Climate Change Impacts on Reservoir based Hydropower Generation in Nepal: A case study of Kulekhani Hydropower Plant

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Climate Change Impacts on Reservoir based Hydropower Generation in Nepal: A case study of Kulekhani Hydropower Plant

By

Manjeet Dhakal

A thesis report submitted in partial fulfillment of the requirements for the degree of Masters of Science in Environment Management

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September, 2011

Certification

This is to certify that this thesis entitled **"Climate Change Impacts on reservoir based Hydropower Generation in Nepal"** submitted by Manjeet Dhakal towards partial fulfillment of Degree of Master of Science in Environmental Management is based on the original research and study under the guidance of Mr. Ngamindra Dahal The thesis in part or full is the property of **School of Environmental Management and Sustainable Development (SchEMS)** and should not be used for the purpose of awarding any academic degree in any other institution

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Abstract

In principle Nepal's hydropower potential is impressive due to rugged mountain terrain from which snow and rain fed rivers produce significant amount of seasonal water flow. Owing to this natural hydrological processes, Nepal projected an image since 1970s that this country has one of the richest hydropower potential in the world through which the country would be able to alleviate poverty by bringing socio-economic transformation of the Nepali society. This potentiality was compared with the wealth of some oil-rich Gulf countries. After 40 years, the country is still struggling hard to meet the domestic energy demand, and the once popular national slogan that ‘Nepal is rich hydropower potential with 83000 MW’ is no more exist. Completed in late 1980s, Kulekhani hydro electricity plant (KHEP) became a showcase example of hydropower development, which is the first and only reservoir based hydropower plan in the country. A strong cloudburst of July 1993 seriously hit the plant as its penstock pipes were swept away and seriously reduced water holding capacity of the reservoir due to sediment deposit. In the project design document, such risks were ruled out and, the watershed has been identified as one of the safe zone from any extreme climatic events. The event had a huge impact on the other projects under pipeline. Since then 18 years have passed but no new reservoir-based hydropower plants are built. This is a rationale behind selection of KHEP as a study site for this case study.

In the context of growing impacts of climate change on water bodies and hydrologic cycles, study on prospects of reservoir based hydropower in Nepal are highly desirable. Storing water in reservoir is one of the globally recommended options to tackle climate change impacts on hydrologic cycle. In this case, the reservoir based hydropower that accumulates water during rainy season and produces electricity throughout the year, is one among the best options to address the current problem of seasonal power shortage. Even though, various reports has suggested further study on this sector, in Nepal, the effects of climate change on this valuable resource remain questionable.

This study mainly focuses on the hydrological and weather time series data in relationship with discharge, level of water in the reservoir and energy generation,. With the allowable 4 % error level, 30 years of rainfall data from 1980 to 2009 of nearby rainfall stations were analyzed. Findings show that, Kulekhani receives 78% of rainfall during monsoon (June-September), the water accumulated during this time is used throughout the year for generation of electricity. Kulekhani is one among the dryer region as compared with the national average and also the annual average rainfall of Kulekhani is decreasing at the rate of about 11.5 mm per year. There is gradual shift in seasons, i.e. rainy days are shifting towards pre-monsoon and winter towards post-monsoon. Among the four rainfall stations area, number of rainy days in Chisapani is decreasing by about 5 days on every 10 years (based on data between 1980 to 2009). The study shows that, annual average monsoon rainfall and numbers of rainy days at Kulekhani are decreasing, which signifies that monsoon is shortening that results same amount of rainfall on lesser number of days during monsoon at Kulekhani.

Likewise, temperature data of last 30 years (1975-2005), discharge of Kulekhani river of past fifteen years (1963 to 1977) and monthly data of reservoir level from 1988 to 2009 were analyzed during the study. Temperature of the watershed area has also increased relatively to data as mentioned in Initial National Communication submitted to UNFCCC by Government of Nepal. The river discharge and the level of water in the reservoir are declining. Other factors such as sediment deposit in reservoir, irregular maintenance of the machines and other

infrastructure also contribute in declining the efficiency of system as well as life span of the Hydropower.

This result shows that winter is becoming dryer and rainy season is getting more and more rain that signifies essential need of reservoir based hydro powers also with greater water holding capacity in its reservoir. Similarly, there is temporal variation of different climate characteristics such as amount and intensity of rainfall, temperature and discharge in the river in study area. With the change in precepetatin pattern, Kulekhani in monsoon is receiving more rainfall on lesser number of days, this shows the chances of more sediment production in the watershed that lead to shorten lifespan of the reservoir. Also, there is possibility of low recharge of groundwater and early drying up spring sources that contribute to the Kulekhnani stream during dry season. That results more power shortage, so in future consideration should be taken while designing such hydropowers that could hold more water throughout the year and also with other various options to maintain the water level.

Hydropower station such as Kulekhani Hydropower needs a clear institutional direction and strategy to make it climate resilient.

Acknowledgement

This research study has been done to fulfill requirement for the degree of Master of Science in Environmental Management. I am indebted to all individuals and organizations for their generous support, inspiration and guidance for successfully carrying out this research study.

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Finally, I am also indebted to the officials of Nepal Electricity Authority (central Office), Kulekhani Hydropower - site offices at Kulekhani and Bhimpledi, Department of Hydrology and Meteorology and villagers of the study area who despite of their busy schedule took interest and enthusiastically participate to provide necessary information for the study.

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List of Abbreviation

ARMA	Autoregressive Moving Average
BCM	Billion Cubic Meters
CBS	Central Bureau of Statics
CDM	Clean Development Mechanism
CNPS	Central Nepal Power System
DHM	Department of Hydrology and Meteorology
DOFD	Directorate of Fisheries Development
DOSC	Department of Soil Conservation
GCM	Global Climate Model
GWH	Gigawatt Hour
Ha	hectare
ICIMOD	International Center for Integrated Mountain Development
ICLD	International Commission of Large Dam
INC	Initial National Communication to UNFCCC
IPCC	Intergovernmental Panel on Climate Change
ISET	Institute for Social and Environmental Transition
ISET-N	Institute for Social and Environmental Transition-Nepal
KHP	Kulekhani Hydropower Plant
KHPP	Kulekhani Hydroelectric Power Project
m^3/ha	meter cube per hectare
MoEnv	Ministry of Environment
MW	Mega Watt
MWH	Mega Watt Hour
NCAR	National Center for Atmospheric Research
NEA	Nepal Electricity Authority
OECF	Overseas Economic Cooperation Fund
OEPC	Organization of the Petroleum Exporting Countries
ROR	Run-off-river
RUPES	Rewarding Upland People for Environmental Services
SCWM	Soil Conservation and Watershed Management
UNDP	United nation Development Programme
UNFCCC	United Nation Framework Convention on Climate Change
VAR	Vector Auto Regression model
VDC	Village Development Committee
WECS	Water and Energy Commission Secretariat
WMO	World Meteorological Organization

I. INTRODUCTION

1.1. Background

Nepal has a huge hydropower potential. In principle, Nepal's hydropower potential is impressive due to rugged mountain terrain from which rain fed rivers produce significant amount of seasonal water flow. For several decades, Nepal's water resources potential has been portrayed as the synonymous with hydropower potential. However, in reality neither of these potentials has been developed to transfer the national economy from subsistence agriculture base to industrial base. Number of challenges have been identified for the under utilization of water resource potential including the hydropower. Dr. Tony Hagen in his book "Kingdom in Himalayas" has also refereed Nepal's hydropower as white coal, as Nepal has greater potential and has suggested that hydro power production must be encouraged.

Nepal with the potentiality of exploiting huge amounts of hydropower still has a large section of population without electricity access and majority of the population depend on imported fossil fuels for cooking, transport, industries and other energy needs. The proper development of hydropower is a must for fulfilling the increasing energy demand and overall economic development of Nation. But the bulk of the economically feasible generation has not been realized yet.

As most of the hydropower's in Nepal is based on run-off-river (ROR) type, the generation of electricity has a large seasonal variation that results acute power crisis during the dry months. Of the total energy consumption in Nepal, electricity accounts for very significant amount dominated by biomass. In Nepal, hydropower development starts from 1911 A. D., when 500 Kw Pharping Hydropower Plant was constructed to supply electricity to the capital city of Kathmandu. Then it took around 23 years for next hydropower (Sundarijal hydropower 640 kW) to be installed and by 1970 the country was fulfilling its demand with an installed capacity of 30 MW.

Nepal has an installed capacity of 689.35 MW of hydropower, whereas the year 2009/10 witnessed new records of power and energy demand, generation and import. In 2009/10 annual Peak Demand was recorded 885.28 MW registering 8.96 % growth over 812.5 MW figure of previous year. Before melting of snow and when there is less rainfall during winter, the discharge level in the river decreases that result to very less production of electricity. In the recent years the installed capacity has always failed to fulfill the peak demand that enforced to power shortage up to more than 18 hours a day during winter *(NEA, 2009).*

In this case, the reservoir based hydropower that accumulates water during rainy season and produces electricity throughout the year, would be of better option to address the current problem of seasonal power shortage. In Nepal Kulekhani Hydropower Project (KHP) is the only reservoir based hydropower that was designed as peaking power station but it has been supporting as emergency stand by station, the power station was forced to operate as and when required.

Predicting climate change impacts on water resources is far from straightforward. However, increasing variability in rainfall is expected to be a major consequence of climate change. There is much uncertainty in predicting changes of different climatic factors as some regions are likely to get drier even within relatively short time frame and others are likely to experience increasing average precipitation. Hydroelectric plants are highly dependent on predictable runoff patterns. Therefore, increased climate variability that can affect frequency and intensity of flooding and droughts, could also have similar impact on electricity generation.

1.2. Statement of the problem

The energy system of Nepal relies heavily on hydroelectric projects, especially run-of-the-river facilities. These hydropower based on run-off-river are only able to reach their installed capacity levels during monsoons. However, during the dry months, the country's hydropower plants generate less energy that results country to face severe power crisis.

In response to this, the government has decided to expedite the construction of storage-based hydropower projects in an effort to bridge the growing demand-supply gap in the nation's power sector. The country's location and topography are also ideal for reservoir-based hydropower plants. The growing demands for water and electricity, coupled with reduced dependability of low season flows under climate change would suggest the need for a greater role for storage hydro facilities as an adaptation response, as opposed to the conventional run-of-river schemes *(HDR 2007/08).*

Hydroelectric plants are highly dependent on predictable runoff patterns. Therefore, increased climate variability, river flow, rainfall changes can affect frequency and intensity of flooding and droughts, could also have similar impact on electricity generation. The study site Kulekhani watershed area also lies in a fragile physiographical region that experiences intense monsoon rainfall events. As hydropower is the major source of electricity in Nepal impacts on hydropower production would lead to serious disruptions in the energy infrastructure.

1.3. Study area

Kulekhani Hydropower is the only reservoir type hydropower station in Nepal that represents the general national scenario of reservoir type hydropower stations at present context. It is situated in the Makwanpur district of the Central development region of Nepal and lies immediately to the southwest of the Kathmandu valley. Currently, two stations (Kulekhani- I and Kulekhani-II) are in operation with installed capacity is 60 and 32 MW respectively having two units each of 30 and 16 MW. Kulekhani III of an installed capacity of 14 MW is under construction.

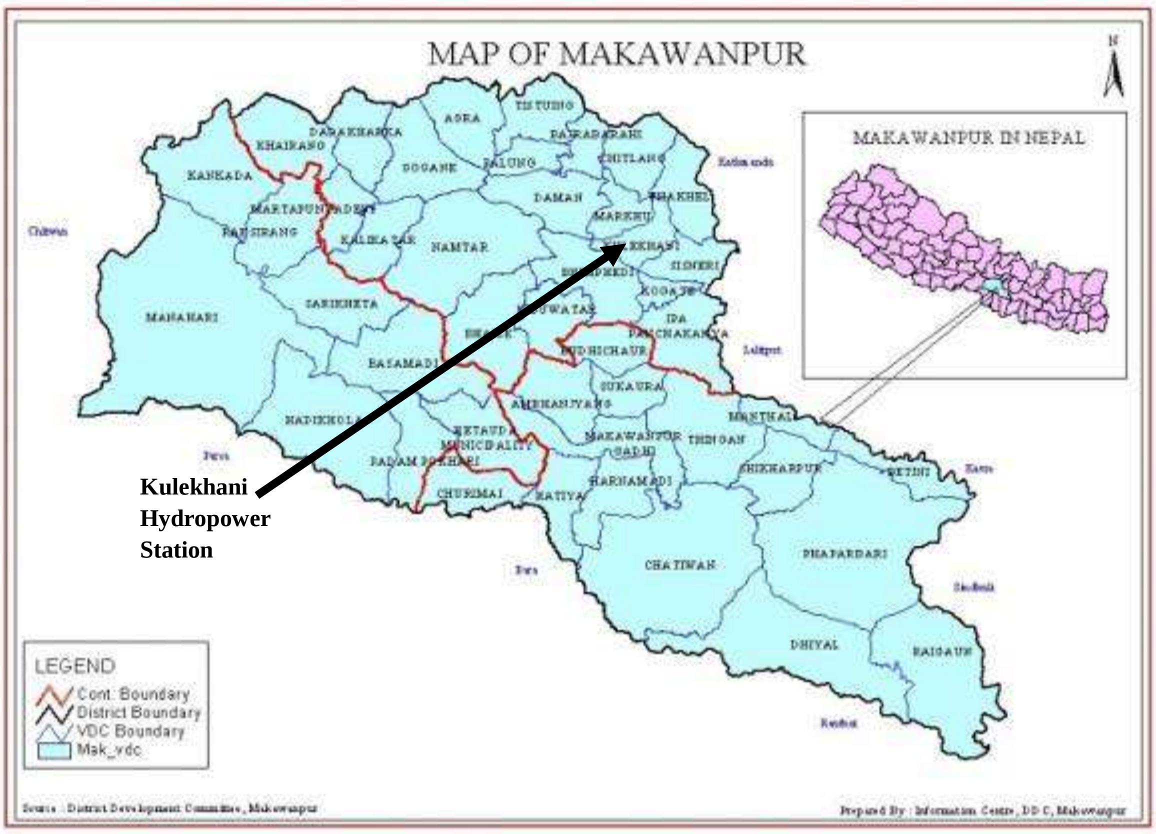


Figure 1.1: Map of Makwanpur District pointing Kulekhani Hydropower Station

The reservoir at the hydropower is fed with water from the Kulekhani watershed that is sub-watershed of the Bagmati basin with an area of approximately 126 km^2. With the supply of Kulekhani Reservoir, two hydropower plants in cascading order are in operation and the third is under construction. The water discharged through powerhouse is released into Rapti River, thus, making this the first project of inter basin transfer.

The watershed is extended approximately from the latitude of 27012'00''N to 27045'00'' N and from the longitude 85000'00'' E to 85012'30'' E. Land use in the watershed include about 53 percent forest, 45 percent agricultural land, and two percent water body *(Upadahaya SK 2008).*

The physiographic and other features of Kulekhani Watershed are described below:

a. Geomorphology and Topology

The Kulekhani river basin is composed of rugged mountains together with valleys, alluvial fans, river terraces and flood plains. Geomorphology of this area can be divided into the Mahabharat range and the midlands valley. The Mahabharat range is characterized by steep topology whereas the midland valleys are relatively flat.

The dominant feature of the Kulekhani watershed is the high variation in altitudes. Terrains elevation varies from 1534 m at dam site to 2621 m at peak of Simbhanjyang over the southern part of the watershed.

Wide flat land spreads throughout the middle part of the watershed mainly Palung, Tistung and Chitlang. The geology of the Kulekhani area consists of Precambrian to Cambrian metamorphic rocks of the Markhu formation, Kulekhani formation, Chisapani formation, Kalitar formation and granites (Stocklin and Bhattarai, 1977) metamorphic rocks.

b. Soil and Land use

Forest occupies about 44% of the entire watershed and the sloping agricultural land is about 34%. The remaining 22% of watershed consist of grazing lands, rock fields, landslides, reservoirs and others *(DOSC).* Major landslides were observed in the southern part of the watershed.

The mountain soils are derived from the parent rock consisting mostly of phyllite, granite and quartzite. Soils are poorly developed in the Mahabharata range, with forest podsols of relatively low fertility and high readability. In most places phyllite being susceptible to weathering gives rise to ferruginous soil. In quartzite zone, there is very little development of soil. In places where granite rocks are exposed the feldspar is highly weathered and gives kaolin-bearing soil. The climate also works differently in the soil formation in the mountainous part.

The midland region is composed of phyllitic shicsts, limestone, sandstones and states. Most slopes are under 250 and weathering horizons are deeper than in Mahabharata range. The soils in the lowlands of midland region are deep, rich alluvial or in situ soils and very suitable for cultivation. Northward, on the ridge slopes are thinner and erodible.

c. General climate

Due to the variation in topography, the climate of Kulekhani watershed varies from subtropical at low lands to temperate at higher elevations. As the watershed is affected by monsoon it has four distinct seasons viz., pre-monsoon (March to May), monsoon (June to September), post-monsoon (October to November) and winter (December to February).

It is under the influence of two major climatic zones namely warm temperate humid zone and cool temperate humid zone, which are mostly found in between the altitude 1500 to 2000m and above 2000m respectively. The average annual precipitation over the watershed is about 1500 mm. May to September is the wettest period whereas the winter is distinctively dry period.

During winter seasons, the higher elevation such as Simbhanjyang and Daman receive precipitation as snowfall.

d. River System

The Kulekhani river system is the tributary of the Bagmati river and falls in the second category as it originates in the Middle Mountains. It is further divided into eight divisions based on the drainage system. Each system is known by the name of the major river that catches all the incoming water drained towards it. They are: Palung Khola, Sankhmool, Tistung Khola, Bisingkhel Khola, Chitlang Khola, Reservoir, Simbhanjyang Khola and Tasar Khola. Each river system represents separate watershed and they are Palung, Kitini, Kunchhal, Bisingkhel, Tubikhel, Simlang, Nalibang, and Tasar respectively.

The tributaries originating from southern mountains have relatively steeper river gradient than those originating from northern mountains. Kulekhani river joins the Bagmati river at about 9 km to southeast of dam. Total length of the rivers in the Kulekhani Watershed is 625 km and the area is 124.97. The average density is 4.96 km/km^2.

e. Demographic Situation

Demographic composition of Kulekhani watershed is heterogeneous. Tamang, Magar, Gurung, Chettri and Brahmin are the major ethnic groups. There are 17779 families and their population is 102,058. Agriculture is the major source of livelihood and their daily life is blended with the nature surrounded them. Land use status is one of the responses to the basic need of population. (*BIWMP, 2002)*.

f. Evolution of Kulekhani Hydropopwer Projects

The main purpose for the construction of this power station was to take the peak load only but the unavailability of the sufficient power with respect to demand, the power station was forced to operate as and when required.

This project was constructed under the financial assistance of World Bank, The Kuwait Fund, OPEC Fund, the UNDP and the Overseas Economic Cooperation Fund (OECF) of Japan and Government of Nepal. The total project cost of the project was US$ 117.843 million and accordingly the project was transferred to NEA with a capital cost approximately NRs. 155 crores. The telemeter system installed for rainfall, water level measurement and indication cost around NRs. 13.74 crores. The cost of road, check dams and inclined tunnel are about 23 crores. The reservoir was completed in 1982 and based on projected sedimentation rates it had a 100 year design life.

