Rainfall Analysis and Comparison of water balance of Meteorological Stations in the Mountain Desert and Wet Zone in Gandaki Basin

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Recommendation Letter

This is to certify that Mr. Tri Ratna Maharjan has prepared the Dissertation entitled "**Rainfall Analysis and Comparison of water balance of the Meteorological stations in the Mountain desert and Wet Zone in Kaligandaki Basin**" to fulfill the partial requirements for Master's degree in meteorology. The study done by him has been carried out under my supervision and guidance.

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ACCEPTANCE LETTER

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ABSTRACT

Water is essential to every human community and is essential resource for economic development, agriculture, productivity, industrial growth etc. Of all the resources of water the primary source of water is rain. The rain water will recharge the ground water and the remaining water will transformed as surface flow.

In the study the water budget in the two considered stations are found to be entirely different. Lumle on the windward side of the Annapurna Range is dominated by Monsoonal rainfall and therefore have surplus of water. Scarcity of water is observed in the winter season. While as in the case of Jomsom there is deficit of water with in whole year. Only in the month of February there seems to be water.

In contrast in the case of Jomsom lie on the leeward side of the Annapurna range, experienced deficit of water during whole year. However, in February there is a slight surplus of water mainly due to western disturbances.

Lumle receives the highest annual rainfall in Nepal which amounts 5430mm of rainfall. During monsoon season (June-September) it receives about 4595mm amounting about 84.63% of the annual value while in the pre-monsoon season (March-May) , post-monsoon season (October-November) and winter season (December-February) it receives about 487mm(9%), 247mm(4.55%)and 100mm(1.85%) respectively. Jomsom on the other hand receives about 263mm of annual rainfall out of which about 138mm (about11.5%) during monsoon season, 58.88mm (22.37%) during pre-monsoon season, 36.48mm (13.86%) in post monsoon season and 30.37mm (11.54%) in the winter season.

There conclusions made from the study of the water availability and surplus of water in the Kali Gandaki watershed basin are:

Potential evapotranspiration is the function of temperature and the geological texture and the high mountain range therefore the water surplus is more in the southern belt of the basin and exceeds the maximum in Lumle, as Lumle receives the maximum annual rainfall throughout the country while decreases drastically towards the north though the distance between the station are not so far the decreasing precipitation is because of high Annapurna Himalayan region.

The study shows the orographic effects on precipitation within the south-facing slopes of the Himalayas. This region showed extremely large gradients in rainfall over small spatial scales (10–20 km), on the timescales of both the monsoon season as well as individual weather events.

From the isohyetal map analysis for the average annual rainfall and during for the monsoon and post monsoon, the maximum gradient is at Lumle while as the minimum gradient is towards Jomsom and some secondary high pockets of rainfall are found to be at Baghara as well as Muna.

For pre monsoon highest pocket is found to be at Lumle and lower towards north of Jomsom.

But for the winter, the high pockets are seen vicinity of Lumle and Beni Bazaar and secondary high pocket at Jomsom but lower toward northern part.

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ACRONYMS

FAO	Food and Agriculture
PET	Potential evapotranspiration
ET	Evapotranspiration
UNESCO	United Nations Educational Scientific and cultural organization
AET	Actual evapotranspiration
C	Centigrade
I	Heat index
VPD	Vapor Pressure Deficit
ICIMOD	International centre for Integrated Mountain Development
ACC	Accretion
WD	Water deficit
WS	Water Surplus
PPTN	Precipitation
ST	Storage
ΔST	Change in storage
LAT	Latitude
N	North
GDP	Gross Development Product
MDI	Moisture Deficit Index
SWS	Soil Water Storage
P-M-method	Penman-Monteith method
DHM	Department of Hydrology and Meteorology

CHAPTER –ONE

1.1 INTRODUCTION

The meteorological station Jomsom and Lumle are quite contrasting with the aspect of rainfall distribution. Lumle station receives more than 5000 mm of annual rainfall and Jomsom station receives less than 300 mm of annual rainfall. These two rainfall pockets are the highest and lowest rainfall pockets of Nepal. Thus an attempt has been made to study of the water balance of these regions to explore its unique and contrasting hydro meteorological characteristics.

Jomsom and Lumle stations lies in the Kali Gandaki basin in west Nepal lying in between Lat 28° 00' to 29°30' and Long 83°09' to 84°12'. It has a very unique topographical pattern. The presence of the Annapurna Himalaya in the middle of the basin with the altitude of 8,091 meters nearly divides the catchment into two distinct parts.

Water balance has been used for computing seasonal and geographic patterns of irrigation demand; the prediction of stream flow and water-table elevations, the flux of water to lake and it is also useful for predicting the effects of weather modification or changes of vegetation cover, on the hydrologic cycle. Therefore, the water balance is a valuable tool in the analysis of water problems in the regions such as the areas like Jomsom which is quite dry and Lumle which is very wet. The wet part of the Kali Gandaki basin has high potentiality of water resources.

The hydrological cycle is complex so the parameters will be difficult to measure and estimate.

The kali Gandaki basin of Nepal has a very contrasting rainfall distribution. The two rainfall pockets are the highest and lowest rainfall pockets of Nepal. The northern part of the basin like that of Mustang area is very dry and techniques for the water harvesting may be needed in the future. These two regions give an excellent example of contrasting rainfall distribution pattern in mountain regions of Nepal. The result obtained for different time scales from the study is quite useful for the water resources planning, projects and managements for various purposes.

The water balance has been defined as "the balance between the incomes of water from precipitation and snowmelt and the out flow of water by evapotranspiration, groundwater recharge and stream flow" (Dunne, 1978). Since 1944 the water balance has been used for computing seasonal and geographic patterns of irrigation demand, the prediction of stream flow and water-table elevations, the flux of water to lake and it is also useful for predicting the effects of weather modification or changes of vegetation cover, on the hydrologic cycle. Therefore, the water balance is a valuable tool in the analysis of water problems in a region.

Nepal is landlocked and agriculture country so the crop yield depends on rain water. The net cultivated area is 2.64 million hector, which is 17.91% of the total land area of the country. Agriculture contributes 60% of the national GDP and employs 90% of the labor force in the county. Poor irrigation system and hilly dominated physical topography makes difficulties in agriculture so must depend upon the rain water. While discussing the water balance the components of hydrological cycle drought over the particular regions. The major parameters affection the drought are precipitation, evaporation interception etc.

There are many different methods to calculate the water balance. In the present study, the method adopted was introduced by Thornthwaite in the early's 1944's, and it has been used for a great variety of purposes and has been modified many times. It calculates an annual water balance using monthly data. Due to inadequate or shortfall of rain-induced water, the precipitation deficiency for a long period cause drought however itself is not drought unless the rainfall below average in the terms of its quantity and the no of rainy days within the period refers drought. Drought as a natural disaster doesn't occur suddenly as cyclones, earthquake or flood. It may prevail as a pocket or over a large area. The reduced amount in rainfall reduces in the negative impact in the yield of agriculture products.

The cultivable land is rain fed. This includes areas where crops are rarely affected by drought and areas where crops experience moisture stress and often fail. The regions with the latter characteristics are often called dry land areas and the agriculture practiced over there is known as dry land agriculture. The magnitude of water deficiency is measured as the moisture deficit index (MDI) and has been evaluated by determining on the basis of annual precipitation and annual potential evapotranspiration, as adapted by Thornthwaite and Mather in 1955. This does not reflect the true nature of MDI for the purpose of crop production, although it does give information regarding the degree of aridity. Since this index sometimes is used as a criterion for crop planning, it would appear more appropriate for it to be based on precipitation and PET during the crop growth period and have discussed its implications for crop production in relation to other meteorological factors. For irrigation the soil water storage (SWS) capacity is defined as the total amount of water that is stored in the soil within the plant's root zone. The soil texture and the crop rooting depth determine this. A deeper rooting depth means there is a larger volume of water stored in the soil and therefore a larger reservoir of water for the crop to draw upon between irrigations. Knowing the soil water storage capacity allows the irrigator to determine how much water to apply at one time and how long to wait for each the irrigation.

The deficit of precipitation has different impacts on groundwater, reservoir storage, soil moisture, snow pack, and stream flow

The main objective of this study is to determine the water balance of the meteorological stations Jomsom as the dry mountainous desert and the meteorological station, Lumle, as a very wet region, using water balance techniques and compare the water balance between Jomsom and Lumle with in Kaligandaki river watershed basin.

1.2 Physical Aspects of Nepal

Situated in the lap of Himalayas, Nepal is located in between latitude 26° 22' N to30° 27' N and longitude 80° 4'E to 88° 12'E and elevation ranges from 90 m to 8848 m. It has an oblong shape stretching approximately 885 km in east-west direction and 193 km in north-south direction. The country is bordering between the two most populous countries of the world, India in south, east and west and China in the north. Geographically Nepal is divided into three regions: Mountain, Hill and Terai. The northern mountain range (Himalayas) is covered with snow all over the year where the highest peak of the world, the Mount Everest stands. The middle range (Hill) is captured by gorgeous mountains, high peaks, valleys and lakes. The geomorphology consists of a large portion of floodplains along the Indus and Ganges river basins, some terraces and hilly areas, and the mountainous terrain of the Himalayas. The Southern range (Terai) is the Gangatic plain of alluvial soil and consists of dense forest areas, national parks, wild life reserves and conservation areas. The Mountain Region covers 35% of the land area of the country but only 2% of the land is suitable for cultivation. The Hilly Region is located between the Mountain Region and Terai Plain. The Hilly Region has several fertile basins, which have served as the political centres of the country such as Kathmandu and Pokhara. The Region accounts 42% of the total land area of Nepal. The Terai Region is the narrow strip of plain attached to the south of the hill with its 23% share of the land area.

Nepal is endowed with abundant water resources however some places have scarcity of water like mountain desert of Jomsom. Nepal is the second richest in water resources possessing 2.3% of the world's water resource with its 6000 rivers of 45000 km in length. About 15% of the country is covered by the Himalayas; most of the rivers are originating from the glaciers in the Himalayan regions. They are fed substantially by snowmelt in dry season. Winter snowfall accumulation makes a significant contribution to these flows during springtime melt before the onset of summer monsoon (Lang and Barros, 2004).

