# ESTIMATION OF WATER BUDGET IN KATHMANDU VALLEY, NEPAL.

**A THESIS SUBMITTED FOR THE PARTIAL FULFILLMENT OF THE REQUIREMENT OF THE MASTER'S DEGREE OF SCIENCE IN HYDROLOGY AND METEOROLOGY, TRIBHUVAN UNIVERSITY, KATHMANDU, NEPAL**


**BY**
**YOGESH PANT**
**CENTRAL DEPARTMENT OF HYDROLOGY AND METEOROLOGY**
**TRIBHUVAN UNIVERSITY**
KATHMANDU, NEPAL

April,2011

## ABSTRACT

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

Many studies related to hydrology and meteorology were carried out in the Katmandu Valley. Most of those studies are discharge calculation and rainfall variability. However there is still lack in the studies of variability of water surplus and water deficit within the valley. Therefore the main purpose of my study is to estimate the water balance components. Thornthwaite method is applied for this purpose. In this study of water budget, seven stations are taken and water balance components are found to be different for each station.

Kathmandu Valley receives 1819 mm of annual rainfall. During monsoon season it receives about 1461 mm amounting about 80% of annual value while in pre-monsoon season, post-monsoon season and winter season it receives about 237 mm (13%), 68 mm (4%) and 53 mm (3%) respectively. The average yearly temperature is 17.6 ˚C. July is the hottest month with Mean Monthly temperature of 22.9 ˚C while January is the coldest month with Mean Monthly temperature of 9.6 ˚C.

From the climatological balance of Katmandu Valley, it is found that there is high amount of water surplus (788 mm) compared to water deficit (23 mm). Therefore soil water demand for dry period could be easily fulfilled by utilizing about 3% of water surplus. The measured specific discharge of Katmandu valley is compared with estimated water surplus and the results showed only 4.48% difference in value. This study will provide the information of climatological balance and specific discharge of the given area. This information will be useful for sustainable management of water resources in local and small watershed environment.

## TABLE OF CONTENTS

## LIST OF TABLES AND FIGURES

**List of Tables:** **Page**

**List of Figures:**

# ACRONYMS

| | |
|---|---|
| AE | Actual Evapotranspiration |
| C | Centrigade |
| CDHM | Central Department of Hydrology and Meteorology |
| DHM | Department of Hydrology and Meteorology |
| ET | Evapotranspiration |
| FAO | Food and Agriculture Organization |
| I | Heat Index |
| ICIMOD | International Centre for Integrated Mountain Development |
| P | Precipitation |
| PE | Potential Evapotranspiration |
| TU | Tribhuvan University |
| ST | Storage |
| ∆ST | Change in Storage |
| T | Temperature |
| WD | Water Deficit |
| WS | Water Surplus |

# CHAPTER ONE
# INTRODUCTION

## 1.1 Topography of Nepal:

Nepal is small landlocked country that covers an area of 147,181 $km^2$ in the centre of Hindu Kush Himalayas between India and China. Nepal stretches from 26º 22' to 30º 27' North latitude and from 80º 04' to 88 º 12' East longitudes. The country looks roughly rectangular in shape with the length from east to west of about 885 km and width ranging from 130 to 260 km. It contains 8 of the 10 highest mountain peaks in the world, including Mount Everest (at 8848 m), although some of its low lying areas are only about 60 m meters above sea level.

The country is divided into three broad ecological regions, i) The higher Himalayas in the north, ii) Hills and Valleys in the middle, and iii) Terai, an extension of Indo-Gangetic plain, in the south.


Fig 1 Location map of Nepal

### 1.1.1 Geographic region of Nepal:

Nepal is divided into five geographic regions according to physiographic as well as topographic region : Terai plan, Siwalik hills, Middle Mountains, High Mountains (consisting of the Main Himalayas and the Inner Himalayan Valleys), and the high Himalayas. (CBS, 2004)

Table 1.1: Geographic regions of Nepal

| Region | Geology and soil | Elevation (m) | Climate | Average temp. |
|---|---|---|---|---|
| Terai (14%) | Gently sloping recently deposited alluvium | 200 | Humid tropical | >25 $^{o}$c |
| Siwaliks (13%) | Testing mudstone,siltstone,sandstone,steep slopes, and weakly consolidated bedrock tends to promote surface erosion despite thick vegetation | 200-1500 | Moist subtropical | 25 $^{o}$c |
| Middle mountains (30 %) | Phyllite, schist, quartzile, granite, limestone, stony and course textured soil, conifer forests commonly found associated with quartzite. | 1000-2500 | temperate | 20 $^{o}$c |
| High mountains (19 %) | Phyllite, schists, quartzite. soil is generally shallow and resistant to weathering | 2200-4000 | Cool to sub alpine | 10-15 $^{o}$c |
| High Himalayas (14 %) | Limestone and shale, physical weathering predominates ,stony soils | >4000 | Alpine to arctic | <0 to 5 $^{o}$c |

## 1.2 Climate of Nepal :

Nepal has a great deal of variations in climate. Although Nepal lies near the northern limit of the Tropics, a very wide range of climates from Subtropical in the southern Terai to Tundra in the northern high Himalayas exists here. The remarkable differences in climatic conditions are primarily related to the enormous range of elevation within a short north-south distance. The presence of the east-west extending Himalayan massifs to the north and the monsoonal alteration of wet and dry seasons also greatly contribute to local variations in climate.

Generally country can be divided into five climatic types.

1. Tundra – climatic type: - Tundra type of climate is found in the higher Himalayas region of Nepal. Almost above snowline (5000 m), a permanent cover of snow and ice, Precipitation mostly falls in the form of snow occurs only.
2. Alpine – climatic type:- In the lower part of the Himalayas region, alpine type of climate is found. Above 4000m, cool summer and frosty winter, snow and ice, precipitation in the form of snow occurs only.
3. Cool temperate – climatic type: - This type of climate is found in the region of High Mountain region of Nepal. Cool summer and cool winter, winter precipitation in the form of snow at high altitude occurs only.
4. Warm temperate – Climatic type: - 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 may occur.
5. Tropical/Subtropical – climatic type: - The sub-tropical type of climate is found in the lower region of Chure range or Terai of Nepal. The tropical type of climate is found in the Chure range or Siwalik of Nepal. Hottest and humid summer, mild and dry winter occurs. (Adopted from Regmi, 1998)

### 1.3 General season in Nepal:

According to season, Climate of Nepal is divided into four parts; these are as follows (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, much 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 the fact, the distribution of pre-monsoonal rainfall in the country are 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; air becomes moist compared to other season. 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 the 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 Bengal 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 weather, lowest temperature and rainfall amount is very less but greater than post monsoon.

**1.4 Description of study area:**

**1.4.1 Topography:**

Kathmandu is surrounded by hills in all sides and is almost circular in shape. Elevation of surrounding hills range from 2000 to 2750m and valley is flat with elevation ranging from 1300 to 1400m .The east to west and north to south axes of valley are about 26km and 37km. Kathmandu valley lies between 27°32 to 27°49 E and 85°11to 85° 32 N with catchments area of 585 sq.km .

The Kathmandu valley, which has the capital city Kathmandu along with four other municipal towns, Lalitpur, Bhaktpur, Kirtipur and Madhyapur-Thime, are the main urban area of Nepal. The valley is located between the Himalayan in the north and the Mahabharata mountains in the south.


Fig.1.1 location map of Kathmandu valley

### 1.4.2 Climate:

The climatic condition of Kathmandu valley depends on the prevailing wind regime from central Asia and the northern hemisphere's cold pole. Summer monsoon (June, July, August, and September) and western disturbance (Dec-June) are considered the main rain weather producing system. In the summer and early autumn the prevailing wind regime in Kathmandu valley is the southwest monsoon (easterly). In the winter the prevailing winds are more westerly. During March to May the valley experiences pre-monsoon thundershower activities and there is a strong wind in this season (Karki, 2007). The temperature in Kathmandu drops below freezing in winter and in summer it may rise to 35 °C. The mean annual air temperature in Kathmandu is 18 °C. The coldest month is January, with a mean temperature of 10 °C. The warmest month is July and august with an average temperature of 24 °C. Fog is common in the morning during the months of October to February (pandey, 1987, Yogacharya, 1998).

## 1.5 Objectives of the study:

- To study the precipitation pattern in the Kathmandu Valley.
- To study the mean monthly temperature pattern in the Kathmandu valley.
- To study the water balance components of Kathmandu valley.
- To compare the recorded specific discharge with the water surplus computed from water budget study.

## 1.6 Station selection for the study

For the water budget computation procedure only seven stations namely Kathmandu Airport, Khokana, Khumaltar,Nagarkot, Panipokhari, Budanilkantha and Godavari are selected as unavaiability of temperature data in the remaining stations; however for the isohyetal analysis of rainfall fifteen stations within the valley are selected.

**Table 1.2: List of stations in Kathmandu Valley**

| S.N | Name of the station | latitude | longitude | Elevation in metre (m) |
|---|---|---|---|---|
| 1 | Bhaktapur | 27.67 | 85.42 | 1330 |
| 2 | Budhanilkantha | 27.78 | 85.37 | 1350 |
| 3 | Changunarayan | 27.70 | 85.42 | 1543 |
| 4 | Chapagaun | 27.60 | 85.33 | 1448 |
| 5 | Godavari | 27.58 | 85.40 | 1400 |
| 6 | Jitpur phedi | 27.78 | 85.28 | 1320 |
| 7 | Kakani | 27.80 | 85.25 | 2064 |
| 8 | Kathmandu airport | 27.70 | 85.37 | 1337 |
| 9 | Khokana | 27.63 | 85.28 | 1212 |
| 10 | Khumaltar | 27.67 | 85.33 | 1350 |
| 11 | Nagarkot | 27.70 | 85.52 | 2163 |
| 12 | Panipokhari | 27.73 | 85.33 | 1335 |
| 13 | Sankhu | 27.75 | 85.48 | 1449 |
| 14 | Sundarijal | 27.77 | 85.42 | 1490 |
| 15 | Thankot | 27.68 | 85.21 | 1630 |

