance makes very difficult to use Global Circulation Model (GCM) or other models developed in the world for preparing the climate scenarios for Nepal (Sharma, K.P.)1.

4.4 Climate Data Analysis

As climate data at Tsho Rolpa were available only after 1993 and even after that, there were certain data gaps in-betweens for the period of 1993-2000. The weather data at Tsho Rolpa were just enough to describe the weather condition aver there. So another weather station in the same district located at Jiri at an aerial distance of about 35 km to the southwest from Tsho Rolpa was used as a data source of temperature, precipitation, and humidity for the period of 1993-2000. Similarly a river gauge station at Tamakoshi Busti located at about an aerial distance of 45 km to the southwest from the lake (at about 60 km downstream of Tsho Rolpa along Tamakoshi River) was taken to analyse the flow pattern in this study.

[1] This summary was prepared based on the information given by the key-informants . All the views written here belong to them. Full list of the key-informants is given in Appendices.

4.4.1 Jiri

The weather data of Jiri Meteorological Station were available for 1971-2000. As per WMO standard, the classical period for analysis of climate data is 3 decades (McCarthy, J.J. et al, 2001, p.984), and the available data for the mentioned period were considered as enough for the analysis for this research.

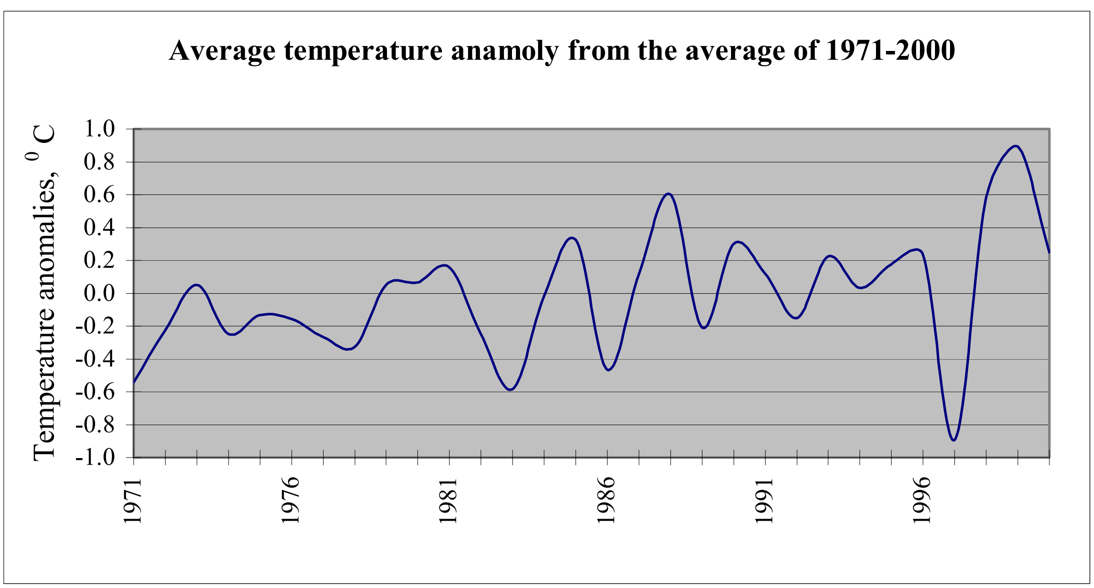
4.4.1.1 Temperature

Based on the available data, the average temperature, extreme maximum, and extreme minimum temperatures were calculated using excel spreadsheet. The analyses of each of these components are given below.

4.4.1.1.1 Average Temperatures

The average temperature of Jiri for the period of 1971-1999 was calculated as 14.1 ^{0} C from the annual averages of the whole period. Annual average values were obtained from the monthly averages of each year. Out of total 30 average annual temperature values from 1971 to 2000; 13 were below the average ones, while 17 were above. The average temperature anomalies for this period is given below in Figure 4.1

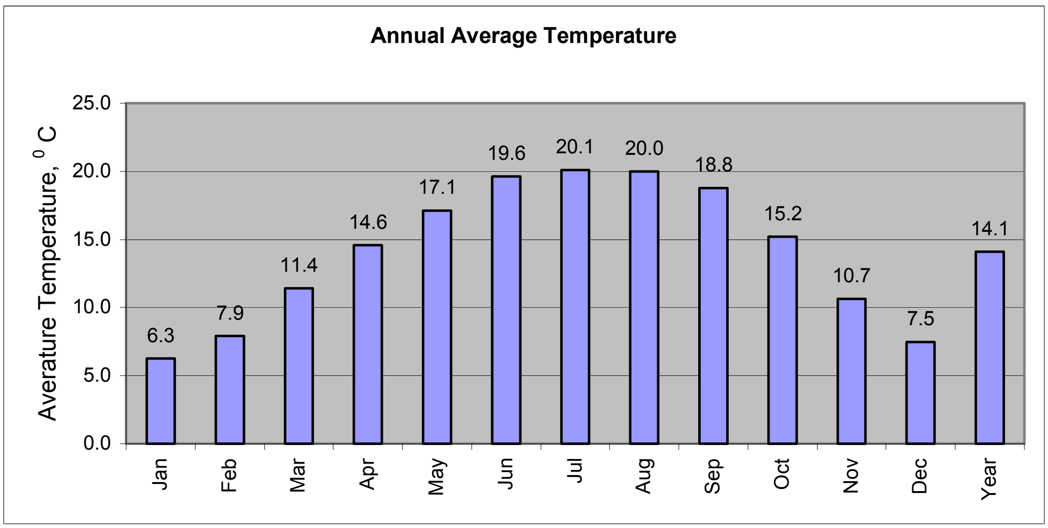
Fig. 4.1: Departures of annual average temperatures from the 30 years average at Jiri



Source: Data from DHM/N, graph by author

Similarly long term average monthly values also were calculated as the average of any particular months of the whole period of 1971-2000. During the whole study period, January was the coldest month for 87 % of the period, while July was the hottest one for 60 % of the times. Seven months (April-October) were found to be warmer than the average temperature and rest of 5 were colder than average. The average temperature of Jiri is given below in Figure 4.2

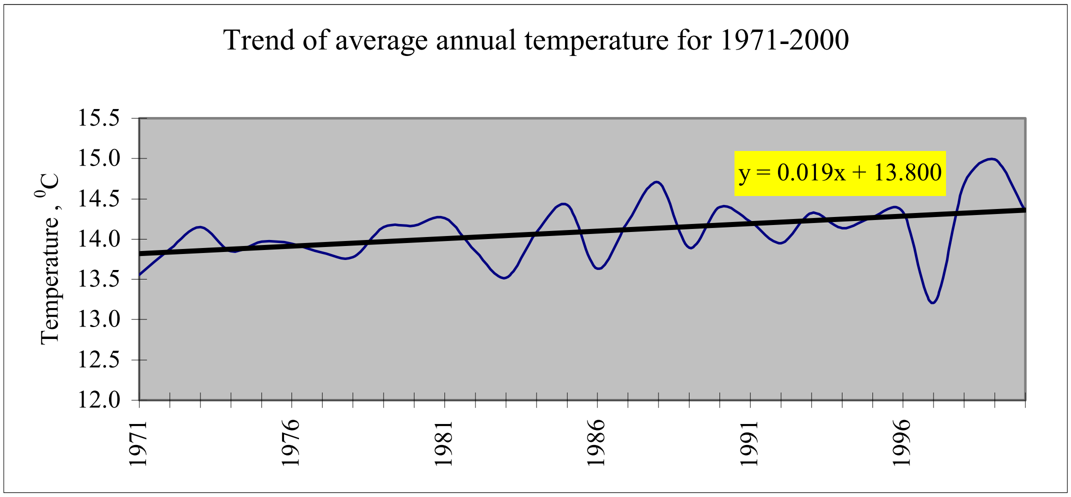
Fig. 4.2: Monthly average temperatures of Jiri of the average of 1971-2000



Source: Data from DHM/N, graph by author

A trend line was made in order to find out the temperature trend over Jiri. The average temperature increased at a rate of 0.019 ^{0} C / year. So Jiri was found roughly 0.56 ^{0} C warmer in terms of average temperature than it was 30 years ago. Despite the increasing trend of average temperature, the average temperature of the year 1997 (13.2 ^{0} C) was even lower than that of the year 1971 by 0.3 ^{0} C. The average temperature data for the year 1971 were found different than those of other years. All the months of the year 1971 except July, August, and September had lower average monthly values than the long-term average monthly values. The satisfactory explanation for that could not be found. The trend of the average temperature is given below in Fig. 4.3.

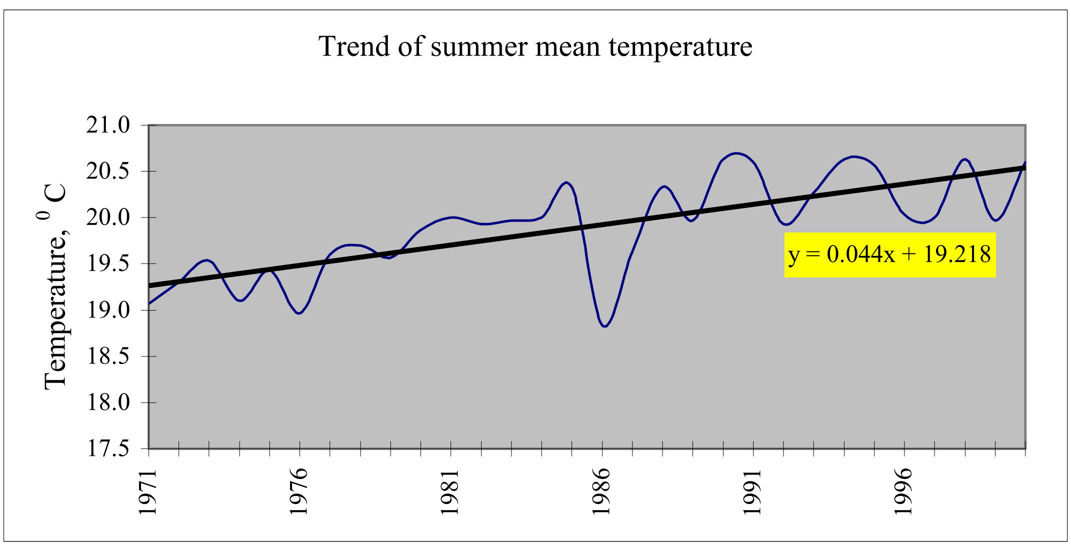
Fig.4.3: Average annual temperature trend at Jiri



Source: Data from DHM/N, graph by author

The average temperature trend for summer months was found to be 0.044 0 C /year and higher than the annual average trend, which is given below in fig. 4.4.

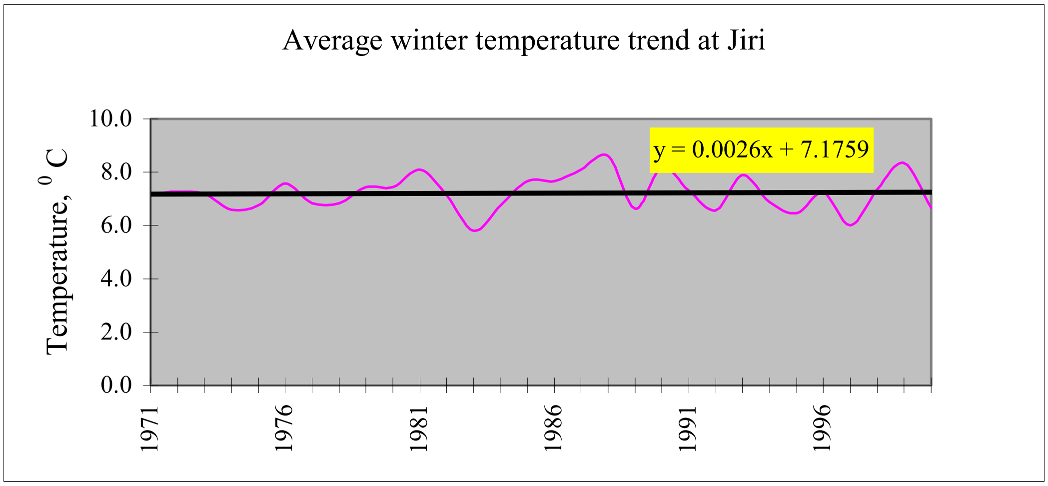
Fig. 4.4: Trend of average summer temperature of Jiri (June-August) for 1971-2000



Source: Data from DHM/N, graph by author

Similarly the mean winter temperatures were calculated over the study period and was found that the mean winter temperature was increasing at a relatively slow rate of 0.0026^0C /year as given below in Fig 4.5.

Fig. 4.5: Mean winter temperature trend at Jiri for 1971-2000

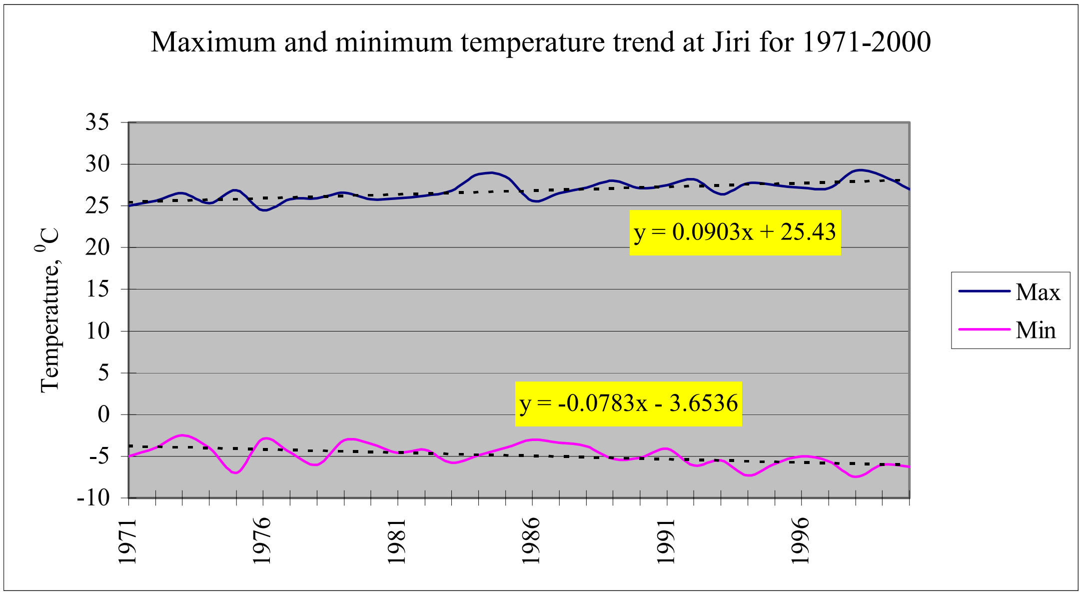


Source: Graph by author, data from DHM/N

4.4.1.1.2 Extreme temperatures

The trends of the extreme temperatures were not found as the same as those of averages. The annual extreme maximum temperature was increasing at a rate of 0.09 ^{0} C /year, while the minimum annual extreme temperature was decreasing at a rate of 0.078 ^{0} C /year, which showed a significantly increasing trend in the temperature fluctuations (difference between maximum extreme and minimum extreme within a same year). The extreme maximum temperature of 29.2 ^{0} C recorded on June 11, 1998 as the maximum extreme temperature of the year (the highest of the ever recorded temperature) was 4.2 ^{0} C higher than that recorded on July 15, 1971 as 25 ^{0} C. Similarly the extreme minimum temperature of –7.5 ^{0} C recorded on January 18, 1998 as the minimum extreme temperature was found to be the lowest of the ever recorded minimum temperature was 2.5 ^{0} C lower than that recorded on January 31, 1971 as –5 ^{0} C. The year of 1998 was the most extreme year out of the whole years of the study period in terms of both highest and lowest temperature records with the largest temperature difference in the whole history of records i.e. 36.7 ^{0}C, while the average temperature range for the whole period was found only 31.7 ^{0}C. The maximum and minimum extreme temperature trends are given below in Fig. 4.6.

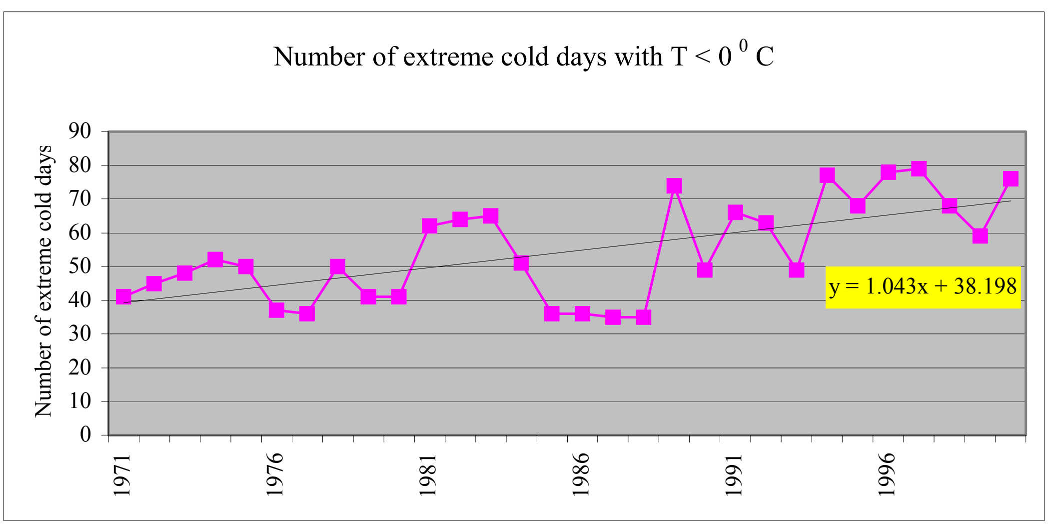
Fig.4.6: Maximum and minimum extreme temperatures at Jiri



Source: Graph by author, data from DHM/N

According to the data, average number of days with temperature less than ^{0}C was found 54. From the analysis, number of such cold days in a year was found to be increasing at a rate of about 1.04 days / year i.e. about 1.9% annually. For example, there were only 41 days with minimum temperature below 0 ^{0}C in 1971, whereas such days were 76 in 2000. The trend is given below in the fig.4.7.