Currently, two stations (Kulekhani- I and Kulekhani-II) are in operation with installed capacity is 60 and 32 MW respectively having two units each of 30 and 16 MW. Kulekhani III of an installed capacity of 14 MW is under construction.

II. LITERATURE REVIEW

2.1 Development of hydropower

Hydropower is an important potential source of low-carbon energy and currently accounts for around one fourth of global electricity generation *(IHA, 2000)*. In addition, providing power through hydropower and other means is likely to increase adaptation options. The global economic prosperity is driving the consumption of energy to record levels, with electricity consumption anticipated to increase at rates faster than overall energy supply. As majority of energy today is provided form thermal sources, i.e. coal, gas and oil; but there are growing global concerns regarding the lack of sustainability of these forms of energy that bring question their use in a long-term and their impact to accelerate the emission of green house gases (GHGs) to atmosphere.

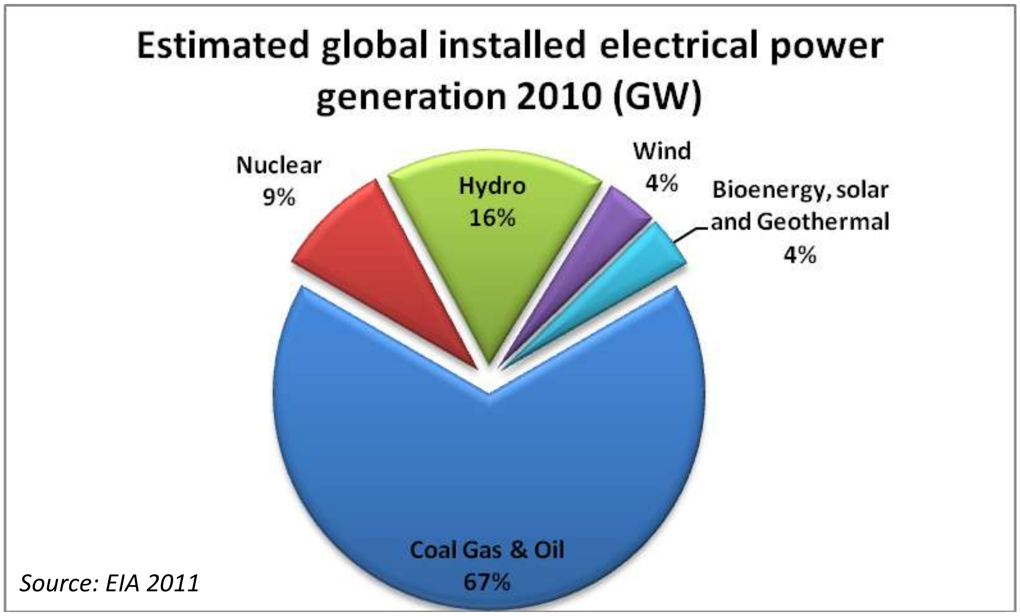
There is no doubt that the world in coming days has to emphasis on sustainable energy policies that include the significant development of renewable energy supplies. Renewable energy technology exists in many forms i.e. wind energy, solar energy and geothermal energy. Yet the largest source of renewable energy comes from a proven technology, hydropower. Hydropower is renewable because it draws its essential energy from the sun which drives the hydrological cycle which in turn, provides a continuous renewable supply of water.

The total energy consumption, world-wide, from all sources, will grow by 60 percent between 1997 and 2020. Consumption is expected to increase from 111,000 TWh/year to 178,000 TWh/year. The global consumption of electricity will be 76 percent higher in 2020 than in 1997. Consumption will increase from 12,000 TWh (1997) to 22,000 TWh (2020) *(EIA, 2000).*

By the year 2050, the world population is expected to increase by 50 per cent, from 6 to 9 billion. Energy consumption per inhabitant per year is generally in correlation with the standard of living of the population, which is characteristic of welfare from an economic, social and cultural point of view. The less developed countries in the world, with 2.2 billion inhabitants, have an annual per capita consumption of primary energy which is 20 times less than those of the industrialized countries (with 1.3 billion inhabitants), and per capita electricity consumption which is 35 times less. The challenge is therefore clear: an inevitable increase in energy consumption in the world, with the risk of a major environmental impact, and climate change, as a result of the combustion of fossil fuels. The right for development is a basic human right, and there is no possible development without energy supply. In view of this situation, all available sources of energy will be necessary, but for environmental reasons, the first priority should be the development of all the technically, economically and environmentally feasible potential from clean, renewable energy sources, such as hydropower. *(IHA, 2010)*

2.2 Global scenario of Hydropower

The world's installed hydropower capacity in 2009 was 980 GW. Over the period from 2005 to 2009, approximately 135 GW of additional capacity was commissioned – an average growth rate of 3% per year *(IAH, 2011).* Hydropower is currently being utilized in some 150 countries, 11,000 stations with around 27,000 generating units. In a regional breakdown, Europe has the highest installed capacity (~260GW), followed by Eastern Asia, lead by China, is rapidly developing its hydro resources and is expected to become the region with the greatest level of deployment within the next two to three years. South America, lead by Brazil, is also developing rapidly. Although comprehensive data are not yet available, it is clear that China has commissioned significant hydropower capacity in the past two years, and now exceeds the US as the country with the highest total installed capacity *(IHA, 2010).*



Source: EIA 2011

Figure 2.1: Estimated Clobal Installed Electrical power Capicity 2010 (GW)

International Hydropower Association has classified hydropower in three categories: such as 'run of river' (where the power is generated through the daily flow of the river), 'reservoir' (where power is generated through the release of stored water) or 'pumped storage' (where stored water is recycled). These generic types can be developed across a broad spectrum of scale, and can be grid connected or form part of a local network.

Most hydropower projects were developed to provide base load to the power system, and this pattern has continued in developing countries. However, the variable nature of the growing portfolio of renewable energy, as well as the costs associated with shutting down thermal energy options (resulting in them being kept running through periods of low demand) means that there is often excess power in a grid at times of low demand. This has lead to an increasingly important role for pumped storage hydro, where, to store energy for use in periods of high demand, water is pumped from a lower to an upper reservoir during off-peak periods.

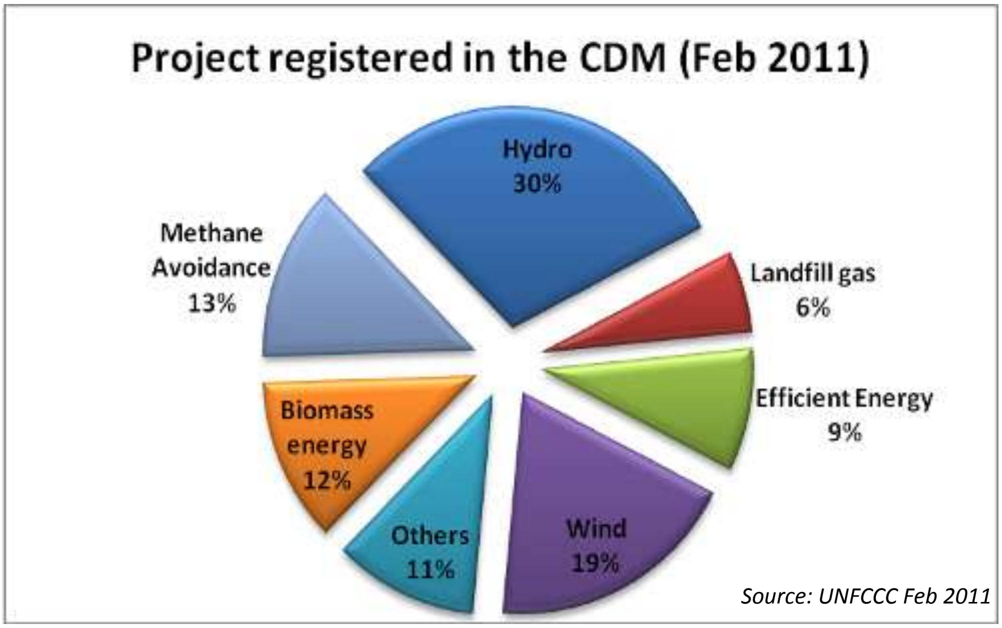
By 2010, there are some 127 to 150GW of pumped storage throughout the world. It is anticipated that the market for pumped storage will increase by 60% over the next five years or so. This is a clear reflection of the increasingly important role that storage will play in the future, with requirements for peak load and intermittent source balancing. However, as pumped storage is a net user of electricity (it requires approximately 20% more electricity to pump the water to the upper storage reservoir than the electricity generated by releasing the water back to the lower reservoir), investment depends on strong, predictable differentials in the market price, between low and peak demand.

2.3 Climate change and Hydropower

Usually, hydropower plants have long life of over 50 years. However, the life of a power plant depends on smooth supply of water- either through run of the river or reservoir. And, flow of water is largely depends on precipitation and discharge levels over various seasons and years. Climate change will particularly affects to the precipitation and flow regime. Therefore, the impacts are inevitable.

In a hydropower context, the issue of climate change can be split into four aspects: greenhouse-gas footprint, hydrological vulnerability, climate change mitigation, and adaptation. Water resources are under increasing competition from multiple uses. This is predominantly driven by population growth and evolving living standards, with further threats from the increasing intensity of weather events linked to climate change. The energy sector is a major water user, thus water and energy policies need to be more closely coordinated.

With the above in mind, it is expected that hydropower will play an increasing role in both climate mitigation and adaptation. The energy services it provides aside, freshwater storage will be required to provide an increasing number of water-related services. This will call for new design approaches for the future, especially around provision for extreme floods and droughts. This will affect both new and existing hydro assets.



Source: UNFCCC Feb 2011

Figure 2.2: Types of Project registered in the CDM (February 2011)

The CDM market is beginning to play a major role in delivering renewable energy to the developing world, and it is anticipated that the hydropower projects sector will continue to be one of the main contributors to the carbon credits market. The majority of hydropower projects in the pipeline are at the validation stage, with 60% at this early stage of the process. By the end of 2010, nearly 1,989 projects are registered to UNFCCC CDM Executive Board, where 541 are hydropower projects, representing 30% of the total, and 54% of the renewable energy project CERs (carbon credits issued from the CDM projects) for this period. When considering the predicted volumes of CERs to be delivered, registered hydro projects are expected to generate around 47 million credits per year, equivalent to 14% of the total.

2.4 Studies on climate change and Hydropower in the global context

Kazuhiko Yamada, IEA Hydro (2009) found that the effects of various climate change scenarios are both uncertain and regionally different. Regions in high latitudes and some wet tropical area scenarios increase in annual precipitation and average temperature: frequent floods, landslides and sediment, sedimentation, disability of flood control, deterioration of water quality, retreat of glaciers and reduced snowpack, decreased summer runoff, increased winter runoff, increased evaporation from reservoirs and variability in hydropower production. Dry regions in mid latitudes, most subtropical regions, and dry tropics Scenarios overall decrease in precipitation and runoff: increase in extreme drought events, increased SS upon precipitation, deterioration of water quality and reduction of hydropower production.

Yao and Georgakakos (2001) developed an integrated forecast-decision system to assess the sensitivity of reservoir performance to various forecast-management schemes under historical and future climate scenarios (based on projections from the Canadian Center for Climate

Modeling and Analysis model). They assessed daily operations for hydropower generation and flood control of Folsom Dam under various combinations of inflow forecast predictions, decision rules, and climate scenarios and are used as case study. The study demonstrated that reliable inflow forecasts and adaptive decision systems can substantially benefit reservoir performance and dynamic operational procedures can be effective climate change coping strategies".

Atsushi IIMI (2007) predicted that there are three main impacts of climate change on hydropower projects. First, the available discharge of a river may change, since hydrology is usually related to local weather conditions, such as temperature and precipitation in the catchment area. This will have a direct influence on economic and financial viability of a hydropower project. Moreover, hydropower operations may have to be reconsidered to the extent that hydrological periodicities or seasonality change. The reason is that, if the flow of water changes, different power generating operations, e.g., peak versus base load, would be possible using other designs for water use, such as reservoirs.

Second, an expected increase in climate variability may trigger extreme climate events, i.e., floods and droughts. For instance, a hydrological model indicates a great risk of Bangladeshi suffering from extreme floods, which are led by substantial increases in (mean) peak discharges in the regional three major rivers, Ganges, Brahmaputra and Meghna (Mirza, 2002). One of his scenarios predicts that the volume of water in the Ganges would increase by 5 to 15 percent, depending on changes in temperature.

Finally, changing hydrology and possible extreme events increase impact with sediment risks and measures. More sediment, along with other factors such as changed composition of water, could raise the probability that a hydropower project suffers greater exposure to turbine erosion. When a major destruction actually occurs, the cost of recovery would be enormous. An unexpected amount of sediment will also lower turbine and generator efficiency, resulting in a decline in energy generated.

2.5 Studies on Climate change and Hydropower in Nepali context

Climate change has a number of implications for stream flow variability in Nepal. Shakya (2003) points out that 90% of debris volume in Nepal is transported by approximately 20% of rainfall. With the intense rainfall projected for the monsoon season, sedimentation is another factor that may shorten life of a hydropower plant. There has also been an observed increasing trend in the number of flooding days. On the other hand, there might be significant declines in the dependability of dry season flows in certain rivers, which is quite critical for both water and energy supply. It in fact point to changes in the characteristics in the level and variability of stream flow, as well as associated events such as flooding and precipitation risks, that might require adequate incorporation in water resource and hydropower planning, particularly because all except one of Nepal's existing hydropower facilities are of the "run of river" type, with no associated dams, which makes them more vulnerable to stream flow variability.

Local hydrology of every river in the world is likely to be affected by climate change in some way. In Nepal, major river basins such as the Karnali, Koshi, Gandaki and Bagmati may have already been affected by climate change *(Sharma, R.H 2005)*. Climate change affects different aspects of local hydrology of river such as timing of water availability and quantity, as well as its quality. Changes in river hydrology will induce risks to water resources facilities that includes flooding, landslides, and sedimentation from more intense precipitation events (particularly during the monsoon) and greater unreliability of dry season flows that possesses potentially serious risks to water and energy supplies in the lean season. The seasonal variability, timing of water availability and change in flood pattern are indicators of the impact of climate change on river hydrology.

Development of hydropower in return also implies large amounts of GHG emission reduction. Snow and glacier areas are considered natural storage of freshwater. The implication of retreating snowline is the increased river flow during monsoons and decreased flow during low-flow season. It has direct impact on firm power of a hydropower project *(INC, MoPE 2001).*

A study on Gandaki River basin shows that an increasing temperature and shifting rainfall patterns directly affect hydropower generation as most of the rivers in the Gandaki basin are snow feed rivers. The Chilime hydropower generation is very constant (i.e. variation is in a pattern relative to others) but in other downstream hydropower stations, the production is not so constant which is due to the flow fluctuations of the river, rain water contribution, and temperature fluctuations. The study concluded with the recommendation that damp based hydropower plants are necessary for constant energy production. Damp integration (if possible) with the existing hydropower can be done with a proper study.

One of the major impacts of climate change is the change in river hydrology. Since the hydrology is changing, the design capacity of corresponding hydropower stations should be revised. In the long run, sufficient water may not be available; water storage in damp should be a good method to control the flow of the river. In particular, greater unreliability of dry season flows poses potentially serious risks to water supplies in the lean season. Hydroelectric plants are highly dependent on predictable runoff patterns. Therefore, increased climate variability, which can affect frequency and intensity of flooding and droughts, could affect Nepal severely in hydroelectric production *(Bajracharya T.R. et al, 2010).*

2.6 Studies on climate Change with references to reservoir based hydropower

VanRheenen et al. (2004) considered the effects of climate change on flood control, hydropower production, agricultural and municipal diversions, and in stream flows for fish. The repsort shows that even with the incorporation of mitigation strategies, such as changing the flood control rule curves, achieving and maintaining status quo system performance (including hydropower production) would not be possible under the climate change scenarios.

Tanaka et al. (2006) study the effects of a range of climate change scenarios on the long-term performance and management of California's water system, including hydropower generation. They found that hydropower production from the major water supply reservoirs would be mostly affected by the amount of water available, with wetter scenarios showing an increase in generation and revenues proportional to the change in stream flow and drier scenarios displaying the opposite pattern. Building of more storage capacities may be required as a solution to this problem in the long run *(INC, MoPE 2001).*

There are two factors that contribute to increased variability of river runoff: glacier retreat; and changes in timing and intensity of precipitation. Runoff will initially increase as glaciers melt then later decrease as deglaciation progresses. In addition, decreased winter snowfall means less precipitation would be stored on the glaciers, so this would in turn decrease the spring and summer runoff. Studies on climate variability in Southwest Asia show that decreased winter snowfall does indeed decrease the spring/summer runoff, and it has caused severe droughts in Iran and Pakistan in areas that depend on water from mountain sources *(Subbiah, 2001)*. Winter runoff, on the other hand, would increase due to earlier snowmelt and a greater proportion of precipitation falling as rain.

2.7 Scenario of Power Projects in Nepal

Annual energy consumption per capita is estimated at about 16 gigajoule. Analysis of energy supply showed that the share of traditional energy (fuel wood, timber, agriculture residue and animal dung) is 87.9%, petroleum products 8%, coal 1.8% and renewable energy is 0.5 % (MoEN, 2008). Nepal with its huge potential of generating electricity has more than 6000 rivers and nearly 14 % of the country area is covered with show and ice. The total average annual runoff rivers of Nepal is about 225 billion cubic meters (BCM) of which only 15 BCM has so far been utilized for economic and social purposes (WECS, 2005).

Table 2.1: A glance of Hydropower Projects in Nepal (2008-09)

Sector	**Capacity (kw)**
Total Major Hydro Grid Connected	472994
Total Small Hydro Isolated	4536
Total Hydro NEA	477530
Total hydro IPP	158315
Total Hydro -Nepal	635845
Total thermal (NEA)	53410
Total Solar (NEA)	100
Total Installed Capacity (including Private and Others)	**689355**

Source: NEA Hydro Power Projects 2008/09

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 689.35 MW of hydropower by 2008/09. 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). Only about 20% of the population has access to electricity, of which only 5% of the rural population (WWC and IHA, 2003). 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 Mahabharata 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.

2.8 Kulekhani Watershed

Total area of the Kulekhani Watershed (KWS) is 12,495.6 ha. It is further divided into 8 sub watersheds. Each sub-watershed has separate drainage. All the water drained from the watershed accumulates in 7 km long reservoir created by constructing 114m high rock filled dam. Kulekhani is mountainous watershed that falls in the chapter III catchment accruing to general criteria adopted for density norms by WMO.