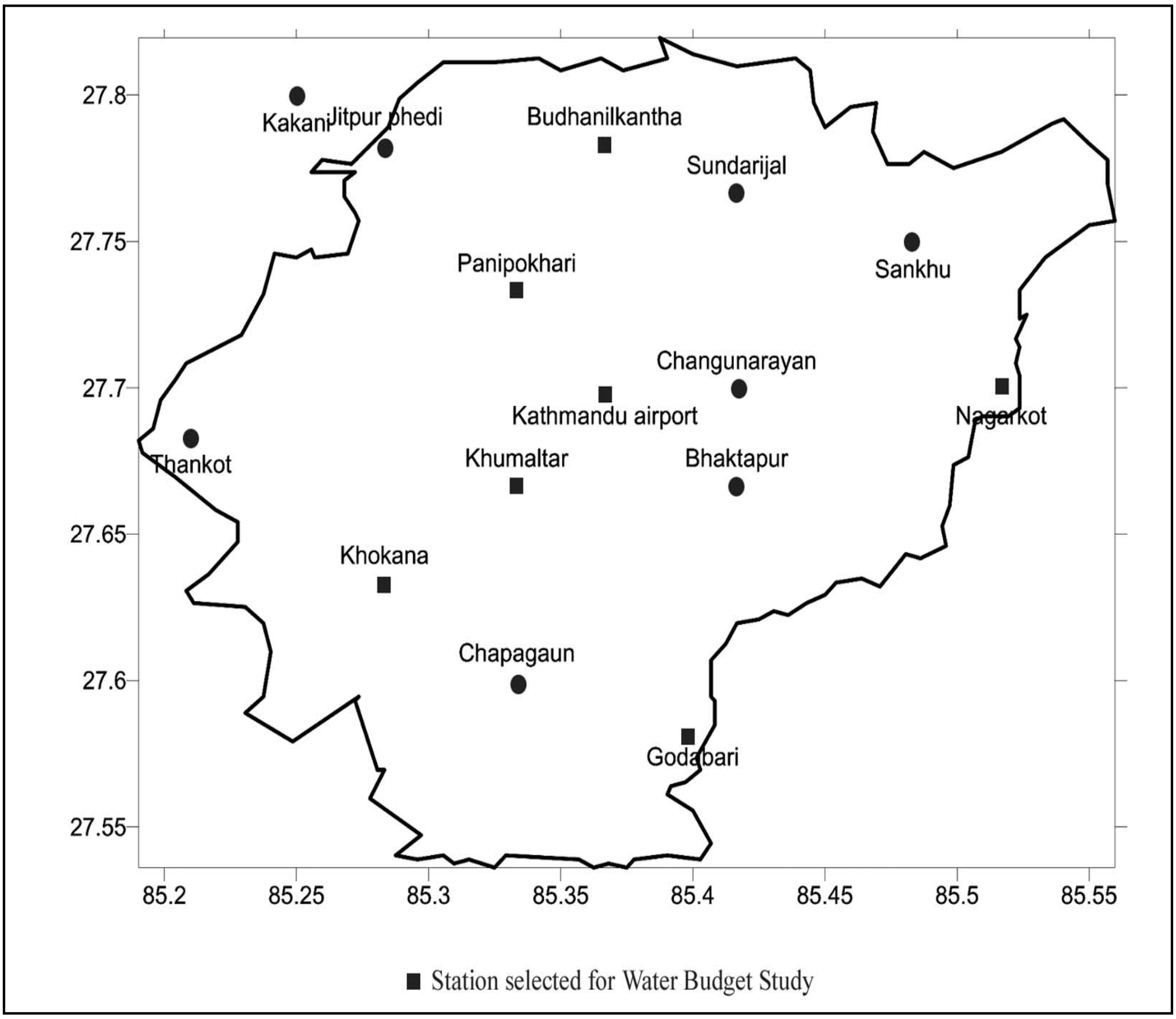


Fig 1.2 locations map of the rainfall stations in Kathmandu Valley

# CHAPTER TWO

## LITERATURE REVIEW

### 2.1 General 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 portions 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 vegetation and direct from land and ground surfaces. It is affected by climate, availability of water and vegetation. ET is a large component of water balance. Over the entire land surface of the earth, rainfall is averaged to an amount of 750 mm per year, of which some two thirds is returned to the atmosphere as evapotranspiration. 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 vegetation as transpiration is referred to as evapotranspiration (ET) (Marther,1972). 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 of ET are inches/day or millimeters/day.

Estimation of evapotranspiration is needed to support 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 water accounting process. Despite its importance, ET is almost impossible to measure or observe directly at a meaningful scale in space or time of measurement 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.

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.

Estimation of ET can be obtained by direct measurements using pan evaporation or by using 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 (Richard et. al, 1998). Evapotranspiration is higher when there is no cloud and bright sunshine but lesser when it is cloudy.

### 2.1.1 Precipitation

The term precipitation denotes all forms of water that reach the earth from the atmosphere .Precipitation may reach the surface of the earth in the form of drizzle, rain, snow, hail, sleets etc. The magnitude of precipitation varies with time and space. Precipitation is 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. For precipitation to form :I) the atmosphere must have moisture, II) there must be sufficient condensation nuclei present III) weather condition must be good for condensation of water vapour to take place, and IV) the product of condensation must reach the earth. The net precipitation at a place and its form depends upon wind, temperature, humidity and pressure within the regions enclosing the cloud and the ground surface at the given place. The well distributed rain gauges in the stations measures the rainfall amount and intensity.

### 2.1.2 Evaporation

According to FAO “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, soil 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 replacements of the saturated air with the drier air depends greatly on wind speed. Hence solar radiation , air temperature, humidity and wind speed are climatological parameters to consider when assessing the evaporation process.

When 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. When 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.

### 2.1.3 Transpiration

According to FAO, 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 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 characterstics, 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.

### 2.1.4 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 (1942) is the evapotranspiration from a large vegetation covered land surface with adequate moisture at all times, since the moisture supply is not restricted, the PET depends solely on available energy. Penman defined PET as the evapotranspiration from any 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 (1942) 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 Penmann method which combines energy- budget and aerodynamic approaches considered the additional meteorological parameters of humidity, wind and sunshine which significantly affect the PET.

### 2.1.5 Actual 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 the plants can remove from the soil.

### 2.1.6 Soil Moisture

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

### 2.1.7 Field Capacity

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

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.

### 2.1.8 Water Deficit

The water deficit is a definite measure of drought, water deficit indicates the amount of supplemental irrigation water needed for optimum crop growth and development during dry period. When the precipitation does not equal potential evapotranspiration, the difference is made up in part from soil moisture storage but the soil becomes drier, the part does not made up is larger. This is the water deficit, the amount by which actual and potential evapotranspiration differ.

### 2.1.9 Water Surplus

In the water balance book keeping procedure, it is assumed that all precipitation in excess of potential plant needs ( the potential evapotranspiration ) when the soil at field capacity will be available as water surplus. 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.

## 2.3 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 the fractions of the mean annual flow of water is the runoff.

## 2.4 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 process of evapotranspiration 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 plants by the following equations:

**Crop water need = Potential Evapotranspiration – Actual Evaporation**

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 is the amount of water that could be evaporated from land, water and plant surfaces if the soil water is in unlimited supply. PET calculations are based on standard weather stations data 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 Thornwaite water balance method at a resolution of 1 kilometer (Maharjan, T.R., 2008). The Thornwaite method is based on an empirical relationship between potential evapotranspiration and mean monthly air temperature. While this method is not the most accurate and may lack theoretical basis, it can provide reasonably accurate estimates of potential evapotranspiration.

# CHAPTER THREE
# DATA AND METHODOLOGY

## 3.1 Data used:

The present study incorporates precipitation and temperature data of Kathmandu valley. The monthly precipitation data of 15 stations for the period 1970-2005 is used and obtained from Department of Hydrology and Meteorology of Nepal. The monthly temperature data of six stations namely Ktm.airport, Panipokhari, Khumaltar, Khokana, Godavari, Budanilkantha and Nagarkot were obtained for the period 1981-2005 from Department of Hydrology and Meteorology of Nepal and is used for the computation of potential evapotranspiration. The monthly temperature and precipitation data are used to compute water balance components. The daily discharge data of Bagmati river at Chovar is obtained for the period 1963-1980 and used to compute monthly specific discharge.

## 3.2 Water balance computation procedure:

Water balance defines to account all the water over a region on both seasonal and annual bases in its all forms and states. The earth surface receives water from precipitation and losses through the process of evapotranspiration. Water evaporates from all water bodies and moist land areas as well as that which is transpired by vegetation rises the moisture content of the atmosphere and is ultimately return to the earth by precipitation. For continental area the equation of the hydrological cycle is;

$$P = E + \Delta S + G + R$$

Where P is the precipitation in millimeter (mm), E is the evapotranspiration in mm; $\Delta S$ the change in water storage on and below the surface of the earth within the region; G the leakage or sub-surface leakage and R the runoff of water in streams and rivers; for large scale G; the leakage can be neglected.

Neglecting G, the equation of hydrological cycle reduces to;

$$P = E + \Delta S + R$$

**This equation is the water balance equation.**

The water balance accounting procedure begins with the subtraction of potential evapotranspiration [PET] from the incoming precipitation (P) in each month. P is a regularly measured element at all observatories. The negative values of (P-PE) indicates refers to the amount that is in excess of the water need. Accumulated potential water loss (APWL) is obtained by a progressively adding all the negative values of (P-PE). But if the soil has never reached the field capacity, the first value of APWL is obtained by a successive approximation method using the field capacity table (field capacity is the maximum quantity of water that the soil can retain against the force of gravity). The amount of soil moisture held in the soil is derived from the APWL and field capacity table. When measured values are not available, field capacity may be assessed by considering the type of the soil and the vegetation growing on it.

The soil moisture decreases when P is lower than PE and increases when P is higher than PE. Hence the change in soil storage (ΔST) is obtained by subtracting the soil moisture in any month from that in the previous month.

When precipitation is equal to or greater than PE, the actual evapotranspiration (AE) will be equal to PE. If precipitation is less than PE, AE is obtained by adding P to the magnitude of (∆ST). The difference of PE and AE gives the value of water deficiency (WS) as:

$$WS = PE - AE$$

Water surplus occurs only after the soil has been recharged to its field capacity as whenever precipitation is higher than PE and soil is not at field capacity. The excess first goes to recharge the soil moisture. This water surplus (WS) can be written as:

$$WS = (P - PE) - \Delta ST$$

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

$$PE = AE + WD$$

$$P = AE + WS$$

**3.3 Method:**

Thornthwaite proposed an empirical method to estimate the potential evapotranspiration from mean temperature data. The method was modified by Thornthwaite and Mather (1955) to make it more useful over a wide range of soils and vegetations.

The method uses air temperature as in index of the energy available for evapotranspiration assuming that air temperature is correlated with the integrated effects of net radiation and other controls of evaporation and that available energy is shared in fixed proportions between heating the atmosphere and evapotranspiration.

The empirical equation developed by Thornthwaite which relates the evapotranspiration to mean air temperature is:

$$PE = 1.6\,(10T/I)^{a}$$

Where PE is the monthly potential evapo-transpiration, T is the monthly mean air temperature ($^{o}$C), I is the heat index for the station which is the sum of 12 monthly heat indices i is given by i = $(Ta/5)^{1..514}$ , and a is a cubic function of I. This method of computing the monthly water balance was revised and summarized by Thornthwaite and Mather (1957).