Fig. 4.7: The trend of number of extreme cold days with temperature below 0 ^{0}C



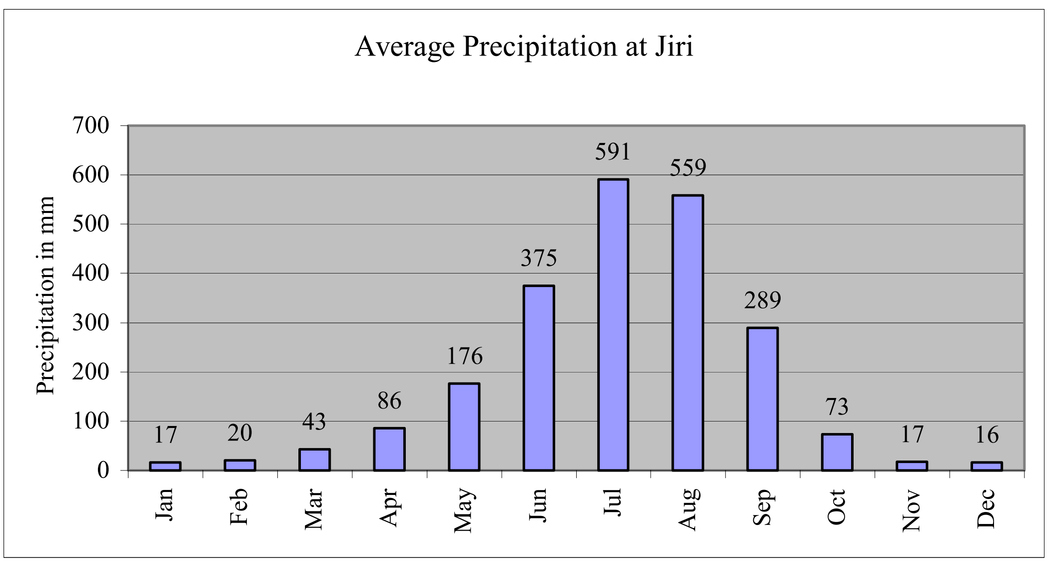
Source: Graph by author, data from DHM/N

Despite the increase in average winter temperature, the extreme minimum temperature was decreasing and the extreme cold days were increasing. On the other hand, the extreme maximum temperature and average summer temperature both were increasing. This resulted in the increasing trend of temperature fluctuation within a year, which might have serious consequences in the nature and environment. For example maximum temperature of 29.2 ^{0}C, the hottest of the whole period; and minimum temperature of –7.5 ^{0}C, the coldest of the same period; both occurred in 1998. Such increasing temperature fluctuations may cause difficulties to adapt the new temperatures for the plant, animals, and environment.

4.4.1.2Precipitation

The average annual precipitation at Jiri for the whole study period of 1971-2000 was found to be 2263 mm. Out of the whole months; December was the driest month with precipitation of 15 mm, while July was the wettest month with 591 mm precipitation. For details, please refer to Annexes. The long-term annual average precipitation is given below in Fig 4.8.

Fig.4.8: Average annual precipitation at Jiri (average of 1971-2000) in mm

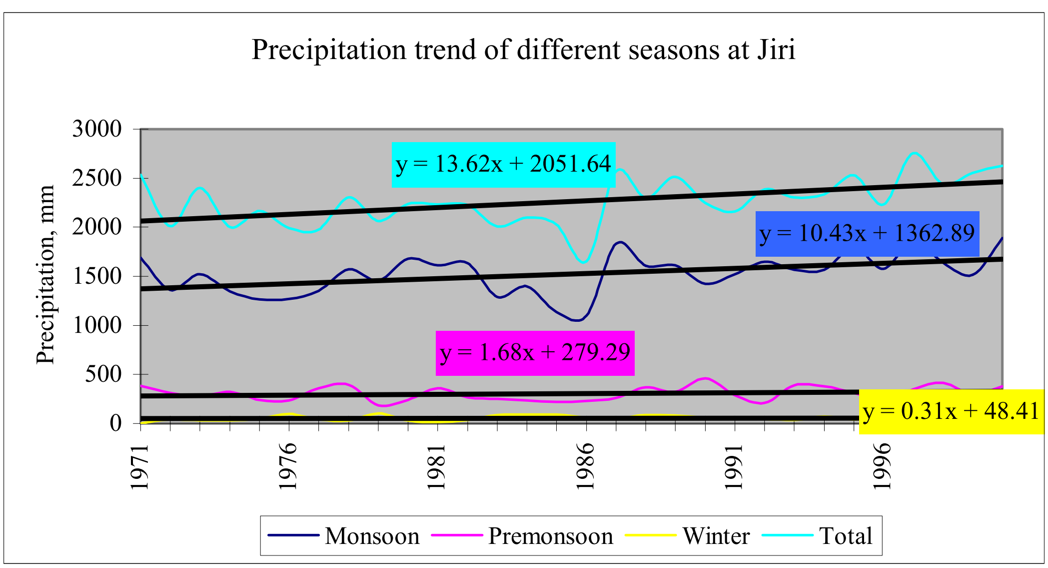


Source: Graph by author, data from DHM/N

The available precipitation data were categorized first into seasonal precipitation i.e. monsoon precipitation (June-August) and post-monsoon precipitation (September-November), winter precipitation (December-February), and pre-monsoon precipitation (March-May). The average summer precipitation was found to be 1525 mm (about 67 % of total annual precipitation), while winter precipitation only about 53 mm (i.e. about 2.3% of annual precipitation). The year 1986 was the driest year of the whole study period with annual precipitation of only 1655 mm while 1997 was the wettest year with annual precipitation of 2754 mm.

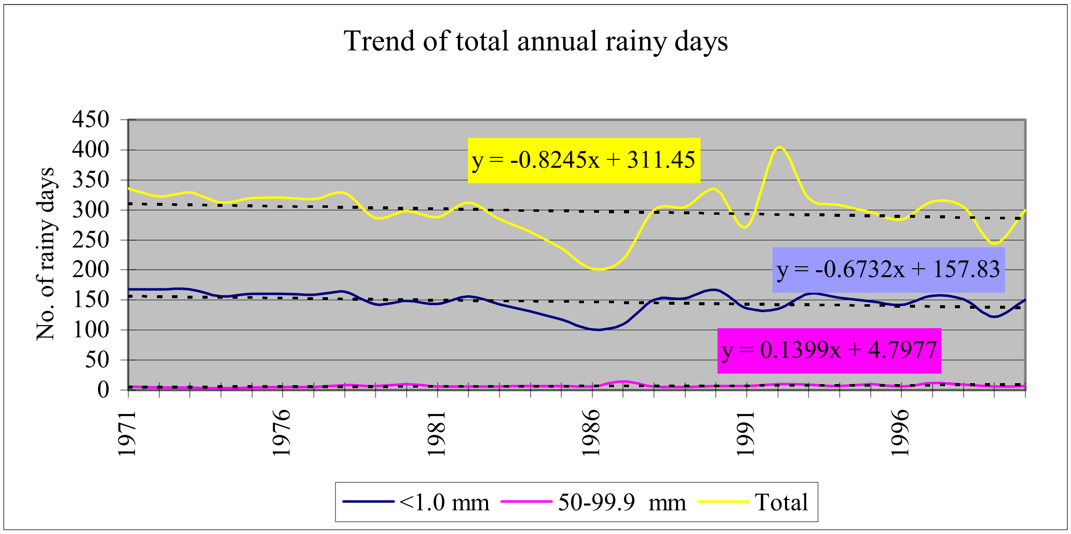
While looking into the change in precipitation, it was found that the total annual precipitation was increasing at a rate of 13.6 mm /year (i.e. 0.6 % annually). The average number of rainy days was found 299 in a year. The number of rainy days was found decreasing at a rate of about 0.82 days/year (i.e.0.27% annually). Furthermore while going into deeper the number of days according to precipitation intensity for 24 hours, numbers of days with precipitation intensity of less than 1.0 mm in 24 hours were decreasing approximately at 0.67 days/year, while those with precipitation intensity of more than 50 mm in 24 hours were increasing approximately at 0.14 days / year.. This analysis showed a significant concentration of annual precipitation into relatively shorter period, despite the significant increase in the absolute amount of precipitation. This resulted in increasing trend of more intense rainfall (i.e. cloudburst) and decreasing trend of shower /drizzle type of rain. While going into seasonal variation, summer precipitation was increasing at 10.43 mm / year (i.e.0.68% annually) in contrary with the winter precipitation rise only 0.31 mm /year. The trends of precipitation in different seasons are given in fig. 4.9, while the trend of annual number of rainy days is given in fig. 4.10.

Fig. 4.9: Trends of precipitation change in different seasons at Jiri for 1971-2000



Source: Graph by author, data from DHM /N

Fig. 4.10: Trends total annual number of rainy days



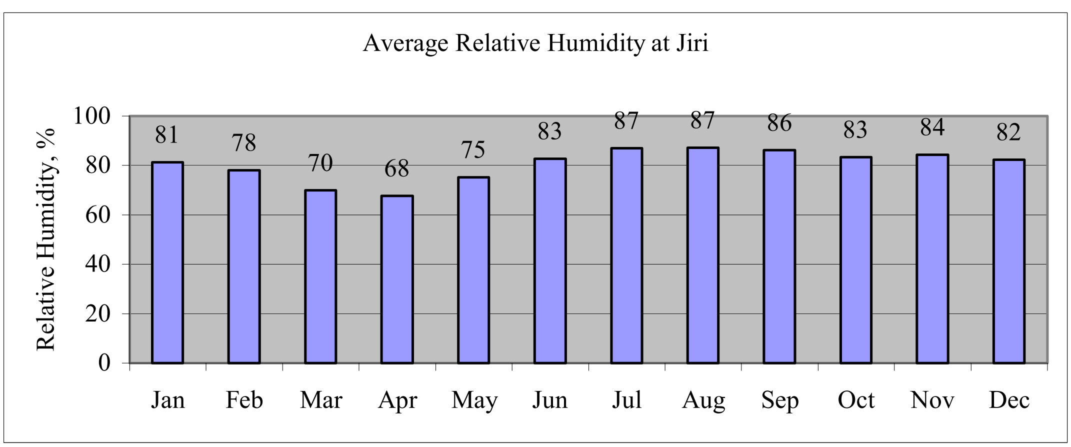
Source: Graph by author, data from DHM/N

The information given above on the trend of precipitation and rainy days showed a significant change in precipitation pattern, i.e. increasing precipitation amount and decreasing number of rainy days resulting in more intense precipitation responsible for increased number of floods and landslide events both in terms of frequency and magnitude.

4.4.1.3 Relative Humidity

Average annual relative humidity of Tsho Rolpa was found to be 80 %. The distribution of annual average relative humidity to months is given in fig. 4.11.

Fig. 4.11 Average monthly relative humidity at Jiri (average of 1971-2000)

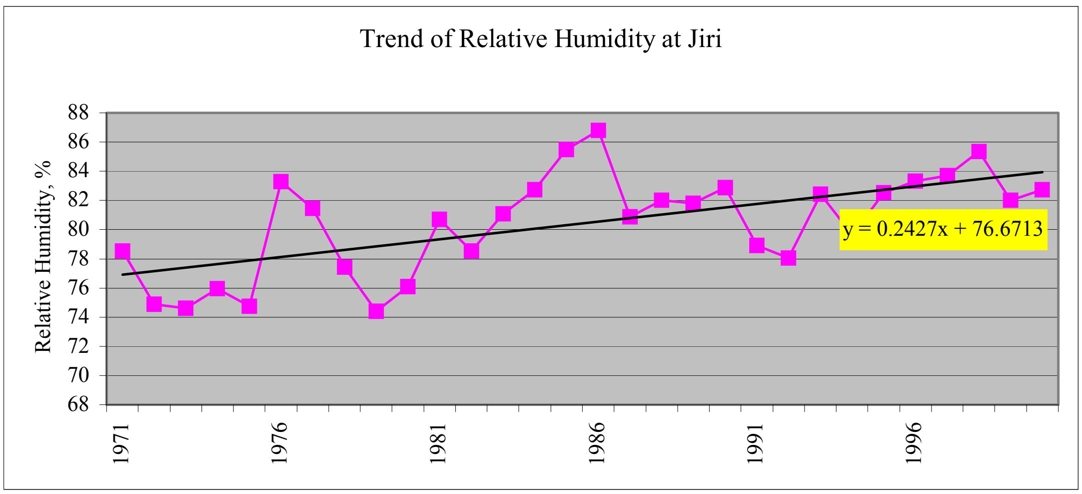


Source: Graph by author, data from DHM /N

As shown above in figure, the average relative humidity varied from 68 % in April to 87 % in June/July. These average values were obtained by making average of the maximum and minimum daily relative humidity values and then getting average for the whole month.

The annual average relative humidity values were significantly increasing over the last 30 years at a rate of about 0.24 % per year. Out of the total period of study, minimum and maximum values of relative humidity were in 1979 (74 %) and in 1986 (87 %) respectively. The trend over the period is given in fig 4.12 below.

Fig. 4.12: Trend of Relative Humidity at Jiri for 1971-2000



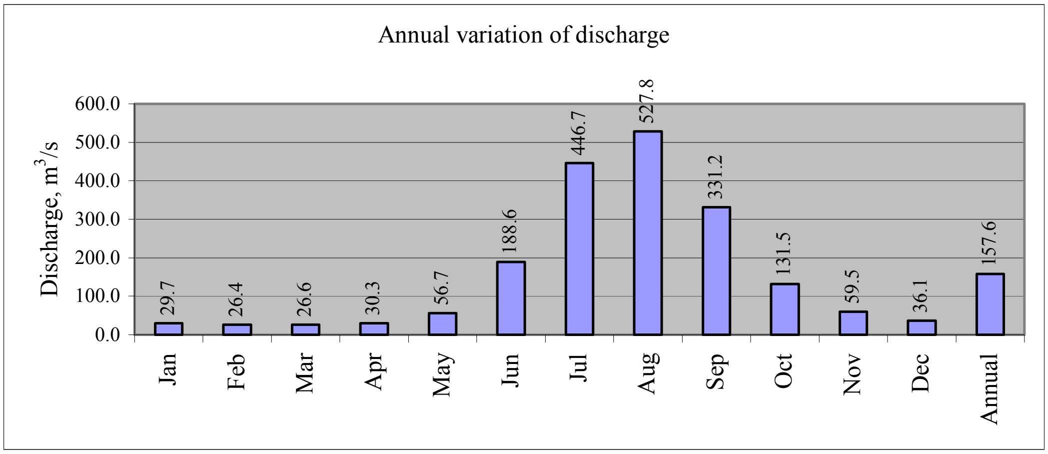
Source: Graph by author, data from DHM/N

4.4.2 Tamakoshi Busti

The river flow data of Tamakoshi River recorded at Tamakoshi Busti for the period of 1971-2000 were analysed to determine the trend in change of flow regime. The detailed data are given in Annexes.

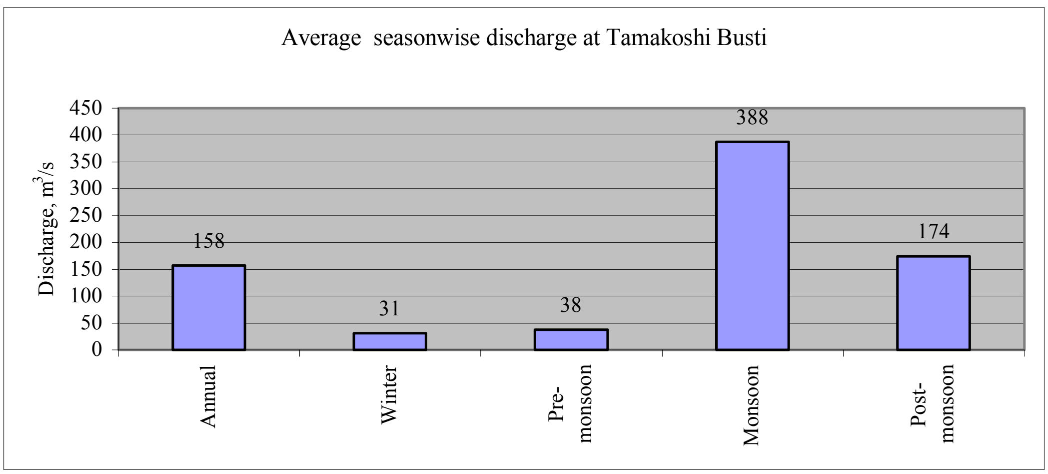
By the analysis, the average annual flow at the station was found to be 157.6 m^3/s. Similarly among the average monthly flows, there was maximum flow in August (527.8 m^3/s), whereas the minimum in February (26.4 m^3/s). The average monthly and seasonal distribution of discharges is given below in fig 4.13 and fig 4.14 respectively.