The watershed is under the influence of two major climatic zones namely warm temperate humid zone and cool temperate humid zone, which are in between altitude 1500 to 2000m and above 2000m respectively. The average temperature in warm temperate humid zone is 15 to 20 degree Celsius and 10 to 15 degree Celsius in cool temperate humid zone. *(Ghimire B.N. 2004*)

Monsoon cloud enters in the month of June in eastern Nepal and slowly it moves towards the west. While moving, it gives heavy precipitation to south of Mahabharata range. The Kulekhani river system is the tributary of the Bagmati River and falls in the second category as it originates in the Middle Mountains. It is further divided into eight divisions based on the drainage system. Each system is known by the name of the major river that catches all the incoming water drained towards it. They are: Palung Khola, Sankhmool, Tistung Khola, Bisingkhel Khola, Chitlang Khola, Reservoir, Simbhanjyang Khola and Tasar Khola. Each river system represents separate watershed and they are Palung, Kitini, Kunchhal, Bisingkhel, Tubikhel, Simlang, Nalibang, and Tasar respectively *(Ghimire, BN 2004).*

The historic cloudburst of July 1993

Kulekhani watershed area lies in a fragile physiographical region that experienced one of the worst climate disasters at around 10’0 clock in the night of 19 July around which the hourly rainfall was recorded to be 65 mm. In the catchment area of the Kulekhani Dam near Kathmandu unleashed 540 mm of rain in a 24 hour period bringing down five million cubic metres of silt and boulders into the reservoir. The rain dumped in one night a sediment load several times larger than the estimate made by Kulekhani’s designers for the entire lifespan of the dam. Ninety hectares of upland was lost, 64 people and 274 animals died. The disruption of water sources and irrigation canal system has resulted problem of water scarcity for drinking and irrigation.

This was the highest death caused by a single event of debris flow in such a small catchments area. The destruction of houses at the debris deposition zone in the alluvium cone area, that claimed most of the human lives, and washout of houses upstream due to gully erosion were the main damages. This storm is one of the severest storms in the history of Nepal, caused lot of damages in Kulekhani watershed.

The urgent rehabilitation measures were conducted by Kulekhani Disaster Prevention Project and Department of Hydrology and Metrology. That catastrophic flood due to erratic cloudburst caused excessive erosion in the watershed therefore deposition of unpredicted amount of sediment piled up in the reservoir. The measurement taken in the December of 1993 shows a deposition of 4.8 M m3, which gives a rate of 381 m3/ha/yr.

After the devastating flood of 1993, two major structures namely: sloping intake and check dam were built in the reservoir to overcome the unforeseen problem of sedimentation in the dead storage and protect main part of the reservoir from direct inflow of sediment respectively. Though the check dam at the mouth of Palung Khola built in 1999, has been effective in stopping major portion of sediment in the upstream of the dam, this has also occupied live volume of the storage *(Joshi G.R. 2008)*

2.9 Kulekhani Hydropower Stations

At present two stations (Kulekhani- I and Kulekhani-II) are in operation with installed capacity of 60 and 32 MW respectively having two units each of 30 and 16 MW. This powerhouse was designed as peaking power station but it has been supporting as emergency stand by station, the power station was forced to operate as and when required. The annual expected energy generation capacity as primary energy is 165 GWH and 46 GWH as secondary energy in Kulekhani I and 104.6 GWh in Kulekhani-II. Energy generated from both the stations contributes about 10% in the national grid system.

The Kulekhani II Hydropower Station with an installed capacity of 32 MW is cascade power station to Kulekhani- I along with a diversion of Mandu river to the specially built intake for Kulekhani-II. Besides this, when needed some water from Rapti river is also fed to the intake of KL-II by pumping. The operation of this powerhouse is completely dependent on the operation of Kulekhani-I power station.

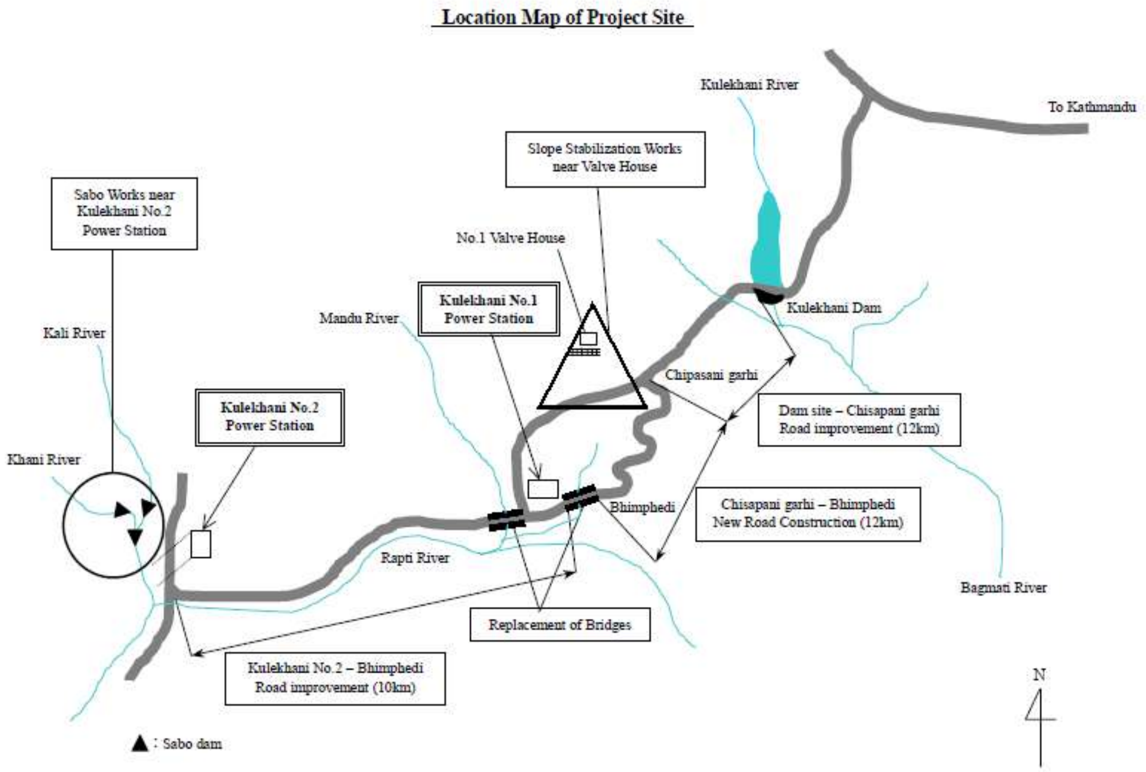


Figure 2.3: Location map of Kulekhani Hydropower Stations

This project was constructed under the financial assistance of World Bank, The Kuwait Fund, OPEC Fund, the UNDP and the Overseas Economic Cooperation Fund (OECF) of Japan and Government of Nepal. The total project cost of the project was US$ 117.843 million and accordingly the project was transferred to NEA with a capital cost approximately NRs. 155 corers. The telemeter system installed for rainfall, water level measurement and indication cost around NRs. 13.74 corers. The cost of road, check dams and inclined tunnel are about 23 corers.

Kulekhani III of capacity 14 MW is under construction and is expected to be completed within few years.

The table below provides some salient features about Kulekhani I and II:

Table 2.2: Salient features about Kulekhani II and II

	Kulekhani- I	Kulekhani- II
Rated net head	550 meter	284.1 meter
Design discharge	12.1 m^3/s	6.65 m^3/s per turbine
Head race tunnel	6233 m, 2.3 m diameter	5748.7 m, 2.5 m diameter
Penstock pipe	1324 m long, 2.1 – 1.5m diameter steel pipe	843 m long, 2.1- 1.5 m dia., steel pipe
Installed capacity	60 MW	32 MW
Turbine Generator Set	2 sets	2 Sets
Type of Turbine	Pelton	Francis
Rated Speed	600 rpm	750 rpm
Type of Generator	Vertical shaft, Synchronous	Vertical Shaft, Synchronous
Capacity	35 MVA	18.8 MVA
Rated Voltage	11 KV	6.6 KV
Power Transformer	11/66KV, 3 phase, 35 MVA, 2 Nos	6.6/132 KV, Single Phase, 12.6 MVA, 3 Nos
Transmission Line		42 km long, 132 KV single circuit
Average Annual Generation	211 GWh (Primary energy 165 GWH and secondary energy 46 GWH)	104.6 GWh
Catchments Area	126 sq. km.	126 sq. km.
Commissioning Date	1977 A.D. - 14th May, 1982	November, 1886
Construction Cost	117.84 million USD	NRs. 1240 million
Financed by	World Bank, Kuwait Fund, UNDP, OECF and OPEC Fund	Government of Nepal, OECF of Japan

Source: Environment resource Group P Ltd (www.erg.com.np)

2.10 Kulekhani reservoir and impacts of dam construction

About 38 % of all dam failures are caused by overtopping of the dam due to inadequate spill capacity and by spillways being washed out during large inflows to reservoir from heavy precipitation runoff. About 33 % of the dam failures are caused by seepage of piping through the dam or along internal conduits, while 23 % of the failures are associated with foundation problems and the remaining failures are due to slope embankment slides, damage or liquefaction or earthen dams from earthquakes and landslide generated waves within the reservoir (*ICLD, 1973)*.

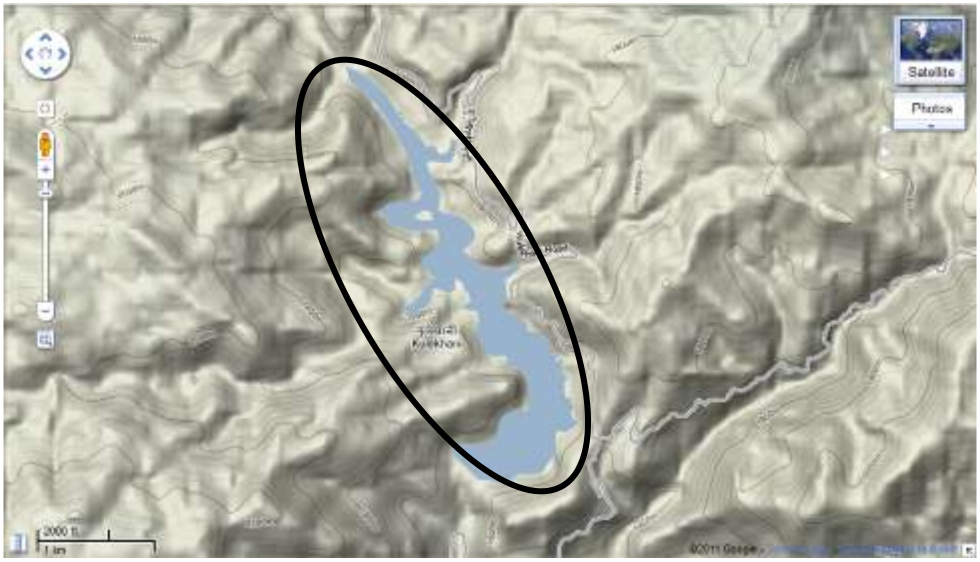


Figure 2.4: Satellite map of Kulekhani Reservoir

Kulekhani Hydropower station is built on inter basin water transfer model. It lies on Bagmati basin that transfers the water to Rapti river basin. The First phase of Kulekhani Hydropower plant was completed and commissioned in 1982 (confirm the date!) and consist of the following components: Kulekhani river Basin including the Chakhel and Sim river diversion, Kulekhani dam, Kulekhani reservoir, Kulekhani dam Spillway, Kulekhani River outlet, Intake and headrace tunnel, Surge tank, penstock, Power Stations, Tailrace tunnel and transmission line and sub stations.

The Kulekhani dam is the zoned rock fill dam, consisting of an inclined core zone, filter core zone, quarry rock zones and a random rock zone. The main dam is 114 m height and has a volume of 4.4 million m^3. Its crest is 397 m long and 10 m wide, and being located at EL 1.534 m, this leaves a freeboard of 4 m above the high water level.

The Kulekhani dam creates an artificial reservoir having a surface area of 2.2 km^2 when full covers the land which was occupied by for about four thousands Ropani cultivated land four hundred fifty houses and fifty corn mills. The overall storage capacity if 85.3 * 106 m^3, while the effective storage is 73.3 * 106 m^3 leaving the dead storage volume of 12.0 * 106 m^3. The high and the low water level are at EL 1.530 and EL 1.764 m respectively making a drawdown zone of 54 m. The total length of reservoir is 7 km.

The impoundments after damming the rivers adversely impact fish biodiversity and the economics of fishing communities that depend on fishing for their livelihood. Dams have contributed to better water storage, irrigation and energy production, but have led to changes in upstream and downstream species composition and, in some instances, to species loss. People are heavily dependent on the land and forest resources for the fulfilment of their basic needs like food, fodder, and fuel wood. Landuse status shows that conservation programme implemented so far has been giving direct benefit of Rs 1, 137,491.00 each year. Local resource based conservation friendly income generation programme run in mutual trust builds symbiotic relation between the surrounding communities and Hydropower promotes natural preservation and prolongs the life of reservoir.

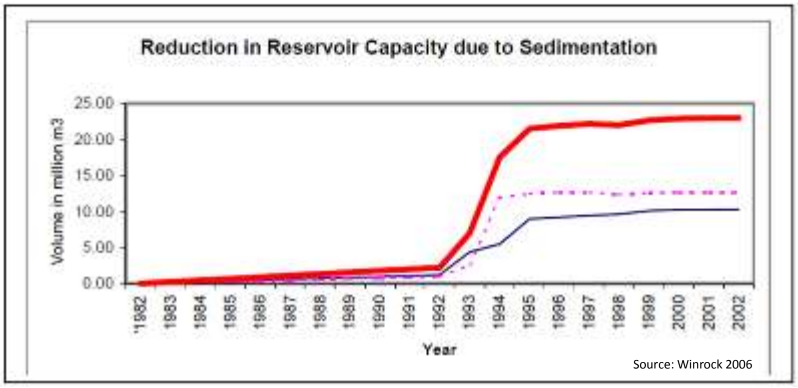
Electrical power generation supports the development of the nation, but the river ecosystems suffer adversely, especially the maintenance of fish species, which were not considered in some of Nepal's earliest hydropower projects.

Potential for aquaculture in the manmade reservoirs in Nepal cover about 1,500 ha, comprising about 0.2% of the nation's water resources (DOFD 2061/62). As the number of reservoirs increases, it is projected that an estimated 78,000 ha more water surface area will be needed for hydropower generation and irrigation purposes (Pradhan 1987). At the same time, national fish production and per capita fish protein consumption will also increase. Poverty can be reduced and food security improves when smallholder farmers and subsistence fishers achieve higher levels of sustainable productivity.

2.11 Sediment deposit in Kulekhani reservoir

The annual average erosion in the catchment has been estimated at 700 m^3/km^2 (UN Department of Humanitarian Affairs 1994). This corresponds to the sediments inflow of 88,200 m^3 per year. It also mentioned that, with the dead storage of 12, 000, 000 m^3, the reservoir's life storage will not be effected during the projects expected life of 100 years.

In March 1993, the Department of Soil Conservation and Watershed Management carried out a monitoring survey and concluded that a total of 2.2 million cubic meters of sediment have been deposited in the reservoir in 10 to 11 years, i.e. from the opening of the reservoir to the end of the monsoon of the year 1992. Of the 2.2 M m^3, 1.2 M m3 was deposited in the dead storage and 1.0 M m^3 was in the live storage. Since 1993, monitoring of sedimentation being done regularly. At the end of 2002, the total volume of sediment reached to 23 million m^3. Of the total deposition, 12.69 million m^3 was deposited in the live storage and 10.31 million m^3 in dead storage, which are about 55% and 45% respectively.



Source: Winrock 2006

Figure 2.5: Reduction in Reservoir Capacity due to Sedimentation

Sedimentation measurement done in the reservoir shows that excessive sediment was deposited in the years 1993 to 1995. Though there are several other factors like heavy rainfall, to bring this situation however, land use is one of the major factors to accelerate the process. Sedimentation, as seen after measurement of sediment in the reservoir, indicates a serious threat on the life span of Indra Sarobar (Kulekhani Reservoir) and demands urgent environmental solution. The problem is in the reservoir but its causes and sources are around in its catchment area. The study carried out by Winrock International indicates that the sediment accumulated in live storage alone has caused a loss of Rs 181 million in a year and it keeps on increasing by Rs 2 million each year. For sustainable use of these natural resources, urgent need for environmental conservation and management of sub-watersheds through the participation of surrounding communities is necessary. Resources are limited so it is not possible to launch a programme throughout the whole catchment area at a time.

Effective conservation program plays a major role in stabilizing the land and minimizing the soil erosion. The conservation behavior like: the growth and maintenance of the forest adoption of conservation friendly agricultural practice by the people living in the upland areas of the reservoir. Particularly during the 1992 to 2001 period can be read in the light of conservation and observe the following:

- The year 1992 was the peak time of increase of agricultural land and decrease of forest area. The rate of deforestation is 11.45% per year.
- In the early years of that period (1993 to 1995) exceptionally high volume of sedimentation deposited in the reservoir.
- In the later years (1996 to 2002), rate of sedimentation decreased in the reservoir.
- The agricultural areas decreased and forest area increased in the Kulekhani watershed.

2.12 Studies on Kulekhani Watershed

Previous studies on hydropower in Nepal moreover focused on its operational assessment and environmental impacts. The feasibility study for the Kulekhani Hydropower Project was conducted by JICA in 1973, in which the Kulekhani Number 1 Hydropower Project was implemented. The feasibility study on the second Kulekhani Hydropower Project was carried out by JICA in 1979.

During the construction of Kulekhani dam, while quarrying the core materials from the borrow pit over Markhu, vegetation of the area was left exposed and eroded, which directly contributed to sedimentation of the reservoir. Considering such devastated condition around the borrow pit: UNDP and FAO assisted a watershed management project in coordination with the DOSC to implement the Kulekhani Watershed Management Project in 1981. This project included number of soil conservation and watershed management activities to recover the bare area in the borrow pit and adaptation of sediment and runoff relation.

The storms of September 1984 and August 1986 had caused severe damages through landslide and debris flow in the Kulekhani watershed. In 1922, the Kulekhani Disaster Prevention Project was released by the NEA for disaster presentation works. Master Plan Study on Sediment Control for Kulekhani Watershed (KDPP) has analyzed the 1993 storm and disaster caused by storm. The study was focused on the rainfall probability analysis, estimation of flood during storm, flood frequency analysis, sediment analysis and hazard assessment in the watershed.

A study carried our at Phedigaun of Palung VDC of Makwanpur district in 2008 on community vulnerability and their adaptive capacity to climate change reveals that rainfall and temperature pattern in the district are undergoing through some visible changes. Rainfall record of Hetauda, Makwanpur Ghadi, Rajaiya and Beluwa stations are increasing, whereas Daman, Markhugaun and Chisapani Ghadi are experiencing negative trend of rainfall. The trend analysis of temperature shows that Daman and Hetauda are warming. Likewise, reduction in agricultural production has been attributed to climatic variability and extreme events, scarcity of irrigation, natural disasters, more use of fertilizers. Because of less rainfall and prolonged drought, water sources in community are drying up resulting water stress and scarcity for drinking and irrigation purpose. Similarly, the forest cover is shrinking as a result people are facing problem on getting enough fodder and fuel wood *(Joshi G.R., 2008).*

There is no doubt that the naturally rich hydro-electricity play a vital role on Nepal’s economy and development, it is important to have a detailed study on the future of these hydro power plants, their efficiency 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.