The main rivers are Koshi, Gandaki (Narayani), Karnali, Mechi, Mahakali, Bagmati and Rapti.

Table 1.1 Topographical Division of Nepal.

S.No	Region	Elevation	characteristics
1	Terai	60-200m	Relatlively low and flat regions in the south i.e. below Churia range as an extension of indogangatic plain within Nepal. Heavy jungle in the northern part known as "charkoshe Jhadi" cultivated land in the most of the southern part. Agricultural production fulfills most of the country's demand.
2	Churia	200-1500m	Small hilly region after Terai toward (siwalik range) forests are less dense, slopes are highly eroded, several potential of mass movement.
3	Middle mountain	1500-2500m	Moderately High Mountain compared with (Mahabharat Range) rugged terrain densely populated area with valley like Kathmandu Pokhara, deep inner valley and enclosed river having older and harder rocks than Churia, favorable for agriculture.
4	High Mountain	2500-4000m	High mountain larger than middle Mountain with steep slopes, some times show falls at the top of high Mt. as common one.
5	High Mountain	4000-8848m	Series of very high mountain chains, including world's famous highest mountain peak, i.e. Mt Everest, in the higher parts semi- desert like condition prevails and in the upper parts snow covers almost all the times.

Adopted from Dahal(1997)

1.2.1 The Higher Himalaya

The Higher Himalayan zone ranges from 3,000m to more than 8,000m and is mostly covered with snow and glaciers. Out of the 14 highest peaks in the world higher than 8,000m, Nepal hosts eight highest peaks, i.e., Mount Everest, Kanchanjunga, Lhotse, Makalu, Dhaulagiri, Manaslu, Cho-Oyu, and Annapurna I. There are higher peaks in the eastern part of Nepal than in the western part. The upper parts of these mountains are formed by eroded sediments, which are underlain by the central crystalline rocks. The whole range consists mainly of high grade metamorphic rocks like schist and gneiss. Sharp peaks and vertical walled valleys characterize the landforms of this zone (ICIMOD 2002).

1.3 General Climate

The climate in Nepal is generally classified into two seasons in terms of magnitude of precipitation. One is the rainy season from June to September and the other is the dry season prevailing in winter up to May. Ample rainfall in the rainy season is brought from the Bay of Bengal by the monsoon, which whirls from southeast in the summer of northern hemisphere. Westerly or northwesterly wind, which is dominant in winters, brings dry air from Siberia resulting dry season. The spatial feature of the rainfall in the country is highly influenced by the topography and altitude differences resulting to significant local changes while diurnal variation and intensity of rainfall govern temporal feature of rainfall pattern. Spatial feature is typical throughout the hills but most significant across the Annapurna range in central Nepal (Regmi, 2005**).** When wind comes from the Mediterranean, it brings winter rainfall especially in western part of Nepal (Ramage-1971). The climate of Nepal is divided into five zones in terms of elevation: Subtropical, Warm temperate (Mesothermal), Cool temperate (Micro thermal), Alpine and Arctic zones (LRMP-1998).

The Terai and the Siwaliks fall in the sub-tropical zone with ample rainfall in the monsoon period of June to September. The middle mountain is in the warm temperate zone with occasional snowfall in winter in the higher regions. The climate of the cool temperate zone extends up to the High Mountains.

Snow falls in winter and stays on the mountaintops throughout the winter. Alpine climate appears in the higher mountain regions with low temperature in summer and extremely frosty conditions in winter. Arctic climate is above snowline where there is perpetual frost. Topographic features, altitude, geographical location controls the whole Nepal in climatic aspects. Generally country can be divided into five climatic divisions.

1. Tundra Climatic: - Tundra type of climate is found in the higher Himalayas region of Nepal. Almost above snowline (5000 m), precipitation forms of snow and there is a permanent cover of snow and ice.

2. Alpine Climatic: - In the lower part of the Himalayas region, alpine type of climate is found. Above 4000m, there is cool summer and frosty winter; precipitation is in the form of snow only.

3. Cool Temperate Climatic: - This type of climate is found in the region of High Mountain region of Nepal. In this type Cool summer and cool winter, winter precipitation in the form of snow at high altitude occurs only.

4. Warm Temperate Climatic: - This type of climate is found in the region of Mahabharata range of middle mountain region of Nepal. Warm summer and cool winter, occasionally snowfall in higher region of hills and precipitation in the form shower and are the characteristics of this climatic type.

5. Tropical/Subtropical – climatic: - The sub-tropical type of climate is found in the lower region of Churre range or Terai of Nepal. The tropical type of climate is found in the Churre range or Siwalik of Nepal. Hottest and humid summer, mild and dry winter occurs. (Adopted from Regmi, 1998)

1.4 General season in Nepal

According to season, Climate of Nepal is divided into four parts; these are as follows (adopted from Nayava, 1981):

A. Pre-monsoon season: (March - May)

B. Monsoon season: (June – September)

C. Post monsoon season: (October - November)

D. Winter season: (December -February)

A. **Pre-monsoon season**: It starts from March to May. In this period, most of the days of the month remain under the domination of the dry westerly wind. This wind system produces dusty and windy weather in the most of the country. Convective activity produces high to moderate rain shower especially in the hilly region. As a matter of fact, the distribution of pre-monsoonal rainfall in the country is associated with the thermal convection associated with orographic effects which results thunderstorm associated with precipitation over the narrow bands with in the region.

B. **Monsoon season**: The season starts from June to September in Nepal is known as rainy season. Monsoon arrives from eastern Nepal on June 10th, and it arrives at Kathmandu on June 12th, within 2 to 3 days, it covers the whole country. The normal date of the retreat of the monsoon is September 23. When the monsoon circulation pattern is established, temperature begins to fall; compared to other seasons. Relative humidity of this season becomes high. In Nepal, 60% to 80% of the annual rainfall falls during this season. Rainfall varies sharply from one place to another due to impact of topography. When the moist south easterly wind approaches, the air stream is forced to rise resulting rainfall on the slope facing southwards. The month of July is the rainiest month of the rainy season.

C**. Post monsoon season**: The season is the changing period from season to another and harvesting season of monsoon crop field preparation is done for winter season crops. Sometimes, the country receives precipitation by cyclonic storm that develops in the bay of Bangal and Arabian Sea. Regmi (1998) indicates the domination of westerly wind flow with falling in temperature gradually as an indication of pre-winter activity, negligible amount of rainfall occurs in this period.

D. **Winter Season or Cold weather season**: It runs from December to February. Northwesterly wind pre-dominates the country in this season. Except in the region of great Himalayan and a high mountain, the winter is normal with great sunny days (Nayava, 1981). In winter, major weather effective elements are the western disturbances and so western Nepal receives higher amount of rainfall than eastern Nepal. This region is relatively dry & cool, lowest temperature and less rainfall but greater than post monsoon rainfall.

1.5 River systems in Nepal

Nepal is considered as the second richest country for water resources in the world having annual runoff of 170million m^3 flowing through more than 6000 rivers and river-lets out of which 960 are more than 10 km long and about 24 of them exceeds 100km in length (Shrestha,H.M.-1995). The average drainage density in Nepal is about 0.3km km^2 in the map scale of 1:50,000 .The total drainage area of all the rivers is about 191,000sq.km.of which 74% lies in Nepal. The total catchments area of the major snow fed river are Koshi, Gandaki and Karnali is about 139360km^2 and drain annually 4930m^3 amounting to 70% of the total annual surface runoff from Nepal estimates 244 billion cubic meters (yogacharya.K.S.,1995).About 60 to 85 % of the annual surface runoff occurs during summer monsoon seasons.

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1.6 Objectives of the study:

- To study the annual precipitation pattern in the stations.
- To study the water balance table of Lumle and Jomsom.
- To compare the water moisture, water surplus and water deficit between the two stations.

1.7 Station selection for the study

The stations in the Kaligandaki basin Lumle and Jomsom are taken for the study. These stations have been selected according to nature of topography and altitude of the nation. The meteorological stations Jomsom and Lumle in the Gandaki Basin have been selected because these stations have reasonable amount of necessary data for the water balance study. Theses stations have been selected because they are located in the nearly sub basins separated by the Annapurna range with contrasting climates. The other stations in the basin taken for the preparation of isohyetal map are as shown in the Fig.1 map and the no of years data of precipitation are mentioned in the table below.

Table 1.2 Meteorological Stations Considered for Isohyetal Maps.

Station Name	Station index	Latitude	longitude	Elevation (m.)	No of years data
Lumle	0814	28°18¨	83°48¨	1740	36(1970-2005)*
Jomsom	0612	28° 47¨	83° 43¨	2744	48(1957-2005)*
Ghami(Mustang)	0610	29º03¨	83º53¨	3465	14
Mustang(Lomanagtang)	0612	29º11¨	83º58¨	3705	15
Ranipauwa(Mukti Nath)	0608	28º49¨	83º53¨	3609	18
Samar Gaoun	0624	28º58¨	83º47¨	3570	11
Samoa	0625	28º54¨	83º41¨	3570	8*
Tatopani	606	28º29¨	83º39¨	1243	17
Baglung	615	28º24¨	83º06¨	2273	6*
Tribeni	620	28º02¨	83º39¨	700	14*
Ghandruk	821	28º23¨	93º48¨	1960	11
Baghara	629	28º34¨	83º23¨	2330	11
Sandepani	208	28º43¨	80º55¨	N/A	13
Gurja Khami	616	28º36¨	83º13¨	2630	14*
Beni Bazar	626	28º28¨	83º36¨	1770	9*
Ghorapani	619	28º24¨	83º44¨	2742	26*
Kushma	627	28º23¨	83º29¨	1550	6*

*The data are not available for some months.