Fig. 4.13: Average Monthly Variation of River Discharges at Tamakoshi Busti



Source: Graph by author, data from DHM/N

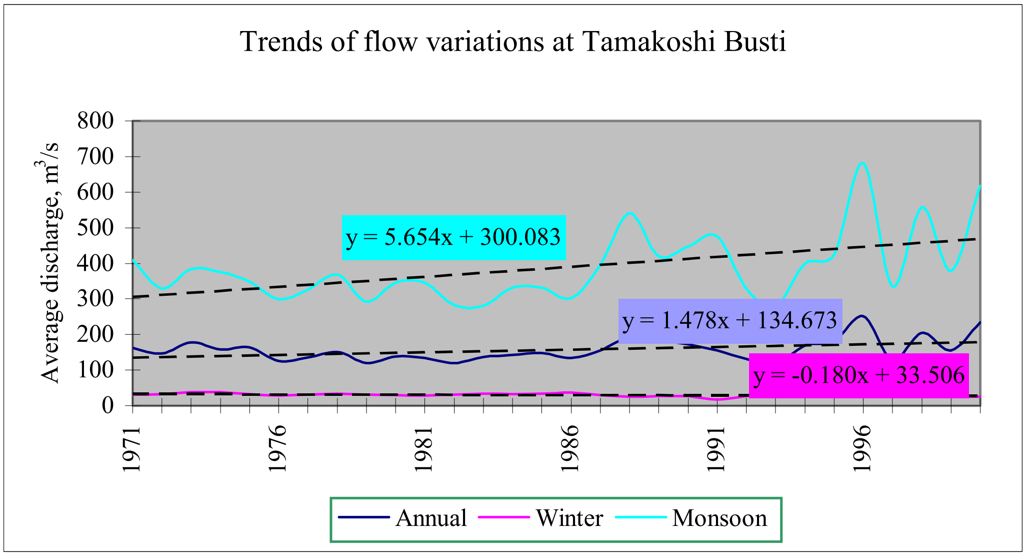
Fig. 4.14: Seasonal Variation of Average Discharges at Tamakoshi Busti



Source: Graph by author, data from DHM/N

The analysis showed a very unsustainable trend of seasonal river flow during the period of study. The average annual river flow was found to be increasing approximately at 1.478 m^3/s per year (i.e. about 0.94% annually). Similarly, the average monsoon flow was found to be increasing approximately 5.654 m^3/s per year (i.e. about 0.1.46% annually), while average winter flow was decreasing at a rate of about 0.18 m^3/s per year (i.e.0.58% annually). The annual, monsoon, and winter river flow trends are given below in fig. 4.15.

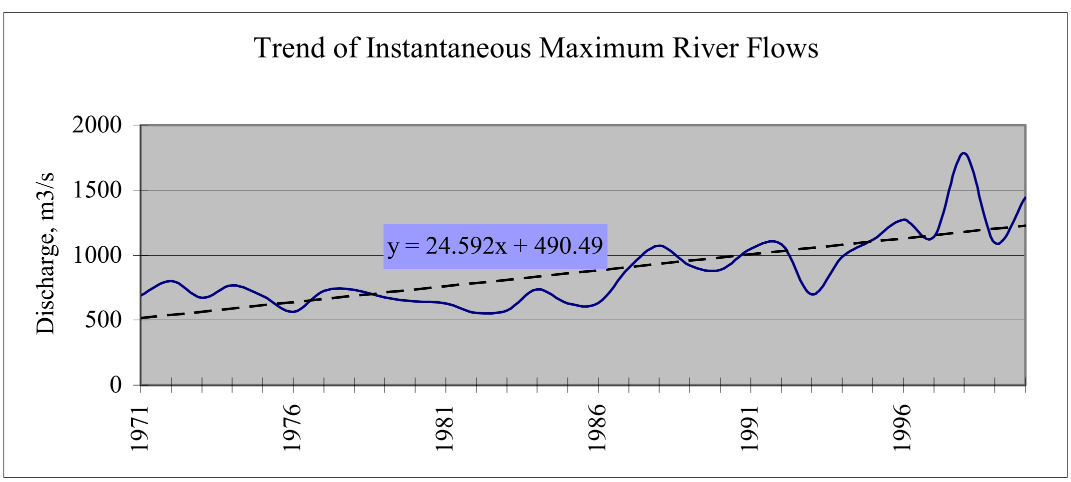
Fig 4.15: Trends of flow variations at Tamakoshi Busti



Source: Graph by author, data from DHM/N

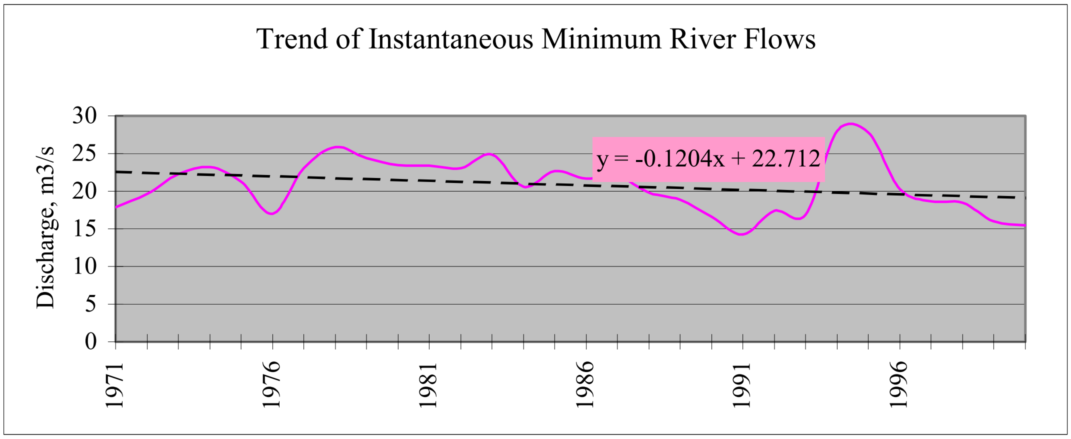
The instantaneous maximum and minimum values were found very far from the average monthly values e.g. 1785 m^3/s was the highest of ever-recorded discharges at that station, while 14.3 m^3/s was the lowest of the all-available discharges. The trends of instantaneous maximum flows and the instantaneous minimum flows were also found very threatening. The instantaneous maximum flows were increasing approximately at 24.592 m^3/s per year, whereas the minimum instantaneous flows were decreasing approximately at 0.12 m^3/s per year, leading to the increasing trend of the coefficient of river regime (i.e. ratio of maximum to minimum instantaneous flows). The trends are given below in fig. 4.16 and 4.17.

Fig. 4.16: Trends of Instantaneous Maximum River Flows at Tamakoshi Busti



Source: Graph by author, data from DHM/N

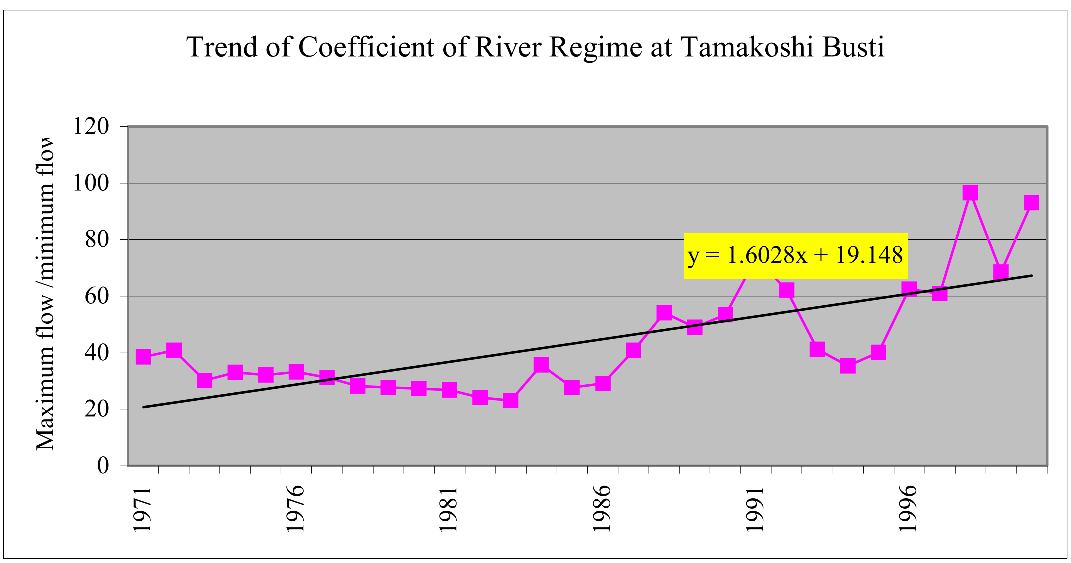
Fig. 4.17: Trends of Instantaneous Maximum River Flows at Tamakoshi Busti



Source: Graph by author, data from DHM/N

The above given figures of instantaneous maximum and minimum river flows showed the trend in different direction, indicating an increasing trend of coefficient of river regime. The average value of the coefficient of river regime for 1971-2000 was found as 44. The coefficient was found increasing at about 1.6 per annum (i.e. 3.6% annually). The trend of coefficient of river regime at Tamakoshi Busti is given below in fig. 4.18.

Fig 4.18: Trend of the Coefficient of River Regime at Tamakoshi Busti



Source: Graph by author, data from DHM/N

4.4.3 Tsho Rolpa

The weather data at Tsho Rolpa started to be recorded after establishment of Automatic Weather Station in June 1993. Again no data were available for the period of June 1996- May 1999. Then data were available after June 1999 to December 2000. Even within the period, when data were available, there were significant numbers of data gaps in-betweens. All available data were as daily-data, which were used to get monthly values. In total there were 52 months with weather data, but out of which only 39 months were without missing daily data. Therefore the analysis of the weather data consisted only of these 39 months, which are given below in Table 4.1, and the observed values are given in annexes.

Table 4.1: List of the Months with Available Weather Data for Tsho Rolpa

Year	Months with complete data	Months with partial data
1993	July, August	June, September
1994	March, May, June, July, August, September, October, November, December	February, April
1995	January, February, March, April, May, June, July, August, September, October, November, December	-
1996	March, May, June, July, August	January, February, April, September
1997	No data	
1998	No data	
1999	July, August, September	June, October, December
2000	January, February, March, April, May, June, July, August	September, December
Total	39	13

Source: DHM/N

4.4.3.1Correlation of Weather Data of Tsho Rolpa with Jiri and Tamakoshi

As stated earlier, Tsho Rolpa is situated at 4580 m asl, whereas Jiri at 2003 m asl, giving an altitudinal difference of 2577 m. Jiri is located at an the aerial distance of 35 km (HMG/N, 1983) to the southwest of Tsho Rolpa Glacier Lake in Dolakha district. Average monthly weather data of Tsho Rolpa were obtained from its daily data. The weather observation at Tsho Rolpa started in summer 1993. The available data for 39 months were used to analyse the correlation between these stations at higher latitude and lower altitude. The data of the same months of the same year of Jiri and Tamakoshi Busti were taken for analysis, in which months the data were available for Tsho Rolpa. The calculation was made with the help of SPSS 10.0 by linear regression analysis.

4.4.3.1.1 Regression Analysis of temperatures of Tsho Rolpa and Jiri.

The linear regression analysis by SPSS 10.0 showed a strong positive relationship between two temperatures(R= 0.942; R-squared = 0.887; significance <0.001). Then the relation between two variables was defined by the equation 4.1 as given below.

$$T_{tsho} = \alpha + \beta * T_{jiri} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.1)$$

Where,

T_{tsho} – temperature at Tsho Rolpa in ^{0} C

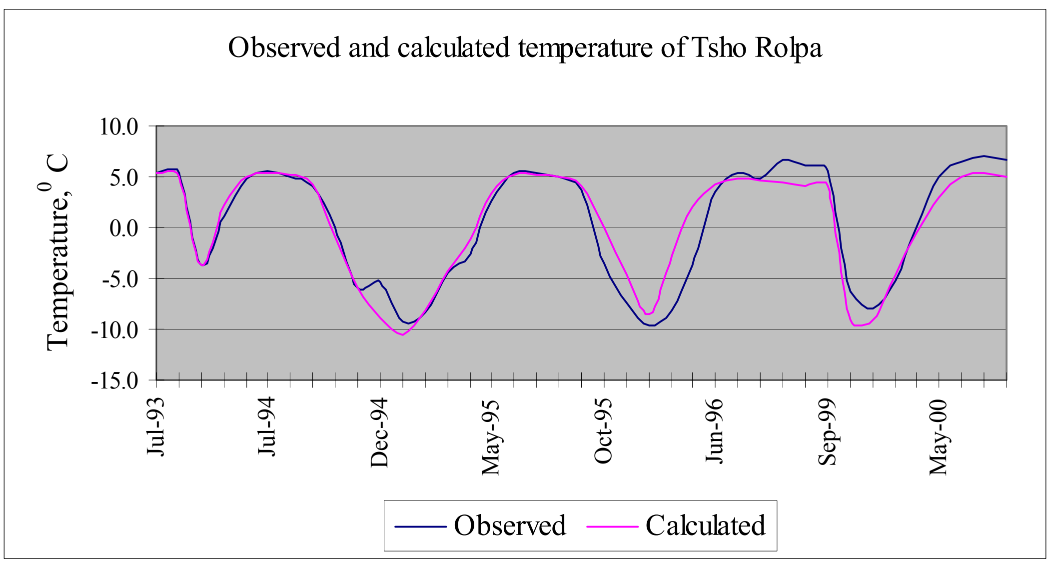
α – coefficient, α = -15.555

β – coefficient, β= 1.004

T_{jiri} – temperature at Jiri in ^{0} C

For checking the accuracy of the equation, the calculated values were then compared with the observed values as given below in fig. 4.19.

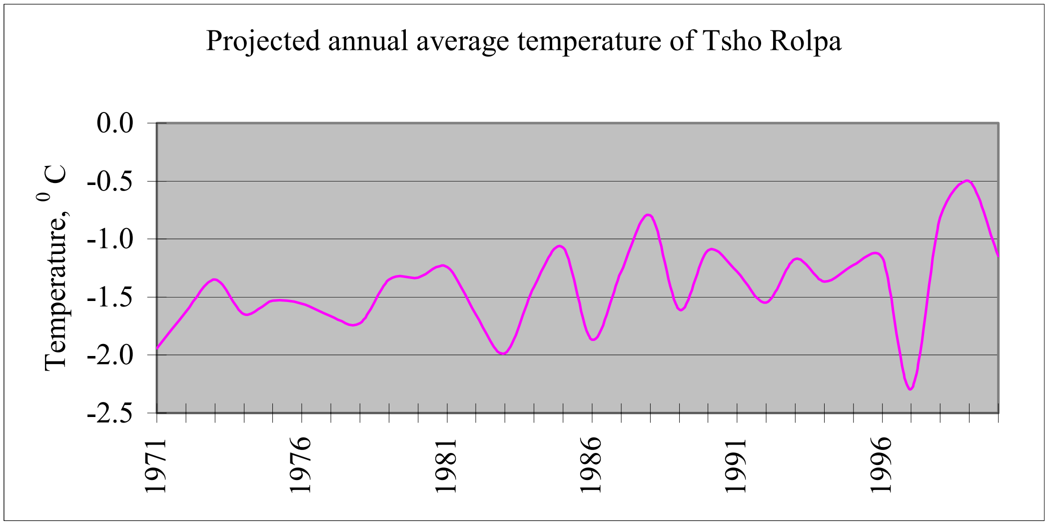
Fig. 4.19: Observed and Calculated Temperatures at Tsho Rolpa



Source: Data from DHM /N and graph by author

The graph clearly shows the strong relationship between two variables, but still there are some things to be considered from the graph. As we see in the graph, the maximum observed values are higher than maximum calculated values. Similarly, the minimum calculated values are lower than the minimum and minimum values of observed and calculated values. It is very difficult to examine this result quantitatively; but qualitatively, it can be said that the temperature range (difference between maximum and minimum temperature) in higher altitude might be even higher than that in lower altitude in the long run. The projected annual average temperature was found as given in fig. 4.20.

Fig. 4.20: Projected Temperature Trend of Tsho Rolpa based on the regression analysis

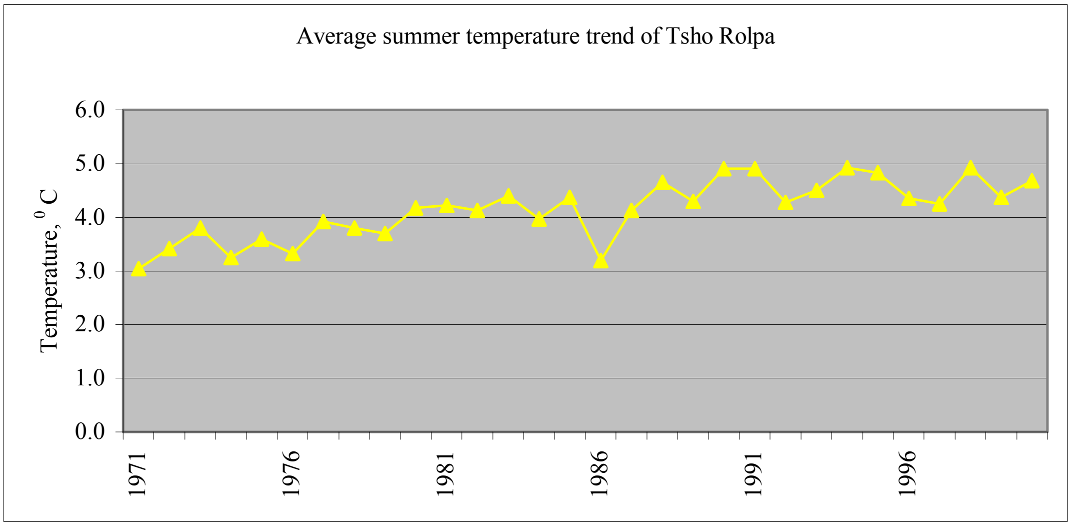


Source: By author using data of Jiri obtained from DHM/N

This graph shows that the annual average temperature varies from –0.5 to –2.3 ^{0}C; and probably, the year 1997 was the coldest year of the whole period, though there is increasing trend of annual average temperature. Similarly the year 1998, the might be the hottest year of the whole period of study.