In order to determine the water balance at a site it is necessary to have the following specific information.

- Latitude
- Mean monthly air temperature
- Mean monthly precipitation
- Necessary conversion and computation table
- Information on the water-holding capacity of the depth of soil for which the balance is to be computed.

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

**To calculate PE**

From the mean monthly air temperature ( long-term averaged ) monthly values of heat index i are obtained from Appendix for temp. degree Celsius. Summing up these monthly values of heat index will obtain yearly heat index I.

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.

For the temperature greater or equal to 26.5°c, daily unadjusted PE are directly found from the appendix.

knowing the latitude of the station , monthly correction factor to adjust daily unadjusted PE to monthly adjusted PE are found from appendix.

Adjusted PET for 30 days can be obtained by multiplying daily unadjusted PE and monthly correction factor. This gives the monthly PE 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: storage (S)

For the negative values of P-PE, locate the storage figures using appendix.
locate the last negative value in column P-PE.
Note the storage value a.
Add to the value of (b) the first positive ( i.e. the positive value next to negative value)
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 evaporation (AE)

When P > PE then PE = AE

When P < PE then AE = P + ΔST

It means that P is the sum of P and ΔST without considering the sign of ΔST.

Step 7: water deficit (WD)

It is the difference between P and PE or

$$WD = P - PE$$

Step 8: Water surplus (WS)

It is the difference between P-PE and 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 way.

$$PE = AE + WD$$

$$P = AE = WS$$

## 3.4 Application 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 farm. 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 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 the soil moisture is present in readily available by frequent examination of sub-soil by the use of soil duper. In recent 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 by gypsum, fiberglass and nylon in which the electrical resistance varies with the moisture. While using these devices often do not provide the information that is needed they provide a sample at only one spot which may or may not representative of 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 assumptions 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 over good sized areas, depending on the climatic data used. In the climatological approach, the moisture in the soil is determined from estimates of combined evaporation from soil surfaces and transpiration from plant leaves ( evapotranspiration). An irrigation schedule can be set up as a bookkeeping procedure. The moisture in the soil may be regarded as a bank account. Precipitation adds to the account, evapotranspiration withdraws from it. We merely need to keep track of the evapotranspiration and restore by irrigation whatever is not promptly returned by precipitation.

When the moisture content in the soil is at field capacity ( the maximum amount of water that can be held in the soil root zone against the downward pull of gravity. This is the water available for use by palnts roots), any precipitation above that needed to satisfy the evapotranspiration demand is lost by downward percolation. This gravitational water is only detained partly. The period depends on the permeability of soil and the amount of gravitational water. when the soil moisture is below the field capacity, 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 ( a 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 removal falls to one-half of the potential rate and plants begin to suffer from lack of water (Aryal, 1995).

An irrigation schedule is a natural outgrowth of the climatic method of computing soil moisture. One can set up limits below which the soil moisture will not allowed to fall for the particular crop and depth of root zone in question. Then by keeping daily account of how much water has been added to and lost from the soil, it is possible to know exactly when the pre-determined level of soil moisture depletion is reached and just how much to irrigate to bring the moisture level back to safe value. If irrigation is scheduled 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 deficiency can develop in the soil to limit growth, and there will be no over-irrigation to damage both soil and crop and to result in wasteful misuses of water.

# CHAPTER FOUR

## ANALYSIS AND RESULTS

### 4.1 Rainfall and Temperature:

Rainfall is a very important factor for the growth of vegetation and for agriculture. Most of the rainfall- about 80% -is observed during monsoon season lasting about four months from June to September. Mean Annual rainfall over Kathmandu valley is 1819 mm, with Mean seasonal value of 53 mm, 237 mm, 1462 mm and 68 mm during winter, Pre-Monsoon, Monsoon and post Monsoon season, respectively. Mean Monthly rainfall have been found to be Maximum in July with value 489mm and Minimum in November with value of 8mm.

Table 4(i): Mean Seasonal rainfall in various stations of Kathmandu valley. (1970-2005)

| Name of station | Winter | Pre monsoon | Monsoon | Post monsoon | Annual |
|---|---|---|---|---|---|
| Bhaktapur | 49 | 226 | 1191 | 61 | 1527 |
| Budhanilkantha | 46 | 290 | 1639 | 64 | 2039 |
| Changunarayan | 55 | 244 | 1341 | 69 | 1709 |
| Chapagaun | 55 | 174 | 1152 | 49 | 1430 |
| Godavari | 62 | 217 | 1548 | 78 | 1905 |
| Jitpur phedi | 51 | 273 | 1587 | 64 | 1975 |
| Kakani | 62 | 299 | 2378 | 94 | 2833 |
| Kathmandu airport | 46 | 206 | 1132 | 68 | 1452 |
| Khumaltar | 50 | 185 | 926 | 60 | 1221 |
| Nagarkot | 50 | 229 | 1562 | 82 | 1923 |
| Panipokhari | 44 | 232 | 1211 | 68 | 1555 |
| Sankhu | 50 | 234 | 1686 | 74 | 2044 |
| Sundarijal | 59 | 270 | 1944 | 64 | 2337 |
| Thankot | 66 | 261 | 1558 | 78 | 1963 |
| Khokana | 57 | 212 | 1077 | 52 | 1398 |
| Average | 53 | 237 | 1461 | 68 | 1819 |
| Percentage of total | 3 | 13 | 80 | 4 | 100 |

For isohyetal of rainfall data for the stations have been taken for 35 years and the isohyetal map is plotted using the " Surfer for windows version 7.2" developed by golden software, INC, Colorado, USA as shown in below.

From the study isohyetal analysis, it can be concluded that variability in monsoonal rainfall over Kathmandu valley are relatively low in the central part of valley floor than that of the base and top of mountains. There exists a pocket area of minimum annual rainfall around Khumaltar which is centrally located while the pocket area of maximum annual rainfall is observed around Sundarijal.