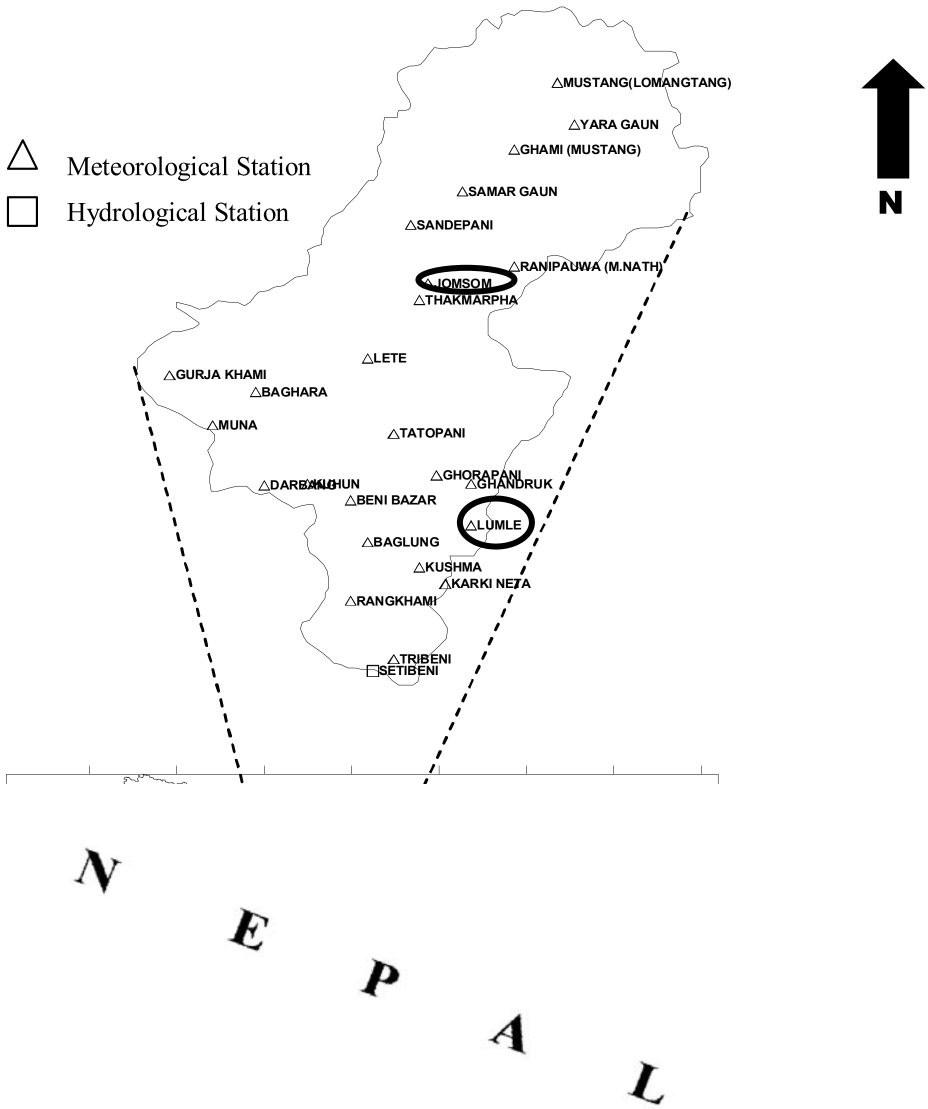

Fig. 1.1 Kali Gandaki Basin Showing the Meteorological and Hydrological Stations

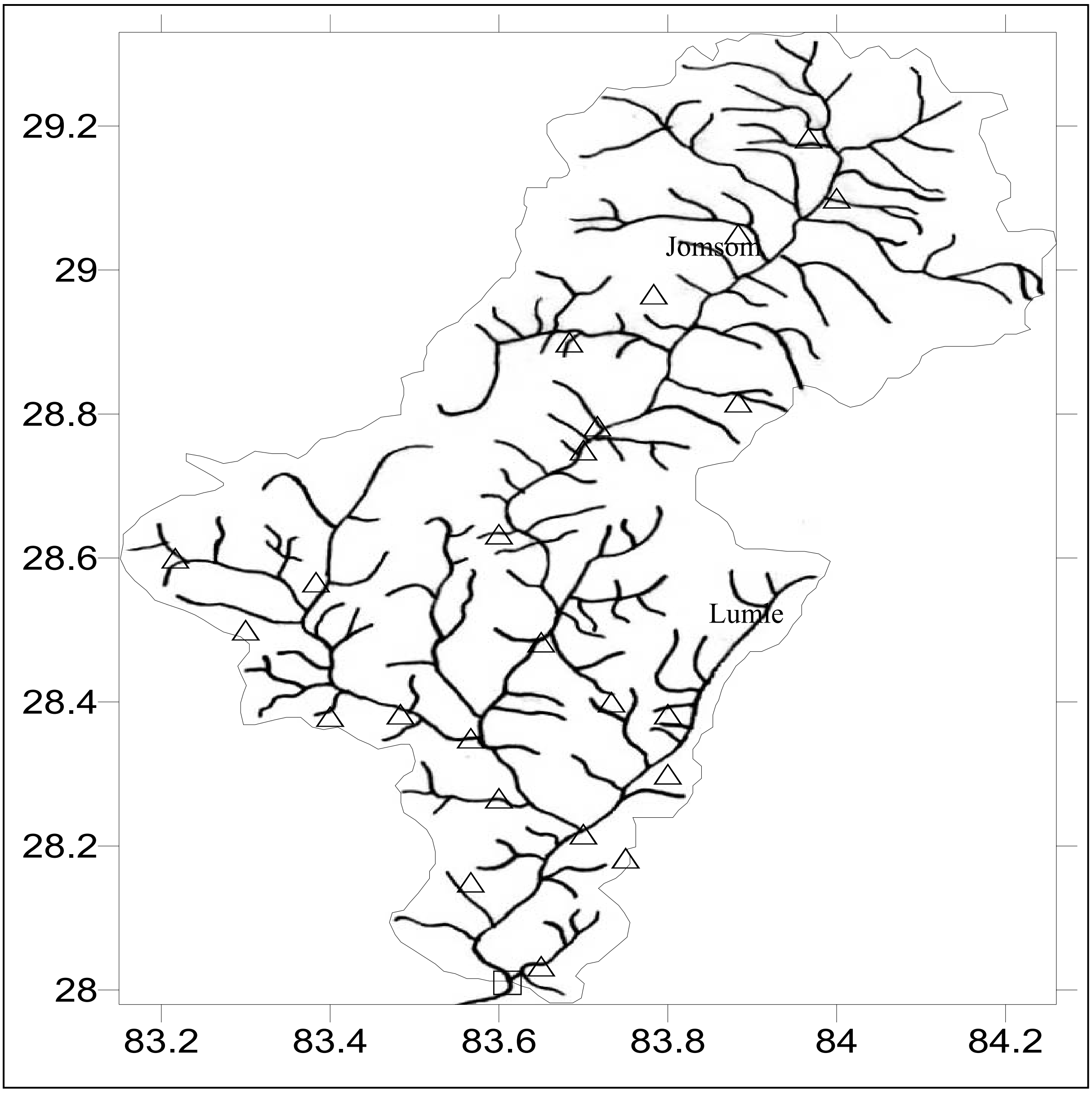

Fig.1.2 River Network Systems in Kali Gandaki Basin (fig. not to scale)

CHAPTER TWO

LITERATURE REVIEW

2.1General Review

The earth receives water as the input from the atmosphere as precipitation and water losses initially occurs as interception and then through the process of evapotranspiration. Some of the water is retained as depression storage, soil maintain and some recharge the ground that will rise the ground water table the remaining portion joins the streams by surface and subsurface runoff. Evapotranspiration (ET) is a collective term for the transfer of water, as water vapor, to the atmosphere from both vegetations and direct from land and ground surfaces. It is affected by climate, availability of water and vegetation. ET is a large component of the water balance. Over the entire land surface of the globe, rainfall is averaged to an amount of 750 mm per year, of which some two thirds is returned to the atmosphere as evapotranspiration (Baumgartner & Reichel, 1975 cited in Becker et. al., 1993). About 62% of continental precipitation evapo-transpires, about 97% of this is from land and 3% from open water bodies. Evapotranspiration represents nearly all the soil and surface water loss from dry environments, where runoff is minimal. The combination of two separate processes by which water is lost on one hand from the soil surface by evaporation and on the other hand from the vegetation by transpiration is referred to as evapotranspiration (ET) (FAO, 1998). Both soil evaporation and plant transpiration represent evaporative processes. Evapotranspiration data are usually presented as a depth of water loss over a particular time period in a manner similar to that of precipitation. Common units for ET are inches/day or millimeters/day.

Estimation of evapotranspiration is needed to support irrigation design and scheduling, watershed hydrology studies, process-based crop growth models, and other models that attempt to simulate the soil water budget.

Evapotranspiration is one of the important parameters in calculating crop water requirement. The estimation of evaporation and transpiration is also a critical part in the water accounting process (Moldel, 1997 as cited in Shilpakar, 2003). However, despite its importance, ET is almost impossible to measure or observe directly at a meaningful scale in space or time of measurement, such as evaporation from the US Class A evaporation pan, have been used, with maps of mean monthly and annual pan evaporation published by the Department of Hydrology and Meteorology (DHM), Nepal. In most of the hydrologic water and nutrient budgets ET is calculated based on the potential evaporation (PE) or reference evapotranspiration (ETo), a term synonymous to potential ET (PET) for a reference crop or vegetation (Jensen et al., 1990; Amatya et al., 1995).

Evapotranspiration is estimated based on the climatic parameters recorded in the representative station and extrapolated for the larger area or can be computed as residual term in water balance. New technologies and technique of remote sensing improve the estimates of evapotranspiration at different spatial scale.

Estimates of ET can be obtained by direct measurements using pan evaporation or by using measured meteorological variables in mathematical equations to predict monthly or daily values.

Since evaporation and evapotranspiration requires continuous supply of energy which is derived mainly from solar radiation, the radiation will be a factor of considerable importance. The evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. Solar energy provides the necessary energy for the evaporation, which affects the evapotranspiration, either through the direct reflection on the plant and the soil or through the air heating and the circulation. Evapotranspiration is higher when there is no cloud and bright sunshine but lesser when it is cloudy.