About 516 MW of Hydropower Plant is under construction and about 1, 422 MW has been planned for construction *(NEA 2010)*. In this scenario, if prior considerations of changing climate are not analyzed the large amount of resources invested on the construction would be of no use.

III. JUSTIFICATION OF THE STUDY

Majority of hydropower stations of Nepal can’t operate up to their installed capacity other than monsoon months (July – October) due to inadequate river flow levels. The energy supply system of Nepal relies heavily on these hydropower plants, especially run-of-the-river facilities, thus, hardly be able to meet the energy demands during low flow season. Therefore, the country is facing serious energy shortage leading to a crisis situation. The reservoir based hydropower plants would serve the gap as they tap the monsoon water in the storage to produce power during dry months or any other energy deficit situations. However, going through the relevant literatures available for this study, it is clear that there are virtually no studies undertaken focusing climate change impacts on functional reservoirs that would serve to run power house.

In the case of Kalekhani, published and unpublished literatures are available but not in the context of climate change and its potential impacts. Irrespective of the potential risks of climate change, NEA in its twenty-fifth anniversary has declared that the organization would develop new regional storage projects. The government has decided to expedite the construction of storage-based hydropower projects in an effort to bridge the growing demand-supply gap in the nation's power sector. The projects include the 600 MW Budhi Gandaki and the 127-MW Upper Seti projects, both of which have been delayed several times.

As water resources are closely linked to climate change, hydropower is also clearly among the most vulnerable areas to global warming. Likewise, increasing variability in rainfall is expected to be a major consequence of climate change. Hydroelectric plants are highly dependent on predictable runoff patterns, moreover the reservoir based system are sensible to changing scenario. Therefore, increased climate variability that can affect frequency and intensity of flooding and droughts, could also have similar impact on electricity generation.

As the study site the Kulekhani watershed area lies in a fragile physiographical region that experiences intense monsoon rainfall events and only a reservoir based hydropower in Nepal till date. Any kind of impact on hydropower production would lead to serious disruptions in the energy infrastructure, as hydropower is the major source of electricity in Nepal. However, the effects of climate change on this valuable resource remain questionable. In order to identify the potential initiatives that the hydropower industry may undertake at the time when the government is in plan to install more reservoir based hydropower, it is important to determine the current state of knowledge of the impacts of climate change on hydrological variables.

IV. OBJECTIVE OF THE STUDY

The broad objective of the study is to assess the impact of climate change on reservoir for hydro power generation in Nepal. Because, the Kulekhani HPP is the only reservoir based hydropower plant in the country, the study has focused it as the case study.

The specific objectives of the study are:

- To analyze the trend of climatic changes taking place in Kulekhani Watershed
- To access the factors influencing water level in Kulekhani reservoir
- To undertake comprehensive analysis of electricity generation with respect to water level in Kulekhani reservoir
- To recommend various options to maintain optimum required water level to ensure full capacity electricity generation throughout the year.

V. Scope and Limitation

The study was carried out at the Kulekhani Watershed that lies at northeastern part of Makawanpur district in the Central Development Region of Nepal.

Scope of work of the proposed study includes following major activities:

- Case study of river basins to analyze changes in river flow with respect to physical and socio economic changes in the basins affecting design capacity of hydropower plant.
- Collection of secondary data its desk study and analysis of the data
- Interpretation and analysis of 30 years of rainfall and temperature data for interpretation of climate change along with the analysis of level of water in reservoir level, discharge of Kulekhani Khola and energy generation from Kulekhani-I.

Taking into consideration the limitation of resource, time and extent within this thesis work, the limitation for thesis work are

- Detailed impact assessment was not carried out. The major focus was on temporal variation of rainfall, temperature, discharge, electricity generation and water level in reservoir.
- The study was based on the secondary data from the concerned agency, the validation of the data depend on the organizational competence
- Budgetary and time constrains to conduct an in-depth study.

VI. MATERIALS AND METHODS

The impact of climate change can be visualized in terms of change in temperature, shift in weather pattern, rainfall distribution which have impacted on the intensity of discharge and water accumulation in reservoir. The activities and natural phenomenon taking place in its catchment area. Any stochastic approach and model were not used, because of unavailability of adequate data of different variables. The study mainly analyzed the hydrological and weather time series along with their relationship with energy generation, discharge and level of water in the reservoir. Following approach and methods were used for the study:

6.1 Data type and Collection

a) **Primary Data Collection**: Primary data were collected through different tools like focus group discussion, interviewing selected respondent, executive committee and related stakeholder as mentioned below:

- The reservoir site and site office was visited on February 2010, and it was found that all the record and documents were only available at Kulekhani site office Bhimphedi, near Hetuada. There are three site offices at Kulekhani: Marku, Kulekhani dam and Bhimphedi. The site office at Kulekhani dam was moreover only for security purpose.
- The site office at Markhu was visited three times during March to May, 2010: the concerned officials were not available at the office at all visits. This opportunity was utilized to have discussion with local people of upstream Kulekhani Watershed.
- The site office at Bhimphedi was visited twice during May to July 2010, it was found that most of the digital information/data was not recorded, but the printed copies available were also in the worst condition. The essential data were digitalized during the study.

b) **Secondary Data Collection**: Secondary data was collected from available literature published and unpublished by different organization including books, journals, magazines, thesis, operational plan of the committee etc. The institution such as, Nepal Electricity Authority (NEA), Department of Hydrology and Metrology (DHM), ICIMOD and Kulekhani Hydropower Stations etc were also consulted for data and information.

Literature Review: Relevant information was collected from different publications and were analyzed, reviewed and incorporated in this study. Following activities were carried out for the collection of secondary data:

- Discussion sessions were carried out with experts, especially from Department of Soil Conservation and Watershed Management, Department of Hydrology and Meteorology, Nepal Electricity Authority and professionals on Climate change.
- The study was based on the secondary data available Information from Nepal Electricity Authority, Department of Hydrology and Meteorology, Winrock International and Department of Survey had been reviewed.
- Rainfall, temperature, water level, discharge rate and electricity generation were determined on the basis of secondary data.

- Distances from the dam with other stations were calculated by there special location (latitude and longitude).

6.2 Data processing, analysis and interpretation

The data collected during the field works was categorized into separate variable as required by the study objectives. The data was logically interpreted along with simple tables, charts, and graphs. The simple statistical tools like percentage, mean, standard deviation, and also appropriate statistical computer software like SPSS (Statistical Package for Social Science) was used in this regard.

Time series analysis was used to uncover the relationship between three important hydrological variables: discharge, precipitation and temperature. The time series model was also created that take into account rainfall distribution. The vector auto regression model designed also yield forecasts. Data gathered through qualitative methods was analyzed in a descriptive way using simple analysis of frequency and proportions.

6.3 Methods for determining

6.3.1 Rainfall data

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

Daily rainfall data of four nearby stations (Thankot, Markhu, Chisapani and Daman) from 1980 to 2009 was analysed during the study. Rainfall is expressed in millimeter (mm) assuming that all the rain falling on a unit horizontal area remains on the surface without runoff, evaporation or infiltration into the soil profile. Secondary data of the rainfall were taken from Department of Hydrology and Metrology (DHM). The total number of rainfall station taken with the measurable accuracy is calculated in table 6.2 below.

Optimum number of stations required for the study was determined using following methods. It was based on statistical principal that a certain number of rain gauge stations are necessary to give average rainfall with a certain percentage of error. If allowable error is more, lesser number of gauges would be required.

The optimum number of rainguages (N) was obtained by the following equation

$$N = \left[\frac{Cv}{E} \right]^2$$

Where,

E = Allowable percentage error in the estimate of basic mean rainfall

C_v = coefficient of variation of rainfall based on existing rainguage station and it is determined as,

$$C_v = \sigma / \bar{p} \times 100\%$$

σ = sample standard deviation

$$\sigma = \sqrt{\frac{\Sigma(pi - \bar{p})^2}{n-1}}$$

$\bar{p}$ = mean average annual rainfall values

$$\bar{p} = \frac{\Sigma pi}{n}$$

n = existing number of rainguages

p_i = normal annual rainfalls at existing rainguages

Under the different scenario the level of errors taken (10, 5 and 4 %), the optimum number of rainfall stations required for the Kulekhani watershed of an area 126 sq. km. is shown in table 6.2 below. Considering an ideal condition for the minimum density of rainguage, one rainguage is sufficient for Kulekhani watershed with 10 % error. However, for accuracy in various practical purposes, four stations were taken minimizing the error level to only 4 %. However, the total number of rain gauges installed within the given catchment area was also only four (one meteorological-Daman and three hydrological stations- Markhu, Chisapania and Thankot).

Table 6.1: Level of error and required number of rainguages

Allowable % error (E)	Optimum number of rainguages (N)
10 %	1
5 %	3
4 %	4

During the study, 30 years of daily rainfall data of the four stations (total 43800) were analyzed, among them 4.4 % of the data was missing. **The missing data** for any one station were calculated by correlating it with other nearby three stations using the Inverse Distance Weighted

(IDW) methods. Similarly, mean rainfall at Kulekhani was also determined by same method but correlating with all four stations.

$$P_c = \frac{\sum_i P_i {d_{ci}}^{-k}}{\sum_i {d_{ci}}^{-k}}$$

Where, P_c is the rainfall for the gauge to be patched, P_i is a neighboring gauge, d_{ci} is the distance between the gauges and k is a weight known as the friction distance that ranges from 1.0 - 6.0. (Vieux, 2001) The most commonly used value for k is 2 (Teegavarapua and Chandramoulia, 2005).

Distance between the raingauge was calculated by their geospatial location (longitude and latitude) as shown in table below:

Table 6.2: Geospatial location and distance of rainfall Stations with Kulekhani dam

	Latitude N	Longitude E	Distance in Km				
			Chisapani	**Daman**	**Markhu**	**Thankot**	**Kulekhani Dam**
Chisapani	$26^0 55$	$86^0 10$		131.3	127.1	128	149.2
Daman	$27^0 36$	$85^0 05$	131.3		6.825	14.76	45.67
Markhu	$27^0 37$	$85^0 09$	127.1	6.825		8.9	41.94
Thankot	$27^0 41$	$85^0 12$	128	14.76	8.9		33.72
Kulekhani Reservoir	$27^0 59$	$85^0 15$	149.2	45.67	41.94	33.72	

6.3.2 Temperature data

The most common measure of global warming is the trend in globally averaged temperature near the Earth's surface. Among the four stations in Kulekhani watershed area, temperature is recorded in Daman only. The spatial distance of Daman from Kulekhani dam is 45.6 km. The maximum, mean and minimum monthly temperature data recorded at Daman for the last 30 years from 1975 to 2005 (annex 2) was analyzed during this study. The temperature data was available at Department of Hydrology and Meteorology (DHM).

6.3.3 Discharge

The discharge of a river is the volume of water which flows through it in a given time. It is usually measured in cubic meters per second. The discharge volume was determined by factors such as climate, vegetation, soil type, drainage basin relief and the activities in dam. The fifteen (15) years mean monthly and annual discharge of Kulekhani khola from 1963 to 1977 was analyzed. The data was available at Kulekhani site office, Bhimphedi. The station closed down in 1978 during the operation phase of Kulekhani dam, due to which latest discharge data was not available for the study.

6.3.4 Reservoir Level

The level of reservoir determines amount of water accumulated in the reservoir that can be used for generation of electricity. The quantity of water to be flowed to the intake to run turbine was determined by the level of water in reservoir. However, it is always not true for Kulekhani Hydropower, because mostly it is operated on need base mechanism. Monthly data of reservoir level from 1988 to 2009 (Annex 3) was analyzed for the study.

6.3.5 Electricity generation

Kulekhani is a casket project comprising projects I, II and III. Projects I and II are in operation while the 14 MW Kulekhani III is under construction. The project I and II are of installed capacity 60 MW and 32 MW respectively. The main purpose for the construction of this power station was to take the peak load only but the unavailability of the sufficient power with respect to demand, the power station most of the time is forced to operate as and when required. Due to many technical reasons, these power stations are operated mostly under its capacity. Monthly electricity generation data (Annex 4) available from Kulekhani site office from 1980 to 2010 were analyzed.

KHEP has significant role to maintain optimum power supply to the national grid systems. In 2009, the peak annual power and energy demand was 885.28 MW that was 8.96 % higher than previous year (812.5 MW) and annual Energy Demand was recorded 4367.13 GWh out of which 3076.69 GWh was contributed by domestic generation, 612.58 GWh was imported and rest 677.860 GWh was managed *(NEA 2010)*.

VII. RESULTS AND DISCUSSION

7.1 Rainfall distribution

Distribution of rainfall within the Kulekhani watershed is not uniform. Elevation as well as exposition of mountains within the watershed plays major roles for uneven rainfall distribution. The total rainfall over the southern and northern parts of the Kulekhani watershed increase with elevation, whereas in the eastern part rainfall generally decreases with elevation.

ISET (2009) reveals that most locations in Nepal receive nearly 80% of annual precipitation during the months of June-September. Similarly, Makwanpur district also receive major part of the annual rainfall falls in monsoon (81%) followed by 4% in Post monsoon, 3% in winter and 12% in Pre Monsoon season *(Joshi G.R., 2008)*. Whereas, the 30 years of daily data (1980-2009) of Kulekhani watershed shows that about 78.24 % of the rainfall occurs in monsoon (June-September\`), 14.67 percent in pre-monsoon (March-May) and 3.63 % percent in winter (December-February) and 3.45% post monsoon season (October-November). This validates the

This result shows that the reservoir level in Kulekhani Hydropower Station rises during monsoon, and water accumulated during this time is used throughout the year for generation of electricity. Kulekhani Hydropower was initially designed as peaking power station, so that this hydropower could produce more electricity when the other run-off-river based hydro powers operates on limited capacity during dry seasons. But it has been supporting as emergency stand by station and is forced to operate as and when required. This demand based operation system of Kulekhani may be helpful to meet the current demand but chaotic utilization of this valuable resource has raise question on its sustainability.

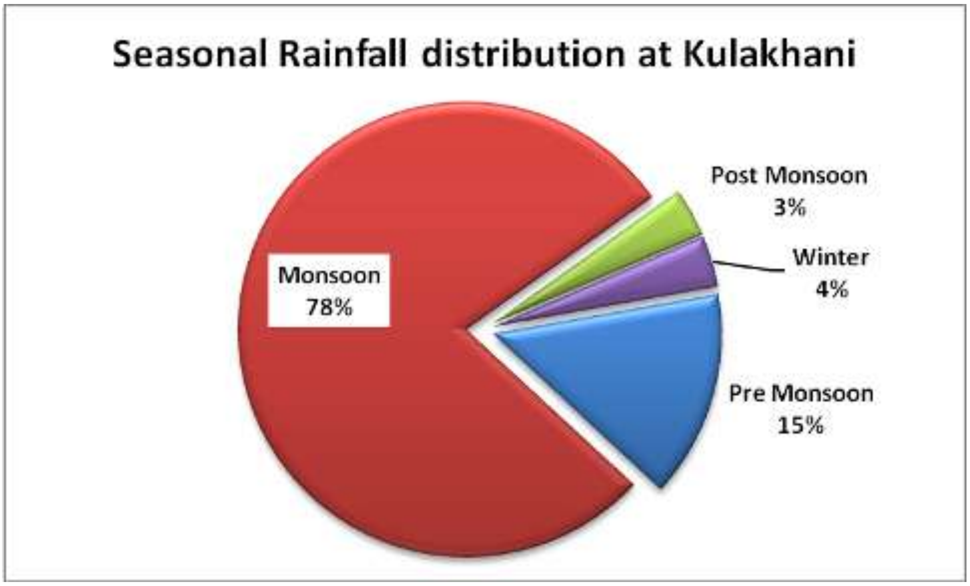


Figure 7.1: Seasonal Rainfall distribution at Kulekhani

A above chart shows rainfall distribution at watershed, it is further supported by daily annual rainfall distribution pattern shown in figure 7.4. It explains that precipitation at watershed peaks up from June to August and is highest during July.

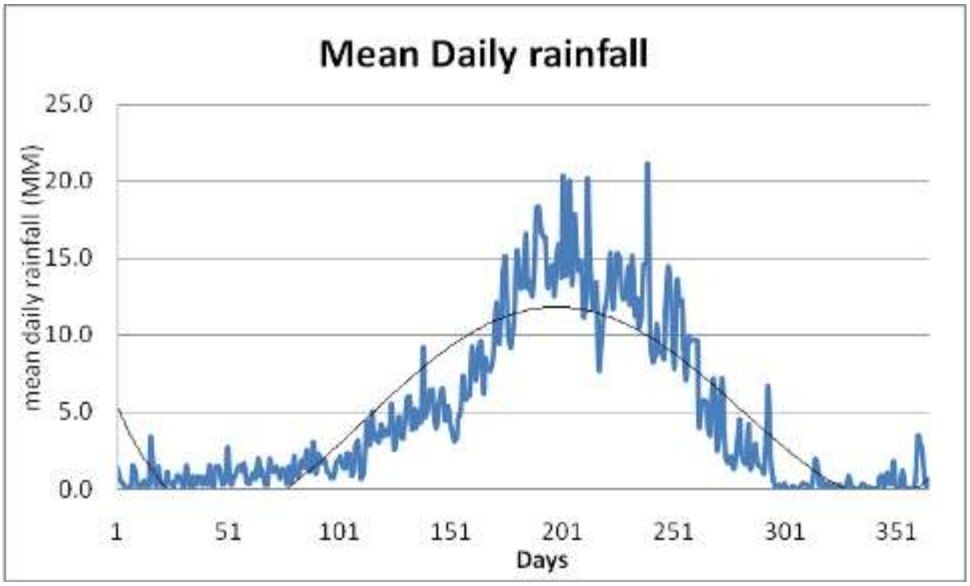


Figure 7.2: Daily rainfall Distribution at Kulekhani

7.2 Average annual rainfall

The study by APN 2007 and Shrestha et al. 2000 illustrate that there no significant change in annual precipitation in Nepal. However this study shows that the annual average rainfall of Kulekhani is decreasing at the rate of about 11.5 mm per year. This point out that Kulekhani falls on the dryer region as compared with the national average.

According to Practical Action (2009) the average annual precipitation (1976 to 2005) trend ranged from -40 to 20 mm in the central development region of Nepal, which is similar to the data analyzed during this study that the average annual precipitation trend is decreasing by about -11.56 mm. Practical Action (2010) shows as increasing trend in extreme events in most of the stations examined (from 1961 to 2006) and there was no any systematic difference in extreme precipitation trend between hills and low land - southern plains of tarai.

Similar to the study Shrestha et al. (2000 explain that rainfall data of Kulekhani watershed (1972 to 2009) have also change in amount, intensity and frequency. As rainfall and electricity generation is positively correlated (r = 0.78 figure 7.5, above), decrease in the annual average rainfall will have similar impact on electricity generation. So discharge and water level in the reservoir decline with rainfall which effect the energy generation in hydropower.