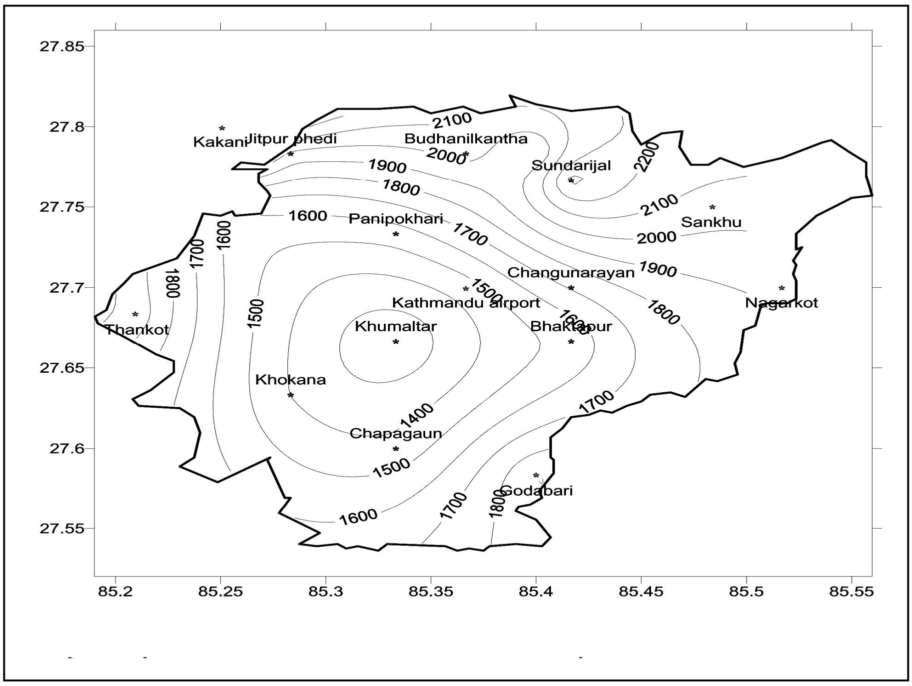


Fig. 4(i): Isohyets of annual rainfall in Kathmandu Valley

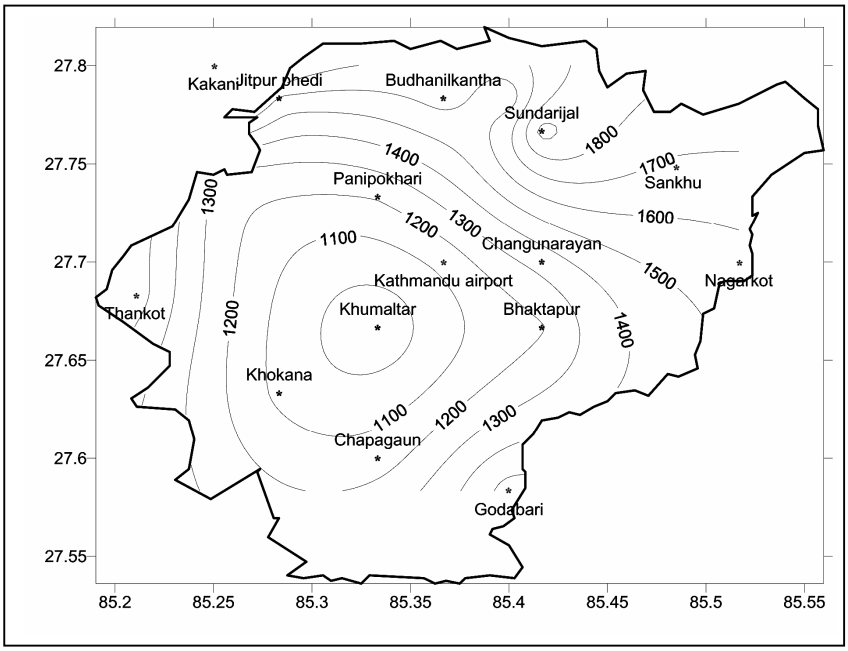


Fig:4(ii) Isohyets of Monsoon rainfall within Kathmandu valley

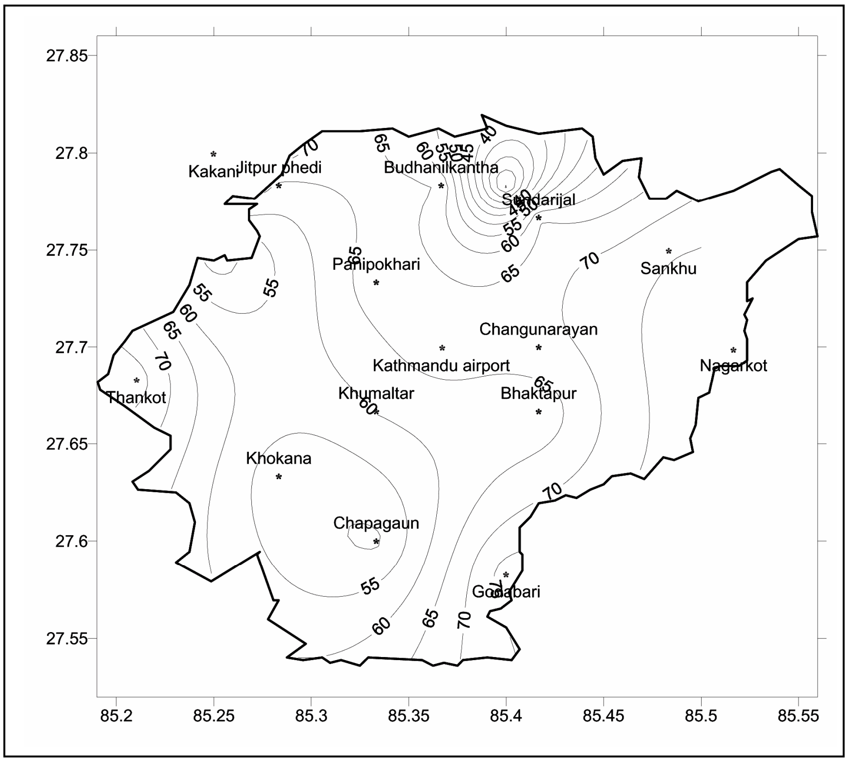


Fig 4(iii): Isohyets of Post Monsoon rainfall within Kathmandu valley

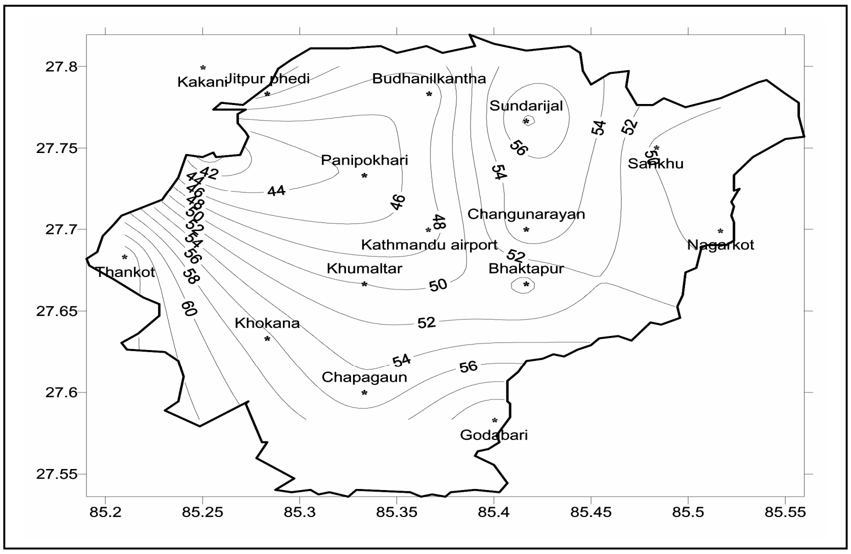


Fig 4(iv): Isohyets of winter rainfall within Kathmandu valley

The mean monthly temperature pattern over the Kathmandu valley showed that there is increasing trend of monthly temperature from the month January to July with maximum temperature in July in all the selected stations while there is decreasing trend of mean monthly temperature from July to January with minimum temperature in January in all selected stations. Furthermore, Nagarkot recorded the lowest mean monthly temperature over the year while Panipokhari recorded the highest mean monthly temperature over the year. The yearly average temperature of the Kathmandu Valley is 17.6 ˚C. The mean monthly temperature for the hottest month of July is 22.9 ˚C while the mean monthly temperature for the coldest month of January is 9.6 ˚C.

Table 4(ii): Mean monthly temperature

| **Monthly temp(˚c)** | Kathmandu Airport | Panipokhari | Nagarkot | Budanikantha | Khokana | Godavari | Khumaltar | Average |
|---|---|---|---|---|---|---|---|---|
| **temp(˚c)** JAN | 10.17 | 10.05 | 7.98 | 10.44 | 9.60 | 9.18 | 9.77 | 9.60 |
| FEB | 12.27 | 12.61 | 9.58 | 12.42 | 11.69 | 11.22 | 11.86 | 11.66 |
| MAR | 16.12 | 16.65 | 13.18 | 16.01 | 15.16 | 15.09 | 15.47 | 15.38 |
| APR | 19.50 | 19.73 | 16.68 | 19.29 | 18.83 | 18.53 | 18.85 | 18.77 |
| MAY | 21.92 | 22.38 | 17.80 | 21.48 | 21.46 | 20.51 | 21.63 | 21.03 |
| JUN | 23.75 | 23.89 | 18.89 | 23.14 | 23.56 | 21.97 | 23.75 | 22.71 |
| JUL | 23.96 | 24.13 | 18.96 | 23.37 | 23.94 | 22.15 | 23.91 | 22.92 |
| AUG | 23.98 | 24.14 | 18.93 | 23.40 | 23.96 | 21.91 | 23.79 | 22.87 |
| SEP | 22.86 | 23.34 | 18.33 | 22.45 | 22.74 | 20.81 | 22.87 | 21.91 |
| OCT | 19.62 | 20.17 | 16.02 | 19.27 | 19.09 | 18.01 | 19.61 | 18.83 |
| NOV | 15.20 | 15.79 | 12.51 | 15.53 | 14.54 | 13.93 | 15.09 | 14.66 |
| DEC | 11.37 | 11.71 | 9.21 | 11.64 | 10.57 | 10.42 | 11.25 | 10.88 |
| | | | | | | | | |

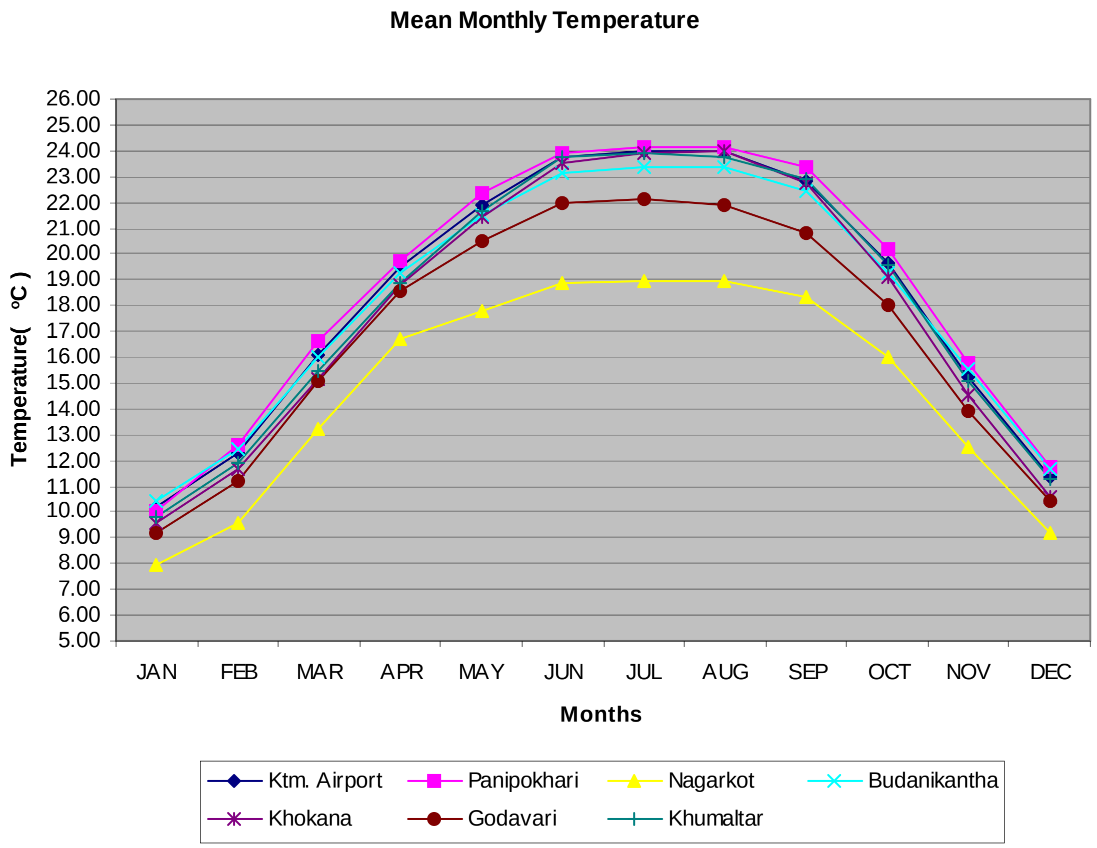


Fig 4(v): Mean Monthly temperature

## 4.2 Water Budget:

The best way to understand how the water balance works is to actually calculate a soil water budget. The input parameters are mean monthly temperature and mean monthly precipitation. The assumed field capacity of the soil is taken as 200 mm. The Thornwaite method has been adopted for the calculation of potential evapotranspiration. The results of water budget for the stations considered are shown in the appendix.

The water budget results depicts that PE is highest in the month of July with the values of 135mm, 131mm, 131mm, 131mm, 124mm, 117mm, and 96mm for the stations Khokana, Kathmandu Airport, Panipokhari, Khumaltar, Budanilkantha, Godavari and Nagarkot respectively. The highest values of PE in this month is attributed to the highest mean monthly temperature. As the mean monthly temperature decreases, PE also decreases and reaches to the minimum value in the month of January. The PE for the month of January is 19mm, 19mm, 19mm, 19mm, 22mm, 19mm, and 19mm for the stations Khokana, Kathmandu Airport, Panipokhari, Khumaltar, Budanilkantha, Godavari and Nagarkot respectively.

The study of water balance depicts that the water budget in the seven stations are different to each other. During pre-monsoon season water deficit occurs at each stations. Panipokahari, Khokana and Budanilkantha records 11 mm of water deficit each. Godavari and Nagarkot records 10 mm of deficit. Similarly Khumaltar and Kathmandu records water deficit 16 mm and 15 mm respectively. There is no deficit occurs during the monsoon season in any stations. During post monsoon and winter season there exist water defict in each station ranging from 2 mm to 9 mm.

The study also depicts that there is no water surplus during pre-monsoon, post monsoon and winter season. However Budanilkantha receives 1 mm of water surplus during pre-monsoon. Similarly Nagarkot and Godavari receives 11 mm and 1 mm of surplus during post monsoon respectively. During monsoon season there is high portion of rainfall contributed to water surplus. Nagarkot contributes highest (1210 mm) and Khumaltar contributes lowest value of water surplus (359 mm). Similarly ktm. Airport, Panipokhari, Khokana, Godavari and

Budanilkantha contributes 563 mm, 635 mm, 505 mm, 1072 mm and 1170 mm of water surplus respectively. The water balance of each station is portrayed in figure a, b,c,d,e,f and g.