2.1.1 Evaporation

According to FAO (1998) "Evaporation is the process whereby liquid water is converted to water vapor (vaporization) and removed from the evaporating surface (vapor removal)". Water evaporates from a variety of surfaces, such as lakes, rivers, pavements, soils and wet vegetation. Energy is required to change the state of the molecules of water from liquid to vapor. Direct solar radiation and, to a lesser extent, the ambient temperature of the air provide this energy. The driving force to remove water vapor from the evaporating surface is the difference between the water vapor pressure at the evaporating surface and that of the surrounding atmosphere. As evaporation proceeds, the surrounding air becomes gradually saturated and the process will slow down and might stop if the wet air is not transferred to the atmosphere. The replacement of the saturated air with drier air depends greatly on wind speed. Hence, solar radiation, air temperature, air humidity and wind speed are climatological parameters to consider when assessing the evaporation process.

Where the evaporating surface is the soil surface, the degree of shading of the crop canopy and the amount of water available at the evaporating surface are other factors that affect the evaporation process. Where the soil is able to supply water fast enough to satisfy the evaporation demand, the evaporation from the soil is determined only by the meteorological conditions. However, where the interval between rains and irrigation becomes large and the ability of the soil to conduct moisture to pear the surface is small, the limited availability of water exerts a controlling influence on soil evaporation.

2.1.2 Transpiration

According to FAO (1998), Transpiration consists of the vaporization of liquid water contained in plant tissues and the vapor removal to the atmosphere. The vaporization occurs within the leaf, namely in the intercellular spaces, and the vapor exchange with the atmosphere is controlled by the stomatal aperture. Nearly all water taken up is lost by transpiration and only a tiny fraction is used within the plant.

Transpiration, like direct evaporation, depends on the energy supply, vapor pressure gradient and wind. Hence, radiation, air temperature, air humidity and wind terms should be considered when assessing transpiration. The soil water content and the ability of the soil to conduct water to the roots also determine the transpiration rate. The transpiration rate is also influenced by crop characteristics, environmental aspects and cultivation practices. Different kinds of plants may have different transpiration rates. Not only the type of crop, but also the crop development, environment and management influence the transpiration rate.

2.1.3 Evapotranspiration (ET)

According to FAO, Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Evapotranspiration is the sum of the water used by plants in a given area in transpiration and the water evaporated from the adjacent soil in any specified time. The concept of potential evapotranspiration (PET) according to Thornthwaite (1990) is the evapotranspiration from a large vegetation covered land surface with adequate moisture at all times, since the moisture supply was not restricted, the PET depends solely on available energy. Penman (1992) defined PET as the evapotranspiration from an actively growing short green vegetation completely shading the ground and never short of moisture availability. Though Penman's definition specifies the important characteristics of reference vegetation, it does not specify the name of vegetation. Thornthwaite (1990) method is basically an empirical relationship between mean monthly PET and mean monthly temperature, where in uniform values of wind and humidity have been assumed while Penman (1992) method, which combines energy-budget and aerodynamic approaches considered the additional meteorological parameters of humidity, wind and sunshine which significantly affect the PET.

Evapotranspiration is the interest reflects the importance for many different fields such as Botany, Animal husbandry, water resources, forest management meteorology climatology and Agriculture.

2.1.4 Precipitation

Precipitation is only the source of water to supply to earth's surface and it can be accurately measured by rain gauges. In the Higher Himalayas precipitation falls as snow fall. The well distributed rain gauges in the stations measures the rainfall amount and intensity. Precipitation is the amount of rain expressed in mm depth of water on an area. Precipitation is the only source of water supply to the surface of earth. It is most variable hydrological element and shows considerable fluctuations on various scales of both time and distance.

From the sea, yearly clouds are generated and come to the north from the Indian Ocean as monsoon from June to September and from Arabian Sea as westerly in

December. In their movement, clouds find the hurdle of NE-SE stretching mountains and starts precipitation.

2.1.5Actual Evapotranspiration

The water balance can be used to calculate values for actual evapotranspiration. As long as precipitation exceeds the potential evapotranspiration, actual and potential evapotranspiration have all the moisture they need to meet the climatic demands. When precipitation is less than PET, it is assumed that actual and potential evapotranspiration have all the moisture they need to meet the climatic demands. When precipitation is less than PET, it is assumed that actual plant water use (actual evapotranspiration) will equal the total precipitation plus whatever water the plants can remove from the soil.

2.2 Soil Moisture

The moisture content in the soil is generally expressed as the percentage ratio of the mass of water to that of dry soil but may be expressed also in terms of the inches of water per given depth of soil. Soil moisture is obvious importance in regard to the growing of plants and is of direct meteorological interest is affecting the thermal conductivity of the soil. So, the rate at which heat is conducted upward to or downward from the atmosphere and also in affecting the rate of evaporation from the soil and transpiration from the vegetations.

2.3 Field Capacity

The mass of water present of dry soil retained by a previously saturated soil when free drainage has ceased is known as soil field capacity. It varies from about 7% in light sand to about 60% in heavy clay.

Field capacity can also be defined as the maximum quantity of water that the soil can retain against the force of gravity. Any higher moisture input to a soil at field capacity drains away.

2.4 Water Deficit

The water defect is a define measure of drought water deficiency indicates the amount of supplemental irrigation water needed for optional crop growth and development during dry period when the precipitation is not equal PET the difference is made up in part from soil moisture storage, but as the soil becomes dries the part does not made up is larger. This is the water defect. The amount by which actual potential evapotranspiration is differ.

2.5 Water Surplus

In the water balance bookkeeping procedure, it is assumed that all precipitation in excess of the potential plant needs (PET). When the soil is not at field capacity the first demand on any excess precipitation over plant water needs is to recharge the soil when that is completed, any excess of water goes to surplus. The water surplus finds its way into streams, either directly as overland flow or indirectly as infiltration to the ground water table-becoming base into the stream.

2.6 Runoff

Runoff is that part of precipitation as well as any other contributions which appeals in surface streams of either perennial or in non-perennial form, this is the flow collected from a drainage basin. The drainage basin is called the catchments area. The drier, the catchment, the smaller fractions of the mean annual flow of water is the runoff.

2.7 Actual and Potential Evapotranspiration

Potential evapotranspiration or PET is a measure of the ability of the atmosphere to remove water from the surface through the processes of evaporation and transpiration assuming no control on water supply. Actual evapotranspiration or AE is the quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration. It estimates the need of water by plant by the following equation:

Crop water need = potential evapotranspiration - actual evapotranspiration

Potential evapotranspiration requires energy for the evaporation process. The major source of this energy is from the sun. The amount of energy received from the Sun accounts for 80% of the variation in potential evapotranspiration.

Wind is the second most important factor influencing potential evapotranspiration. Wind enables water molecules to be removed from the ground surface by a process known as eddy diffusion.

The rate of evapotranspiration is associated to the gradient of vapor pressure between the ground surface and the layer of atmosphere receiving the evaporated water.

Potential evapotranspiration (PET) is the amount of water that could be evaporated from land, water, and plant surfaces if soil water were in unlimited supply. PET calculations are based on standard weather station data (or in our case, interpolated climatic data from our previous study), and correlate well with the distribution of forest types, and, to some degree, the susceptibility of the landscape to fire.

PET can also be calculated using the Thornthwaite water balance method at a resolution of 1 kilometer (Thornthwaite 1948). The Thornthwaite method is based on an empirical relationship between potential evapotranspiration and mean air temperature. While this method is not the most accurate, and may lack theoretical basis, it can provide reasonably accurate estimates of potential evapotranspiration (Palmer and Havens 1958).

We applied this formula to mean monthly temperature data with a grid cell resolution of approximately 1 km. Mean monthly temperatures were calculated by averaging mean monthly minimum and maximum temperatures.

2.8 Factors Affecting Evapotranspiration (ET)

The rate of ET for a given environment (vegetation) is a function of four critical factors. The first and most critical factor is soil moisture. Evaporation can not take place if there is no water in the soil. However, if adequate soil moisture is available, three additional factors- plant type, stage of plant development and weather — affect ET rate. Plant type refers to the species or variety of plant being grown and can greatly influence the rate of ET. Grass and many non-native plants require considerable water when grown in the desert. In contrast, many native plants are adapted to the desert and require much less water. Stage of plant development also plays a critical role in determining ET. Plant development encompasses both the relative activity of the plant (e.g. dormant vs. actively growing) and plant size.

Weather is the fourth and last of the critical factors affecting ET. Weather conditions dictate the amount of energy available for evaporation and therefore play a crucial role in determining ET rate. Four weather parameters — solar radiation (amount of sunshine), wind speed, humidity and temperature — impact the rate of ET.

Solar radiation contributes huge amounts of energy to vegetation in the desert and thus is the meteorological parameter with the greatest impact on ET on most days. In actuality, solar radiation is one component of the total radiant energy balance of vegetation referred to as net radiation. Invisible, infrared radiation represents the other component of net radiation. On most days, however, solar radiation is the dominant component of net radiation because the infrared balance is negative and often small.

Wind is the second most important factor in determining ET rate. The wind has two major roles; first, it transports heat that builds up on adjacent surfaces such as dry desert or asphalt to vegetation which accelerates evaporation (a process referred to as advection). Wind also serves to accelerate evaporation by enhancing turbulent transfer of water vapor from moist vegetation to the dry atmosphere. In this case, the wind is constantly replacing the moist air located within and just above the plant canopy with dry air from above.

Humidity and temperature work in concert with each other to determine the dryness or drying power of the atmosphere. The vapor pressure deficit (VPD) is the meteorological variable used to quantify the drying power of the atmosphere. The VPD estimates the difference (or gradient) in vapor pressure (concentration of water vapor) between the moist vegetation and the drier atmosphere above. Relative humidity, the humidity variable most commonly reported in weather forecasts, is a poor indicator atmospheric dryness.

Excess of the relative atmospheric humidity ceases evapotranspiration. The airflow circulation may blow away the water vapor from evaporation surface on which saturation air is distributed by wind.

The final parameter affecting ET rate is temperature. Temperature impacts ET through its impact on VPD and advection. In addition to these factors temperature impacts ET is some more subtle ways. When all other factors are equal, ET will be higher for warm as compared to cool vegetation because less energy is required to evaporate water from the warm vegetation. Temperature also impacts the relative effectiveness of the radiant energy and wind in evaporating water. Radiant energy is more effectively utilized for ET when temperatures are high. In contrast, wind has more impact on ET when temperatures are low.