Joshi (2008) states that the mean annual rainfall in Makwanpur district is 2065.04 mm. The study area doesn't possess any climatology station but it is close to Daman Station. So we can assume that the rainfall pattern or change demonstrated by this station can also represent the study area.

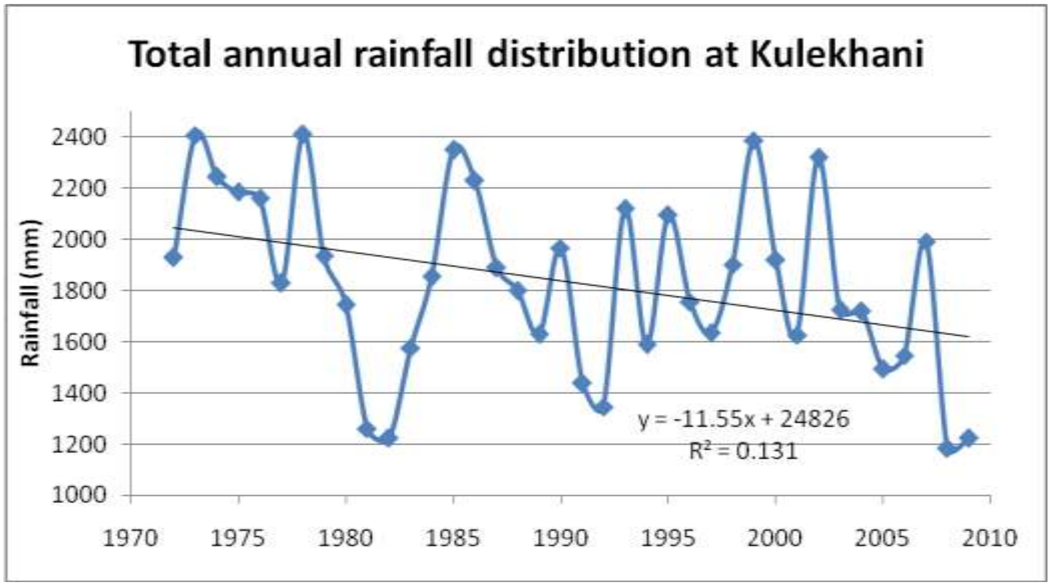


Figure 7.3: Total annual Rainfall distribution at Kulekhani

Average annual precipitaton distrbution of four nearby stations from Kulekhani (Chisapani, Marphu, Daman and Thankot) are divergent with one another. From past 31 years data analysis of rainfall trend, it can be concluded that total amount of precipitaton is increasing at Chisapani. In its contradiction total precipitation is declining in other stationsincluding Markhu, Daman and Thankot in a similar way with annual average.

Chisapani is farthest distance rainfall station among others, this signifies that changes in rainfall trend of Chisapani have lesser impact in reservoir as compared to other stations. In this condition, as remaining stations have decreasing trend of annual average precipitation, water level in the reservoir will also drop off in future. As, water is main component for generating electricity in Nepal, the decreasing trend of precipitation will have significant impact on electricity generation at Kulekhani.

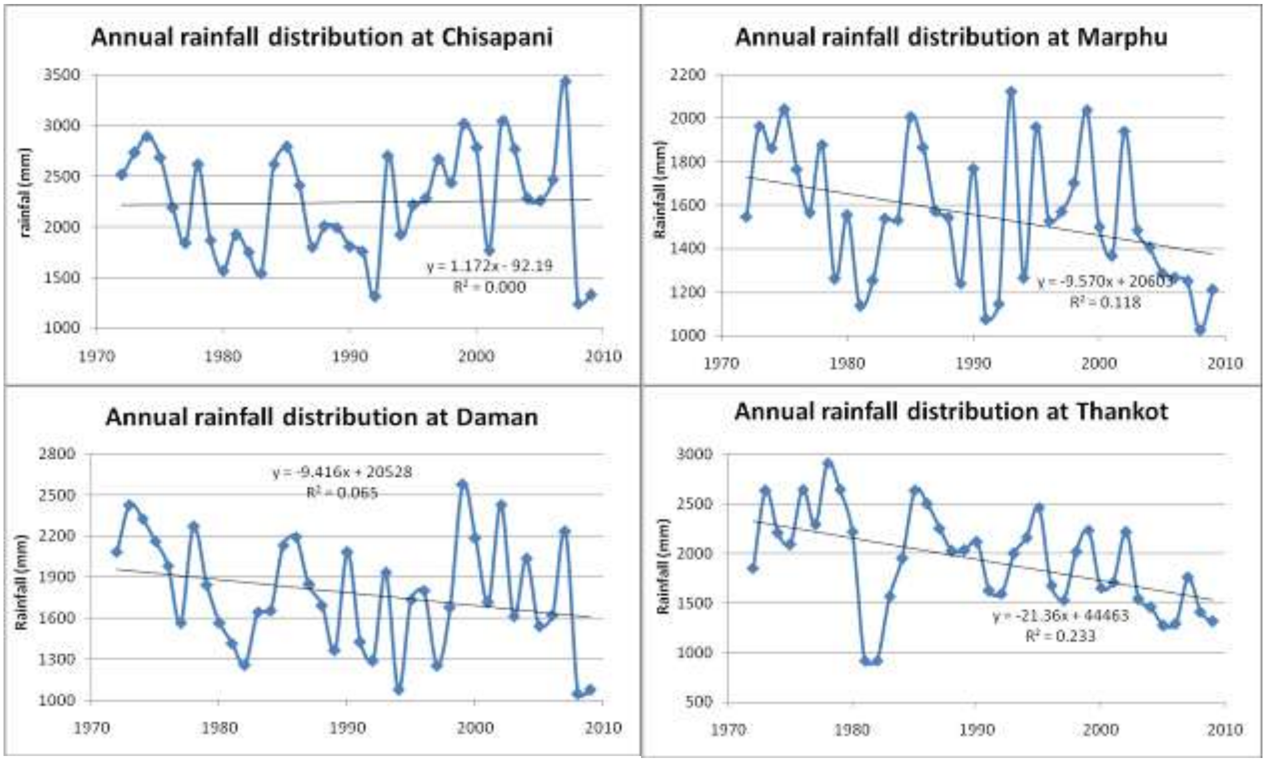


Figure 7.4: Rainfall distribution at different stations

7.3 Seasonal rainfall distribution

7.3.1 Pre Monsoon

Pre-monsoon average annual rainfall distribution of around 90 days from March to May, and data shows that the rainfall trend is increasing. The figure below signifies that annual rainfall as well as the distribution of rainfall throughout the year is increasing in pre-monsoon in Kulekhani. This increasing trend also signifies that Kulekhani receives more rain during pre-monsoon, supported by figure below it also shows the non-rainy days during pre-monsoon at Kulekhani is decreasing.

While, observing this decreasing trend it can also be predicted that the monsoon is gradually shifting earlier, this prediction is further supported by figure 7.7 which shows that the pre-monsoon rainfall is decreasing in Kulekhani. If this would be the case, it may have positive impact on hydropower production, because during March to May, water level in the river is very low (figure 7.16) and water from this rainfall could feed the reservoir.

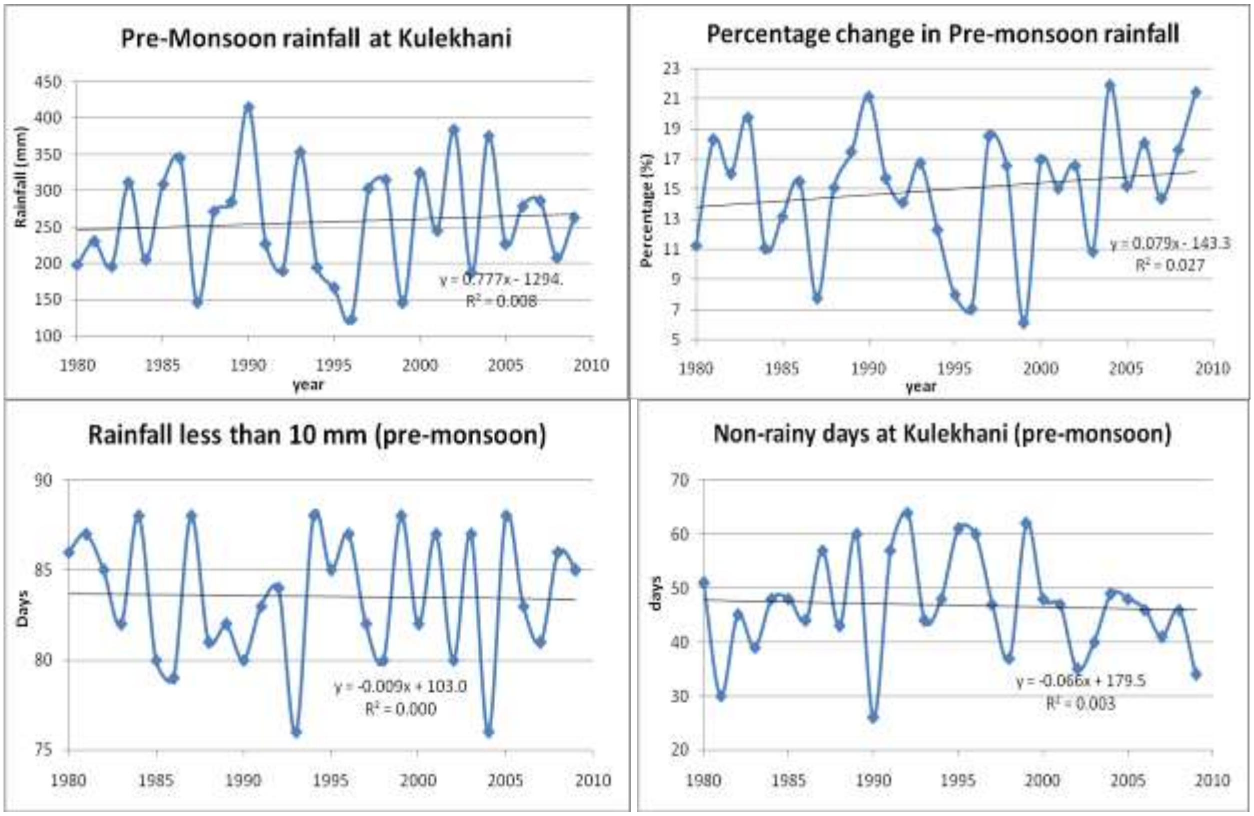


Figure 7.5: Pre-monsoon rainfall distribution

7.3.2 Monsoon Rainfall

As mentioned earlier, the same study carried out by APN 2007, Shrestha et al. 2000 also says that there is no significant change in monsoon precipitation in Nepal. Whereas, according to the study carried by NCVST 2009, monsoon rainfall in eastern and central Nepal is projected to increase more than western Nepal. However, the trend of 30 years (1980-2009) monsoon rainfall of Kulekhani is decreasing and the decreasing trend is very less signifcant at around 1.2 mm per year.

APN 2007 report states decreasing trend in the number of annual rainy days during the last four decades. This national prediction is similar to the trend of rainfall days in Kulekhani, the figure below shows that non rainy days in Kulekhani is increasing.

Alalysis shows that annual average monsoon rainfall and rainy days at Kulekhani is decreasing whereas, in comparision to other seasons throughout the year monsoon is getting more rainfall and days with more than 10 mm rainfall are increasing. This indicates that, monsoon is shortening which means that Kulekhani is getting same amount of rainfall on lesser number of days. If this trend goes on, it will have negative impact on Kulekhani reservoir. When there is heavy raifall in short interval the reservoir could not replinish as water during monsoon will overflow from dam and there will be less water during dry season. Kulekhani hydropower cannot be operated as peak demand system in such condition. The recommendation could be to increase the capacity of reservoir or make smaller check dams at upstream, which can hold water for some duration.

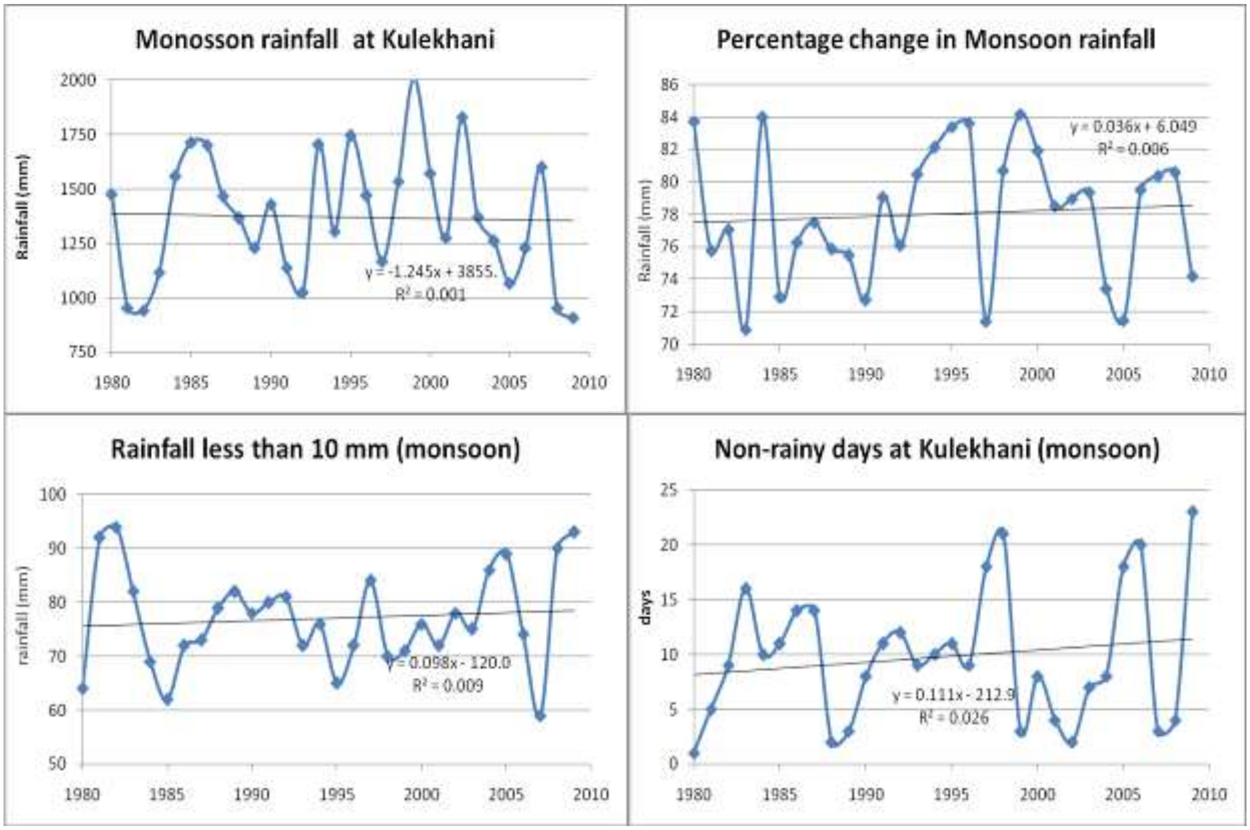


Figure 7.6: Monsoon rainfall distribution

7.3.3 Post Monsoon Rainfall

The trend of annual average post-monsoon rainfall and total post-monsoon is decreasing at Klekhani watershed than in other season. Similarly, the trend of non-rainfall days and rainy days less than 10 mm rainfall in Kulekhani is also increasing which shows that post-monsoon is getting less rainfall as well as lesser number of rainy days.

The rainfall pattern shows that, post-monsoon period is getting dryer, it can also be predicted that similar to monsoon shifting earlier, post-monsoon is also shifting later towards winter. As the reservoir is replinished by the monson ranfall earlier, the changes in the rainfall distribution during the post-monsoon will not have much significant impact.

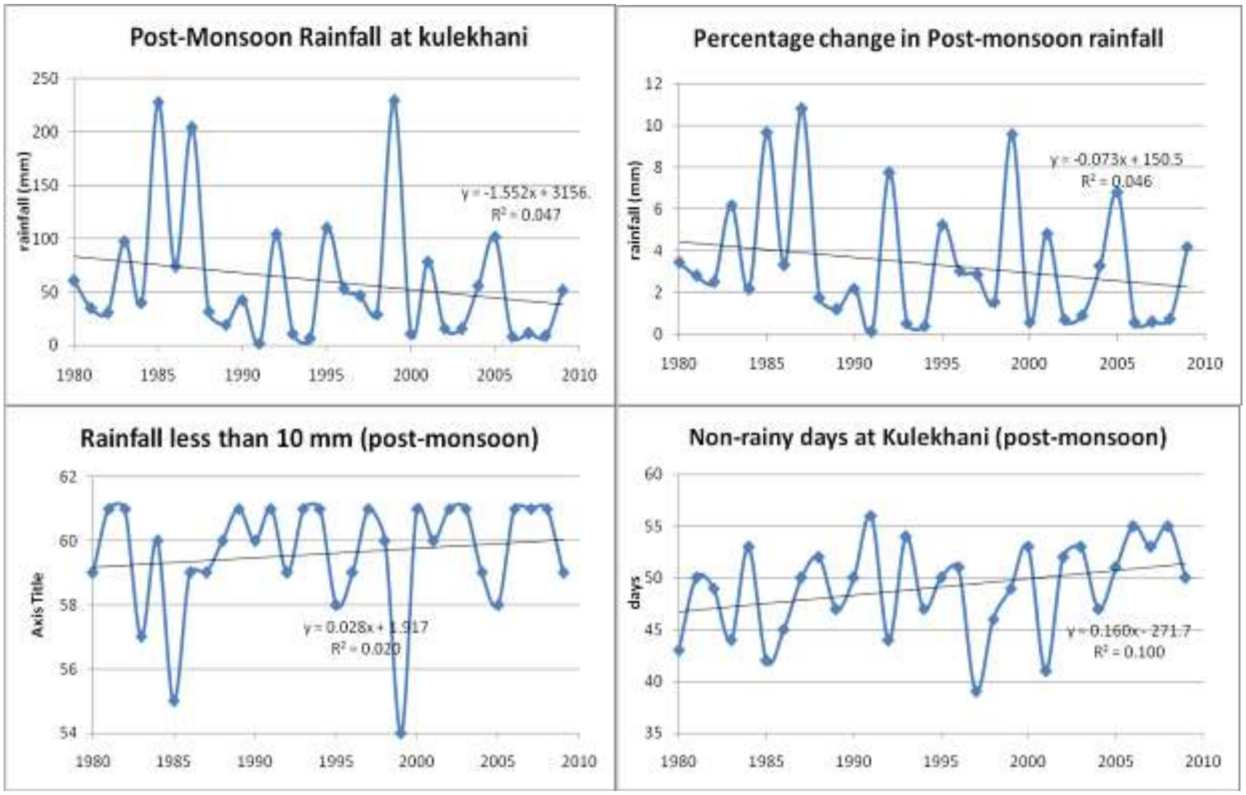


Figure 7.7: Post-monsoon rainfall distribution

7.3.4 Winter rainfall

Annual average winter rainfall and the amount of rainfall during winter in comparison to other seasons is decreasing at Kulekhani watershed. Winter also gets less rainfall as well as lesser number of rainy days as no rainfall days and days with less than 10 mm rainfall is increasing as per analyzed data. Thus winter is getting drier.