Furthermore from the analysis of deficit and surplus, it could be seen that there is slightly increasing trend of water surplus with elevation while no relation of water deficit with elevation is observed. The increasing trend of surplus with elevation is attributed to the higher values of rainfall in higher elevation.

Table 4(a): summary of water deficiency and surplus

| Station name | Condition | Pre-monsoon | Monsoon | Post monsoon | Winter | Total |
|---|---|---|---|---|---|---|
| | | March-May | Jun-Sep | Oct-Nov | Dec- Feb | |
| | | mm | mm | mm | mm | mm |
| Ktm.Airport | WD | 15 | 0 | 5 | 5 | 25 |
| | WS | 0 | 563 | 0 | 0 | 563 |
| Panipokhari | WD | 11 | 0 | 7 | 8 | 26 |
| | WS | 0 | 635 | 0 | 0 | 635 |
| Khumaltar | WD | 16 | 0 | 7 | 5 | 28 |
| | WS | 0 | 359 | 0 | 0 | 359 |
| Khokana | WD | 11 | 0 | 9 | 5 | 25 |
| | WS | 0 | 505 | 0 | 0 | 505 |
| Godavari | WD | 10 | 0 | 2 | 2 | 14 |
| | WS | 0 | 1071 | 1 | 0 | 1072 |
| Budanilkantha | WD | 11 | 0 | 6 | 8 | 25 |
| | WS | 1 | 1169 | 0 | 0 | 1170 |
| Nagarkot | WD | 10 | 0 | 3 | 3 | 16 |
| | WS | 0 | 1199 | 11 | 0 | 1210 |

.