Similarly the average summer temperature of Tsho Rolpa, calculated from the average monthly temperatures of summer months (June-August) of Jiri, varied from 3 to 5^{0}C. The calculated trend of average summer temperature of Tsho Rolpa is given below in the fig.4.21.

Fig. 4.21: Calculated Trend of Average Summer Temperature at Tsho Rolpa



Source: Graph by author, data calculated by regression analysis, original data from DHM/N

4.4.3.1.2 Regression analyses of precipitation and relative humidity of Tsho Rolpa and Jiri.

The regression analysis of relative humidity values of Tsho Rolpa and Jiri showed a relatively weak relationship (R- squared = 0.161), so the projection of relative humidity of Tsho Rolpa was not carried out.

Similarly for determining the relationship of both precipitation records were used for regression analysis, which showed good relationship between two variables (R-square = 0.765; significance <0.001). Then the relation between two variables was defined by the equation 4.2 given below.

$$P_{tsho} = \alpha_1 + \beta_1 * P_{jiri} \quad \text{..(4.2)}$$

Where,

P_{tsho} – precipitation at Tsho Rolpa in mm

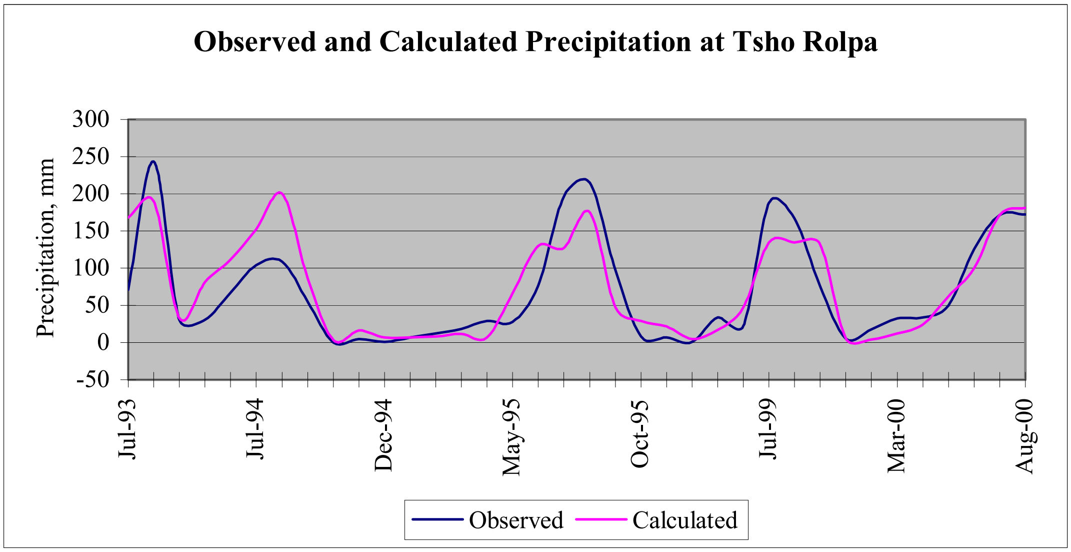
α_1 – coefficient, α_1 = 15.618

β_1 – coefficient, β_1= 0.266

T_{jiri} – precipitation at Jiri in mm

The calculated and projected values of precipitation are given below in fig 4.22.

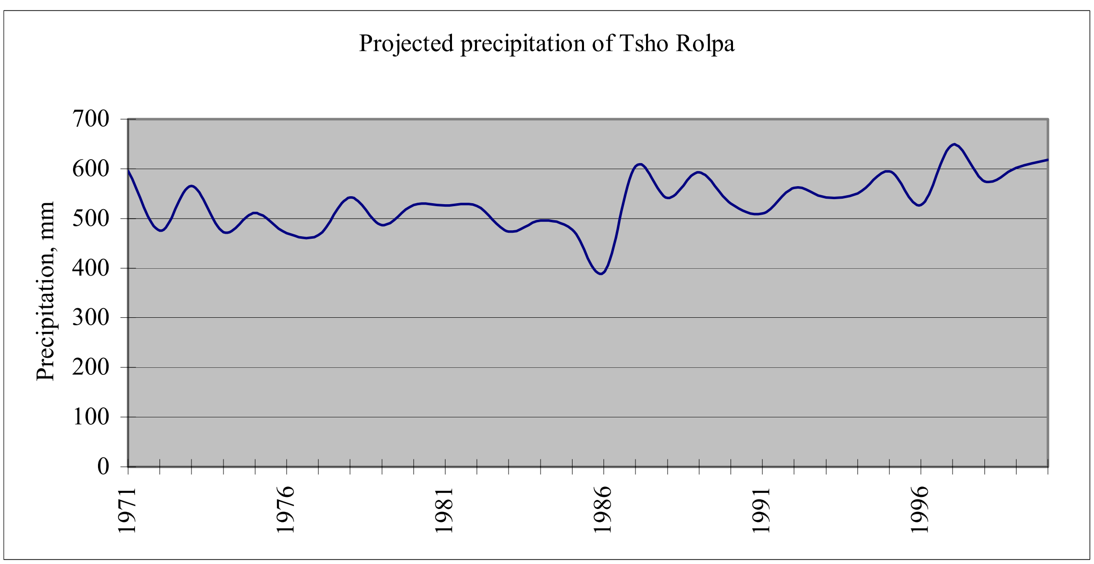
Fig. 4.22: Calculated and Observed Precipitation Values at Tsho Rolpa



Source: Data from DHM /N and graph by author

The graph shown above explains a close relationship between two values, though still there are some differences. For example, the maximum observed precipitation values are higher than the calculated, though timing for that is not so different. It may be possible that the maximum precipitation values increase in higher altitude. Yamada (1998) has pointed out that the precipitation in higher altitudes of Nepal Himalayas might be higher than in the lower altitudes (Yamada, 1998, p.69). The result obtained in the fig 4.22 is in line with that possibility. The projected precipitation values are given below in fig. 4.23.

Fig. 4.23: Projected annual precipitation values of Tsho Rolpa



Source: Graph by author using data from DHM/N

The summer average and winter average values were calculated using the values of Jiri in linear regression equation 4.2 given above.

4.4.3.1.3 Regression analysis of discharge of Tsho Rolpa and Tamakoshi Busti

The discharge data of Tsho Rolpa were available only for 27 months. The discharge data of Tamakoshi for the same 27 months were taken and a linear regression analysis was carried out. A strong relationship between these two sets of observation data were found (Regression, R = 0.828; R^2 = 0.685, and significance < 0.001, standard error = 0.64). Then the discharge values for the observed months were calculated by using the discharge data of Tamakoshi Busti. The regression equation defining the relationship of discharges of Tsho Rolpa and is given in equation 4.3 as below.

Q_{tsho}= 0.532+1.812/100* $Q_{tamakoshi}$…………………………………. (4.3)

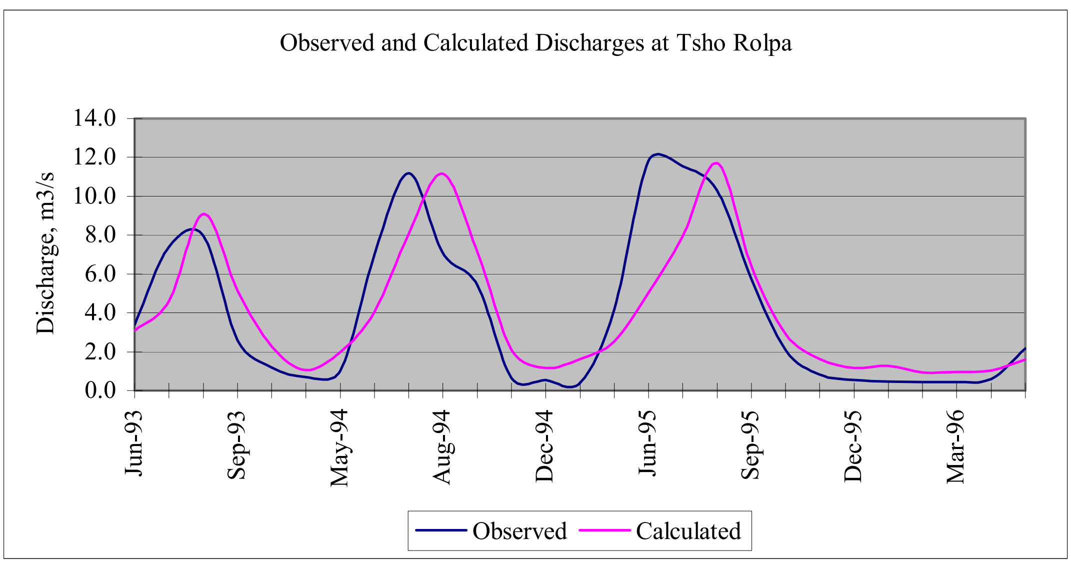
Where,

Q_{tsho}- Discharge at Tsho Rolpa, m^3/s

$Q_{tamakoshi}$ – Discharge at Tamakoshi Busti, m^3/s

Using the relation defined by the equation 4.3, the discharge values were calculated and compared with the observed values as given in fig. 4.24

Fig 4.24: Calculated and Observed Discharges at Tsho Rolpa



Source: Graph by author, data from DHM/N and regression analysis

By the observation of the graph, some differences between the observed and calculated values were found. The peak discharge points of the calculated graph were found shifted to the right i.e. about one month later than that of the observed graph. Calculated graph represents the Tamakoshi Busti, which has 32 % of snow covered area within its basin, while the observed graph represents Tsho Rolpa, which has 72 % of glacier covered area within its basin. The alteration in peak flow might be due to difference in snow area within its basin. Further research is required to make exact conclusion. But qualitatively, it can be said that, the timing of peak flow is different in both stations, as the driving factor for the peak flow also seems to be different due to different portion of snow-covered area. All the projected values of temperature, precipitation, and discharge are given in annexes. A summary is given below in Table 4.2.

Table 4.2: Calculated Values of Tsho Rolpa based on the Observed Values at Jiri and Tamakoshi Busti

Description	Jiri	Tamakoshi Busti	Tsho Rolpa
Annual Average Temperature, ^{0}C	14.1	-	-1.4
Average Summer Temperature, ^{0}C	19.9	-	4.4
Average Winter Temperature, ^{0}C	7.2	-	-8.3
Annual Average Precipitation, mm	2263	-	618
Average Summer Precipitation, mm	1525	-	498
Average winter Precipitation, mm	53	-	30
Annual Average Discharge, m^3/s	-	157.6	3.4
Average Monsoon Discharge, m^3/s	-	385	7.4
Average Winter Discharge, m^3/s	-	31	1.1

Source: Author's calculation and DHM/N data

4.4.4 Assessment of Tsho Rolpa Glacier Lake with the changed climate parameters

Direct observations of Tsho Rolpa Glacier Lake were started only in 1993; all the older data concerning the lake were collected after 1993 using different maps, images, photographs etc. Summer temperature and summer precipitation play more significant role on mass balance of glaciers. Based on the correlation analysis, the increase in summer temperature by 0.044 ^{0}C annually causing a significant melting of snow /glacier and increase in summer flow. In addition to that, the increase in summer precipitation by 10.43 mm/year (i.e. 0.7% annually) was accelerating the increase in outflow from Tsho Rolpa. Due to lack of sufficient data the real relative contribution of increased temperature and increased precipitation to the increased flow could not be calculated for Tsho Rolpa, but based on the analysis of Jiri and Tamakoshi Busti, increased snow/melt glacier would have greater contribution to increase in flow than increased precipitation. As summer flow was increasing at 1.46% annually at a faster rate than summer precipitation increase at 0.7 % per annum.

Annual average flow of Tsho Rolpa was calculated as 3.4 m^3/s based on the correlation with Tamakoshi, which is equivalent to 1381.7 mm per year. The annual calculated precipitation for Tsho Rolpa was 507 mm. Then using simple relation of discharge, precipitation and snow/glacier melt is given by equation 4.4 (Yamada, T., 1998, p.69):

$$Q = P + \Delta G - E \quad \text{..(4.4)}$$

Where,

Q – Annual average runoff or discharge

P – Annual precipitation

E – Evapo-transpiration

ΔG – Melting of snow / glacier

Even without considering the evapo-transpiration loss, the annual average melting of snow/glacier was found as 874.7 mm, which was relatively large (Yamada, 1998, p.69). The fast increasing summer temperature at 0.044^0C per annum, most probably has the direct relation to such significant melting of snow and glacier. Further detailed research required for quantifying the exact relative contribution. But just for qualitative assessment, it was clear that a significant volume of water was coming from snow and glacier melting.

With the increasing temperature, the contribution of snow /glacier melting to the outflow from the lake would be increasing, and less and less snow/glacier volume would be left as water storage. This might lead to the critical point somewhere in the future, when no more glaciers would be left for melting.

Presently constructed outlet channel was with design capacity of 14 m3/s and maximum capacity of 35 m3/s. Therefore even as the design flow, the channel could drain out about 5700 mm of annual runoff, which was far higher than the annual runoff at present. So the rising of lake water level at present was found unlikely. In addition to that, further lowering of lake water level by 17 m more was recommended by the previous study. Thus in normal working conditions of the channel and gates in it, the calculated annual outflow of water of about 107 million m^3, almost as the lake volume, would not make any rise in water level in the lake. But the previous study reports had pointed out that, there were strong possibilities of falling of huge ice mass and soil/rock mass from the hills and mountains surrounding the lake due to ice melt or landslides. Such events would create a high wave on the lake water surface capable of overtopping the moraine dam and damaging it. After lowering the lake level by 3 m, such risk also had been lowered to some extent.

As the previous studies had shown that, the moraine dam consisted of ice core inside in it, the increased temperature might badly cause its collapse due to ice melt. As per their findings, still 17 m more lowering was necessary to be safe from the collapse of ice cored moraine dam. So, in the present condition, the collapse of the dam is more likely due to the melting of dead ice (caused by increasing summer temperature) inside the dam, rather than due to the rise in water level in the lake.

4.4.5 Permanent Snowline and its Relation to Temperature Increase.

The average summer temperature of the Tsho Rolpa was calculated as 4.4 ^{0}C at 4580 m asl. From the topographical map of HMG/N published in 1996, the permanent snowline was found at minimum of 4720 m asl (HMG/N, 1996a, sheet No 278202). But not all the surface areas above that level were found with permanent snow cover. About 21 % area of the whole drainage basin of Tsho Rolpa even above 5000 m asl was not covered by permanent snow and glacier (Yamada, 1998, p.46). The average summer temperature was found increasing by 0.044 ^{0} C annually. Assuming the same temperature gradient as from Jiri To Tsho Rolpa, as 0.6 ^{0} C per 100 m altitude, the upward movement of the permanent snowline could be calculated as about 7 m annually. Even considering the average annual temperature increase as 0.019 ^{0} C, the average upward movement of snowline might be at about 3 m per year.

CHAPTER FIVE: SUMMARY AND DISCUSSION

5 General

There were two levels of data collection, firstly, meteorological and hydrological data from Department of Hydrology and Meteorology of Nepal (DHM/N); and secondly, people's knowledge and information on the study subject from direct interviews with the local people, politicians, journalists, key informants, and experts both at local and national level. The information obtained from key informants and experts was just summarised, but that obtained from the local people was analysed from different angles and perspectives using cross tabulation analysis in order to find the interrelationship between different variables. The data obtained from DHM/N regarding hydrological and meteorological observations were analysed separately for individual parameters of Tsho Rolpa, Jiri, and Tamakoshi. The available data of Tsho Rolpa were not enough to make a trend analysis. So the nearest available stations Jiri (for meteorological data) and Tamakoshi Busti (for hydrological data) were used as data sources. The available data of Tsho Rolpa and those of the stations then correlated to find their interrelationship. After the regression and correlation analyses, the strength and direction of their interrelationship were determined.

Though average weather parameters of Tsho Rolpa were found from the regression analysis, the trend of these parameters were analysed for the stations themselves located at the lower level rather than Tsho Rolpa Glacier Lake.

5.1 Summary of findings from local people

The study was aimed to find out whether there were changes on weather pattern during the last 20-30 years, if so, then what they were and what were the impacts caused by them on water resources. Besides that the research was aimed to assess the people's information level, their understanding, and attitude towards the glacier lake outburst flood phenomenon, their preparedness against such floods etc.

5.1.1 General Information on climate change and water resources

- More rainfall during summer monsoon and less rainfall during winter season.