Electricity generation is positively coorelated with rainfall, less rainfall during winter means negative impact on electricity generation. With regards to decreasing rainfall period and amount, it can be predicted that electricity generation capacity of the hydropower is decreasing, which directly depends on water level in reservoir.

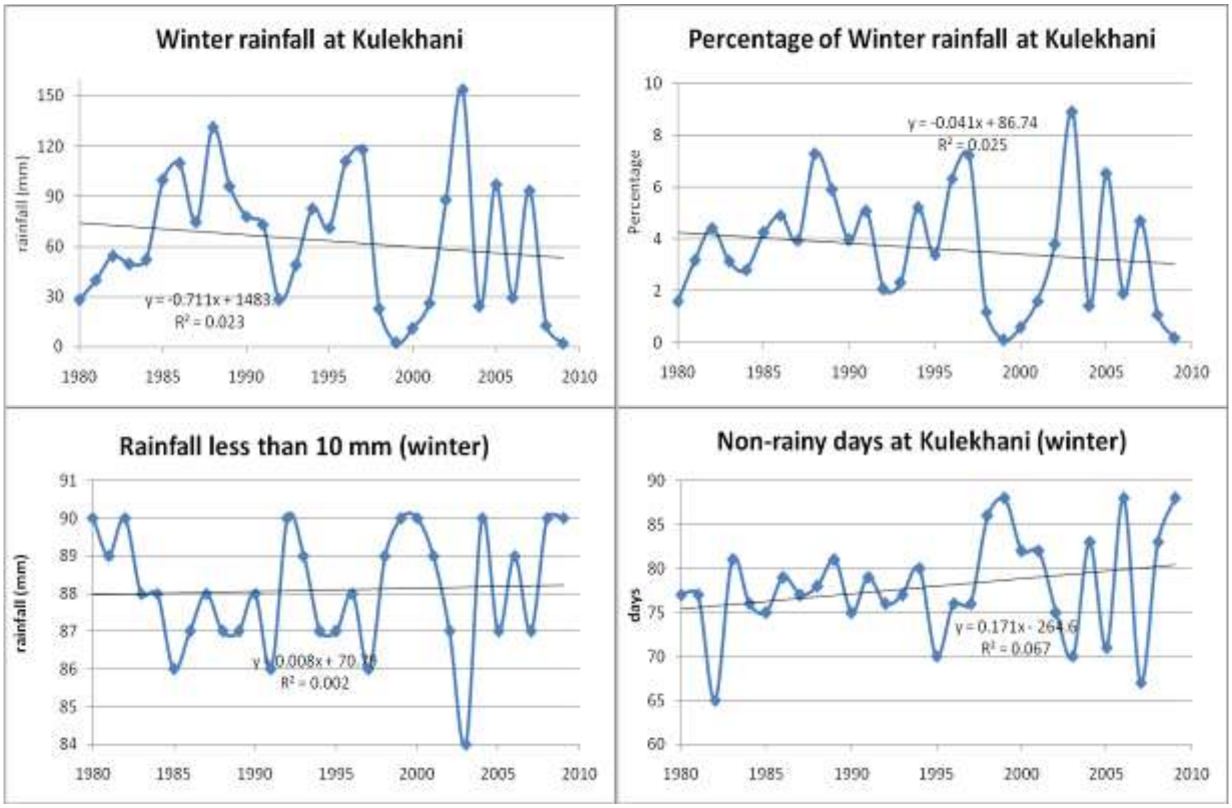


Figure 7.8: Winter rainfall distribution

7.4 Non-rainy days at Kulekhani

The past records of about 39 years (1972 to 2009) shows that the numbers of non-rainy days are increasing at Kulekhani watershed area. Among the four different rainfall stations, Markhu have sharp increase in non-rainy days followed by Chisapani and Daman. But there is moderate increase in rainy days in Thankot station. Analyzing the trend of all four stations, it can be predicted that the Kulekhani Watershed is drying and if it goes on it will have negative impact on water accumulation in reservoir, which finally affect electricity generation.

The figure below shows the trend of non-rainy days of different station at Kulekhani watershed area:

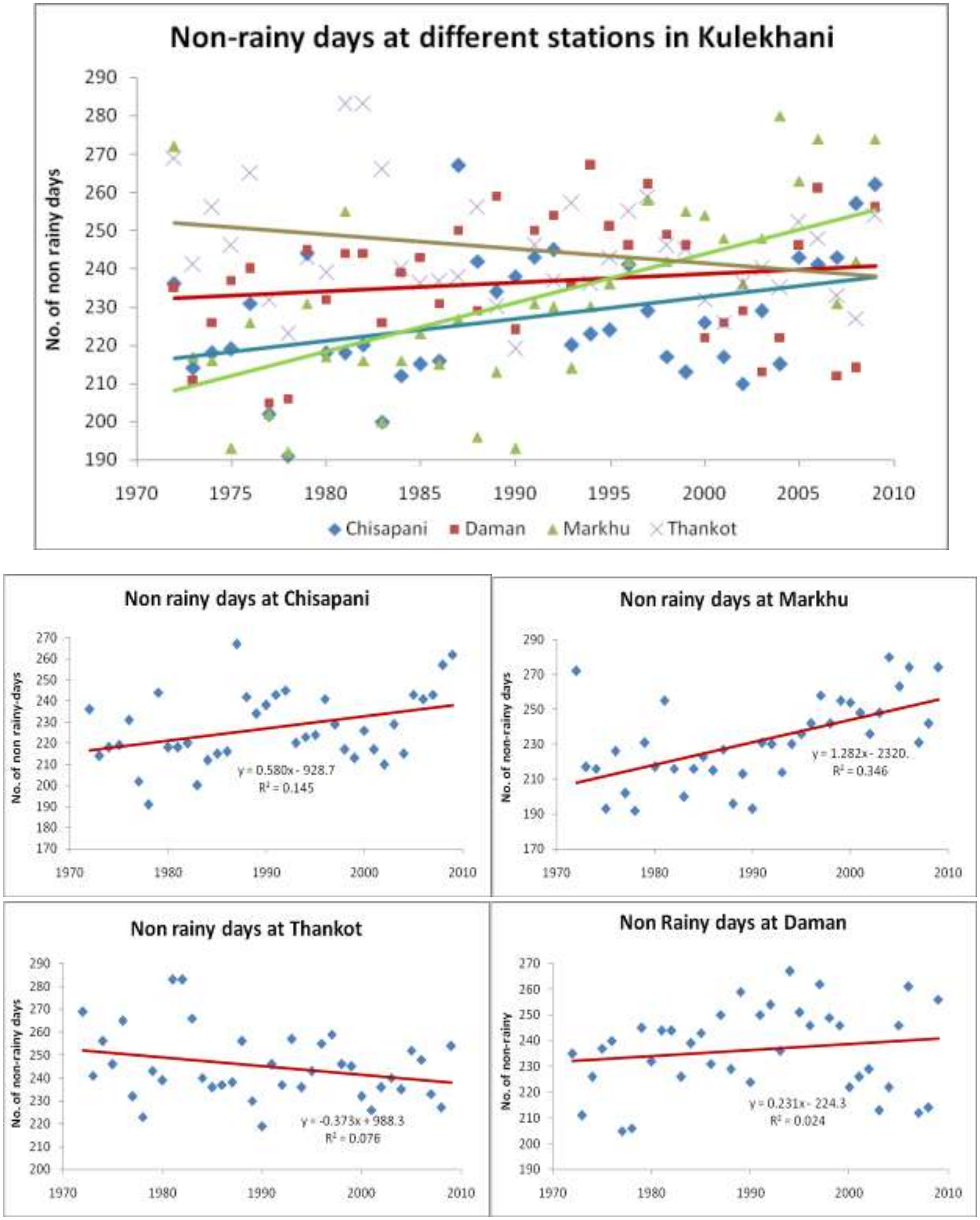


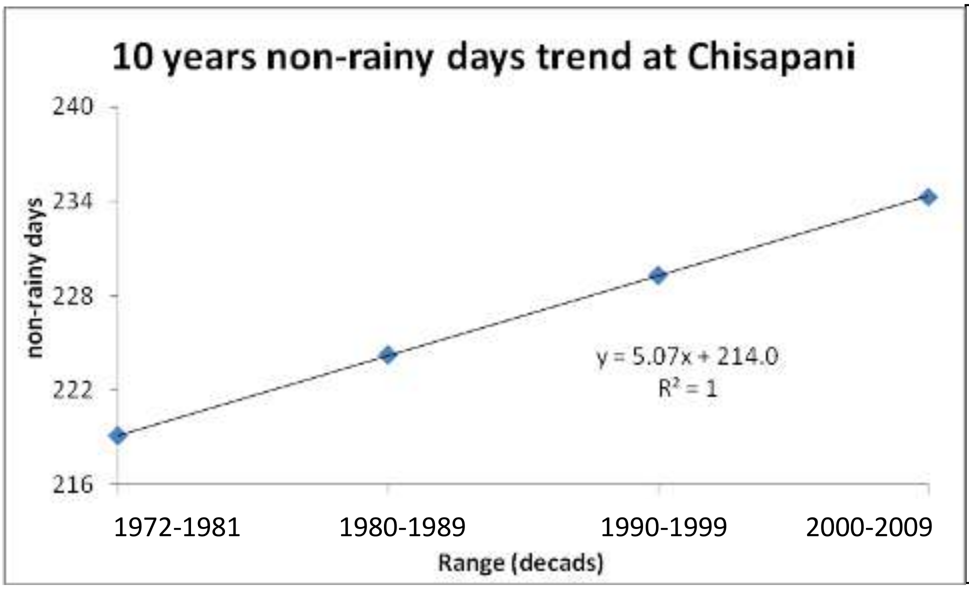
Figure 7.9: Non-rainy days at different stations in Kulekhani

The chart below illustrates average non rainy days on every decade in different stations and Kulekhani for past 40 yrs period. The average number of days without rainfall is rising in Chisapani, Daman and Marphu whereas declining in Thankot. The overall trend of non-rainy days at Kulekhani watershed is increasing, this shows that Kulekhani is getting more dryer on every decades. Rainfall in this area is likely to decline in the long run.

Table 7.1: Non-rainy days at Kulekhani and other stations

Year (range)	Average non-rainy days for decades				
	Chisapani	Daman	Markhu	Thankot	Kulekhani
1972-1981	219.1	228.1	222.1	249.7	184.1
1980-1989	224.2	239.7	217.8	250.8	179.8
1990-1999	229.3	248.5	233.1	244.3	189.7
2000-2009	234.3	230.1	255	238.3	184

Result obtained by analysing the daily data from 1980 to 2009 of four nearby stations



Among the four rainfall stations area, number of non-rainy days in Chisapani is increasing by about 5 days on every 10 years. Since the value of R^2=1, the data variablity can be defined with high level confidence.

Figure 7.3: Ten years non-rainy days at Chisapani

7.5 Temperature Analysis

MOEN 2001 states that the mean temprature of Nepal is around 15°C with increases order from North to south with the exception of mountain valleys. APN 2007 found that annual mean temperature in Nepal increased steadily at a linear rate of 0.4 °C per decade from 1975 to 2005. Alike ICIMOD (2007) stated, the temperature rise in Nepal was within a range of 0.2- 0.6 °C per decade between 1951 and 2001 particularly during autumn and winter.

Shrestha et. al. 1999 states that warming trend is high in the mountains and hills compared to tarai. The trend of mean maximum temperature ranged from 0.068 - 0.128 °C per year in most of the middle mountain and Himalayan regions while the same ranged below 0.038 °C per annum in tarai and plain. The study carried out by Practical Action (2009) also showed that the annual mean temperature trend over Nepal ranged from -0.04 to 0.08 °C in central region during the period 1976 - 2005.

The temperature increasing trends in Nepal is high compared to the global average temperature rise of 0.74 °C in the last 100 years (1906 to 2005) and 0.13 °C per decade in the last 50 years (1956 to 2005) (IPCC 2007). Baidya et al (2008) found a general increasing trend in the extreme temperature events with a consistent higher magnitude in the mountains than in the plains.

Practical Action and IPCC 2007 reported an average mean annual temperature (1973 - 2005) of Daman is about 13.2 ^{o}C. Temperature was above the usual after 1993. It also shows the rising trend of air temperature by 0.06 ^{o}C with depict some short of warming up from last 30 years, which falls within the range of annual mean temperature trend of central region (0.04 - 0.08), hills and mountain (0.038 – 0.128 oC). These observations are showing consistency with the temperature analysis done here.The observed increasing trend (0.06 ^{o}C) is also similar to the Nepal's annual mean temperature trend mentioned in Initial National Communication report submitted to UNFCCC by Nepal.

The temperature statistics for the station Daman (st905) is shown in Annex 2.

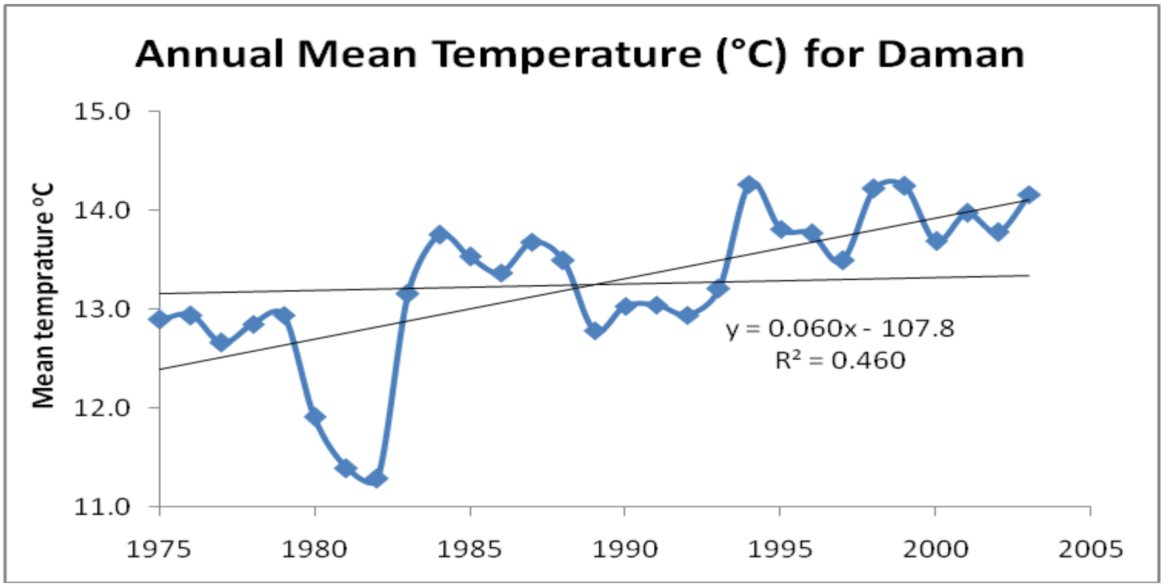


Figure 7.4: Annual mean temperature trend

7.6 Discharge

The Kulekhani Khola (river) is also known as Palung Khola is the main stream of the watershed. The discharge data was taken from Kulekhani site office that was established by Department of Hydrology and Meteorology (hydrological station no 570) in 1962. But, the station was closed down in 1978 during the operation phase of Kulekhani dam.

The Summary of the mean monthly and annual discharge (m^3/s) for Kulekhani khola for year 1963 to 1977 is given in the table below:

Table 7.2: Mean monthly and annual discharge for Kulekhani Khola

Mean Monthly and Annual Discharge (m3/s) for Kulekhani Khola													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1963	1.17	1.06	1.13	1.15	1.65	1.13	6.61	7.64	5.75	3.52	2.16	1.75	35
1964	1.47	1.39	1.17	0.91	1.26	2.21	7.24	12.1	15.2	4.49	1.84	1.5	51
1965	1.32	1.3	1.22	1.76	1.47	3.73	17.2	18.4	5.71	3.16	2.85	1.77	60
1966	1.6	1.47	1.17	0.74	1.12	1.14	10.4	20.8	10.3	3.33	2.2	1.73	56
1967	1.09	0.93	0.86	1.02	0.65	4.53	11.8	6.92	5.65	3.36	2.32	1.7	41
1968	1.66	1.46	1.63	1.21	1.1	2.52	5.72	6.33	2.62	7.12	2.25	1.47	35
1969	1.18	0.89	0.87	0.92	0.95	0.88	3.1	6.89	4.18	1.91	1.1	0.83	24
1970	0.82	0.72	0.64	0.6	0.64	3.42	21.5	8.96	5.26	3.3	2.19	1.46	50
1971	1.15	1.11	1.1	1.98	2.13	21.6	5.17	7.68	4.27	3.82	2.22	1.86	54
1972	1.72	1.78	1.62	1.41	1.38	1.45	26.3	5.6	7.92	3.51	1.15	1.58	55
1973	1.38	1.24	1.58	0.96	1.29	10.2	7.34	7.95	9.51	9.51	5.14	2.74	59
1974	1.59	1.33	1.14	1.16	1.26	1.66	7.15	15.6	3.5	3.5	1.96	1.5	41
1975	1.28	1.18	0.88	0.76	1.07	2.11	14.8	11	4.7	4.7	2.35	1.67	47
1976	1.46	1.25	1.02	1.09	1.44	7.96	6.04	4.75	2.3	2.3	1.75	1.45	33
1977	1.28	1.22	1.07	1.39	1.64	1.57	3.16	3.47	1.8	1.8	1.6	1.63	22
mean	1.345	1.222	1.140	1.137	1.270	4.407	10.235	9.606	5.911	3.955	2.205	1.643	3.67

Source: DHM

Kulekhani Khola is the main river that feed the reservoir, therefore any changes in discharge rate of it will affect water level in the reservoir and finally electricity generation. Considering monthly discharge data from 1963 to 1977, discharge level in Kulekhani Khola increases from June to August, during the rainy season. The water accumulated during this time can be used to generate electricity throughout the whole year.

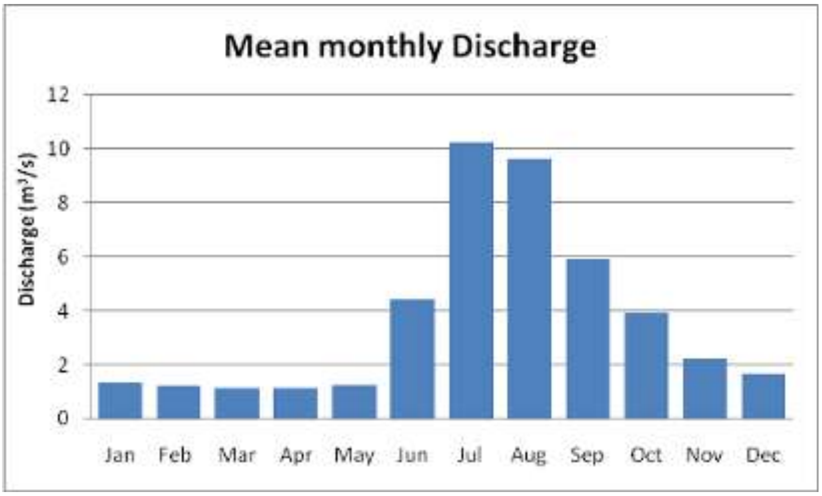


Figure 7.5: Mean monthly discharge (m^3/s) of Kulekhani Khola

The melting of glaciers and snow in the mountains has affected the major river discharge in Nepal during dry season. IPCC (2007) has predicted that the annual river discharge increases until around 2030 and then decrease because of rapid melting of snow and glacier in the beginning, and then significant decrease of available snow and glacier mass thereafter.