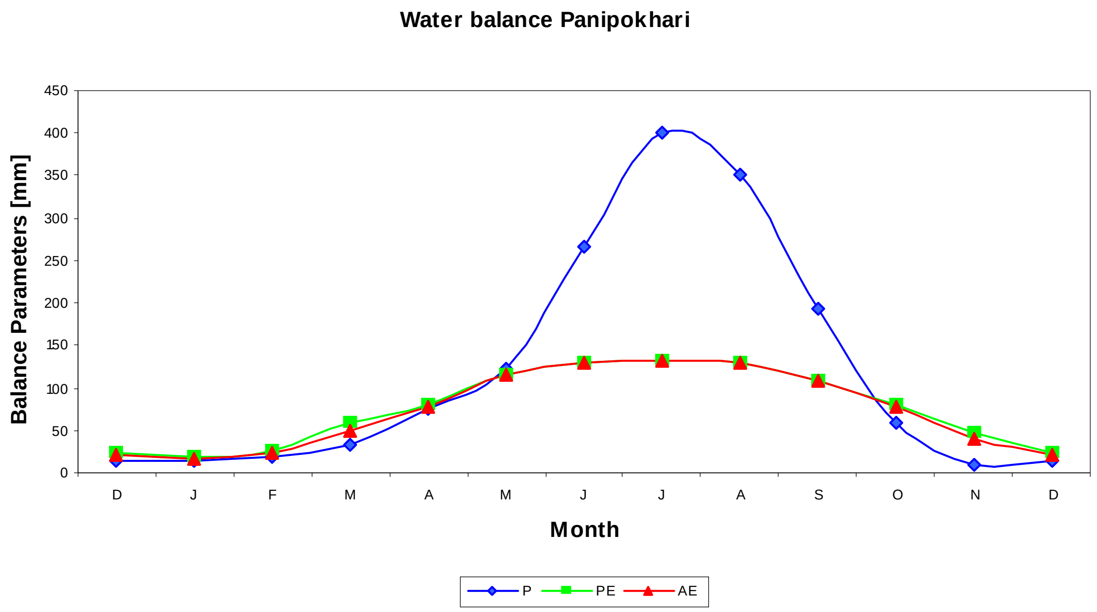


Fig 4(a) water balance of Panipokhari

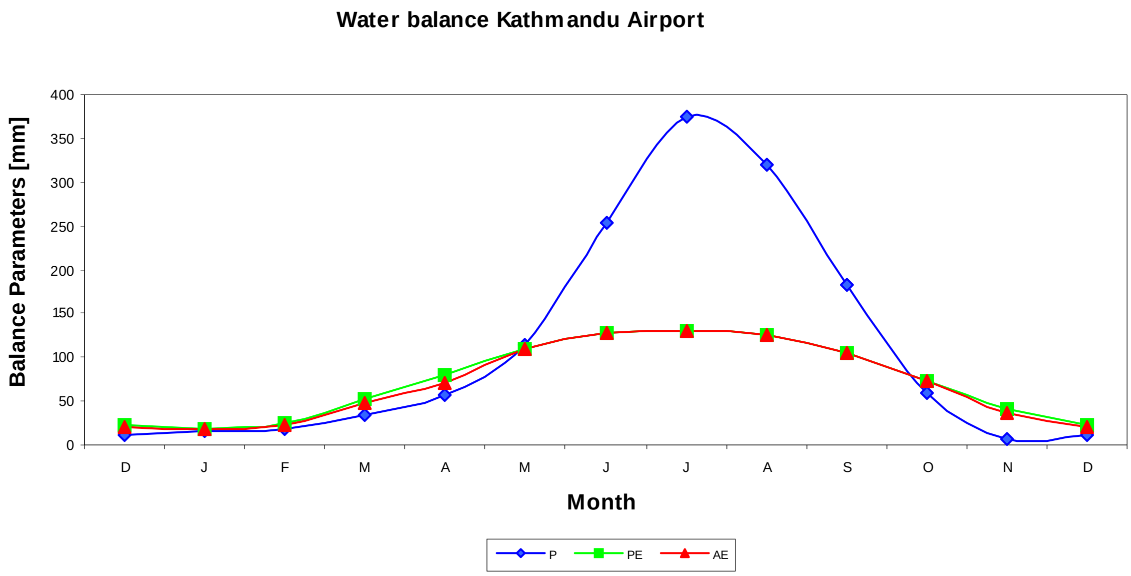


Fig 4 (b): Water balance of Kathmandu Airport

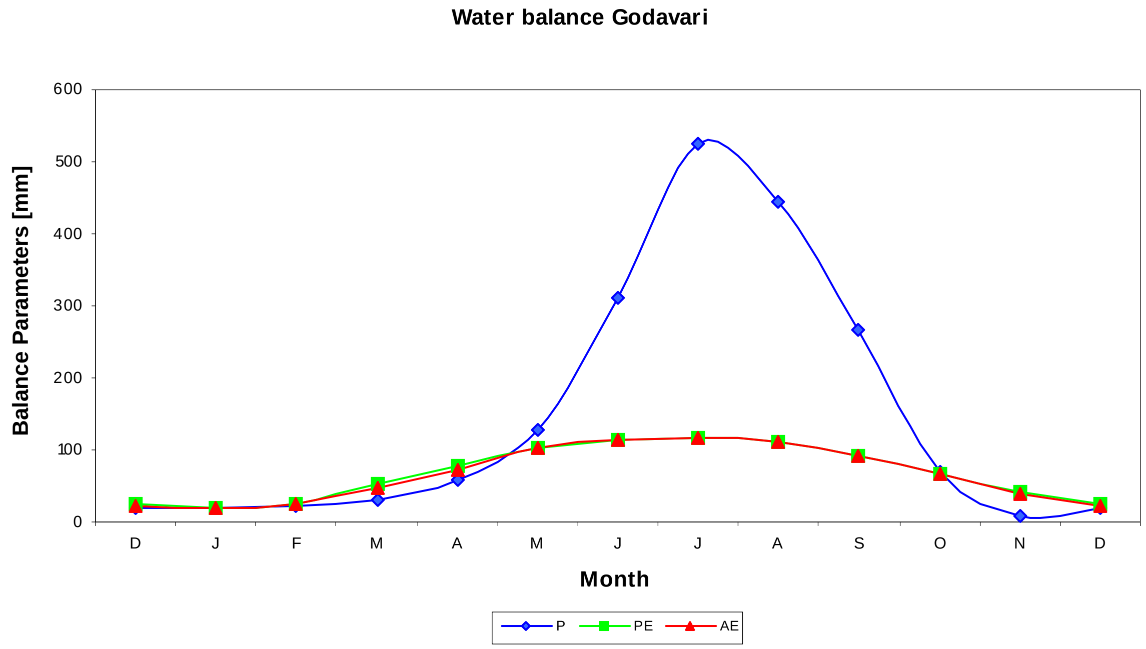


Fig 4 (c) Water balance of Godavari

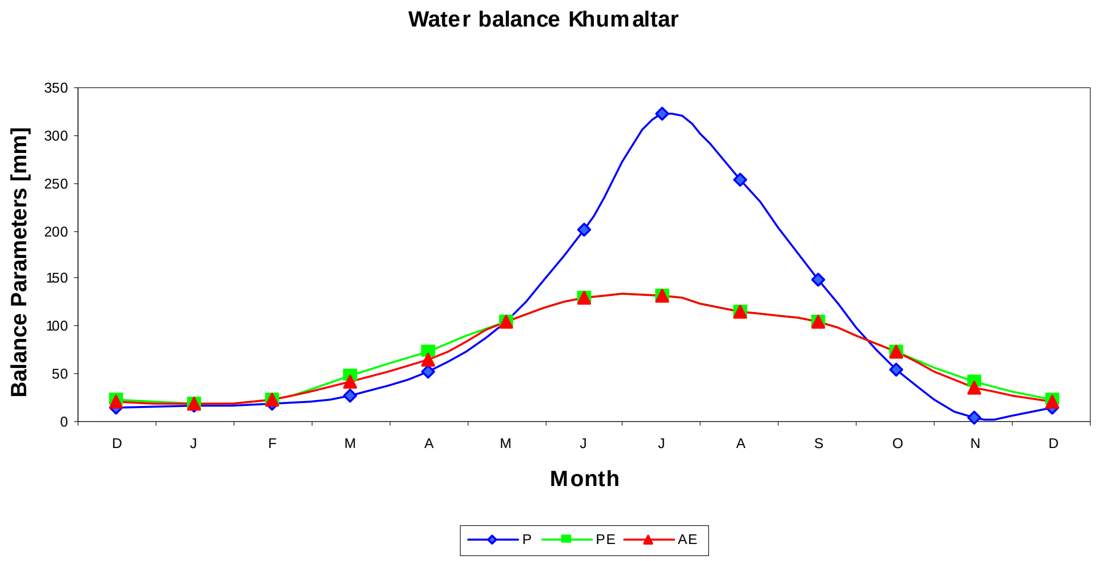


Fig 4 (d) Water balance of Khumaltar

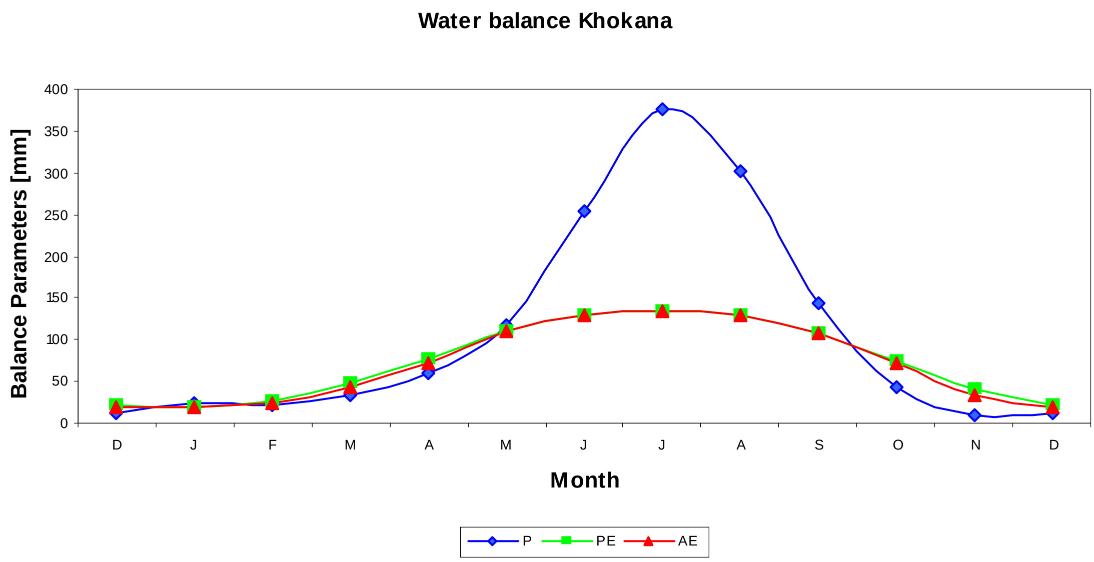


Fig 4(e) Water balance of Khokana

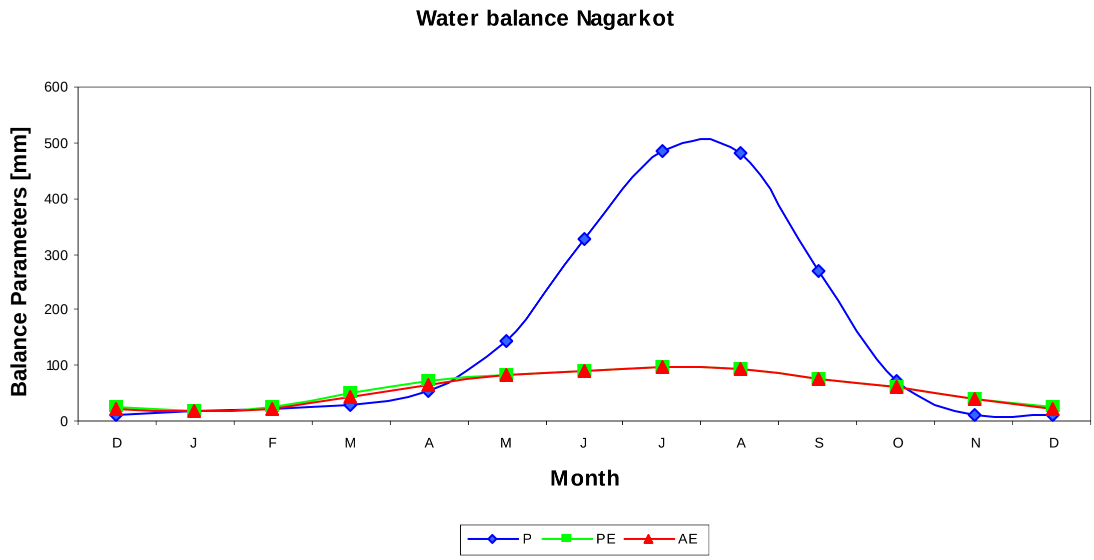


Fig 4 (f) Water balance of Nagarkot

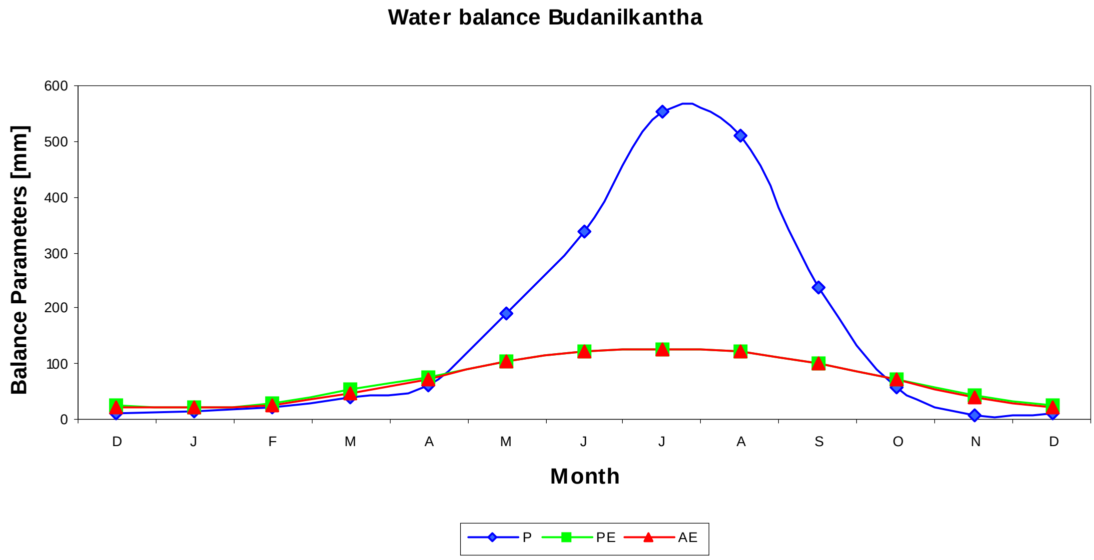


Fig 4 (g) Water balance of Budanilkantha

Table 4(b): deficit and surplus

| Station Name | Station Elevation (m) | Deficit (mm) | Surplus (mm) |
|---|---|---|---|
| Khokana | 1212 | 25 | 505 |
| Panipokhari | 1335 | 26 | 635 |
| Kathmandu Airport | 1337 | 25 | 563 |
| Khumaltar | 1350 | 28 | 359 |
| Budanilkantha | 1350 | 25 | 1170 |
| Godavari | 1400 | 14 | 1072 |
| Nagarkot | 2163 | 16 | 1210 |

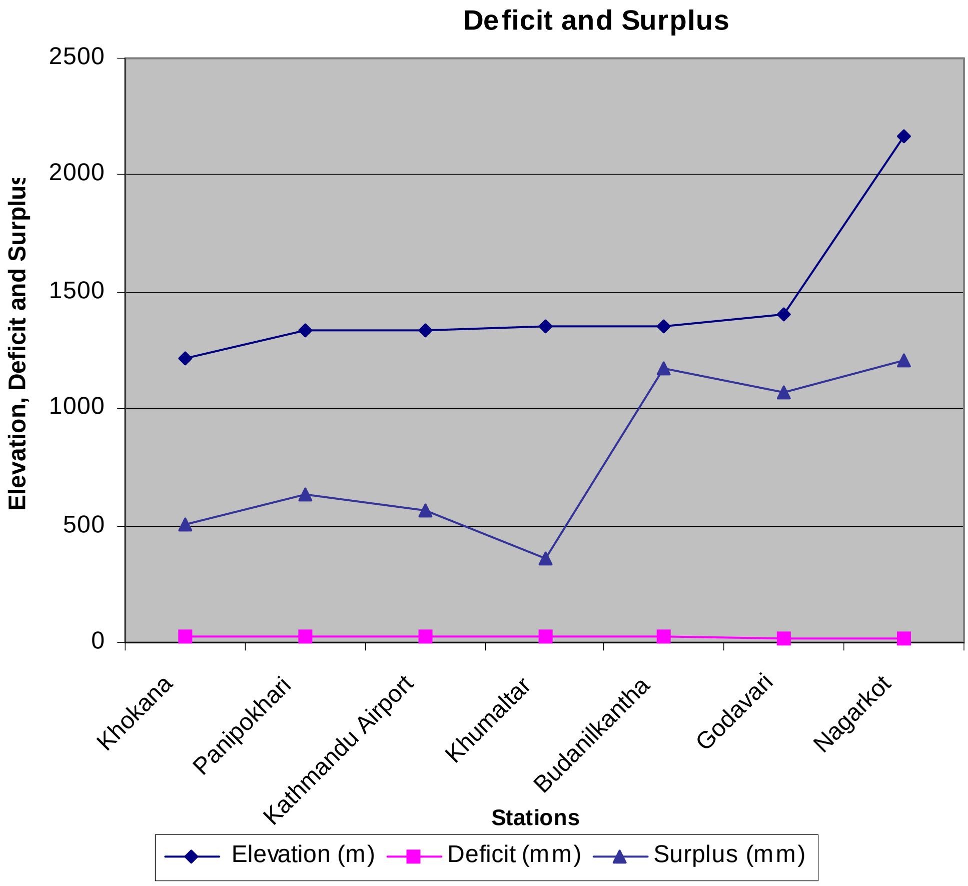


Figure 4 (h):Deficit and Surplus

**4.3 Specific Discharge**

Discharge per unit area of an upstream watershed is called specific discharge. The specific discharge of Kathmandu valley is computed by the records of daily discharges at the outlet point of Kathamndu Valley. For this purpose Chovar which is the outlet point of the Kathmandu valley is taken. From the daily discharges data from the year 1963 to 1980 mean monthly discharge ( shown in appendix) and average yearly discharge is calculated which is about 15.52 $m^3$/sec. From the cathchment area of Kathmandu Valley ( 585$km^2$ ), the specific runoff of the catchment area is computed. The annual rainfall (1819 mm ) and specific runoff (825mm) obtained from the above calculation is shown in table 4.3 (i). Average yearly water surplus contributed by all seven stations is computed and the comparison of climatic balance and specific runoff is shown below in table 4.3 (ii).