Evapotranspiration in the Hind-Kush Himalaya has been discussed in an ICIMOD publication on the basis of Wyss' study (1993). The mean potential evapotranspiration in the region ranges from about 1000 mm in the high areas of the Tibetan plateau to about 2000 mm in the Tharr Desert. In general, a decreasing gradient from south to north and from east to west can be seen.

CHAPTER THREE

Methodology

3.1Theories and Concepts

3.1.1Methodology and Water Balance Components

Mean of the data are used to estimate

1) PET

Methods used for the estimation of PET

a) Thronthwaite method
b) Penman's method

PET estimation from Thronthwaite method is used to estimate water balance parameter and Moisture index from Thronthwaite book keeping procedure. Potential evapotranspiration can be calculated using the following formula.

$$PET = 1.6\left(\frac{10T}{I}\right)^{a}$$

Where:

2) PET= monthly potential evapotranspiration (cm).

   T= mean monthly temperature (C).

   I= a heat index for a given area which is the sum of 12 monthly index values i.

i is derived from mean monthly temperatures using the following formula:

$$i = \left(\frac{T}{5}\right)^{1.514}$$

a= an empirically derived exponent which is a function of I,

And calculated as

$$a = 6.75*10^{-7}*I^{3} - 7.71*10^{-5}*I^{2} + 1.79*10^{-2}*I + 0.49$$

Penman Monteith method needs a lot of sophisticated meteorological data (minimum temperature, maximum temperature, relative humidity, wind speed and sunshine duration in a day.

2) Water balance

3) Moisture index

The UNESCO (1979) 'aridity index' can be used to quantify the deficit on the severity of 'dryness' based on the ratio of annual precipitation to annual potential evapotranspiration.

The distribution of the aridity index, corresponding with the thresholds are for the hyper-arid (<.0.03), arid (0.03-0.25), semi-arid (0.25-0.5), and sub-humid climatic regimes (>0.5).
Aridity index is defined as the ratio of annual water deficiency to annual water need, usually express in percentage.

$$I_a = \frac{Wd}{PET} * 100 \qquad\qquad I_a = \frac{PET - AET}{PET} * 100$$

where, PET=Potential evapotranspiration

AET=Actual evapotranspiration

WD= water deficit

3.2 Thornthwaite Method for Water-Balance Computation

To facilitate the use of this method, a step-by-step description to estimate the various components and book keeping procedure follows.

To calculate PET:

1. From the mean monthly air temperature (Long-term averaged) monthly values of heat index are obtained from Appendix for temperature degree Celsius. Summing up these monthly values of heat index will obtain yearly heat index.
2. For the temperature values less than 26.5°c, daily-unadjusted potential evapotranspiration are found from Appendix-for the given values of temperature and I.
3. For the temperature greater of equal to 26.5° C, daily unadjusted PET are directly found from Appendix
4. Knowing the latitude of the station, monthly correction factor to adjust daily unadjusted PET to monthly adjusted PET are found from Appendix
5. Adjusted PET for 30 days can be obtained by multiplying daily unadjusted PET and monthly correction factor. This gives monthly PET in mm.

To calculate other parameters:

Step I P is the rainfall and can be snowfall

Step 2 P-PE

This is the difference between precipitation and the adjusted potential evapotranspiration.

If p is less than PE, the value is negative.

If P is more than PE, the value is positive.

Step 3 Accumulated potential water losses (Acc pot. WL)

<u>In wet climate</u>

Where P>PE (annual values)

Start with 0 in the month just before the one where negative value of PE has started.

<u>In dry climate</u>

Find the potential value of water deficiency with which to start accumulating negative value for PE.

The starting value can found out as follows:

i. Sum up all the negative P-PE values

ii. Sum up all the positive P-PE values.

iii. Locate the value arrived in `a' (Thornthwaite and Mather,1957) and locate corresponding value of actual retention.

iv. Follow horizontally across on this line until it intersects the sloping line whose value equals to the sum of the positive P- PE (Step b). Read the value of the potential deficiency with which to tart accumulation.

Step 4 Storage (St)

For the negative values of P-PE, locate the storage figures using Appendix.

(a) Locate the last negative value in column P-PE

(b) Note the storage value a'

(c) Add to the value of (b) the first positive (i.e. the positive value next to negative value)

(d) Complete the procedure for the rest of the month.

Step 5 Change in soil storage (Δst)

It is the difference in the storage value of two consecutive months.

Step 6 Actual Evapotranspiration (AE)

When $P > PE$

Then $PE = AE$

When $P < PE$ Then $AE = P + \Delta st$

It means that AE is the sum of P and Δst without considering the sign of

St.

Step 7 Water Deficit (WD)

It is the difference between PE-AE Or,

WD = PE-AE

Step 8 Water Surplus (WS)

It is the difference between (P-PE) – Δst Or,

WS = (P-PE) – Δst.

The accuracy of the computation may be tested with yearly total of PE, P, AE, WD and WS in the following manner.

PE = AE + WD

P=AE+WS

3.3Application of water balance

If a farmer proposes to supply supplementary water to his crops, he must have some practical means of determining how much water to use and when it is needed for his particular form common practice among farmers is to watch the plants for sign of moisture efficiency as the basis for supplying water. This is not very satisfactory for by the time the plants begin to show signs of water need, they are already suffering and yield has been reduced correspondingly. Instead of watching the crop for indication of drought, some investigators suggest watching the soil instead. Others have stated that the only known way to be sure that soil moisture is present in readily available form by frequent examination of sub-soil by the use of soil duper. In resent years several devices have been developed to be installed permanently in the soil to provide a continuous indication of the amount of moisture remaining. These devices are the elements made of gypsum, fiberglass and nylon in which the electrical resistance varies with the moisture. while using, these devices of ten do not provide the information that is needed they provide a sample at only one spot which may or may not representative of a wider area, and they assume that the response of the sensor to moisture changes is similar in all respects to that of soil so that the measured values will represent conditions in the soil. This assumption is seldom satisfied.

The climatological approach to the problem of determining soil moisture content, while indirect is simple and practical. It avoids the errors involved in calibration and exposure of measuring instruments and can provide average values, good sized areas, depending upon the climatic data used. In the soil is determined from estimates of water that enters it as a result if precipitation and causes through the combined evaporation form soil surfaces and transpiration from plant leaves. An irrigation schedule can be moisture in the soil may be regarded as a bank account. Precipitation adds to the account evapotranspiration and restore by irrigation whatever is not promptly returned by precipitation.

When the moisture content of soil is at field capacity (the maximum amount of water is held in the soil root zone against the downward pull of gravity, water available for plant roots), the precipitation above that needs to satisfy the evapotranspiration demand is lost by downward percolation. The gravitational water is only detained briefly. The period depends on the permeability of soil and the amount of gravitational water when the soil moisture is below the field capacity. The precipitation in excess of climatic demand for water first brings the soil moisture storage up to field capacity. The amount of water can be stored in the root zone of the soil depends on its depth and on the soil type and structure.

Evapotranspiration from a most soil or vegetation cover immediately begins to lower the moisture content of the soil. As the soil dries, the ability of the plants to capture water from soil increases. At first water is removed at the potential rate limited only by the amount of energy available from the sun but by the time one inch of water has been removed, the rate of water loss from the soil has dropped below the potential rate. When one half of the water is gone from the soil, the rate of water is gone from the soil rate of water removal falls to one half of the potential rate and plants begin to suffer from lack of water.

An irrigation schedule is a natural outgrowth of the climatic method of computing soil moisture will not allow falling for the particular crop and depth of root zone in equation. Then by keeping daily precipitation of how much water has been added to and last from the soil, it is possible to know exactly when the pre- determined level of soil moisture level back to safe value. If irrigation is schedule either by keeping continuous account of soil moisture content or of the amount of water that has been removed from the soil, no great moisture other irrigation to damage both soil and crop and result in water wasteful misuses of water.

CHAPTER FOUR

4.1Analysis and Results

The annual rainfall of Jomsom and Lumle using 48 years and 36 years of data respectively have been used for the rainfall characteristics. Which are as indicated in Fig 4.1 and Fig 4.2 as shown in the below graph.

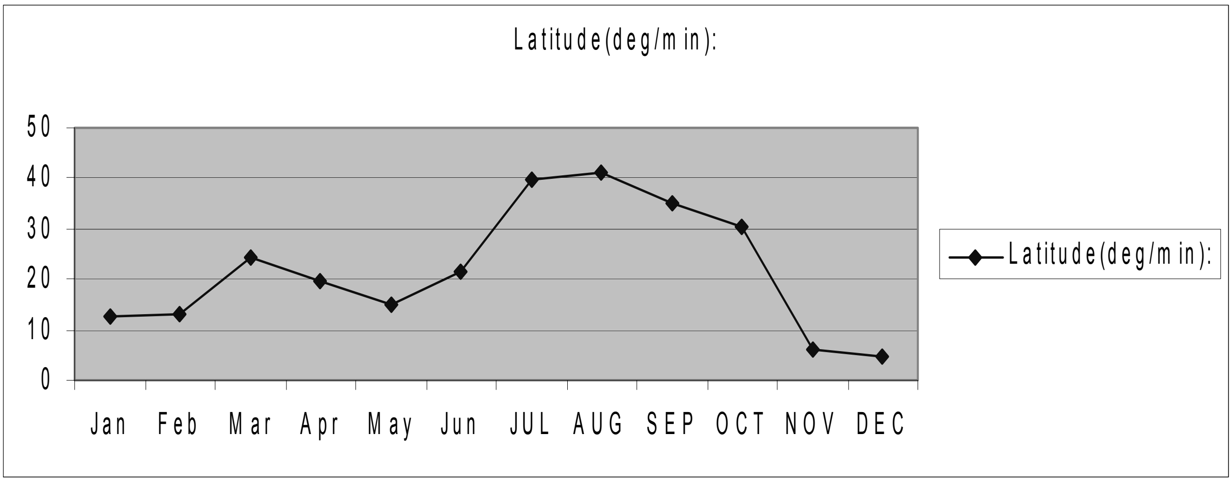

Fig.4.1 Annual Rainfall of Jomsom.

In the station Jomsom there is some rain during winter due to western disturbances and relatively more rainfall during March and April due to local thunder activities. Rainfall about 40 mm is observed during July and August in the monsoon.