Practical Action (2009) has suggested further studies for individual glaciers and rivers, since the change in temperature and precipitation vary from one region to another the river discharge will also be affected accordingly. It further states, that the annual discharge of snow fed rivers is increasing, except that of Narayani River, which has slight decreasing trend and some rivers that originate from middle mountains i.e. west Rapti and east Rapti have shown a negative trend. The same study has further suggested the need of assessment of the impacts of climate change on discharge of major river systems to understand the specific changes as the varied regional climate change will have varied impacts on river discharges over the regions and over the seasons. The discharge data of Kulekhani river remain unknown after the station closed down in 1978 during the operation phase of Kulekhani dam, this study has limitation to show latest temporal variation on discharge

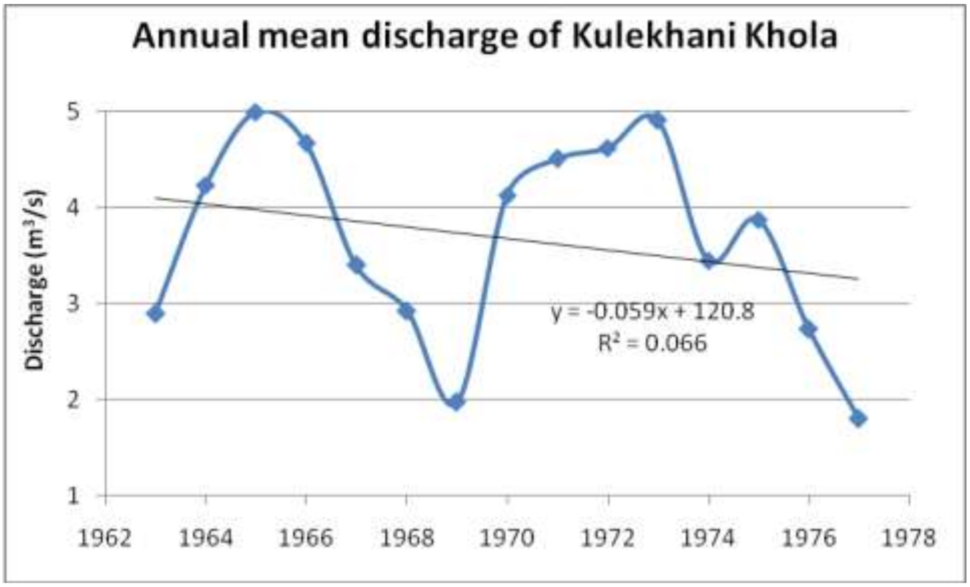


Figure 7.6: Annual discharge of Kulekhani Khola

While analyzing the discharge of Kulekhani khola of 11 years (1963 to 1977), it was found that the discharge level is in decreasing trend. As the amount of rainfall and its intensity is decreasing, this could be one of the main reasons affecting the discharge level. Variation in the Kulekhani river discharge have direct impact in the reservoir and finally in hydropower generation as it is the main stream.

7.7 Reservoir Level

The figure below shows the strong positive linear relation between water level in the reservoir and energy generation from Kulekhani hydropower (r = 0.82). As the value of R^2 is greater than 5, it shows that the variable are significanntly distributed.

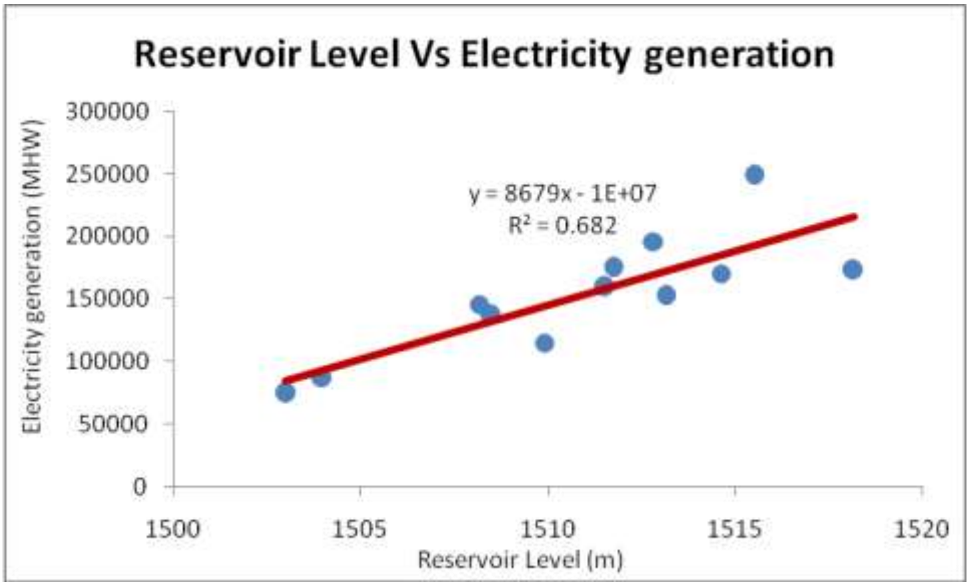


Figure 7.7: Reservoir level – energy generation relation

Data available from 1998 to 2010 shows that the water in the reservoir rises from August and peaked at October-November, on the other side water level start decreasing from January and during May. When discharge in the river falls the level of water also decreases, because of high demand of electricity in nation grid or Central Nepal Power System (CNPS).

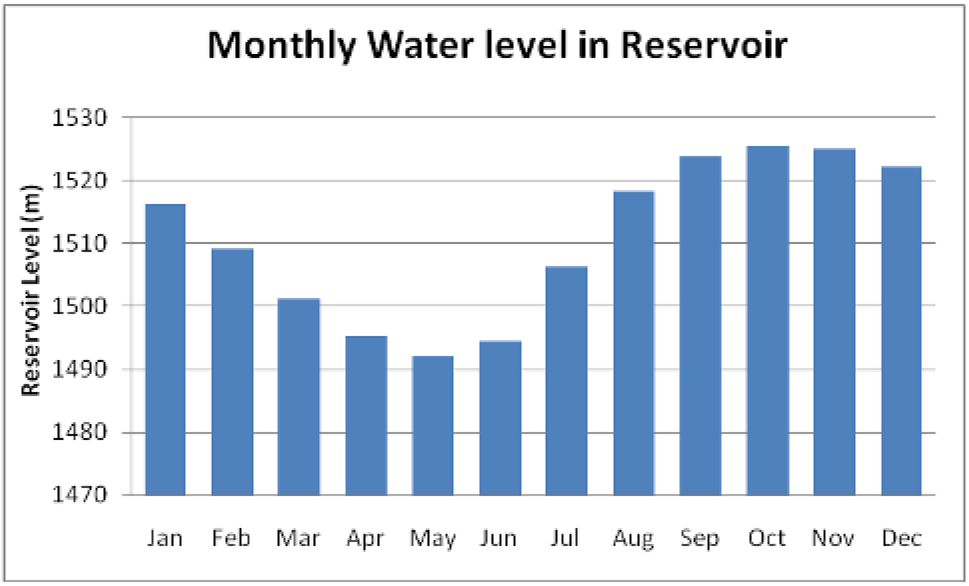


Figure 7.8: Monthly water level in Reservoir

A study by Winrock International (2004) states that the erosion processes in the Kulekhani watershed transport an enormous amount of sediment to the reservoir. This sediment deposited in the reservoir reduces the life of the reservoir. A monitoring survey conducted by the Department of Soil Conservation and Watershed Management (March 1993) concluded that a total of 2.2 million cubic meters of sediment have been deposited in the reservoir in 10 to 11 years. The same study by Winrock International further states sedimentation measurement done in the reservoir shows that excessive sediment was deposited in the years 1993 to 1995 and heavy rainfall is one among the other factors to accelerate the process.

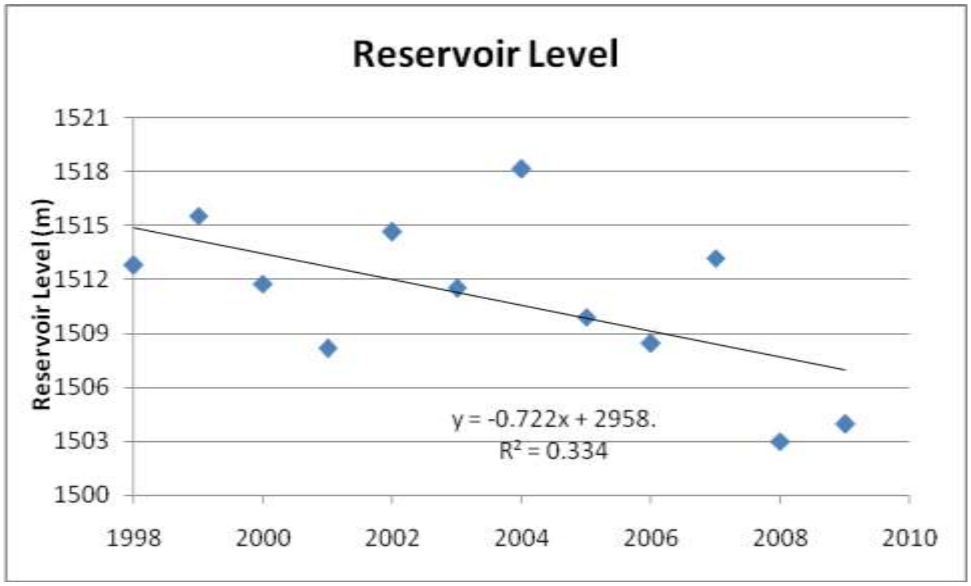


Figure 7.16: Level of water in the Kulekhani reservoir

The earlier studies indicate that, sedimentation in the reservoir as a serious threat on the life span of Kulekhani Reservoir and demands urgent environmental solution. The past record of about 10 years demonstrates that the amount of water in the reservoir is decreasing. Decrease in water level is resulted due to: decrease of total amount of rainfall in the watershed, decrease in discharge level of Kulekhani Khola, sedimentation, high demand of electricity. Continuity of the same trend will have similar negative impact on electricity generation in long run.

7.8 Electricity generation

Based on the energy generation data from 1982 to 2010, the monthly energy generation distribution is shown in figure below. The figure shows that from February the amount of electricity generation decreases till May and then to December, it slowly increases when there is high discharge in the river from July.

As mentioned earlier, the Kulekhani Hydropower Project is the only hydropower based reservoir system in Nepal, a special character about the reservoir based hydropower here is, that the hydropower produce maximum energy during the dry season and lesser amount during other seasons. During the dry seasons, the Central Nepal Power System (CNPS) is feed mostly from the energy generated from the Kulekhani Hydropower Stations.

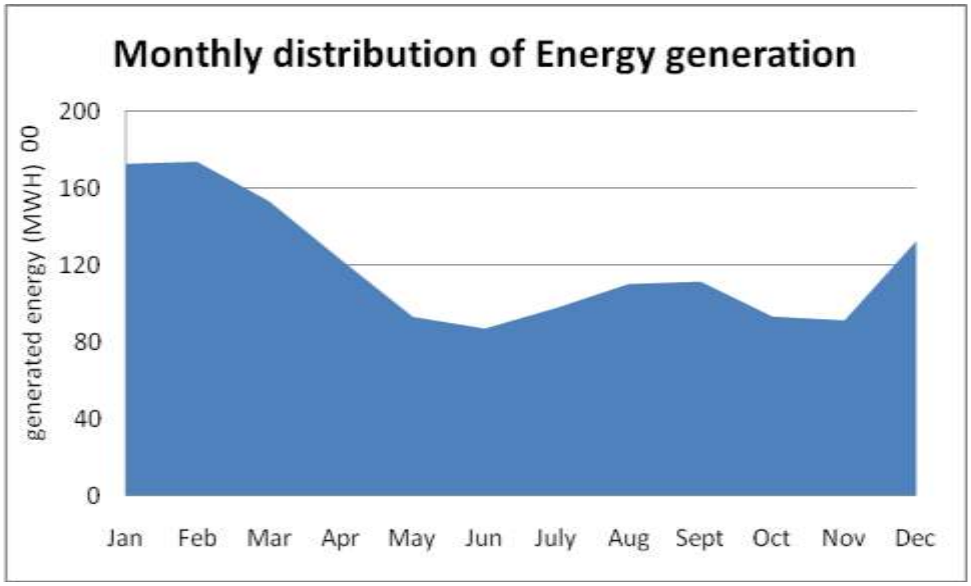


Figure 7.97: Monthly distribution of Energy generation (MWH)

The figure below shows the level of energy generation from 1982 to 2010, as Kulekhani Hydropower Project is demand-based hydropower; it is very difficult to make any assumption or define the trend with the base of its past records. However, decreasing discharge rate and amount of water will probably decrease the generation of hydro electricity in Kulekhani.

During the year 1993 the amount of energy generation was very low, it may be because of damage occurred due to the heavy rainfall on July 1993, which was recorded as one of the devastating disaster in Nepal's history. According to the officials at Kulekhani dam, the damage was also able to minimize because of the use of efficient early warning system installed at the project area, even though they were very less efficient.

Likewise, in the year 2000 there was highest amount of annual rainfall ever recorded (about 2400 mm) in Kulekhani watershed area. This may be the reason that, energy generation was highest in this year.

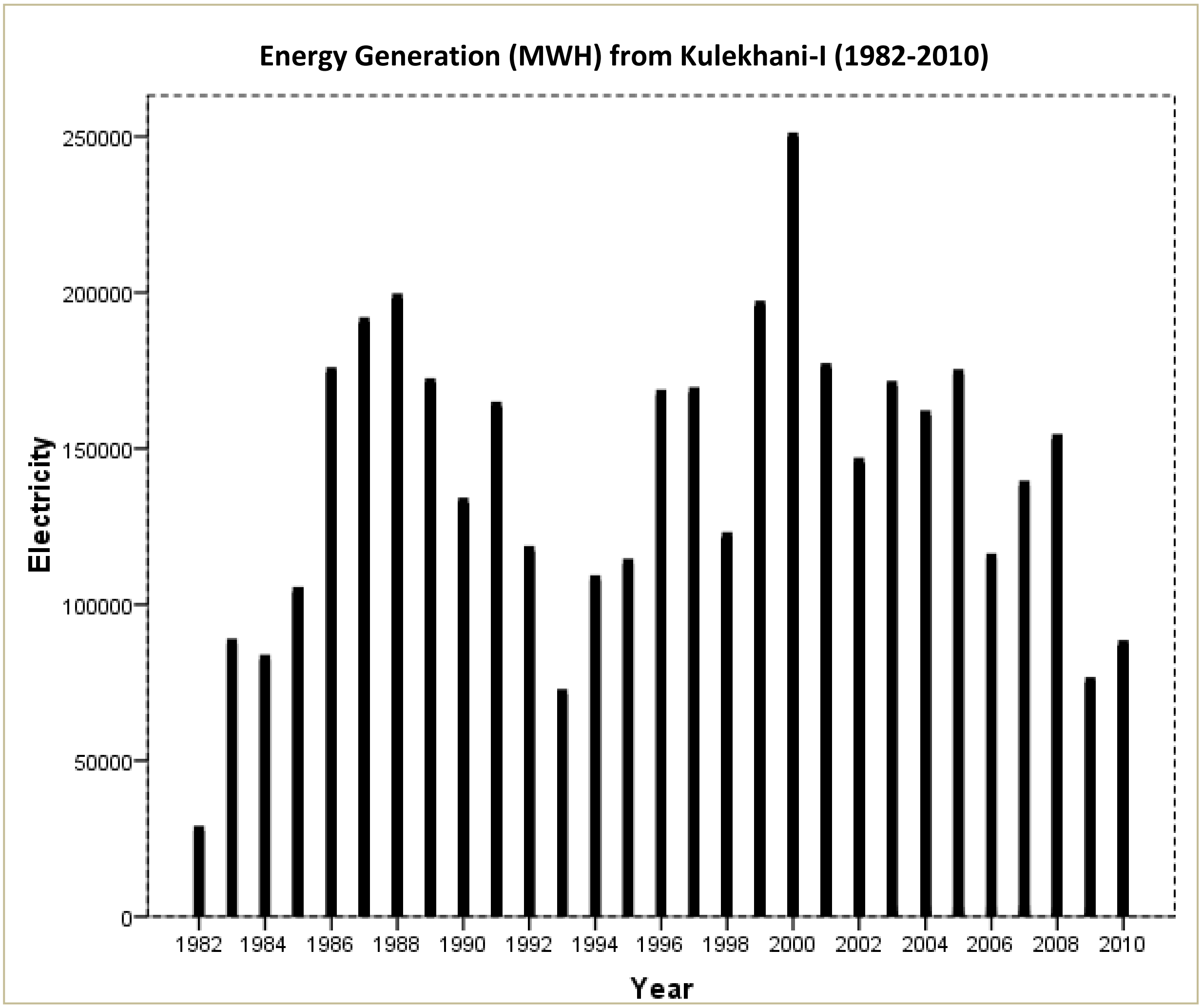


Figure 7.18: Energy generation (MWH) from Kulekhani-I

7.9 Rainfall – energy generation relation

In general, energy production is directly correlated to the amount of rainfall. The study result also shows that rainfall in Kulekhani is positively correlated with the electricity generation (the value of r = 0.78). This shows that energy generation increases with the increase amount of rainfall. Nevertheless, there are other factors that limits the energy generation the value of r is less than 1, i.e. moderate value. During the inspection visit at the site and hydro power station it was observed that the number of other factor limiting the energy generation are irregular and unplanned operation, carelessness in the maintenance of hydropower station and sedimentation. The low energy production in 1993 indicates the impact of the historic storm of July 1993 that filled a significant portion of the KHEP reservoir-bed and damaged the penstock pipelines disrupting power production for months was collapsed for months without generation of power.