- Snowfall was decreasing in mid mountains and even stopped in low mountains, but not so clear information on snowfall in high mountains
- Both the quantity of frost and the duration of its occurrence were decreasing.
- Predictability of weather pattern decreased drastically.
- In past the character of summer monsoon rainfall was mostly of drizzle and shower types, while in the recent years that was mostly of cloudburst and downpour types.
- Extreme cold feeling was decreasing in terms of magnitude and similarly the total time in one year, when they felt cold also was decreasing.
- Spring sources, the only source of drinking water for most of the hills and mountains, were decreasing in terms of water volume and in terms of spring numbers, especially in dry seasons
- The dry season river flows, generally fed by the local springs, were also decreasing.
- Floods, extreme rainfalls, landslides, and draught period were increasing in terms of frequencies and magnitudes.
- In the places, where no mosquito existed 20 years ago, there were complains of mosquito bites, especially in summer.
- The time required to irrigate the same field from the same source of water was increasing but it was not clear whether it was due to reduction of water volume in the source or reduction of soil moisture in the field or both.
- Rice farming started even in the high mountains. But it was not clear whether it was due to new hybrid varieties of rice or due to warming or both, because several new varieties of rice were being developed during the last 20 years.
- Many new vegetables were introduced even in mid and high altitude areas, where they did not exist 20-30 years ago.
- Many indigenous species of crops, vegetables and fruits were decreasing and some of them disappeared.
- There was no dominating view on the forest area, but it was clear that artificial pine forest was emerging in place of natural forest and many of wild animal /bird species disappeared.

5.1.2 Specific information on Tsho Rolpa Glacier Lake and its potential outburst flood

- Most of the people in the downstream of Tsho Rolpa were familiar with the name of Tsho Rolpa Glacier Lake, but very few knew about the real situation of the lake.

- Potential threat of glacier lake outburst flood (GLOF) for most of the people was something new, which they did not know before. Therefore, even after many attempts of information dissemination about GLOF events among them, most of them still thought that such GLOF event was unlikely. Only those, who had seen before or even suffered directly by GLOF events thought that Tsho Rolpa GLOF was very likely. Apart from that, some of educated people, intellectuals, and development workers told that the GLOF was likely.
- Most of the people had no clear and right information about the ongoing remedial measurers for lowering the lake water level. The remedial measures were meant to reduce the potential risk of outburst flood from Tsho Rolpa and to warn them as soon as possible in case of outburst flood. But the attitudes of the people living even at the highly risk-prone areas of the GLOF were not so supportive towards these remedial measures. No direct involvement of these people, either in decision making for planning or in implementation of these projects was found. This resulted in misunderstanding among the potential sufferers about these projects. Significant numbers of people thought that there were vested interests of donors and implementing agencies to be involved in these projects rather than reduction of potential risk from GLOF.
- Even though the people from risk-prone areas were not so convincing on the outburst flood, they could not sleep at their homes at night due to fear of flooding for the summer months of 1997-2000. They had made their temporary huts at safer places upwards from the existing houses for living at night, which they had destroyed after knowing the completion of lake lowering project in June 2000. This fact told the information that even those, who thought the potential GLOF was unlikely, also had the fear of it and losing their life and property. If the survey were conducted before the lowering the lake (i.e. before risk reduction), the responses of people towards the likelihood of potential GLOF from Tsho Rolpa, most likely, would be totally different.

5.2 Summary of findings from hydrological and meteorological data

The correlations of temperature, precipitation, and discharge values of Tsho Rolpa with those of lower level station were found strong enough to project the average values at Tsho Rolpa. So the average values at Tsho Rolpa were calculated by simple linear regression analysis. The hydrological and meteorological information of Tsho Rolpa and Jiri/Tamakoshi Busti are given below in Table 5.1 and 5.2 respectively.

Table 5.1 Calculated Annual Weather Data and Flow Values of Tsho Rolpa

Description	Unit	Value
Annual Average Temperature	^0C	-1.4
Average Summer Temperature	^0C	4.4
Average Winter Temperature	^0C	-8.3
Annual Average Precipitation	mm	618
Average Summer Precipitation	mm	498
Average winter Precipitation	mm	30
Annual Average Discharge	m^3/s	3.4
Average Monsoon Discharge	m^3/s	7.4
Average Winter Discharge	m^3/s	1.1
Total Basin Area	Km^2	77.6
Area with Snow and Glacier	%	72

Source: Values calculated by author, data from DHM/N

Table 5.2 Weather Parameters at Jiri and Tamakoshi Busti (Average of 1971-2000)

S.N	Description	**Unit**	Values	Trend /year	
				Amount	%
1	**Temperature at Jiri**				
1.1	Annual Average	^0C	14.1	0.019	0.14
1.2	Summer Average	^0C	19.9	0.044	0.22
1.3	Winter Average	^0C	7.2	0.0026	0.04
1.4	Average Extreme Maximum	^0C	26.8	0.09	0.33
1.5	Average Extreme minimum	^0C	-4.9	-0.078	-1.59
1.6	Extreme cold days ($T< 0^0C$) in a year	No.	54		
2	Precipitation at Jiri				
2.1	Annual Average Precipitation	mm	2263	13.6	0.60
2.2	Average Monsoon Precipitation	mm	1525	10.43	0.68
2.3	Average Winter Precipitation	mm	53	0.31	0.59
2.4	Annual rainy days	No.	299	-0.82	-0.27
2.5	Drizzly days with (P< 1mm /day)	No.	147	-0.72	-0.48
2.6	Days with heavy rain (P>50 mm/day)	No.	7	0.153	2.19
3	Relative Humidity at Jiri	%	80	0.24	0.3
4	River Flow at Tamakoshi Busti				
4.1	Annual Average Flow	m^3/s	157.6	1.478	0.94
4.2	Average Summer Flow	m^3/s	385	5.654	1.47
4.3	Average Winter Flow	m^3/s	31	-0.18	-0.58
4.4	Average Instantaneous Maximum Flow	m^3/s	872	24.59	2.82
4.5	Average Instantaneous Minimum Flow	m^3/s	21	-0.12	-0.95
4.6	Coefficient of River Regime (Max/Min)	-	42	1.60	3.81

Source: Values calculated by author, data from DHM/N

- Total basin area of the River at Tamakoshi Busti = 2753 km^2
- Permanent snow area within the basin of Tamakoshi Busti = 881 km^2 (32 % of total basin area)

5.3 Discussion

5.3.1 Temperature

- Annual average temperature was found increasing at a rate of 0.019 ^{0}C/year or 0.19 ^{0}C per decade, which is about 27 % higher than the global warming rate of 0.15^{0}C/ per decade (Houghton, J.T. et al, 2001, p.26). The average temperature of Jiri has increased by 0.57±0.3 ^{0}C, with 95 % of confidence limits of close to 0.27 and 0.87 ^{0}C.
- Average winter temperature at Jiri was increasing, though in small rate of 0.0026 ^{0} C/ year, corresponded to the people's response on decreasing cold feeling.
- Average summer temperature at Jiri was increasing even faster, approximately at 0.044 ^{0} C/ year (0.44 ^{0} C per decade). The average summer temperature of Jiri has increased by 1.32±0.4 ^{0}C, with 95 % confidence limits of close to 0.92 and 1.72^0 C.
- Extreme maximum temperature at Jiri was increasing at even higher rate of about 0.09^{0}C/ year. The temperature of 29.2 ^{0} C recorded on June 11, 1998 was the highest ever recorded temperature at Jiri.
- Surprisingly, the extreme minimum temperature was found decreasing at a rate of 0.078^{0}C/year despite the increase in average winter temperature. The temperature recorded on January 18, 1998 as –7.5 ^{0}C was the lowest ever recorded temperature at Jiri. The explanation for this could not be obtained from the local responses as well from other sources.
- As the trends of maximum and minimum temperatures were of different directions, the inter-annual temperature fluctuations were found increasing at a rate of about 0.169^0 C/year. In 1998, the difference of extreme maximum and extreme minimum temperatures of 36.7 was the highest of all the period of recording. On an average the difference was found to be 31.7 ^{0}C.
- As the both sides of the extreme were found increasing, this might have impacted seriously on the plants, animals, and environment because they might feel difficulties in adapting the new temperature.

5.3.2 Precipitation / Relative Humidity

- Annual total precipitation was found increasing at a rate of 13.62 mm/year (136.2 mm per decade) or 6% of annual average per decade, which showed a significant difference between the increase rates of global precipitation and precipitation at Jiri.The study made by Intergovernmental Panel on Climate Change (IPCC) has indicated that the precipitation in much of the Northern Hemisphere mid- and high latitudes had increased at 7-12% of annual zonally averaged precipitation per decades for the zones 30^0 N to 85^0 N (Houghton, J.T. et al, 2001, p.142), while the precipitation over the tropical land areas increased at 2.4 % per century (Houghton, J.T. et al, 2001, p.103). There is little evidence for the precipitation trend in Indian monsoon (Houghton, J.T. et al, 2001, p.143), by which the precipitation over Jiri is dominated, so it could not be compared with the other standard Indian monsoon trend. From this explanation, it was found that the precipitation at Jiri was increasing nearly at a rate of mid- and high latitudes land areas but not as the rate of tropical land areas.
- Average annual precipitation was increased by 408.6±39.6 mm (i.e16.3 –19.8 %) since 1971 at 95 % confidence limits.
- In contrary with the increase in annual precipitation, the numbers of rainy days were found decreasing at 0.9 days /per year. Furthermore, among the available rainy days, the days with insignificant precipitation (i.e. less than 1 mm/day) were decreasing at 0.72 days/year, while the days with heavy precipitation (i.e. more than 50 mm/day) were increasing at 0.15 days/year. This analysis showed a significantly increasing trend in intensity of precipitation (not only amount of precipitation).
- Increased intensity of precipitation was found responsible not only for the frequent landslides due to slope failure in the hills, but also more frequent and heavier flash floods in the rivers.
- The increased intensity of precipitation was distinctly expressed by the interviewees in terms of changed rainfall pattern from drizzle/shower type in the past to the downpour /cloudburst type at the present. This is natural that more intense rainfall causes more surface runoff and less infiltration into the ground for the same geology and land cover.
- Though the annual precipitation was found increasing, the distribution of increased precipitation was not even throughout the year. The average summer precipitation was about 67 % of total annual precipitation but the increase in summer precipitation was

found 77% of increase in annual precipitation. This clearly indicated again that more and more precipitation was concentrating into summer.

- Average relative humidity was increasing at an average rate of 0.24 % per year.

5.3.3 River Flow

- Average annual discharge and summer monsoon flow of Tamakoshi were increasing at a rate of 1.478 m^3/s per year (i.e. about 0.9% annually) and 5.654 m^3/s per year (i.e. about 1.5 % annually) respectively.
- Increase in annual average river flow is almost 1.5 times higher than that the increase in precipitation, which might be probably due to the glacier retreat caused by rapid warming.
- Increase in summer precipitation was 10.43 mm per year (i.e. annually 0.68 % annually), which was only about 45 % of the increase rate of summer-monsoon river flow. This showed that about 55 % of the increase in river flow was caused due to snowmelt and glacier retreat.
- Increased precipitation along with increased temperature was found as the most probable influencing factor for the formation of numbers of glacier lakes and for the outburst floods from them in Nepal Himalayas during the last three decades.
- Rapidly increasing summer temperature not only accelerating the melting of snow and ice in glacierized areas, but also causing more precipitation in liquid form. Therefore, increasing summer temperature is doubling the role for increasing monsoon flow in the river. This has direct impact on negative mass balance of glaciers.
- As in the case of precipitation, the increase in river flow was not evenly distributed over the year. The summer monsoon flow was about 2.4 times higher than the annual average flow, but the increase of summer monsoon flow was about 3.8 times larger than the increase of annual average flow.
- The average winter flow of the river was decreasing at a rate of 0.18 m3/s per year despite the increase in winter precipitation. Therefore the contribution of winter precipitation into winter flow was found insignificant. It also might be possible that the spring-water sources were drying up faster than the increase in winter precipitation.
- In the hills and mountains, the precipitation is only available source for ground water recharge. Less infiltration due to the more intense rainfall causes less ground water

recharge, which ultimately reduces the spring water volume. This statement was found completely valid for the study area, as the most of the interviewees were reporting the disappearance of spring sources and decrease in water flow from springs during dry seasons. The explanation for the drying-up of small rivers, as most of the interviewees reported, is also the same i.e. less ground water recharge.

- The monsoon flow was increasing at 1.47 % per year but the monsoon precipitation was increasing only 0.68 % per year. The apparent difference between increase in precipitation and increase in river discharge during summer monsoon, most probably, was due to the contribution by snow and ice melting from the glaciers in high altitudes. The summer temperature was increasing at 0.22 % per year, which might have contributed significantly to the higher increase in monsoon river flow.
- The decreasing extreme minimum temperature and increasing extreme cold days (i.e. $T < 0^0C$) could not be justified by the people's view, as most of them reported as decreasing cold-feeling. This might be verified by further research.

5.3.4 High Altitude Weather Parameters

- As mentioned above the summer temperature of Jiri has increased roughly by 1.32 ^{0}C. The temperature of Tsho Rolpa also has probably has changed at least at the same amount because warming rates in high-elevation regions of Nepal (Middle Mountains and Himalaya) are higher than that in lower southern regions (Shrestha, A.B. et al, 1999, p.2775). Generally temperature from Jiri to Tsho Rolpa decreased at a rate of 0.6 ^{0}C by 100 m (15.5 ^{0}C temperature difference was found in 2577 m altitude difference between Tsho Rolpa and Jiri giving a temperature gradient of 0.6 ^{0}C by 100 m). This temperature gradient was found similar to that was found and used for the high mountain areas of Nepal Himalaya (Yoshihiro et al, 1991, p.186). Assuming this gradient valid, the snowline in the mountains above Tsho Rolpa might be moving upward approximately at 7.3 m per year. In this way, the snowline in the high mountains above Tsho Rolpa probably has moved upward at an elevation of approximately 220 m since 1971. There might be some standard error due to limited number of data points, which could be reduced by using more stations and more data for the analysis.
- Average annual precipitation at Jiri has increased roughly by 408.6 mm since 1971. Similar increase could be expected, if not more, in the annual precipitation of Tsho

Rolpa. But the previous study, and even the regression analysis in this study qualitatively showed that the increase in precipitation in higher altitude might be greater than that in lower altitude. Therefore, the annual precipitation at Tsho Rolpa might have increased roughly by 408.6 mm as minimum.

- The increased summer temperature probably has caused rapid increase in glacier retreat in Tsho Rolpa Glacier Lake basin, accumulating more water in the lake.
- Increased annual precipitation and increased summer temperature have caused rapid increase in water level in Tsho Rolpa Glacier Lake. The studies have shown that the lake area has increased from 0.62 km^2 in 1972 to 1.65 km^2 in 1997(DHM, 2001, p.3) i.e. the lake in 1997 increased by 166% of its area in 1972 during 25 years (about 6.65% per year), which could be considered as the combined effects of increased temperature and increased precipitation simultaneously.
- The Trakarding glacier, the mother glacier of Tsho Rolpa retreated about 5 km from 1963 to 1993, which was considered as a result of rapid increase in temperature, especially in summer. Both accumulation and melting of snow in glacierized areas of Nepal Himalayas were found occurring in summer. So weather parameters during summer season were found very much influencing on the glaciers in the Nepal Himalayas
- As there was rapid increase both in temperature and in precipitation, many more glacier lakes would appear in the Nepal Himalayas in the future and many of them might cause outburst floods.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study supported most of the research hypotheses stated:

- "Glaciers in Nepal Himalayas are retreating very fast resulting in rapid increase in the numbers of glacier lakes"
- "Rapid rise in water level in glacier lakes is increasing the threat of their outburst towards the lives and the properties of the people living in the downstream"
- "Temperature in the mountains of Nepal is increasing very fast"
- "There is increasing summer precipitation and decreasing winter precipitation"
- "There is decreasing trend of river flows during low flow period and increasing trend of flood magnitudes and frequencies"
- "There is decreasing trend of snowfall and snow cover"
- "The springs and spring fed rivers are drying up."

These hypotheses were found true but their justification depended on how deep they were analysed and how far the data were available for that. But one hypothesis stated: "Rapid rise in water level in glacier lakes is increasing the threat of their outburst towards the lives and the properties of the people living in the downstream, therefore they are trying to migrate into other places" was found only partially true. Though the risk of potential outburst flood from Tsho Rolpa was found very likely from experts' interviews, scientific reports, and previous studies; the views of the local people living directly under the threat of potential outburst flood was not in line with the scientific results. During the time of research most of the contacted people expressed the view of such outburst flood as unlikely, though there was strong fear of floods 2 years ago before the lowering of lake water level. Even at the time of strong fear of outburst flood, they were not prepared to migrate into other places because their means of subsistence were limited within the area.

Despite an increase in annual flow, there was decrease in low flow, resulting in more concentration of high flows during relatively shorter period of summer, which had increased the flood potential. Increase in river flow was higher than the increase in precipitation due to significant contribution of flow by snow and glacier melt caused by increased temperature. The water storage in the high mountains, thus, was found decreasing, threatening the existence of the mountainous rivers of the Nepal Himalayas in the long run. The rapid melt of snow and glaciers not only has been depleting the water resources in the Himalayas, but also creating disastrous outburst floods threatening millions of people and properties in the downstream. Due to poor literacy level; insufficient participation of the people in the projects, even directly concerned with their lives and properties; remoteness of the glaciers; insufficient awareness programmes, and sensitisation activities etc. were impeding the adaptation and mitigation activities of such changes in the Himalayan glaciers, though there were not so many things, that could be done by these mountain-people alone in this regard. The biggest obstruction for risk reduction programmes was the extreme poverty in the mountain areas, which had dominated in every sector of mountain life.