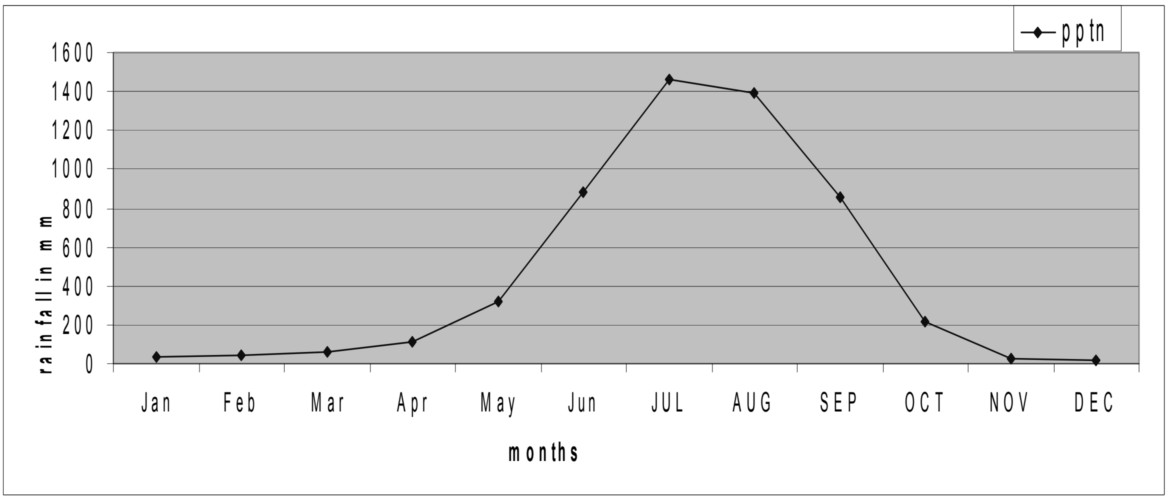

Fig.4 2 Annual Rainfall in Lumle

In the case of Lumle as in Fig 4.2 there is relatively less rain in the winter and pre monsoon. Some thunderstorm activities contribute rainfall during April and May. In the monsoon season Lumle receives high amount of rainfall.

For Isohyetal analysis of rainfall the rainfall data has been carried out using the software "Surfer for Windows Version 7.02" developed by Golden Software, INC, Colorado, USA of the various seasons (annual, pre-monsoon, monsoon, post-monsoon and winter season) with reference to the stations shown in the Fig.1.1.For the isohyetal potting is taken using the 21 stations including Lumle and Jomsom in the basin as shown in the Fig.1.1.

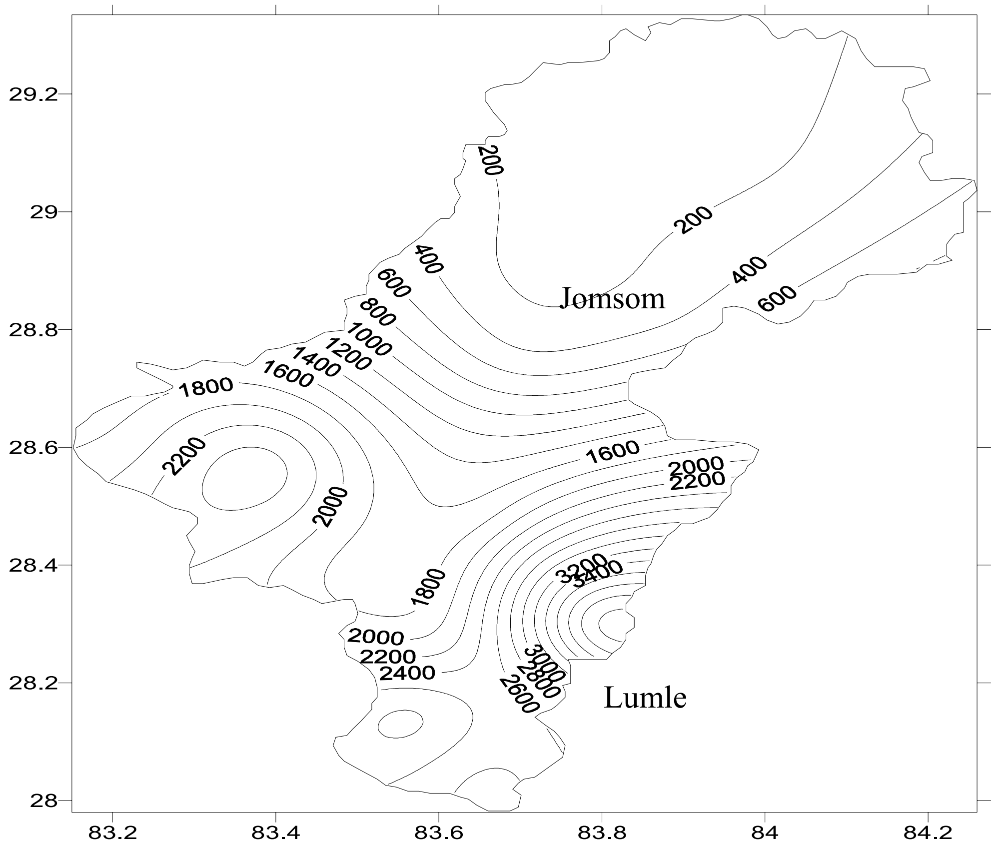

Fig.4.3 Isohytal Analysis of Kali Gandaki Basin for the Annual basis in terms of average Rainfall in mm