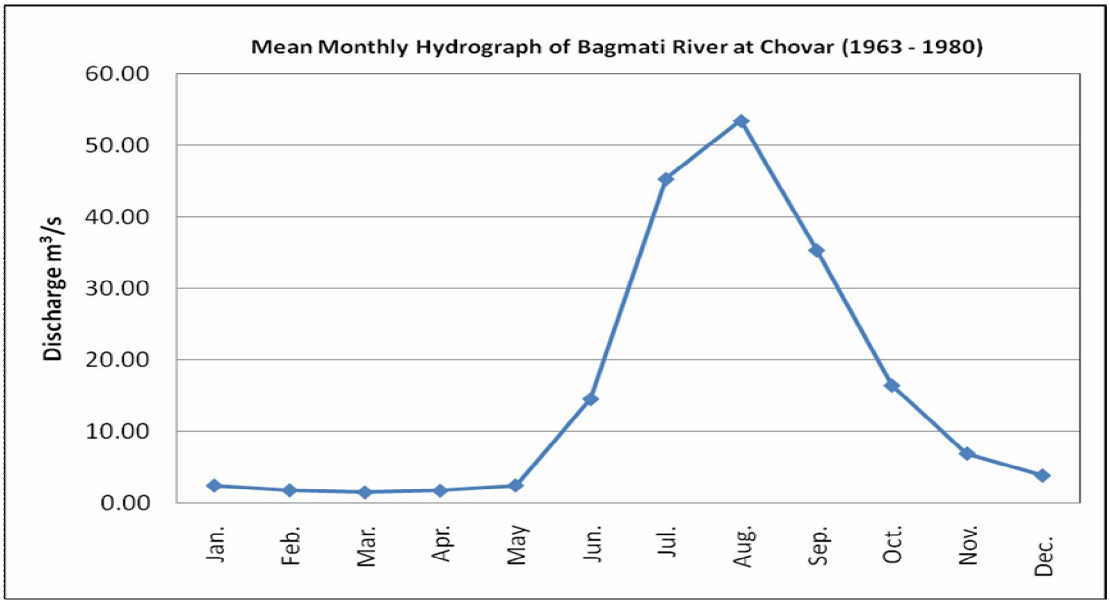


Fig. 4.3(i) Mean Monthly discharge

Table 4.3(i) Seasonal rainfall- runoff relation in Kathmandu Valley

| Parameters | Pre-Monsoon March-May (mm) | Monsoon June-Sep (mm) | Post-Monsoon Oct-Nov (mm) | Winter Dec-Feb (mm) | Total (mm) |
|---|---|---|---|---|---|
| Rainfall | 237 | 1461 | 68 | 53 | 1819 |
| Runoff | 25.93 | 659 | 103.79 | 36.56 | 825 |

Table 4.3 (ii) Water availability and surplus in Kathmandu Valley

| Station | Water surplus calculated by | Measured Specific | Difference |
|---|---|---|---|
| | climatic record. | Runoff | (%) |
| Kathmandu | 788 mm | 825 mm | 4.48% |

The measured specific runoff depth of Kathmandu valley is 825 mm. It is obtained from measured runoff data. From the water balance calculation, water surplus is estimated to be 788 mm. Both method yielded results with a difference of 4.48 %.

While the annual water surplus of the Kathmandu Valley is about 43% of the annual rainfall, there exists still a high depletion (2.5m/year) of ground water table (MPPW,2002), this is attributed to a) Excessive withdrawal of ground water( by means of deep boring, tube well etc.). b) Negligible ground water recharging (due to the massive increase in impervious land due to construction of paved area, pitched roads and residential area) ( Upadhayay, 2006).

In order to improve the water availability in the dry period, suitable structures like storages tanks may be useful for sustainable management of water. An example is shown in Nakarmi and Neupane (2000).

# CHAPTER FIVE
## CONCLUSION AND RECOMMENDATIONS

### 5.1 Conclusion:

The mean annual rainfall of the Kathmandu valley basin is 1819 mm while 80% of annual rainfall occurs during monsoon season. The boundaries receives higher value of annual rainfall as compared to central and inner parts of Kathmandu valley in all seasons.

The month of July is the hottest month with mean monthly temperature of 22.9 ˚C while January is the coldest month with mean monthly temperature of 9.6 ˚C. The average yearly temperature of the valley is 17.6 ˚C.

The study of water budget of Kathmandu valley depicts that there is high amount of water surplus (788 mm) compared to water deficit (23 mm). Therefore soil water demand for the dry period could be easily fulfilled by utilizing about 3% of water surplus.

There is an increasing trend of water surplus with elevation while there is no clear trend of water deficit with elevation.

The comparison of estimated water surplus from the study of water balance table and observed estimated specific discharge showed that the value of both method are close to each other, therefore it seems that the method of climatic water balance is applicable for the given condition.

It can be further concluded that there is high value of water surplus during monsoon season, so the drinking water problem of Kathmandu valley can be minimized if optimum measure is done for the natural and artificial ground water recharging for sustainable water resource management.

### 5.2 Limitations and Recommendations:

Since each station used in the study shows high degree of variation in the water budget components therefore dense network of stations with long-term recorded data should be used for better results. There are some problems in data missing and /or poor in data quality. This may affect on analysis of meteorological condition. Thus the missing of the data and their quality should be controlled and updated as far as possible.

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 can be adopted. It is also used to provide quantitative information on changing stream runoff and water table recharge associated with land use change. Furthermore, this helps to assist the irrigation project. So this study must be done on the national scale for the better results in agriculture and to manage the water resources.

## REFERENCES:


- Aryal,D.,(1993): **A study of water balance of Nepal**. An Unpublished M.Sc. Dissertation submitted to CDHM T.U.
- CBS, (2004): **Statistical Pocket Book.** Central Bureau of statistics, National Planning Committee, Government of Nepal.
- Karki, R.C., (2007): **Rainfall pattern over Kathmandu Valley during Summer Monsoon Season and Its- Long Term Change**. Unpublished M.Sc. Dissertation submitted to CDHM,T.U.
- Maharjan, T.R., (2008): **Rainfall Analysis and Comparision of Water Balance of Meteorological Stations in the Mountain Desert and Wet Zone in Gandaki Basin**. An Unpublished M.Sc. Dissertation submitted to CDHM, TU.
- Mather, J.R., (1972). **The Climatic Water Budget**, Lextington Books
- MPPW, (2002): **Optimizing Water Use in Kathmandu Valley,** Inception Report. Kathmandu, Ministry of Physical Planning and Works.
- Nakarmi, G.; Neupane, P.R., (2000): **An attempt to harvesting rainwater at Kubinde, Kavre, Nepal**. In Allen. R.; Schreier, H.; Brown S.; Shah, P.B.(eds.). PARDYP- research for development in the HKH – The First Three Years ( 1996 to 1999). ICIMOD, Kathmandu.
- Nayava, J.L., (1981):**Climates of Nepal and their implications for agriculture Development**. the Australian National University Canberra. An unpublished dissertation Paper for Ph. D, Australia.
- Pandey, R.K., (1987): **Geography of Nepal.** Center for Altitude Geography, Kathmandu, Nepal
- Regmi, S.K., (1998): **Synoptic perspective of drought with reference to rainfall in Nepal**. An Unpublished M.Sc. Dissertation submitted to CDHM, TU.

- Richard, G. Allen, R., Luis, S. Pereira, D., Smith, M., (1998): **Crop evapotranspiration, Guidelines for computing crop water requirements,** FAO irrigation and drainage paper-56, Rome.
- Thornthwaite, C.W., (1942): **Measurement of Evapotranspiration from Land and Water Surfaces**, US Department of Agriculture Technical Bulletin no.817.
- Thornthwaite, C.W., Mather J.R., (1955): **The Water Balance Publication of Climatology**, Vol. 8 No.1.
- Thornthwaite, C.W., Mather J.R., (1957): **Instruction and Tables for computing Potential Evapotranspiration and Water balance**, Publication in Climatology, 10-181-311.
- Upadhayay, S. (2006): **Study of Urban Flooding in Metropolitan Kathmandu**, An Unpublished M.Sc. Dissertation submitted to CDHM, T.U.
- Yogacharya, K.S., (1998): **Meteorological aspects.** A compendium on environmental statistics 1998 Nepal, HMG/ National Planning Commission Secretariat, Central Bureau of Statistics, Kathmandu, Nepal.

**Publications Web Sites**:

**http://www. fao.org**

**http://www. Drought.unl.edu/monitor/spi/htm**

**APPENDIX**

Table: water balance of Khokana

Station Name: Khokana

Field capacity: 200 mm

200 Assumed | Measured

| Year | D | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | 11 | 24 | 22 | 33 | 61 | 118 | 255 | 376 | 302 | 144 | 43 | 9 | 11 | 1398 |
| PE | 22 | 19 | 26 | 49 | 77 | 109 | 129 | 135 | 129 | 108 | 74 | 41 | 22 | 918 |
| P-PE | -11 | 5 | -4 | -16 | -16 | 9 | 126 | 241 | 173 | 36 | -31 | -32 | -11 | 480 |
| Acc | 138 | 5 | 5 | 5 | 4 | 13 | 139 | 200 | 200 | 200 | 171 | 146 | 138 | 1226 |
| ST | 138 | 143 | 140 | 130 | 120 | 129 | 200 | 200 | 200 | 200 | 171 | 146 | 138 | 1917 |
| ΔST | -8 | 5 | -3 | -11 | -10 | 9 | 71 | 0 | 0 | 0 | -29 | -25 | -8 | 0 |
| AE | 19 | 19 | 25 | 44 | 71 | 109 | 129 | 135 | 129 | 108 | 72 | 34 | 19 | 893 |
| WD | 3 | 0 | 1 | 5.2 | 6.0 | 0 | 0 | 0 | 0 | 0 | 2.3 | 6.7 | 3 | 25 |
| WS | 0 | 0 | 0 | 0 | 0 | 0 | 55 | 241 | 173 | 36 | 0 | 0 | 0 | 505 |

APPENDIX

Table: water balance of Khumaltar

Station Name Khumaltar
Field capacity : 200 mm 200 Assumed Measured

| Year | D | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | 15 | 17 | 18 | 28 | 53 | 104 | 202 | 322 | 253 | 149 | 55 | 5 | 15 | 1221 |
| PE | 24 | 19 | 24 | 49 | 74 | 105 | 129 | 131 | 115 | 105 | 74 | 41 | 24 | 890 |
| P-PE | -9 | -2 | -6 | -21 | -21 | -1 | 73 | 191 | 138 | 44 | -19 | -36 | -9 | 331 |
| Acc | 145 | 1 | 1 | 1 | 1 | 1 | 74 | 200 | 200 | 200 | 182 | 152 | 145 | 1157 |
| ST | 145 | 144 | 140 | 126 | 113 | 113 | 186 | 200 | 200 | 200 | 182 | 152 | 145 | 1899 |
| ΔST | -7 | -1 | -4 | -14 | -13 | -1 | 73 | 14 | 0 | 0 | -18 | -30 | -7 | 0 |
| AE | 22 | 18 | 22 | 42 | 66 | 105 | 129 | 131 | 115 | 105 | 73 | 35 | 22 | 862 |
| WD | 2 | 1 | 2 | 7 | 8 | 0 | 0 | 0 | 0 | 0 | 1 | 6 | 2 | 28 |
| WS | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 177 | 138 | 44 | 0 | 0 | 0 | 359 |