Some of the conclusions are summarized below as follows:

- Average temperature was increasing at relatively faster rate of 0.019^0C per year, while summer temperature at even faster rate of 0.044 ^{0}C per year.
- The extreme maximum temperature was increasing very fast, 0.09 ^{0}C per year (0.33% annually), which might have serious impacts on nature and environment including water resources.
- Despite the increase in average winter temperature, the extreme minimum temperature was decreasing.
- The extreme cold days (i.e. temperature below 0^0C) were increasing at about 1.04 days per year (i.e.1.92% annually).
- Annual precipitation was increasing at 0.6% per annum, but the annual rainy days were decreasing at 0.82 days per year (1.52% annually). Even among available rainy days, the rainy days with high-intensity precipitation (> 50 mm per day) were increasing, while those with low-intensity precipitation (<1 mm per day) were decreasing. Thus more and more precipitation was concentrating into summer season and draught period was becoming longer and longer.
- Though annual river flow was increasing at 0.94 % annually, the winter river flow was decreasing. Summer monsoon flow was increasing even faster at 1.47 % annually due to increasing summer precipitation and significant contribution of snow and glaciers melt caused by rapidly increasing summer temperature.
- Increasing summer temperature was not only accelerating the snow and ice melting in the glacierized areas, but also causing more and more precipitation fall in liquid form i.e. rainfall. The increasing share of liquid precipitation (i.e. rainfall) and decreasing

trend of solid precipitation (i.e. snowfall) not only causing floods during summer, but also lowering the mass accumulation in glacierized areas.

- Increasing precipitation and increasing temperature were responsible for the rapid growth of Tsho Rolpa Glacier Lake.
- People's information about the climate parameters and river flows were very much in line with the observed weather data.
- The level of understanding of potential threat of the possible glacier lake outburst flood was found not satisfactory among the people.
- The attitude of the people towards the risk reduction projects was not clear, even not supportive. There were significant numbers of people saying that the risk reduction project was done not to reduce the risk but to fulfill someone's vested interest.
- The participation of the people in risk identification and risk reduction projects was found very low.
- People were not sensitised enough about the potential risk of outburst flood. The more the people were educated, and the nearer to Tsho Rolpa they lived, the better they understood about the risk of its outburst.
- Increasing temperature and increasing precipitation may accelerate the formation of the glacier lakes in the Nepal Himalayas, many of which may lead to the potential GLOF hazards.

6.2 Recommendation

Based on the findings and analysis of this study, the following recommendations have been made:

- Monitoring of glaciers and glacier lakes is necessary to assess the potential risks of glacier lake outburst flood.
- With retreat of glaciers and snowmelt, the water storage in the Himalayas will decrease leading to some critical point; after which the glacier will disappear, subsequently, no more water storage will be left. So it is very important to predict, this critical time for each glacier. In other words, the water balance in the glaciers should be assessed.
- The information dissemination and public awareness campaign on massive scale should be started about the climate change, its impacts on water resources including

economy and development including, and other natural disasters related to climate and water.

- Water efficient technology should be developed for irrigation as well as for drinking water in order to adapt with increasing water deficit.
- Integrated water resource management should be conducted in an efficient and proper way with enough participation of people. Watershed management, afforestation, land terracing etc should be practised in order to maintain the ground water storage.
- The feasibility study of any water resource projects, whether hydropower or irrigation schemes, at glacier-fed rivers should include the comprehensive study of the glacier, and glacier lakes etc on the headwater of the considered river. .
- Each and every step during the time of extreme fear of natural disaster should be very carefully made in order to avoid the increase of rumours and misunderstanding among the people. For example, the minister's helicopter flight to the Tsho Rolpa area in summer 1997, not only created huge fear of outburst flood and panic among the local people, but also made them to think the GLOF event unlikely.
- As the ratio of maximum to minimum river flows was found increasing, this information should be seriously considered during the planning of any water resource projects.
- The involvement of the people in planning and implementation of any projects, like risk reduction projects in our case, should be increased, as more as possible. This will create the feeling of ownership of such projects among the people, which will make the projects more sustainable.
- The general civil structures across the river and flood protection structures should be designed with due consideration of increasing summer flows in the river.

CHAPTER SEVEN: PROPOSITIONS FOR FUTURE RESEARCH

Based on the results obtained and difficulties faced during the present research some propositions for the future research have been made as followings:

- Deeper study on the river flow pattern and the relative contribution of snow/ glacier melt and precipitation to the increased river flow, i.e. solid and liquid precipitation composition in high altitude areas.
- Study on mass balance of the glaciers including snow cover.
- More scientific research on determining the trend of climatic parameters in high Himalayas, where long-term data are lacking.
- Special climate models are necessary to study the climate change in relation to altitude. The presently available climate models based on the aerial coordinates are not sufficient to represent the climatic variation and its impacts over the high altitudinal range like in Nepal.
- More study on precipitation and streamflow relation covering more area and more stations in order to reduce the level of error.
- More studies on the relationship of climate parameters in the low and high altitudes, and their consequent impacts.
- Comprehensive water balance study, including the evaporation and transpiration loss, ground water storage, and snow/glaciers for the Nepal Himalayas.
- Further study is required on the reservoir planning and river flow simulation of Nepal Himalayas as an adaptation measure against the decreasing trend of low flows in the rivers.
- Impacts of increase of temperature range on nature and environment including water resources should be studied.
- Change in relative proportion of solid and liquid precipitation in high altitude due to increase in temperature should be studied.

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Annex- I : Questionnaire for Local People

For assessing the vulnerability of climate change from residents

No. …………..
Date of interview:………….
Place of interview:…………

Name (optional) : ……………………………………… Sex : ……………..
Age: …………………………… Education: ………………
Occupation: ……………………… Ethnic group : ……………..
Social / political status (if any): ……………………………………………………………
<u>Present permanent address :</u>
District : …………………. VDC : …………… …………. Village/ ward: ……………

1. How long are you living in this place? ……………

Climate /Weather

2. In which month the seasons begin and how long do they prolong?
   Rainy: ………………Winter : ……………….Summer: ………………
3. Do you feel any changes in the beginning time and duration of the particular seasons for the last 20–30 years? If yes, please name them and their effects.
4. Do you feel any changes in rainfall pattern, summer hot or winter cold pattern and intensity for the last 20–30 years? If yes, please mention.
5. What might be the reasons for such changes, if any? What are the impacts from such changes?
6. How long are you feeling such changes?
7. Do you feel any changes in the forms of precipitation – rainfall / snowfall, timing and place for the last 20 years?

Bio-diversity

8. What kind of agriculture species do you produce? How long are you growing them? Any new changes in species of place cropping for the last 20 years?

Summer crops: Winter crops: Time of cropping / harvesting: Production (increase / decrease):

9. Information on rice or any other tropical cropping (as an indicator for climate change), When started its cropping? …..
10. Cropping pattern – past and present, any changes if any? Cycle, coverage ?
11. Forest species – present and past , birds, animals , flora and fauna
12. Do you know some disappeared species or newly appeared ones ? if yes, please name them.
13. Flooded Khet or Bari , if any? Changes in magnitude and frequency.

14. Fish species (present and past)

Socio-economic

15. What is the status of migration? What are the possible effects on economy, social cohesion?
16. Housing condition? Any changes in housing pattern for the last 20-30 years, if any? Reasons?
17. Clothing pattern? Any changes in clothing pattern for the last 20-30 years, if any? Reasons?
18. Do you know any disappeared / newly appeared springs for the last 20 years? Do you feel any changes in spring flow – increase or decrease for that period?

Calamity

19 What type of water related extreme events are you facing? Any changes? Frequency, magnitude, unpredictability, (flooding, intense rainfall, shadow rainfall, landslide)

20. What kind of coping strategy are you making against these events.
21. Have you heard about Tsho Rolpa Glacier Lake? If yes, when and how?
22. How do you consider the risk of potential Outburst Flood from Tsho Rolpa? If you consider it as likely, what are the measures are you applying to reduce the risk? Are you planning to migrate to other places in order to get rid of from the Glacier Lake Outburst Flood (GLOF)?
23. Have you heard any other GLOF events? If yes, when and how?
24. Are there any past records of complaints of GLOF? What are the sources of information?

Annex- II: Questionnaire for Key Informants

For assessing the vulnerability of climate change to the water resources

No. ………………………

Date of interview:………..

Place of interview:……….

Name : ……………………………………….

Sex: ……………..

Age: ……………………………

Education: ………………

Designation/field of expertise:

Occupation: …………

Contact address : ……………………………………………………………

Water resources and man-made climate change

1. How vulnerable are the water resources of Nepal with the anthropogenic climate change and how critical is it?
2. How to measure the vulnerability of climate change with respect to water resources for Nepal ?
3. What are specific features for assessing the vulnerability of climate change to water resources in Nepal?
4. What might be the impact of climate change on water balance, hydropower generation, irrigation, water supply etc with long-term perspective?
5. What might be the relation of global, regional and local climate change impacts in relation to water resources of Nepal?
6. Do you feel any threat for the sustainability of water resources from global warming? If yes, what they might be and what are the steps to be done for the mitigation and adaptation for them?
7. What measures should be applied to cope with the impacts of climate changes on the water resources of Nepal? What might be the approach and modality?
8. What should be the approach for coping the problem – bottom-up or top-down? How the participatory approach with decentralized planning can be practiced to challenge the threat of global warming in relation to water resources of Nepal?

Water related extreme events and climate change

9. What do you know about the risk of potential Tsho Rolpa GLOF?
10. Do you see any linkages between climate change and GLOFs?
11. Which of the climate changes – global, regional or local climate change do have significant effects on glaciers, GLOFs and overall water resources of Nepal? What might be the degree of influences from the global, regional or local climate changes on water resources of Nepal?
12. How to relate more frequent extreme rainfalls and longer draught period in Nepal in recent decades with climate change?

Annex –III: List of the Key Informants Contacted During Field Visit

- Prof Dr Bidur Upadhaya, Chief; Central Department of Hydrology and Meteorolgy, TU Nepal
- Mr Tek Bahadur Gurung, Natural Resource Management Officer, UNDP Nepal
- Mr Bikash Pandey, Country Director, Winrock International Nepal
- Mr Adarsha Prasad Pokharel, Director General, DHM Nepal
- Dr. Arun Bhakta Shrestha, Engineer Hydrologist, DHM Nepal
- Dr. Birbal Rana, Glaciologist, DHM Nepal
- Mr Kamal Prakash Budhathoki, Meteologist, DHM Nepal
- Dr Narendra Man Shakya, Water Resources Engineer, TU Nepal
- Mr Praddep Kumar Mool, Tsho Rolpa and GLOF Expert, ICIMOD
- Mr Ajaya Dixit, Water Resource Expert, Nepal Water Conservation Foundation
- Mr Rishi Kesh Adhikari, Engineer working in Tsho Rolpa GLOF Risk Reduction Project, BPCH
- Mr Narayan Popkharel, Engineer, BPCH
- Dr Keshav Prasad Sharma, Senior Divisional Hydrologist, DHM Nepal
- Dr Madan Lal Shrestha, Deputy Director General, DHM Nepal
- Mr Ngamindra Dahal, Meteorologist, Nepal Water Conservation Foundation
- Dr. Rabindra Nath Bhattarai, Director , Centre for Pollution Studies, TU Nepal
- Mr. Raju Aryal, Meteorologist, DHM Nepal
- Mr Pashupati Chaulagain, former member of parliament of Dolakha
- Mr Dev Shankar Poudel, former member of parliament of Ramechhap
- Mr Anand Pokharel, former member of parliament of Dolakha
- Mr. Rajendra Manandhar, journalist, Dolakha
- Mr. Sambhu Gautam, journalist, Dolakha
- Mr Jagadish Ghimire, Development Manager, Our Neighbours

Annex –IV: Regression Analysis of the data of Tsho Rolpa with Jiri and Tamakoshi Busti

1. Regression Analysis of Discharge Values of Tsho Rolpa and Tamakoshi Busti

Model Summary

	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
Model					R Square Change	F Change	df1	df2	Sig. F Change
1	.828	.685	.672	2.2656	.685	54.305	1	25	.000

a Predictors: (Constant), Discharge at Tamakoshi

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
1	(Constant)	.532	.640		.830	.414
	Discharge at Tamakoshi	1.812E-02	.002	.828	7.369	.000

a Dependent Variable: Discharge at Tsho, m^3/s

2. Regression Analysis of Temperatures of Tsho Rolpa and Jiri

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.942	.887	.884	1.9260

a Predictors: (Constant), Temperature in Jiri

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
1	(Constant)	-15.555	.989		-15.727	.000
	Temperature in Jiri	1.004	.059	.942	17.057	.000

a Dependent Variable: Temperature in Tsho Rolpa

3. Regression Analysis of Precipitation of Tsho Rolpa and Jiri

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.748	.559	.546	45.72

a Predictors: (Constant), Precipitation at Jiri

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
1	(Constant)	15.618	10.599		1.473	.150
	Precipitation at Jiri	.266	.041	.748	6.562	.000

a Dependent Variable: Precipitation at Tsho

4. Regression Analysis of Humidity of Tsho Rolpa and Jiri

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.401	.161	.138	18.186

a Predictors: (Constant), Humidity at Jiri

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
1	(Constant)	-13.321	32.671		-.408	.686
	Humidity at Jiri	1.042	.391	.401	2.661	.011

a Dependent Variable: Humidity at Tsho Rolpa

Annex –V: Information Collected by the Interview with Local People

(Calculated by SPSS 10.0 from the data collected by author)

1. Ethnic Group of the Respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Brahmin	19	25.7	25.7	25.7
	Chhetri	14	18.9	18.9	44.6
	Sherpa	17	23.0	23.0	67.6
	Tamang	4	5.4	5.4	73.0
	Newar	13	17.6	17.6	90.5
	Others	7	9.5	9.5	100.0
	Total	74	100.0	100.0	

2. Age group of the Respondent

	Age Group	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	25-40 yrs	24	32.4	32.4	32.4
	41-50 yrs	18	24.3	24.3	56.8
	51-60 yrs	16	21.6	21.6	78.4
	Above 60 yrs	16	21.6	21.6	100.0
	Total	74	100.0	100.0	

3. Administrative/political zone in local level

	Name of VDC	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Bigu	2	2.7	2.7	2.7
	Chankhu	1	1.4	1.4	4.1
	Dandakharka	1	1.4	1.4	5.4
	Gaurishankar	6	8.1	8.1	13.5
	Jhyaku	7	9.5	9.5	23.0
	Jhyanku	1	1.4	1.4	24.3
	Jiri	7	9.5	9.5	33.8
	Khare	3	4.1	4.1	37.8
	Laduk	9	12.2	12.2	50.0
	Lamabagar	1	1.4	1.4	51.4
	Lamidanda	6	8.1	8.1	59.5
	Phasku	1	1.4	1.4	60.8
	Sunkhani	3	4.1	4.1	64.9
	Suri	3	4.1	4.1	68.9
	VNP	22	29.7	29.7	98.6
	Warang	1	1.4	1.4	100.0
	Total	74	100.0	100.0	

4. Name of respondent's village

	Village	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Beding	6	8.1	8.1	8.1
	Bigu	1	1.4	1.4	9.5
	Chankhu	1	1.4	1.4	10.8
	Chapleti	1	1.4	1.4	12.2
	Charikot	9	12.2	12.2	24.3
	Charkot	1	1.4	1.4	25.7
	Chhaparku	1	1.4	1.4	27.0
	Dolakha	6	8.1	8.1	35.1
	Gumkhola	2	2.7	2.7	37.8
	Jagat	2	2.7	2.7	40.5
	Jhyanku	7	9.5	9.5	50.0
	Jilu	1	1.4	1.4	**5. 51.4**
	Jiri	7	9.5	9.5	60.8
	Kothe	1	1.4	1.4	62.2
	Majhmati	1	1.4	1.4	63.5
	Makai Bari	1	1.4	1.4	64.9
	Nayapul	1	1.4	1.4	66.2
	Nikasi	1	1.4	1.4	67.6
	Phasku	1	1.4	1.4	68.9
	Putung	2	2.7	2.7	71.6
	Ramkot	2	2.7	2.7	74.3
	Singati	12	16.2	16.2	90.5
	Sisikuna	1	1.4	1.4	91.9
	Suri	2	2.7	2.7	94.6
	Tatopani	3	4.1	4.1	98.6
	Tinekhu	1	1.4	1.4	100.0
	Total	74	100.0	100.0	

6. Education level

	Education Level	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Illiterate	12	16.2	16.2	16.2
	Just literate	27	36.5	36.5	52.7
	School education	24	32.4	32.4	85.1
	Higher education	11	14.9	14.9	100.0
	Total	74	100.0	100.0	

7. Information about Tsho Rolpa Glacier Lake

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	know	73	98.6	98.6	98.6
	do not know	1	1.4	1.4	100.0
	Total	74	100.0	100.0	

8. Source of information of the lake, if know

	Source	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Pesonal visit	30	40.5	40.5	40.5
	Villagers	35	47.3	47.3	87.8
	Media	8	10.8	10.8	98.6
	Sherpas	1	1.4	1.4	100.0
	Total	74	100.0	100.0	

9. Possibility of outburst flood from the lake

	Answer	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	yes	28	37.8	37.8	37.8
	no	37	50.0	50.0	87.8
	do not know	9	12.2	12.2	100.0
	Total	74	100.0	100.0	

10. Information on other outburst floods

	Answer	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	yes	37	50.0	50.0	50.0
	no	37	50.0	50.0	100.0
	Total	74	100.0	100.0	