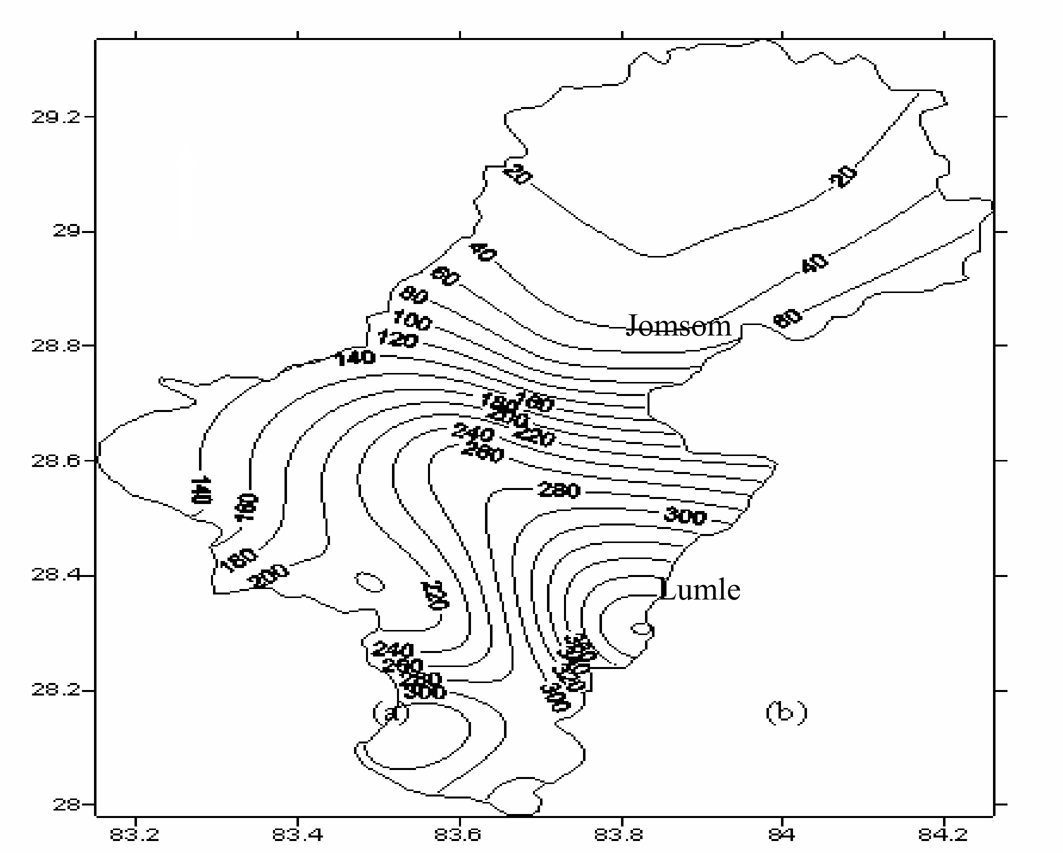

Fig.4.4 Isohyets during Pre-monsoon

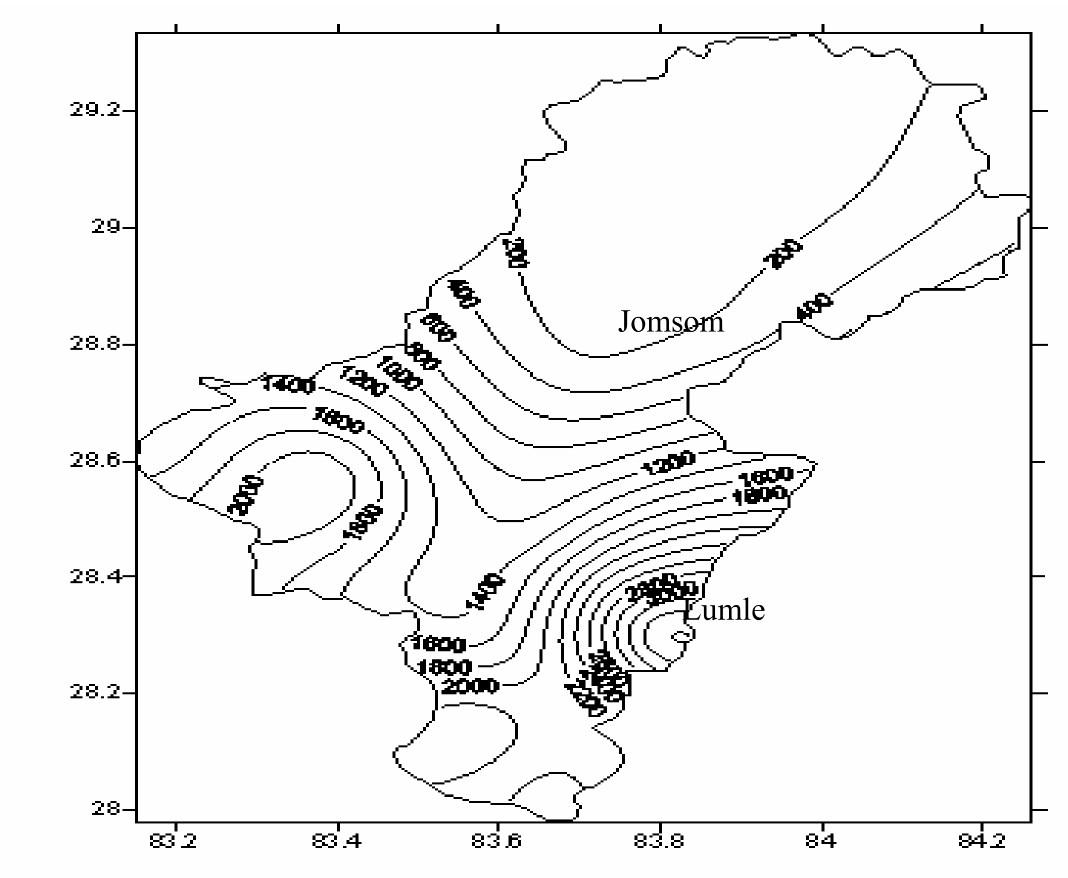

Fig.4.5 Isohyets of Kali-Gandaki during Monsoon

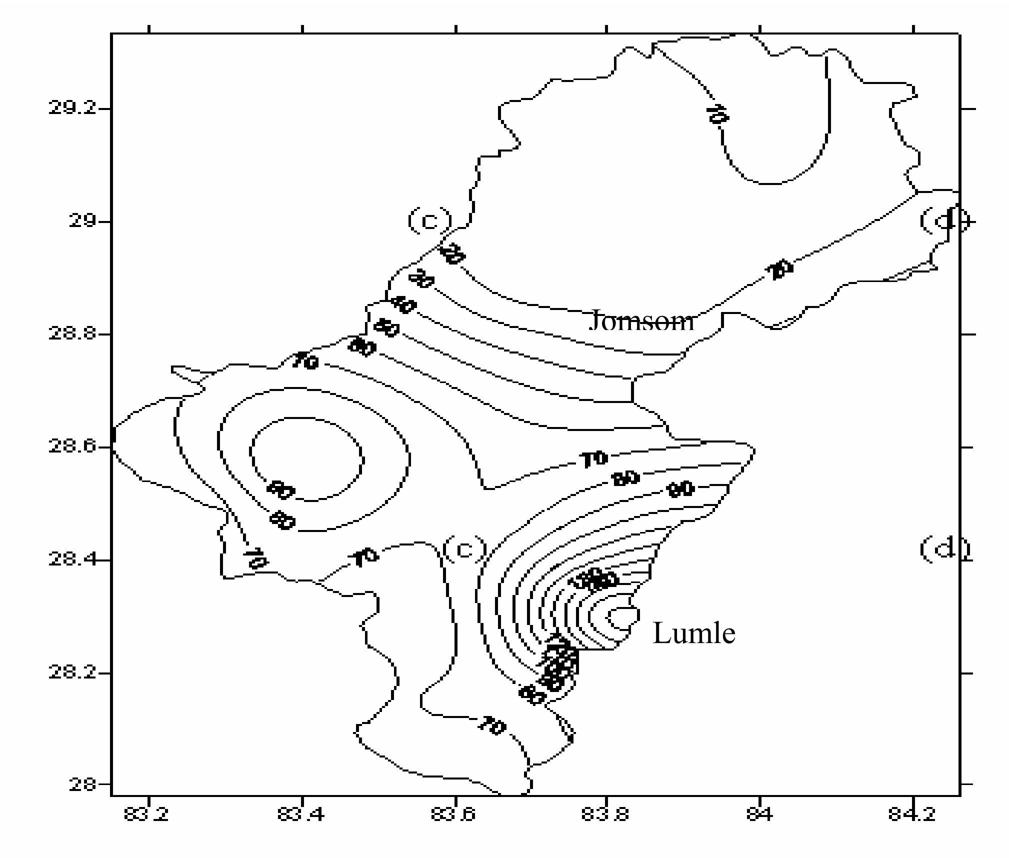

Fig.4.6 Isohyets during Post Monsoon

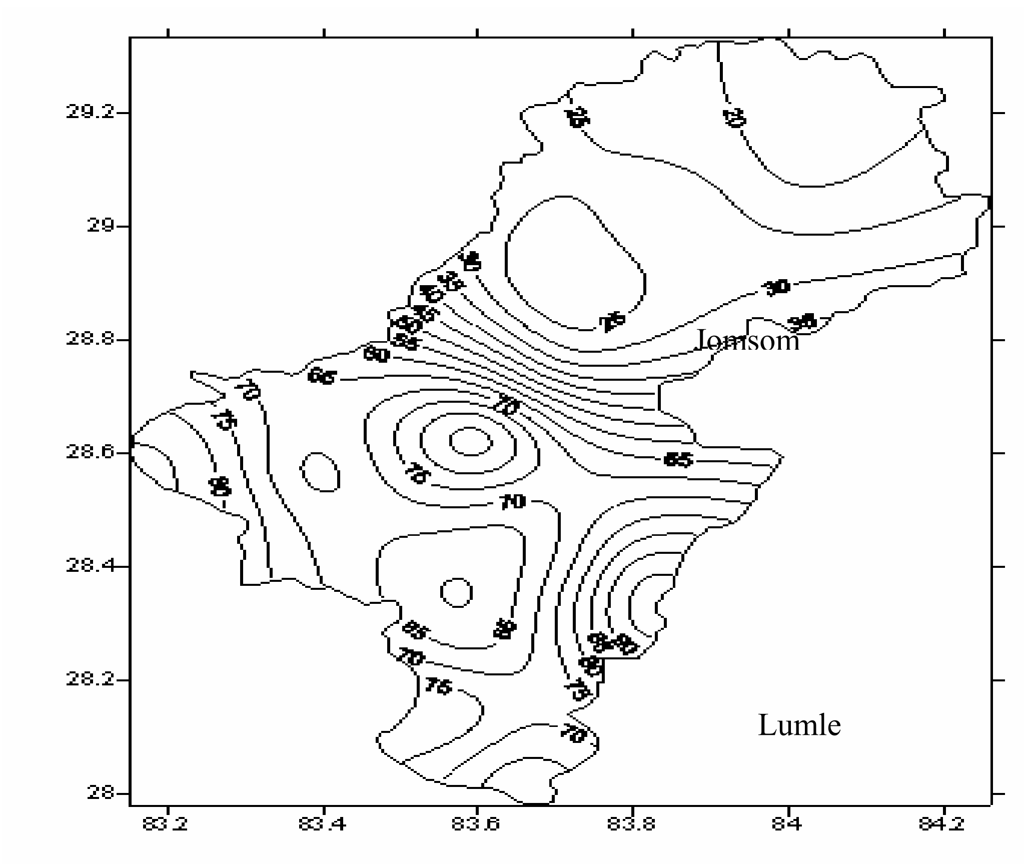

Fig.4.7 Isohyets during Winter

The annual isohyetal Fig 4.3 indicates that Lumle gets 3400-3500mm of rainfall where as Jomsom gets less than 200mm. There are small pockets at Muna and Baghara about 2400mm and at Rangkhami is about 2700-2800mm of rainfall in the western and Southwestern part of the Basin.

4.3 Illustration for water balnace

The Thronthwaite method has been adopted for the calculation of PET and the results of water balance for the two stations are shown in the Table 4.1 and Table 4.2 respectively.

Table 4.1 Water Balance of the Station Jomsom.

Jomsom	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
rain fall	11.0	14.0	15.3	18.7	21.3	23.0	22.9	22.7	21.3	18.0	14.3	11.8	214.3
PET	12	13	37	51	74	87	104	98	77	50	26	13	642.0
AE	10	13	21	23	19	14	40	34	36	36	7	2	255.0
P-PE	-1.0	1.0	-21.7	-32.3	-52.7	-64.0	-81.1	-75.3	-55.7	-32.0	-11.7	-1.2	0.0
Acc	0	0	0	0	0	0	0	0	0	0	0	0	0.0
st	0	0	0	0	0	0	0	0	0	0	0	0	0.0
∆st	0	0	0	0	0	0	0	0	0	0	0	0	0.0
WD	2	0	16	28	55	73	64	64	41	14	19	11	387.0
WS	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0

Table 4.2Water Balance of the Station Lumle.

Lumle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
pptn	34.2	46.3	61.1	109.5	316.6	881.2	1458.4	1395.7	860.4	219.6	27.7	19.8	5430.4
pet	19	26	53	74	98	98	99	95	80	62	41	33	778.0
AE	19	26	53	74	98	98	99	95	80	62	41	32	777.0
P-PE	15.2	20.3	8.1	35.5	218.6	783.2	1359.4	1300.7	780.4	157.6	68.7	-13.2	4734.4
Acc	15.2	35.5	43.6	79.1	200	200	200	200	200	200	131.3	118.0	1622.7
st	15.2	50.7	94.3	294.3	200	200	200	200	200	200	200.0	118.1	1972.6
∆st	15.2	50.7	94.3	294.3	200	200	200	200	200	200	200	118.1	
WD	0	0	0	0	0	0	0	0	0	0	0	1	1.0
WS	15.2	20.3	8.1	35.5	218.6	783.2	1359.4	1300.7	780.4	157.6	-13.3	-12.2	4653.4