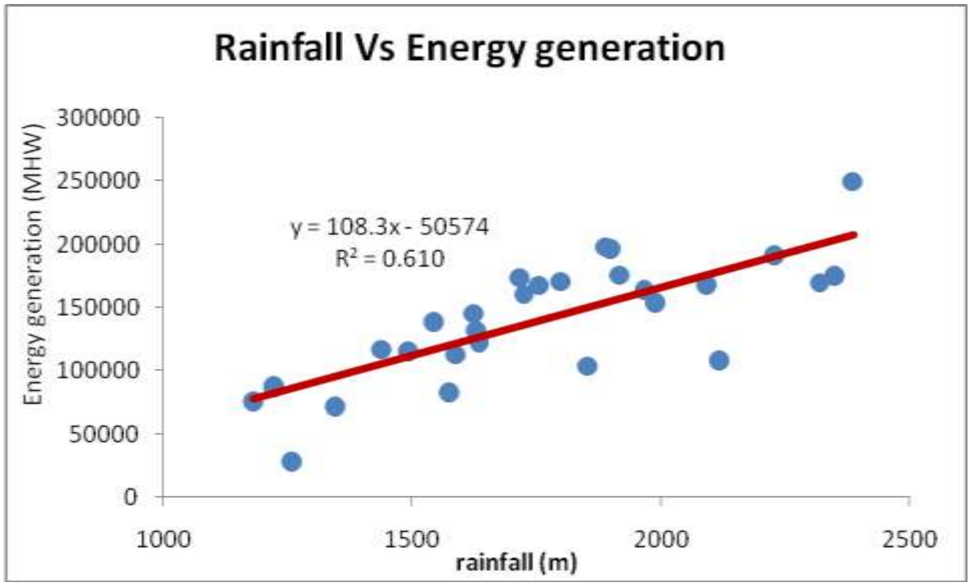


Figure 7.19: Rainfall and Energy generation relation

7.10 Mean Monthly Rainfall – mean monthly discharge relation

The correlation r between these two variables is very high (r = 0.922), which provides evidince to believe that there exist strong linear relation between rainfall and river runoff at Kulekhani khola. The relation between two variables is also significant (R^2=0.851). It proves that, increase in river discharge is mostly due to rainfall, including infiltration and uses of rain water for different purposes.

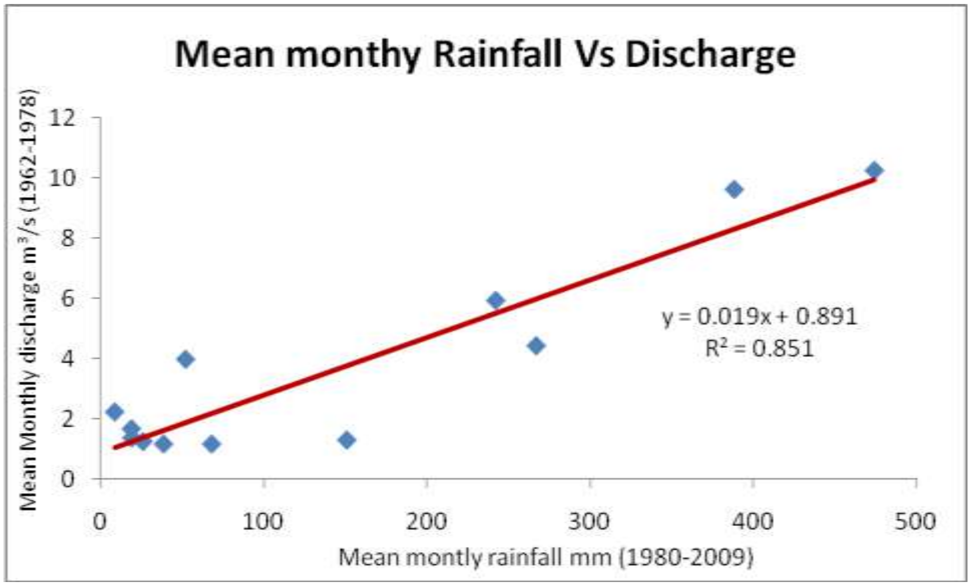


Figure 7.20: Mean monthly rainfall – mean monthly discharge relation

The analysis presented above confirms that Nepal's first and only reservoir based hydropower plant – the KEHP has already witnessed changes in temperature and rainfall pattern negatively.

Rise in mean temperature and reduced rainfall and number of rainfall days in the Kulekhani are enough to warrant for a more comprehensive research and pro-active steps for adaptation planning.

Joshi 2007 also states that agricultural production in the area is decreasing because of climatic variability and extreme events, scarcity of irrigation, natural disasters, more use of fertilizers. Because of less rainfall and prolonged drought, water sources in community are drying up resulting water stress and scarcity for drinking and irrigation purpose. Natural disasters have caused significant damage to socioeconomic and environmental assets of the village. These natural disasters are posing serious threat to livelihood of people through disruption of agricultural and natural vegetation, loss of water scarcity, loss of valuable agricultural land, loss of human life and properties. The local people are practicing various means to cope and adapt with adverse impacts but these are not enough to accommodate all those consequences.

VIII. CONCLUSION AND RECOMMENDATIONS

Change in rainfall pattern resulting in anomalies in hydro resources such as river flow has a significant effect on hydropower. Especially this unpredictable change has a significant effect on reservoir as it accumulates large volume of water within its limited capacity. This condition will affect the dependability of flow and assurance in the long run and hence the changing climatic parameters results in an unavoidable factor in the forecasting system of hydropower projects.

The results obtained from the study are essential for planning, management and researches relating to hydro power plants, water resources and other climatic factors, some generalizations are drawn from this study.

8.1 Conclusion

- The percentages distribution of the total amount of rainfall throughout the year has increased on Pre-monsoon and Monsoon and decreased in winter and post-monsoon season. Similarly, NCVST (2009) has projected more extremely high rainfall events are likely occur during monsoon and decrease slightly in the winter. This implies that the watershed will have less rechargeable rainfall and higher rates of sediment production. This signifies higher costs of construction and maintenance of reservoir-based hydro electricity plants.

- Similarly, there is temporal variation in different climate characteristics such as rainfall, temperature and discharge in the river. The past record of 30 years shows that the amount of rainfall, number of rainy days and the level of water in the reservoir of the study area have decreased. However, temperature of the watershed area has increased relatively to the national reference. This shows that the climatic condition of the reservoir has been impacted according to time interval.

- Rainfall as a main component for electricity generation has decreased in amount, its frequency and as well as interval. The study shows that there is sharp decline in the trend of amount of annual rainfall, number of rainy days and the amount of higher (quantity) rainfall days. With the change in precepetatin pattern, Kulekhani in monsoon receives more rainfall in lesser number of days, this shows that monsoon is shortening. Therefore, consideration should be taken while designining the reservoir that could hold monsoon rain to ensure there will be not water deficit on the reservoir on other seasons. In this condition, hydropower such as Kulekhani being operated as peak demand hydropower system will not be able to produce electricity throughout the year particularly on dry seasons.

- Temperature as one of the climatic characteristic has been gradually rising in Kulekhani, in the similar figure mentioned in Initial National Communication submitted to UNFCCC by Government of Nepal. It shows the rising trend of air temperature depict some short of warming up from last 30 years. Annual mean temperature at Daman is about 13^0C. Whereas, minimum temperature is found to be - 2.5 in January, 1983. Hence, rising trend can be predicted in upcoming years.

- There is decline in discharge level in the Kulekhani River. Variation in the rainfall pattern of Kulekhani area is one of the reasons to affect the discharge level. As Kulekhani river is the main river that fed the reservoir, this variation in the river discharge will have direct impact in the reservoir and also in hydropower generation. Because, the water accumulated during rainy days will be used to generate electricity throughout the whole year.

- The past record of 10 years shows that the amount of water in the reservoir is decreasing. There are number of reasons such as: gradual declining of the reservoir capacity due to sediment deposit in the bed, reducing rainfall amount, longer and intense drought, and reduced decrease discharge level of Kulekhani stream.

- Kulekhani Hydropower Project is the only hydropower based on reservoir system in Nepal and is operated mostly to meet peak hour demand. Full reservoir is the best possible option to maintain the supply for peak demand. Management has adopted a policy to store maximum amount of water during monsoon rains for dry season when demand of electricity is maximum while the ROR based power stations run at their minimum level due to low discharge levels in the river. Other factors such as sediment deposit in the reservoir, irregular maintenance of the machines and other infrastructure also contribute in declining the efficiency of system as well as life span of the power station.

8.2 Recommendation

- Kulekhani HEPP is critically important to maintain power supply in the national grid and expected to operate smoothly in the near future until another reservoir based HPP comes into operation. Though government has made huge investment for its operation and maintenance, there are little efforts on research and information about its long term future particularly from climate change perspectives. This study has attempted an initial stage towards this goal. A further and comprehensive study is the most to enhance resilience of the KHPP in the growing concerns of climate change with more statistical and mathematical modeling.

- The July 1993 cloudburst had serious impacts on the entire Kulekhani watershed, particularly on the KHPP. This provides strong evidence that similar or stronger cloudbursts may strike the watershed anytime in the future. Adequate precautionary measures could help reduce vulnerability of extreme climate events including flooding and droughts.

- The rainfall distribution trend clearly reflects decline in amount and intensity of the rainfall as well as discharge in the main river that feed the reservoir. To maintain the water level in the reservoir, discharge level of Kulekhani river should be increased or need to seek possibility of diversion of other rivers from upstream. During the construction of Kulekhani Hydropower Chakhel and Sim river were diverted.

- Kulekhani Hydropower was initially designed as peaking power station but it has been supporting as emergency stand by station and the power station was forced to operate as and when required. So a clear institutional direction and strategy is required to make a wise-use of this hydropower, so that it can generate electricity throughout its life span.

- To prevent and minimize the damage cause by severe climate events, early warning system and medium range weather forecast is essential which would be useful for extreme flow for reservoir's safety and settlement downstream.

- The rainfall distribution in this region is very uneven and basin has insufficient rain-gauge network, recording rainguage network should be increased for rainfall intensity data and most essential for hydrologic models and other detail hydrological study. Additional recording rain gauge station is essential for more meaningful hydro-metrological analysis. Likewise, one or more discharge-gauging station must be installed in upper part of the Palung khola and as well as near the outlet of the dam

- Annual average monsoon rainfall and number of rainy days at Kulekhani are decreasing whereas, in comparison to other seasons throughout the year monsoon gets more rainfall. In this condition, Kulekhani being operated as peak demand hydropower system will not be able to produce electricity throughout the year particularly on dry seasons. To increase lifetime of the reservoir and its capacity to generate electricity, small check dams should be constructed in the river that feed the reservoir in order to reduce rate of sediment deposition in dam and reduce risk.

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Annexes

Annex 1: Photographs

Kulekhani Reservoir: Level of water in the reservoir

Kulekhani Reservoir (view from northen side)

Settlements near Kulekhani dam

Fish farming at Kulekhani Reservoir

Kulekhani Reservior (view from north-east)

Kulekhani reservoir (view from eastern side)

Annex 2: Mean monthly temperature (^{o}C) for Daman

Station number: 0905 (Daman)
Latitude: 27°36'
Longitude: 85°05'
Elevation: 2314

Year	Jan	Feb	Mar	Apr	May	Jun	JUL	AUG	SEP	OCT	NOV	DEC
1975	5.7	7.6	11.6	15.5	15.8	17.1	16.6	17.8	15.9	15.1	9.5	6.7
1976	5.5	8.2	11.4	14.3	15.1	16.5	17.4	17.0	16.3	13.7	11.7	8.4
1977	6.0	8.5	12.5	12.9	13.8	16.7	18.0	17.6	16.7	12.7	10.3	6.6
1978	5.0	6.7	8.8	13.4	15.7	17.0	17.4	17.9	16.3	15.7	11.1	9.5
1979	7.0	6.6	9.1	14.1	17.8	16.9	17.2	17.1	16.4	14.0	12.2	7.3
1980	5.8	6.3	8.6	14.5	13.7	15.0	16.8	17.0	15.4	12.7	9.6	7.6
1981	5.9	7.3	8.6	10.4	13.2	14.7	16.4	16.4	15.1	14.0	9.1	5.9
1982	6.0	5.9	8.3	11.1	14.3	14.8	16.2	16.7	15.1	13.0	8.5	5.8
1983	4.2	6.4	10.8	13.1	15.1	17.9	18.7	18.4	17.7	16.3	11.1	8.5
1984	6.4	8.8	12.8	15.3	16.5	18.3	17.8	18.9	16.4	16.0	9.9	8.2
1985	6.5	7.0	13.6	15.7	15.4	18.0	17.3	18.7	16.9	15.3	10.0	8.1
1986	7.7	8.4	11.4	14.6	15.2	17.9	18.4	17.9	16.9	13.7	10.9	7.7
1987	8.0	9.3	10.5	14.6	15.9	18.2	17.8	17.7	18.1	14.9	11.3	8.1
1988	7.1	8.7	10.3	14.8	16.2	17.2	17.8	17.7	17.7	15.8	10.9	8.0
1989	5.2	7.7	8.8	13.9	16.8	17.2	17.6	17.3	16.6	15.4	9.6	7.6
1990	8.5	6.7	8.3	13.2	15.3	18.0	17.6	17.8	17.2	14.0	11.8	8.3
1991	5.5	8.9	11.2	14.0	16.2	16.8	18.3	17.6	16.6	14.8	9.5	7.3
1992	5.6	6.1	12.4	16.3	14.7	17.6	17.1	17.5	17.1	13.7	10.4	7.1
1993	6.0	7.3	11.9	12.9	15.4	17.3	18.3	17.9	17.1	15.2	11.2	8.1
1994	7.5	7.4	12.1	14.9	17.2	18.1	18.9	19.7	19.7	16.5	11.5	7.9
1995	4.8	6.9	12.1	17.9	18.6	18.3	18.2	18.1	17.8	13.7	11.8	7.9
1996	6.5	8.1	12.6	14.7	17.1	17.3	17.9	18.2	17.2	15.3	13.1	7.6
1997	5.2	4.4	12.5	12.3	18.2	17.3	17.2	18.3	18.0	16.9	12.3	9.6
1998	8.0	9.5	12.9	16.2	17.3	17.8	18.1	17.8	17.0	15.5	12.3	8.3
1999	10.5	14.0	14.9	17.5	16.7	17.2	17.4	16.2	15.8	13.8	10.2	6.9
2000	5.7	5.4	10.3	15.4	17.1	18.1	18.5	18.6	17.0	15.9	13.7	9.0
2001	6.8	9.2	11.7	15.0	15.6	18.2	19.3	17.2	17.8	16.4	12.1	8.6
2002	7.2	8.9	12.0	13.9	16.0	18.0	17.9	18.8	17.0	14.6	12.8	8.5
2003	7.5	7.4	11.5	14.3	15.9	17.6	18.0	19.0	19.1	17.2	14.1	8.5

Annex 3: Level of water in the Reservoir

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	1510.59	1504.87	1500.38	1497.085	1491.8	1497.03	1515.55	1527.025	1528.86	1528.91	1527.635	1524.085
1999	1518.16	1511.025	1501.68	1491.83	1487.885	1505.155	1525.105	1528.515	1529.73	1530.37	1529.88	1527.12
2000	1520.7	1510.81	1498.91	1489.58	1486.215	1487.025	1506.325	1527.475	1530.375	1530.3	1528.755	1524.81
2001	1517.93	1507.64	1495.045	1487.405	1486.075	1487.28	1499.86	1517.12	1524.63	1526.02	1525.795	1523.32
2002	1517.775	1510.45	1501.375	1494.415	1492.775	1496.305	1514.575	1529.72	1530.065	1530.2	1530.06	1528.005
2003	1521.065	1509.545	1500.19	1497.15	1495.54	1492.105	1497.58	1512.29	1524.855	1529.995	1529.525	1528.45
2004	1524.92	1519.015	1512.125	1508.99	1503.45	1497.17	1510.21	1526	1529.375	1530.05	1529.665	1526.995
2005	1524.62	1517.335	1506.065	1497.605	1490.905	1492.705	1502.175	1513.075	1518.875	1519.725	1519.455	1516.58
2006	1511.125	1504.65	1498.18	1493.59	1492.885	1496.17	1500.33	1511.13	1523.075	1525.7	1524.655	1520.145
2007	1512.955	1507.935	1503.03	1495.31	1490.295	1499.175	1511.535	1521.245	1529.225	1530.075	1529.875	1527.505
2008	1521.635	1513.73	1505.25	1498.42	1493.745	1490.775	1493.115	1496.13	1501.85	1508.48	1508.295	1504.495
2009	1500.695	1496.565	1493.67	1493.895	1493.705	1493.745	1500.56	1510.615	1515.3	1516.505	1516.455	1515.765

Annex 4: Total Generated Energy in (MWH) From 1982 to 2009 (FY 038/39 to 066/67 Ashwin)

MTH	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Jan	12477	11287	10601	18512	17440	19192	15563	10828	27183	19607	12935	19997	17108	15550	26586
Feb	10932	9342	8275	18999	19250	17068	15431	8331	21002	15286	9911	17296	15651	14488	20735
Mar	10261	10263	9256	20453	19206	16487	12139	5902	15798	9750	5329	17423	8803	26664	14542
Apr	10607	7240	10608	15848	15971	16402	10019	6573	10598	4424	2098	25476	4562	15781	10996
May	7958	5527	8316	15866	12914	14037	11219	7262	5082	3352	2486	10929	4367	14195	372
Jun	5576	5072	10112	16032	15511	15340	13818	5611	7339	4617	2785	4598	6670	12443	4538
Jul	661	5058	9047	12940	17572	15831	16808	17250	3358	7903	7438	353	6304	10845	9904
Aug	3318	3074	5594	13222	15344	17780	15482	18641	10097	8981	5155	8896.5	4303	17147	10694
Sep	4194	3636	4715	9020	12146	14897	17011	16134	11687	8081	4659	7904.5	7044	11833	14945
Oct	2964	2595	6154	8437	13319	14478	12135	10800	13194	6418	3481	5337.5	4959	6492	11385
Nov	7462	7518	7756	10020	14462	17825	13273	12011	12254	10551	5064	8857	11499	8314	16612
Dec	11007	11681	13578	15062	17260	18740	17985	13251	25818	18133	9951	11709	21778	13445	26676
Total	87417	82293	104012	174411	190395	198077	170883	132594	163410	117103	71292	107781	113048	167197	167985

MTH	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Mean
Jan	15104	18481	26333	24925	21475	30871	19192	23347	17132	20412	23738	6195	10268	18297.82
Feb	13610	16867	26755	25096	19134	29963	19540	20983	18371	10226	20110	10214	9495	16512.89
Mar	10124	20205	20815	19588	20027	13435	16577	18940	5886	15124	21113	2381	11040	14197.54
Apr	9847	11864	11148	5554	8026	8533	11986	17813	6777	14271	9013	3313	6576	10425.86
May	11336	7649	12322	5717	8070	7189	9578	8448	7012	9091	10518	4421	5884	8254.179
Jun	10885	19168	17430	10164	9115	5520	12880	6890	9045	6361	10589	3610	5682	9192.893
Jul	7712	15562	33355	9023	10551	12147	10517	16627	7953	8954	3742	10316	4290	10429.32
Aug	6714	31986	34278	17107	10315	15542	9086	10798	7188	7407	5672	8097	4756	11666.95
Sep	16513	13346	21139	16103	8885	14250	11329	11960	7091	6348	15260	3654	5156	10676.45
Oct	7816	8025	14836	9072	6617	8293	9850	10665	5623	6697	8382	2131	4595	8026.804
Nov	4436	13204	11962	15161	8098	8106	9566	9223	9062	12319	8412	8295	6612	10283.36
Dec	7474	19380	19307	18242	15108	16177	20508	18091	13560	20838	16467	12487	12642	16298.39
Total	121571	195737	249680	175752	145421	170026	160609	173785	114700	138048	153016	75114	86996	143155.5