11. Reasons for visiting the lake

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Living nearby	7	9.5	22.6	22.6
	Personal interest	8	10.8	25.8	48.4
	Under job	16	21.6	51.6	100.0
	Total	31	41.9	100.0	
Missing	*Not visited*	*43*	*58.1*		
Total		74	100.0		

12. Cross tabulation between Reasons for visiting the lake and Education level

		Education level				Total
		Illiterate	Just literate	School education	Higher education	
Reasons for visiting the lake	Living nearby	1	5	1		7
	Personal interest		1	3	4	8
	Under job	3	6	5	2	16
Total		4	12	9	6	31

13. Cross tabulation between Reasons for visiting the lake and Possibility of outburst flood from the lake

		Possibility of outburst flood from the lake			Total
		yes	no	do not know	
Reasons for visiting the lake	Living nearby	7			7
	Personal interest	6	1	1	8
	Under job	5	10	1	16
Total		18	11	2	31

14. Cross tabulation between Altitude group of the village of residence and Possibility of outburst flood from the lake

		Possibility of outburst flood from the lake			Total
		yes	no	do not know	
Altitude group of the village of residence	Up to 1000 m	1	2		3
	1100-1500 m	4	22	1	27
	1600-2000 m	16	12	8	36
	2100-2500 m	1	1		2
	3100-3800 m	6			6
Total		28	37	9	74

15. Cross tabulation between Distance from Tsho Rolpa and Information on other outburst floods

		Information on other outburst floods		Total
		yes	no	
Distance from Tsho Rolpa	10- 20 km	6		6
	21-30 km	1	4	5
	31-40 km		8	8
	41-60 km	18	20	38
	61-80 km	12	5	17
Total		37	37	74

16. Cross tabulation between Ethnic Group and Information on Tsho Rolpa GLOF

		Information about Tsho Rolpa Glacier Lake		Total
		know	do not know	
Ethnic Group	Brahmin	19		19
	Chhetri	14		14
	Sherpa	17		17
	Tamang	4		4
	Newar	13		13
	Others	6	1	7
Total		73	1	74

17. Cross tabulation between Ethnic Group and Possibility of outburst flood from the lake

		Possibility of outburst flood from the lake			Total
		yes	no	do not know	
Ethnic Group	Brahmin	8	6	5	19
	Chhetri	5	9		14
	Sherpa	7	9	1	17
	Tamang		4		4
	Newar	8	4	1	13
	Others		5	2	7
Total		28	37	9	74

18. Cold feeling for the last 20-30 years

		Frequency	Percent	Valid Percent	Cumulative Percent
Cold Feeling	Increased	2	2.7	2.7	2.7
	Decreased	63	85.1	85.1	87.8
	No change	3	4.1	4.1	91.9
	Don't know	6	8.1	8.1	100.0
	Total	74	100.0	100.0	

19. Change in hailstone from the past

		Frequency	Percent	Valid Percent	Cumulative Percent
Hailstone	Increased	3	4.1	4.1	4.1
	Decreased	41	55.4	55.4	59.5
	No change	6	8.1	8.1	67.6
	Do not know	24	32.4	32.4	100.0
	Total	74	100.0	100.0	

20. Change in frost from the past

		Frequency	Percent	Valid Percent	Cumulative Percent
Frost	Decreased	65	87.8	87.8	87.8
	No change	9	12.2	12.2	100.0
	Total	74	100.0	100.0	

21. Change in snowfall from the past

		Frequency	Percent	Valid Percent	Cumulative Percent
Snowfall	Decreased	24	32.4	32.4	32.4
	No change	12	16.2	16.2	48.6
	Do not know	38	51.4	51.4	100.0
	Total	74	100.0	100.0	

22. Change in summer rainfall

		Frequency	Percent	Valid Percent	Cumulative Percent
Summer rainfall	Increased	58	78.4	78.4	78.4
	Decreased	9	12.2	12.2	90.5
	No change	3	4.1	4.1	94.6
	Do not know	4	5.4	5.4	100.0
	Total	74	100.0	100.0	

23. Change in winter rainfall

		Frequency	Percent	Valid Percent	Cumulative Percent
Winter rainfall	Decreased	67	90.5	90.5	90.5
	No change	1	1.4	1.4	91.9
	Do not know	6	8.1	8.1	100.0
	Total	74	100.0	100.0	

Annex –VI: Hydrological and Meteorological Information

(DATA SOURCE: DHM)

1. Average Monthly Temperature of Jiri, ^{0}C

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1971	7.0	7.2	11.4	13.9	15.9	19.5	19.2	18.5	16.9	15.3	10.5	7.4	**13.6**
1972	7.2	7.5	11.6	15.4	16.4	19.3	19.6	19.0	17.7	15.2	10.5	7.1	**13.9**
1973	7.2	7.7	11.9	16.8	16.9	19.1	20.0	19.5	18.5	15.1	10.4	6.7	**14.2**
1974	6.2	8.0	12.1	15.6	17.0	18.8	19.2	19.3	17.6	16.6	10.2	5.6	**13.9**
1975	5.4	8.0	11.8	15.8	17.6	19.6	19.3	19.4	18.0	16.0	9.8	6.9	**14.0**
1976	5.9	9.0	11.4	15.4	16.4	18.7	19.6	18.6	18.3	14.8	11.4	7.8	**13.9**
1977	6.2	7.2	12.3	14.4	15.3	18.9	20.1	19.8	18.8	14.1	11.8	7.1	**13.8**
1978	5.0	7.7	9.9	14.0	17.6	19.6	19.6	19.9	18.0	15.2	11.0	7.8	**13.8**
1979	7.0	7.8	11.0	15.2	17.7	19.0	19.9	19.8	18.0	14.6	12.3	7.5	**14.2**
1980	5.9	8.4	11.2	16.0	17.2	19.5	20.3	19.8	19.0	14.3	10.4	8.0	**14.2**
1981	7.2	9.2	11.2	13.8	16.9	19.5	20.1	20.4	18.8	15.6	10.5	7.9	**14.3**
1982	7.1	6.8	10.6	14.2	16.8	19.6	20.2	20.0	18.6	13.6	11.2	7.5	**13.9**
1983	4.7	6.2	10.9	12.9	16.3	19.5	20.3	20.1	19.6	15.0	10.2	6.5	**13.5**
1984	5.4	7.4	12.2	15.1	17.3	20.0	19.9	20.1	17.8	16.4	9.9	7.5	**14.1**
1985	6.0	8.5	13.5	15.2	17.0	19.9	19.5	21.6	18.4	14.9	10.1	8.5	**14.4**
1986	6.4	8.0	11.2	14.0	15.2	18.4	18.5	19.6	18.2	14.8	10.7	8.6	**13.6**
1987	7.0	8.7	11.5	13.9	17.0	19.3	20.0	19.6	19.5	15.0	10.5	8.6	**14.2**
1988	7.5	9.4	11.7	14.9	17.7	19.7	20.8	20.5	19.5	15.6	10.2	8.9	**14.7**
1989	5.8	7.3	11.2	13.6	17.8	19.7	20.0	20.2	19.2	15.4	9.7	6.8	**13.9**
1990	8.4	8.0	10.2	13.8	17.4	20.7	20.7	20.5	19.6	14.5	10.8	8.2	**14.4**
1991	6.0	8.9	11.1	13.7	17.4	19.9	21.2	20.7	19.7	15.6	9.4	7.0	**14.2**
1992	6.2	6.7	12.4	15.0	15.9	19.5	20.1	20.2	19.2	15.3	10.1	6.8	**14.0**
1993	6.5	9.0	9.9	13.9	17.2	19.5	20.8	20.5	19.1	15.9	11.4	8.2	**14.3**
1994	6.7	7.3	11.8	13.9	17.7	20.4	20.9	20.6	19.7	14.5	9.5	6.6	**14.1**
1995	4.9	7.4	11.3	14.3	18.8	20.6	20.6	20.5	19.5	15.5	10.8	7.1	**14.3**
1996	6.2	8.4	12.8	14.4	17.5	19.7	20.3	20.1	19.2	15.4	10.9	7.1	**14.3**
1997	5.1	6.0	10.8	12.3	15.7	19.0	20.7	20.3	18.9	12.6	10.2	6.9	**13.2**
1998	5.8	8.6	10.6	14.3	18.0	20.9	20.7	20.3	19.7	17.4	12.2	7.7	**14.7**
1999	6.0	10.7	12.1	16.9	19.4	20.5	19.9	19.5	19.5	16.0	11.1	8.3	**15.0**
2000	6.4	6.4	10.8	14.9	18.5	20.5	20.8	20.5	18.8	15.6	11.8	7.2	**14.4**
Mean	**6.3**	**7.9**	**11.4**	**14.6**	**17.1**	**19.6**	**20.1**	**20.0**	**18.8**	**15.2**	**10.7**	**7.5**	**14.1**

2. Other Temperature Data, 0C

Year	Average seasonal			Extreme		Temp. Range	Temperature Deviation from the mean, ^{0}C			Days with T<0^0C
	Summer	Winter	Pre-monsoon	Max	Min	Max-Min	Ave.	Max	Min	No.
1971	19.1	7.2	13.7	25.0	-5.0	30.0	-0.5	-1.8	1.3	41
1972	19.3	7.3	14.5	25.6	-4.0	29.6	-0.2	-1.2	2.3	45
1973	19.5	7.2	15.2	26.5	-2.5	29.0	0.0	-0.3	3.8	48
1974	19.1	6.6	14.9	25.3	-4.0	29.3	-0.3	-1.5	2.3	52
1975	19.4	6.8	15.1	26.9	-7.0	33.9	-0.1	0.1	-0.7	50
1976	19.0	7.6	14.4	24.5	-2.9	27.4	-0.2	-2.3	3.4	37
1977	19.6	6.8	14.0	25.8	-4.5	30.3	-0.3	-1.0	1.8	36
1978	19.7	6.8	13.8	25.9	-6.0	31.9	-0.3	-0.9	0.3	50
1979	19.6	7.4	14.6	26.6	-3.1	29.7	0.0	-0.2	3.2	41
1980	19.9	7.4	14.8	25.8	-3.5	29.3	0.1	-1.0	2.8	41
1981	20.0	8.1	14.0	25.9	-4.6	30.5	0.2	-0.9	1.7	62
1982	19.9	7.1	13.9	26.2	-4.2	30.4	-0.3	-0.6	2.1	64
1983	20.0	5.8	13.4	26.8	-5.8	32.6	-0.6	0.0	0.5	65
1984	20.0	6.8	14.9	28.8	-4.9	33.7	0.0	2.0	1.4	51
1985	20.3	7.7	15.2	28.5	-4.0	32.5	0.3	1.7	2.3	36
1986	18.8	7.7	13.5	25.6	-3.0	28.6	-0.5	-1.2	3.3	36
1987	19.6	8.1	14.1	26.5	-3.4	29.9	0.1	-0.3	2.9	35
1988	20.3	8.6	14.8	27.2	-3.8	31.0	0.6	0.4	2.5	35
1989	20.0	6.6	14.2	28.0	-5.3	33.3	-0.2	1.2	1.0	74
1990	20.6	8.2	13.8	27.1	-5.2	32.3	0.3	0.3	1.1	49
1991	20.6	7.3	14.1	27.5	-4.1	31.6	0.1	0.7	2.2	66
1992	19.9	6.6	14.4	28.2	-6.1	34.3	-0.1	1.4	0.2	63
1993	20.3	7.9	13.7	26.4	-5.5	31.9	0.2	-0.4	0.8	49
1994	20.6	6.9	14.5	27.7	-7.3	35.0	0.0	0.9	-1.0	77
1995	20.6	6.5	14.8	27.5	-5.9	33.4	0.2	0.7	0.4	68
1996	20.0	7.2	14.9	27.2	-5.0	32.2	0.2	0.4	1.3	78
1997	20.0	6.0	12.9	27.1	-5.6	32.7	-0.9	0.3	0.7	79
1998	20.6	7.4	14.3	29.2	-7.5	36.7	0.6	2.4	-1.2	68
1999	20.0	8.3	16.1	28.6	-6.0	34.6	0.9	1.8	0.3	59
2000	20.6	6.7	14.7	27.0	-6.3	33.3	0.3	0.2	0.0	76
Average	**19.9**	**7.2**	**14.4**	**26.8**	**-4.9**	**31.7**				**54**

3. Average Monthly Precipitation for 1971-2000

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1971	2	0	63	104	219	504	661	523	294	142	20	0	**2532**
1972	25	17	59	47	208	421	542	397	201	72	25	0	**2014**
1973	9	20	44	38	193	459	497	562	345	191	44	0	**2402**
1974	19	0	46	122	152	232	508	606	241	60	5	10	**2001**
1975	34	19	17	69	155	264	511	491	460	148	0	0	**2168**
1976	39	42	0	59	179	397	360	512	267	111	11	16	**1993**
1977	4	4	39	131	186	230	544	575	134	75	22	31	**1975**
1978	12	17	63	132	198	444	606	522	245	50	10	4	**2303**
1979	4	28	20	88	77	394	590	472	216	71	35	69	**2064**
1980	0	26	66	17	158	381	555	745	234	51	0	5	**2238**
1981	14	0	43	123	191	400	648	564	230	4	14	0	**2231**
1982	3	34	51	97	119	424	614	594	194	63	32	1	**2226**
1983	42	22	35	90	125	159	634	496	333	32	16	22	**2006**
1984	26	21	25	81	131	396	604	397	376	0	0	43	**2100**
1985	9	20	14	71	137	126	603	410	401	155	15	64	**2025**
1986	0	26	4	95	130	343	533	226	191	55	17	35	**1655**
1987	2	29	57	115	87	500	823	512	299	125	1	18	**2568**
1988	4	31	109	134	124	354	784	469	202	11	22	54	**2298**
1989	45	31	76	16	232	421	480	713	448	39	8	6	**2515**
1990	2	50	70	106	287	492	463	466	243	59	7	5	**2250**
1991	24	13	35	124	129	392	431	698	282	2	22	10	**2162**
1992	18	23	0	20	192	411	631	604	356	109	16	5	**2385**
1993	19	17	46	193	151	338	575	655	272	25	12	0	**2303**
1994	30	27	66	68	245	360	512	694	265	0	54	14	**2335**
1995	14	20	33	14	267	539	529	734	187	108	76	6	**2527**
1996	58	26	56	21	143	326	608	645	284	67	0	0	**2234**
1997	27	13	17	165	167	353	918	587	374	65	5	63	**2754**
1998	0	30	102	127	188	380	684	574	267	65	21	0	**2438**
1999	7	0	6	18	267	396	560	560	547	191	3	1	**2556**
2000	11	2	37	89	251	411	719	759	292	51	0	3	**2625**
Average	**17**	**20**	**43**	**86**	**176**	**375**	**591**	**559**	**289**	**73**	**17**	**16**	**2263**

Seasonal Distribution of Precipitation for 1971-2000

	Seasonal Distribution, mm					Number of rainy days with precipitation, mm in 24 hours						
Year	Mon-soon	Pre-Mon-soon	Post-Mon-soon	Winter	Total	>1.0	1.0-9.9	10-24.9	25-49.9	50-99.9	> 100	Total
1971	1688	386	456	2	**2532**	168	88	43	31	6	0	168
1972	1360	314	298	42	**2014**	168	76	41	33	4	0	168
1973	1518	275	580	29	**2402**	168	84	45	28	4	0	168
1974	1346	320	306	29	**2001**	156	83	48	22	3	0	156
1975	1266	241	608	53	**2168**	160	81	51	24	4	0	160
1976	1269	238	389	97	**1993**	160	89	46	21	5	0	160
1977	1349	356	231	39	**1975**	159	96	41	17	5	0	159
1978	1572	393	305	33	**2303**	164	79	60	17	8	0	164
1979	1456	185	322	101	**2064**	143	80	39	17	7	0	143
1980	1681	241	285	31	**2238**	149	78	45	16	10	0	149
1981	1612	357	248	14	**2231**	144	71	44	23	6	0	144
1982	1632	267	289	38	**2226**	156	79	54	17	6	0	156
1983	1289	250	381	86	**2006**	143	68	50	18	6	0	143
1984	1397	237	376	90	**2100**	131	58	47	20	7	0	131
1985	1139	222	571	93	**2025**	118	47	43	21	7	0	118
1986	1102	229	263	61	**1655**	101	44	36	15	6	0	101
1987	1835	259	425	49	**2568**	109	38	36	21	14	0	109
1988	1607	367	235	89	**2298**	150	75	43	26	6	0	150
1989	1614	324	495	82	**2515**	153	74	46	27	5	0	153
1990	1421	463	309	57	**2250**	167	86	56	18	7	0	167
1991	1521	288	306	47	**2162**	136	66	44	19	7	0	136
1992	1646	212	481	46	**2385**	135	135	101	23	10	0	135
1993	1568	390	309	36	**2303**	160	88	44	19	9	0	160
1994	1566	379	319	71	**2335**	154	77	50	20	7	0	154
1995	1802	314	371	40	**2527**	148	64	52	22	10	0	148
1996	1579	220	351	84	**2234**	142	64	48	24	6	0	142
1997	1858	349	444	103	**2754**	157	74	46	24	12	0	157
1998	1638	417	353	30	**2438**	151	73	49	23	9	0	151
1999	1516	291	741	8	**2556**	122	49	47	20	6	0	122
2000	1889	377	343	16	**2625**	150	70	39	34	7	0	150
Ave.	**1525**	**305**	**380**	**53**	**2263**	**147**	**74**	**48**	**22**	**7**	**0**	**147**