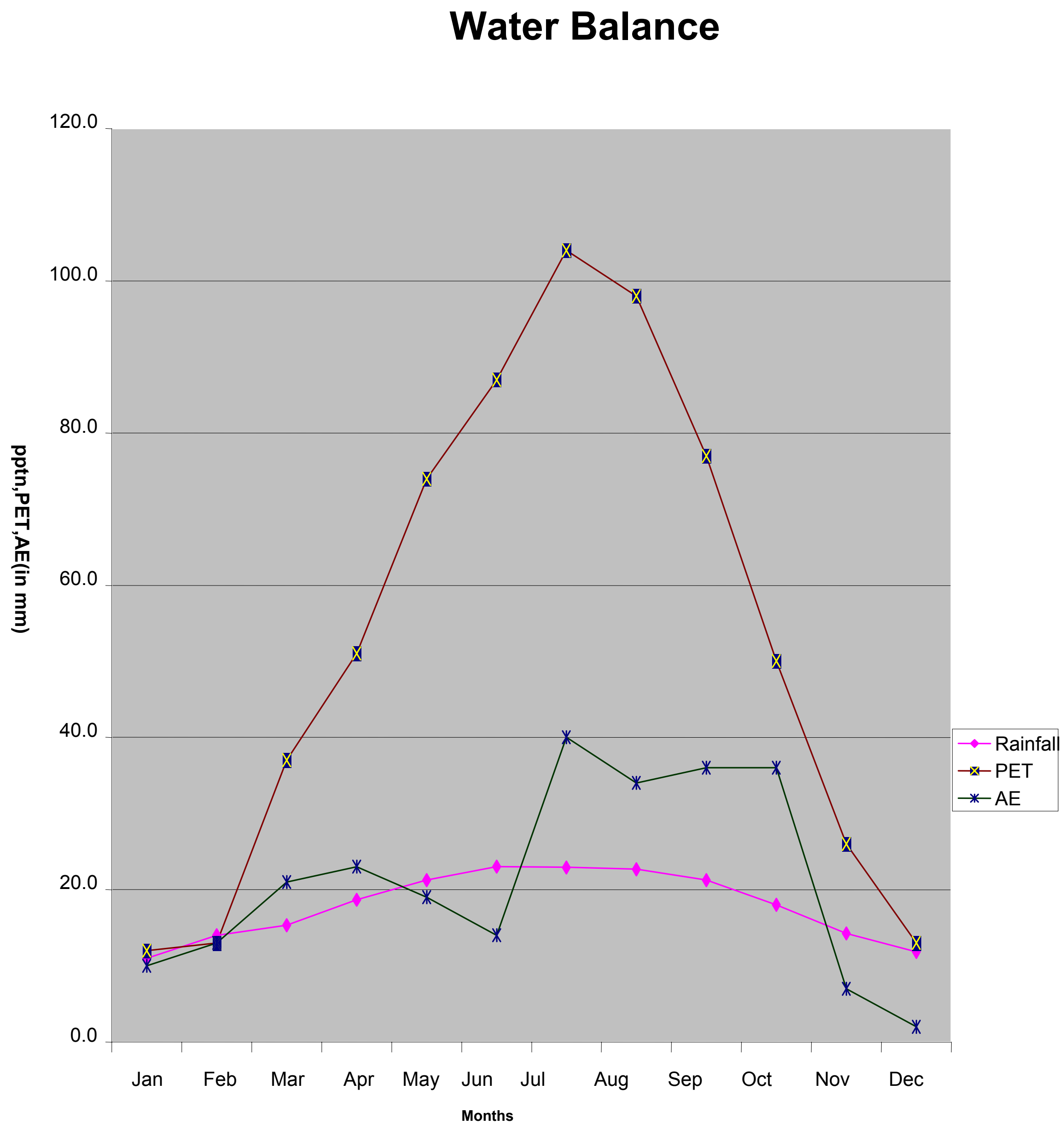

Fig.4.8 Water balance in Jomsom

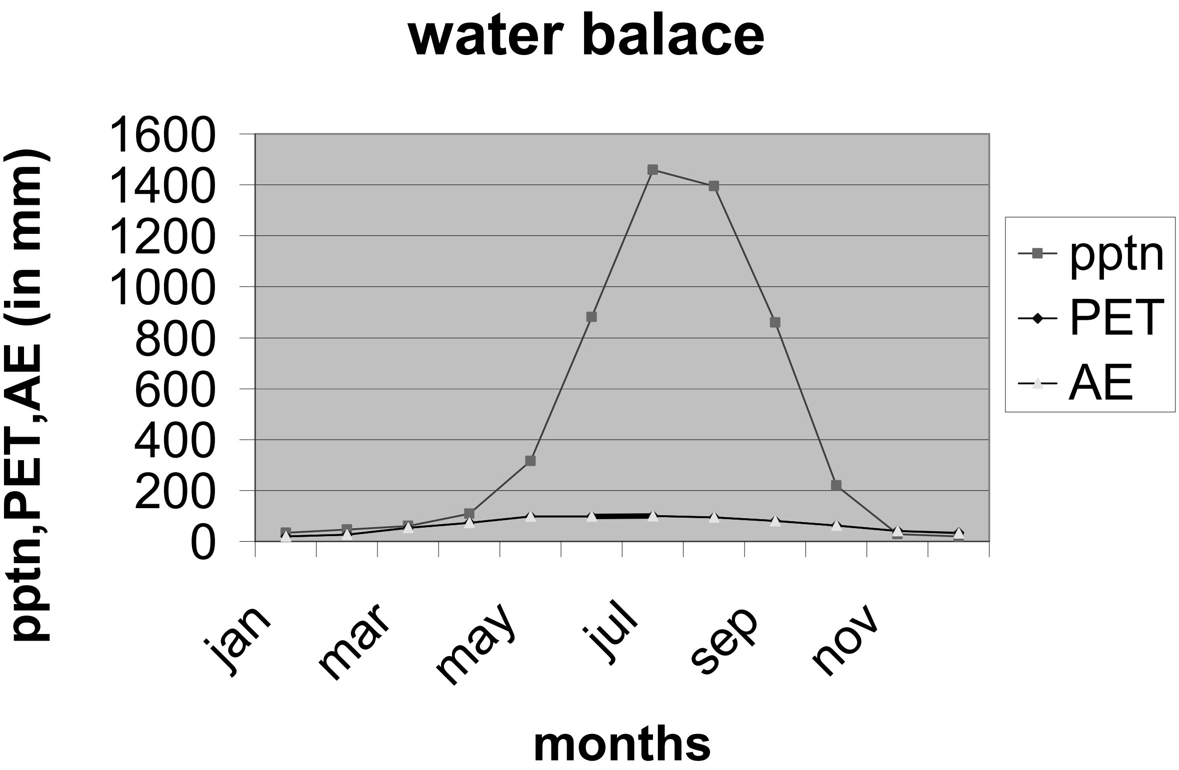

Fig.4.9 Water Balance in Lumle

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CHAPTER FIVE

Conclusion and Recommendation

5.1 Conclusion:

The study of water balance for the stations as shown in the Table 4.1 and table 4.2 in the Kaligandaki basin depicts that water budgets in the two stations are entirely different. Lumle situated in the hilly region having sufficient amount of water annually have the domination of the monsoonal rainfall. There is no scarcity of water in the whole annum in accordance with water balance as shown in the Table 4. However, there is little bit of scarcity of water in the months of winter.

While in the case of Jomsom there is deficit of water during the whole year except in the month of February.

Lumle receives the highest annual rainfall throughout Nepal about 5430mm of rainfall. During monsoon(June-September) it receives about 4595mm that is about 84.63% of the annual value while pre-monsoon season (March-May) , post-monsoon season (October-November) and winter season (December-February) it receives about 487mm(9%), 247mm(4.55%)and 100mm(1.85%) respectively. While Jomsom receives about 263mm annual rainfall out of which about 138mm (11.5%) during monsoon season, 58.88mm(22.37%)during pre-monsoon season, 36.48mm(13.86%)in post monsoon season and 30.37mm(11.54%)in the winter season.

From the study of water availability and surplus of water in the Kali Gandaki watershed basin following conclusions can be drawn.

Potential evapotranspiration (by Thronthwaite method) is the function of temperature and the latitudinal position geological texture and the slope aspect of high mountain range. Therefore the water surplus is more in the southern belt of the basin and the maximum in observed at Lumle, Lumle receives the maximum annual rainfall in the country. The rainfall drastically decreases northwards towards Jomsom which is in the rain shadow due to high Annapurna Himalayan belt. The annual rainfall amount at Jomsom and Lumle are 5430mm and 263mm respectively although the distance between them is not so far.

The study shows the orographic effects of precipitation is on the south-facing slopes of the Himalayas. This region showed extremely large gradients in rainfall over small spatial scales (10–20 km), on the timescales of both the monsoon season as well as individual weather events.

From the analysis of Isohyetal map for the annual average rainfall and for the monsoon and post monsoon, the maximum gradient is observed at Lumle while the minimum gradient is observed towards Jomsom. Some secondary high pockets of rainfall are also observed at Baghara and Muna.

During pre monsoon period highest rainfall pocket is found at Lumle and the rainfall amount lowers toward north of Jomsom. But during winter, the high pockets are seen at the vicinity of Lumle and Beni Bazaar and secondary high pocket at Jomsom but lowers toward northern part.

5.2 Limitations and Recommendations

The study has been carried out primarily for the stations Lumle and Jomsom, and other secondary data are taken for short periods for the stations as shown in the Table 1.2 are used for supporting the isohyetal maps. In the northernmost part, with higher remote Mountains, scarcity of precipitation data has caused in drawing isohyets. In this study there are some missing data for several months of some stations which might have affected the results.

Water deficit study is very much useful for the cropping system in the context of Nepal. From the study of water deficit and water surplus the amount of water that will be available for the crop can be known and on the basis of the water balance various cropping pattern can be adopted. Furthermore, this helps to assist the irrigation project .So this study must be done on the national scale for better results in agriculture and to manage the water resources, forest resources and other resources as well.

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TABLE: ADJUSTING FACTOR (N) FOR POTENTIAL EVAPOTRANSPIRATION COMPUTED BY THE THORNTHWAITE EQUATION (NORTHERN HEMISPHERE)

Lat. deg.	J	F	M	A	M	J	J	A	S	O	N	D
0	1.04	0.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
10	1.00	0.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99
20	0.95	0.90	1.03	1.05	1.13	1.11	1.14	1.11	1.02	1.00	0.93	0.94
30	0.90	0.87	1.03	1.08	1.18	1.17	1.20	1.14	1.03	0.98	0.89	0.88
35	0.87	0.85	1.03	1.09	1.21	1.21	1.23	1.16	1.03	0.97	0.86	0.85
40	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81
45	0.80	0.81	1.02	1.13	1.28	1.29	1.31	1.21	1.04	0.94	0.79	0.75
50	0.74	0.78	1.02	1.15	1.33	1.36	1.37	1.25	1.06	0.92	0.76	0.70