4. Monthly Relative Humidity at Jiri for the Period of 1971-2000

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1971	72	62	63	75	87	85	87	85	86	81	81	81	**79**
1972	84	75	66	66	69	75	84	82	86	78	75	62	**75**
1973	71	69	66	54	73	79	84	86	86	79	77	76	**75**
1974	71	69	58	69	72	77	84	87	86	83	81	77	**76**
1975	77	77	58	51	68	77	85	83	86	84	81	74	**75**
1976	73	78	78	86	87	93	87	91	87	84	86	73	**83**
1977	81	74	66	76	81	86	88	88	86	85	85	85	**81**
1978	77	76	61	66	79	83	87	85	88	82	80	69	**77**
1979	79	80	59	59	67	73	85	84	82	80	72	76	**74**
1980	75	76	71	66	64	79	83	88	79	76	79	81	**76**
1981	87	77	70	77	78	78	88	87	85	80	81	83	**81**
1982	77	77	69	68	67	82	86	87	87	81	83	81	**79**
1983	83	80	70	70	78	82	86	85	86	84	87	85	**81**
1984	85	84	74	68	81	84	87	86	86	86	87	88	**83**
1985	86	88	77	69	77	90	92	93	89	87	90	90	**86**
1986	87	87	82	84	84	86	89	91	89	88	90	87	**87**
1987	86	84	76	64	63	87	91	90	85	81	83	83	**81**
1988	84	81	70	68	74	83	88	89	86	85	88	89	**82**
1989	89	81	76	58	73	84	90	88	90	84	87	85	**82**
1990	85	86	77	70	80	83	89	86	85	85	86	86	**83**
1991	85	68	67	63	73	84	88	88	86	80	83	85	**79**
1992	81	81	59	56	72	80	86	87	83	82	88	85	**78**
1993	85	80	74	73	79	84	88	88	87	83	86	86	**82**
1994	81	76	78	61	74	82	85	87	88	81	85	81	**80**
1995	82	78	68	61	73	91	91	89	89	89	91	92	**83**
1996	82	84	81	65	76	86	89	87	87	86	89	89	**83**
1997	87	82	77	78	71	81	89	90	88	88	89	87	**84**
1998	86	84	81	79	81	84	89	90	88	88	89	87	**85**
1999	84	76	65	67	79	84	88	88	89	88	90	88	**82**
2000	86	80	67	70	80	87	88	89	88	86	88	87	**83**
Av	**81**	**78**	**70**	**68**	**75**	**83**	**87**	**87**	**86**	**83**	**84**	**82**	**80**

5. Average Monthly Hydrograph of River Tamakoshi at Busti

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1971	27.7	21.6	19.7	25.3	41.7	292.0	438.0	496.0	294.0	174.0	75.4	42.1	**162.3**
1972	28.6	22.9	22.3	23.5	76.0	144.0	383.0	461.0	342.0	142.0	75.1	44.6	**147.1**
1973	31.4	24.6	26.4	40.8	77.8	261.0	386.0	506.0	410.0	218.0	97.8	58.1	**178.2**
1974	40.2	29.7	27.8	40.1	68.0	167.0	461.0	497.0	304.0	156.0	71.4	42.5	**158.7**
1975	30.5	25.0	22.5	35.5	71.4	199.0	419.0	426.0	397.0	214.0	78.7	42.5	**163.4**
1976	28.1	22.0	18.5	20.6	46.4	179.0	307.0	410.0	287.0	103.0	52.7	35.1	**125.8**
1977	27.9	25.0	23.6	27.0	40.0	109.0	410.0	457.0	262.0	130.0	64.4	42.0	**134.8**
1978	32.5	28.0	28.0	34.1	91.5	211.0	430.0	462.0	257.0	138.0	62.2	40.1	**151.2**
1979	30.7	26.4	24.7	27.3	51.8	121.0	371.0	385.0	218.0	94.7	52.1	36.9	**120.0**
1980	28.8	25.3	24.7	31.0	44.5	151.0	433.0	454.0	281.0	104.0	51.1	34.9	**138.6**
1981	27.8	24.9	23.8	26.6	39.4	140.0	434.0	463.0	254.0	91.9	47.3	31.8	**133.7**
1982	26.1	24.7	24.2	30.3	40.0	145.0	331.0	372.0	242.0	101.0	59.6	42.4	**119.9**
1983	32.6	27.4	26.8	29.9	61.9	134.0	345.0	362.0	341.0	168.0	71.0	43.5	**136.9**
1984	31.8	25.8	24.6	25.6	66.2	193.0	451.0	349.0	341.0	112.0	57.1	39.3	**143.0**
1985	29.2	24.9	24.6	27.3	37.5	143.0	424.0	426.0	347.0	173.0	79.9	47.2	**148.6**
1986	34.8	27.6	24.5	31.1	37.9	206.0	362.0	337.0	292.0	138.0	72.3	46.8	**134.2**
1987	30.2	24.3	23.8	30.9	44.5	186.0	517.0	486.0	307.0	117.0	57.7	36.3	**155.1**
1988	25.6	21.0	32.7	24.9	55.4	187.0	655.0	781.0	345.0	117.0	52.9	28.6	**193.8**
1989	23.5	33.9	41.5	28.9	55.9	215.0	485.0	561.0	497.0	183.0	64.0	20.9	**184.1**
1990	21.4	46.8	50.4	32.9	56.3	212.5	484.0	647.0	361.5	104.7	36.5	13.3	**172.3**
1991	19.3	25.6	33.7	36.9	56.8	210.0	483.0	733.0	226.0	26.4	9.0	5.6	**155.4**
1992	22.3	23.4	25.9	29.6	22.7	87.0	332.0	566.0	357.0	61.1	18.9	33.8	**131.6**
1993	25.2	21.2	18.0	22.3	48.6	140.7	224.0	473.0	254.0	95.7	28.8	34.1	**115.5**
1994	40.9	36.9	35.5	41.7	79.8	194.3	415.0	587.0	364.0	123.0	85.4	34.5	**169.8**
1995	56.5	52.5	52.9	61.0	111.0	248.0	408.0	617.0	324.0	132.0	61.1	34.8	**179.9**
1996	40.9	21.7	23.0	27.0	59.3	297.0	769.0	977.0	571.0	124.0	64.0	35.1	**250.7**
1997	25.2	20.9	19.3	19.9	31.4	128.0	469.0	411.0	211.0	110.0	52.9	36.2	**127.9**
1998	24.8	19.9	21.2	31.4	76.0	247.0	594.0	831.0	369.0	151.0	59.8	31.7	**204.7**
1999	22.0	18.2	16.7	24.2	56.7	172.0	475.0	492.0	326.0	162.0	63.6	35.8	**155.4**
2000	23.7	18.5	16.5	21.5	55.0	339.0	706.0	810.0	553.0	180.0	61.7	33.8	**234.9**
Ave.	**29.7**	**26.4**	**26.6**	**30.3**	**56.7**	**188.6**	**446.7**	**527.8**	**331.2**	**131.5**	**59.5**	**36.1**	**157.6**

6. Observed Discharge Values of Tamakoshi Busti

Year	Discharge, m3/s							Coeff. of River Regime, max/min
	Annual	Winter	Pre-monsoon	Monsoon	Post-monsoon	Inst. Max	Inst. Min	
1971	162	30	29	409	181	688	18	38
1972	147	32	41	329	186	803	20	41
1973	178	38	48	384	242	671	22	30
1974	159	37	45	375	177	768	23	33
1975	163	33	43	348	230	685	21	32
1976	126	28	29	299	148	564	17	33
1977	135	32	30	325	152	723	23	31
1978	151	34	51	368	152	732	26	28
1979	120	31	35	292	122	674	24	28
1980	139	30	33	346	145	642	24	27
1981	134	28	30	346	131	628	23	27
1982	120	31	32	283	134	556	23	24
1983	137	35	40	280	193	575	25	23
1984	143	32	39	331	170	735	21	36
1985	149	34	30	331	200	628	23	28
1986	134	36	31	302	167	632	22	29
1987	155	30	33	396	161	903	22	41
1988	194	25	38	541	172	1073	20	54
1989	184	26	42	420	248	922	19	49
1990	172	27	47	448	168	885	17	53
1991	155	17	42	475	87	1050	14	73
1992	132	26	26	328	146	1082	17	62
1993	115	27	30	279	126	696	17	41
1994	170	37	52	399	191	987	28	35
1995	180	48	75	424	172	1117	28	40
1996	251	33	36	681	253	1270	20	63
1997	128	27	24	336	125	1140	19	61
1998	205	25	43	557	193	1785	19	96
1999	155	25	33	380	184	1096	16	69
2000	235	25	31	618	265	1441	16	93
Ave	**157.6**	**30.7**	**37.9**	**387.7**	**174.0**	**871.7**	**20.8**	**44.0**

7. Observed Weather Data of Tsho Rolpa and Jiri (July 1993- August 2000)

	Tsho Rolpa			Jiri		
	Temperature, ^0C	Precipitation, mm	Humidity, %	Temperature, ^0C	Precipitation, mm	Humidity, %
Jul-93	5.4	71	96	20.8	575	88
Aug-93	5.3	243.5	97	20.5	655	88
Mar-94	-3.8	30.5	63	11.8	66	78
May-94	1.1	30.5	86	17.7	245	74
Jun-94	4.9	67	93	20.4	360	82
Jul-94	5.5	104	96	20.9	512	85
Aug-94	5.1	109	97	20.6	694	87
Sep-94	4	55	93	19.7	265	88
Oct-94	0	0	63	14.5	0	81
Nov-94	-6	5	67	9.5	54	85
Dec-94	-5.4	0.5	33	6.6	14	81
Jan-95	-9.2	6.5	39	4.9	14	82
Feb-95	-8.3	12.5	52	7.4	20	78
Mar-95	-4.4	18	51	11.3	33	68
Apr-95	-2.6	29	60	14.3	14	61
May-95	2.6	28	75	18.8	267	73
Jun-95	5.4	76.5	82	20.6	539	91
Jul-95	5.3	196	82	20.6	529	91
Aug-95	5	215	81	20.5	734	89
Sep-95	3.7	97	80	19.5	187	89
Oct-95	-3.6	8	57	15.5	108	89
Nov-95	-7.5	7	46	10.8	76	91
Dec-95	-9.7	0.5	50	7.1	6	92
Mar-96	-8.1	34	65	12.8	56	81
May-96	-3.7	22	72	17.5	188	76
Jun-96	3.5	.	92	19.7	.	86
Jul-96	5.4	.	97	20.3	.	89
Aug-96	4.8	.	94	20.1	.	87
Jul-99	6.7	188	89	19.9	560	88
Aug-99	6	167	91	19.5	560	88
Sep-99	5.6	76	82	19.5	547	89
Jan-00	-6.3	5	41	6.4	11	86
Feb-00	-8	18	44	6.4	2	80
Mar-00	-5.2	32	51	10.8	37	67
Apr-00	0	34	58	14.9	89	70
May-00	5	50	74	18.5	251	80
Jun-00	6.4	125	87	20.5	411	87
Jul-00	7	172	90	20.8	719	88
Aug-00	6.6	172	92	20.5	759	89

8. Observed Values of Discharges at Tsho Rolpa and Tamakoshi Busti

Month	Tsho Rolpa, m^3/s	Tamakoshi Busti, m^3/s
Jun-93	3.4	141
Jul-93	7.4	224
Aug-93	8	473
Sep-93	2.6	254
Mar-94	1.2	96
Apr-94	0.7	29
May-94	1	80
Jun-94	7	194
Jul-94	11.2	415
Aug-94	7.1	587
Sep-94	5.4	364
Nov-94	0.6	85
Dec-94	0.5	34
Apr-95	0.4	61
May-95	4.2	111
Jun-95	11.8	248
Jul-95	11.6	408
Aug-95	10.3	617
Sep-95	5.7	324
Oct-95	2.1	132
Nov-95	0.8	61
Dec-95	0.5	35
Jan-96	0.5	41
Feb-96	0.4	22
Mar-96	0.4	23
Apr-96	0.6	27
May-96	2.2	59

9. **Observed and Calculated Values of Temperature, Precipitation, and Discharge at Tsho Rolpa**

	Temperature T, 0C		Precipitation P, mm	
Month	Observed	Calculated	Observed	Calculated
Jul-93	5.4	5.3	71	169
Aug-93	5.3	5.0	244	190
Mar-94	-3.8	-3.7	31	33
May-94	1.1	2.2	31	81
Jun-94	4.9	4.9	67	111
Jul-94	5.5	5.4	104	152
Aug-94	5.1	5.1	109	200
Sep-94	4.0	4.2	55	86
Oct-94	0.0	-1.0	0	4
Nov-94	-6.0	-6.0	5	16
Dec-94	-5.4	-8.9	1	7
Jan-95	-9.2	-10.6	7	7
Feb-95	-8.3	-8.1	13	8
Mar-95	-4.4	-4.2	18	11
Apr-95	-2.6	-1.2	29	7
May-95	2.6	3.3	28	66
Jun-95	5.4	5.1	77	130
Jul-95	5.3	5.1	196	127
Aug-95	5.0	5.0	215	175
Sep-95	3.7	4.0	97	47
Oct-95	-3.6	0.0	8	29
Nov-95	-7.5	-4.7	7	21
Dec-95	-9.7	-8.4	1	5
Mar-96	-8.1	-2.7	34	17
May-96	-3.7	2.0	22	48
Jun-96	3.5	4.2	-	
Jul-96	5.4	4.8	-	
Aug-96	4.8	4.6	-	
Jul-99	6.7	4.4	188	135
Aug-99	6.0	4.0	167	135
Sep-99	5.6	4.0	76	132
Jan-00	-6.3	-9.1	5	6
Feb-00	-8.0	-9.1	18	4
Mar-00	-5.2	-4.7	32	12
Apr-00	0.0	-0.6	34	24
May-00	5.0	3.0	50	62
Jun-00	6.4	5.0	125	100
Jul-00	7.0	5.3	172	172
Aug-00	6.6	5.0	172	181

Discharge Q, m3/s		
Months	Observed	Calculated
Jun-93	3.4	3.1
Jul-93	7.4	4.6
Aug-93	8.0	9.1
Sep-93	2.6	5.1
Mar-94	1.2	2.3
Apr-94	0.7	1.1
May-94	1.0	2.0
Jun-94	7.0	4.1
Jul-94	11.2	8.1
Aug-94	7.1	11.2
Sep-94	5.4	7.1
Nov-94	0.6	2.1
Dec-94	0.5	1.2
Apr-95	0.4	1.6
May-95	4.2	2.5
Jun-95	11.8	5.0
Jul-95	11.6	7.9
Aug-95	10.3	11.7
Sep-95	5.7	6.4
Oct-95	2.1	2.9
Nov-95	0.8	1.6
Dec-95	0.5	1.2
Jan-96	0.5	1.3
Feb-96	0.4	0.9
Mar-96	0.4	0.9
Apr-96	0.6	1.0
May-96	2.2	1.6

10. Projected Weather and discharge parameters of Tsho Rolpa

	Temperature, ^0C		Precipitation, mm		Discharge, m^3/s
Year	Annual	Summer	Annual	Summer	Annual
1971	-1.9	3.6	689	543	3.5
1972	-1.6	3.8	551	431	3.2
1973	-1.3	4.1	655	511	3.8
1974	-1.6	3.6	548	438	3.4
1975	-1.5	4.0	592	475	3.5
1976	-1.6	3.5	546	424	2.8
1977	-1.7	4.1	541	410	3.0
1978	-1.7	4.2	628	499	3.3
1979	-1.3	4.1	565	460	2.7
1980	-1.3	4.4	611	525	3.0
1981	-1.2	4.5	609	506	3.0
1982	-1.6	4.5	608	501	2.7
1983	-2.0	4.5	549	447	3.0
1984	-1.4	4.5	574	487	3.1
1985	-1.1	4.9	554	425	3.2
1986	-1.9	3.4	456	360	3.0
1987	-1.3	4.2	699	583	3.3
1988	-0.8	4.9	627	497	4.0
1989	-1.6	4.5	685	564	3.9
1990	-1.1	5.2	614	458	3.7
1991	-1.3	5.1	591	495	3.3
1992	-1.5	4.5	650	548	2.9
1993	-1.2	4.8	628	505	2.6
1994	-1.4	5.2	637	503	3.6
1995	-1.2	5.1	688	545	3.8
1996	-1.2	4.6	610	511	5.1
1997	-2.3	4.5	748	609	2.8
1998	-0.8	5.2	664	522	4.2
1999	-0.5	4.5	696	564	3.3
2000	-1.1	5.1	714	596	4.8
Ave.	-1.4	4.4	617.5	498.1	3.4

11. Calculated Annual Average Values of Tsho Rolpa

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Discharge, m^3/s	1.1	1.0	1.0	1.1	1.6	3.9	8.6	10.1	6.5	2.9	1.6	1.2	3.4
Temperature, ^0C	-9.3	-7.6	-4.1	-0.9	1.6	4.2	4.6	4.5	3.3	-0.3	-4.9	-8.1	-1.4
Precipitation, mm	20	21	27	38	63	115	173	164	93	35	20	20	618

12. Observed Annual Average Values of Jiri (1971-2000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Discharge, m^3/s	29.7	26.4	26.6	30.3	56.7	188.6	446.7	527.8	331.2	131.5	59.5	36.1	157.6
Temperature, ^0C	6.3	7.9	11.4	14.6	17.1	19.6	20.1	20.0	18.8	15.2	10.7	7.5	14.1
Precipitation, mm	17	20	43	86	176	375	591	559	289	73	17	16	2263