APPENDIX

Table: water balance of Ktm. Airport

Station Name Ktm.Airport
Field capacity : 200 mm 200 Assumed Measured

| Year | D | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | 12 | 16 | 18 | 34 | 57 | 115 | 254 | 374 | 321 | 183 | 60 | 8 | 12 | 1452 |
| PE | 22 | 19 | 26 | 53 | 80 | 109 | 129 | 131 | 125 | 105 | 74 | 41 | 22 | 914 |
| P-PE | -10 | -3 | -8 | -19 | -23 | 6 | 125 | 243 | 196 | 78 | -14 | -33 | -10 | 538 |
| Acc | 150 | 1 | 1 | 1 | 1 | 7 | 132 | 200 | 200 | 200 | 186 | 158 | 150 | 1237 |
| ST | 150 | 148 | 142 | 129 | 115 | 121 | 200 | 200 | 200 | 200 | 186 | 158 | 150 | 1952 |
| ΔST | -8 | -2 | -6 | -13 | -14 | 6 | 79 | 0 | 0 | 0 | -14 | -28 | -8 | 0 |
| AE | 20 | 18 | 24 | 47 | 71 | 109 | 129 | 131 | 125 | 105 | 74 | 36 | 20 | 889 |
| WD | 2 | 1 | 2 | 6 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 2 | 25 |
| WS | 0 | 0 | 0 | 0 | 0 | 0 | 46 | 243 | 196 | 78 | 0 | 0 | 0 | 563 |

APPENDIX

Table: water balance of Budanilkantha

Station Name: Budanilkantha

Field capacity : 200 mm — 200 Assumed — Measured

| Year | D | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | 9 | 16 | 21 | 38 | 62 | 190 | 339 | 553 | 511 | 236 | 56 | 8 | 9 | 2039 |
| PE | 24 | 22 | 29 | 53 | 77 | 105 | 122 | 124 | 122 | 102 | 71 | 43 | 24 | 894 |
| P-PE | -15 | -6 | -8 | -15 | -15 | 85 | 217 | 429 | 389 | 134 | -15 | -35 | -15 | 1145 |
| Acc | 145 | 1 | 1 | 1 | 1 | 86 | 200 | 200 | 200 | 200 | 186 | 156 | 145 | 1375 |
| ST | 145 | 140 | 135 | 125 | 116 | 200 | 200 | 200 | 200 | 200 | 186 | 156 | 145 | 2002 |
| ΔST | -11 | -4 | -5 | -10 | -9 | 84 | 0 | 0 | 0 | 0 | -14 | -30 | -11 | 0 |
| AE | 20 | 20 | 26 | 48 | 71 | 105 | 122 | 124 | 122 | 102 | 70 | 38 | 20 | 869 |
| WD | 4 | 2 | 3 | 5 | 6 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | 4 | 25 |
| WS | 0 | 0 | 0 | 0 | 0 | 1 | 217 | 429 | 389 | 134 | 0 | 0 | 0 | 1170 |

APPENDIX

Table: water balance of Nagarkot

Station Name Nagarkot
Field capacity : 200 mm 200 Assumed Measured

| Year | D | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | 11 | 19 | 20 | 30 | 54 | 145 | 328 | 484 | 481 | 269 | 73 | 9 | 11 | 1923 |
| PE | 24 | 19 | 24 | 49 | 71 | 84 | 90 | 96 | 92 | 77 | 62 | 41 | 24 | 729 |
| P-PE | -13 | 0 | -4 | -19 | -17 | 61 | 238 | 388 | 389 | 192 | 11 | -32 | -13 | 1194 |
| Acc | 160 | 1 | 1 | 1 | 1 | 62 | 200 | 200 | 200 | 200 | 200 | 170 | 160 | 1396 |
| ST | 160 | 160 | 157 | 142 | 131 | 192 | 200 | 200 | 200 | 200 | 200 | 170 | 160 | 2111 |
| ΔST | -11 | 0 | -3 | -14 | -12 | 61 | 8 | 0 | 0 | 0 | 0 | -30 | -11 | 0 |
| AE | 22 | 19 | 23 | 44 | 66 | 84 | 90 | 96 | 92 | 77 | 62 | 39 | 22 | 713 |
| WD | 2 | 0 | 1 | 5 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 16 |
| WS | 0 | 0 | 0 | 0 | 0 | 0 | 230 | 388 | 389 | 192 | 11 | 0 | 0 | 1210 |

APPENDIX

Table: water balance of Panipokhari

Station Name: Panipokhari
Field capacity : 200

200 Assumed ; Measured

| Year | D | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | 13 | 13 | 18 | 34 | 75 | 123 | 266 | 400 | 351 | 194 | 59 | 9 | 13 | 1555 |
| PE | 24 | 19 | 26 | 59 | 80 | 116 | 129 | 131 | 129 | 108 | 79 | 46 | 24 | 946 |
| P-PE | -11 | -6 | -8 | -25 | -5 | 7 | 137 | 269 | 222 | 86 | -20 | -37 | -11 | 609 |
| Acc | 142 | 1 | 1 | 1 | 1 | 8 | 145 | 200 | 200 | 200 | 181 | 150 | 142 | 1230 |
| ST | 142 | 138 | 133 | 117 | 114 | 121 | 200 | 200 | 200 | 200 | 181 | 150 | 142 | 1897 |
| ΔST | -8 | -4 | -5 | -16 | -3 | 7 | 79 | 0 | 0 | 0 | -19 | -31 | -8 | 0 |
| AE | 21 | 17 | 23 | 50 | 78 | 116 | 129 | 131 | 129 | 108 | 78 | 40 | 21 | 920 |
| WD | 3 | 2 | 3 | 9 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 6 | 3 | 26 |
| WS | 0 | 0 | 0 | 0 | 0 | 0 | 58 | 269 | 222 | 86 | 0 | 0 | 0 | 635 |

APPENDIX

Table: water balance of Godavari

Station Name: Godavari
Field capacity : 200 mm   200 Assumed   Measured

| Year | D | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | 19 | 20 | 23 | 31 | 59 | 127 | 311 | 525 | 445 | 267 | 69 | 9 | 19 | 1905 |
| PE | 24 | 19 | 26 | 53 | 77 | 102 | 115 | 117 | 112 | 93 | 68 | 41 | 24 | 847 |
| P-PE | -5 | 1 | -3 | -22 | -18 | 25 | 196 | 408 | 333 | 174 | 1 | -32 | -5 | 1058 |
| Acc | 166 | 1 | 1 | 1 | 1 | 26 | 200 | 200 | 200 | 200 | 200 | 170 | 166 | 1366 |
| ST | 166 | 167 | 165 | 148 | 135 | 160 | 200 | 200 | 200 | 200 | 200 | 170 | 166 | 2111 |
| ΔST | -4 | 1 | -2 | -17 | -13 | 25 | 40 | 0 | 0 | 0 | 0 | -30 | -4 | 0 |
| AE | 23 | 19 | 25 | 48 | 72 | 102 | 115 | 117 | 112 | 93 | 68 | 39 | 23 | 833 |
| WD | 1 | 0 | 1 | 5 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 14 |
| WS | 0 | 0 | 0 | 0 | 0 | 0 | 156 | 408 | 333 | 174 | 1 | 0 | 0 | 1072 |

APPENDIX

Table : Mean Dischage of Bagmati River at Chovar

| Month | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | Average Discharge ($m^3/s$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan. | 2.84 | 2.67 | 2.2 | 3.79 | 2.27 | 2.7 | 2.54 | 1.11 | 1.72 | 1.53 | 2.08 | 1.6 | 3.63 | 3.41 | 2.74 | 3.24 | 2.75 | 2.39 | 2.51 |
| Feb. | 1.3 | 1.56 | 1.27 | 2.28 | 1.61 | 2.1 | 1.49 | 1.05 | 1.38 | 2.05 | 1.46 | 0.72 | 3.24 | 3.17 | 2.32 | 1.36 | 3.66 | 1.13 | 1.84 |
| Mar. | 3.8 | 1.05 | 1.33 | 0.96 | 2.24 | 1.24 | 2.01 | 0.77 | 1.27 | 2.46 | 3.34 | 0.71 | 1.18 | 0.88 | 0.7 | 1.39 | 1.21 | 1.32 | 1.55 |
| Apr. | 2.64 | 1.74 | 2.23 | 0.33 | 2.2 | 0.77 | 1.21 | 0.6 | 5.61 | 1.68 | 0.52 | 1.14 | 1.54 | 2.7 | 2.14 | 2.61 | 1.88 | 0.51 | 1.78 |
| May | 2.38 | 2.3 | 0.98 | 1.28 | 1.25 | 1.34 | 2.06 | 0.85 | 5.06 | 0.73 | - | 4.26 | 2.59 | 5.76 | 3.52 | 5.28 | 1.47 | 1.78 | 2.52 |
| Jun. | 6.84 | 6.86 | 8.87 | 2.89 | 5.3 | 9.68 | 1.32 | 7.34 | 72.9 | 7.87 | 19.1 | 2.28 | 6.8 | 37.6 | 22.3 | 23.9 | 3.54 | 16.4 | 14.54 |
| Jul. | 27.6 | 32.5 | 36.5 | 29.7 | 38.2 | 53.2 | 17.9 | 57.6 | 44.2 | 94.5 | 49.2 | 47.3 | 65 | 40.8 | 45.5 | 61.5 | 34.2 | 41.3 | 45.37 |
| Aug. | 58.4 | 41.4 | 51.5 | 66.3 | 46 | 49.2 | 46.9 | 58.8 | 45.9 | 36 | 55.5 | 79.8 | 62.4 | 56.3 | 35 | 80.1 | 46.9 | 45.3 | 53.43 |
| Sep. | 36.4 | 34.6 | 17.7 | 23.3 | 27.4 | 18.8 | 22.9 | 43 | 22.1 | 38.8 | 62.1 | 61.6 | 92 | 34 | 19.5 | 39.4 | 19.3 | 24.1 | 35.39 |
| Oct. | 16.3 | 11.9 | 10.6 | 7.9 | 8.2 | 26.6 | 8.04 | 19.8 | 14.4 | 16.4 | 39.2 | 15.1 | 25.9 | 14.2 | 10.8 | 31.7 | 9.63 | 9.34 | 16.45 |
| Nov. | 7.76 | 5.87 | 9.57 | 4.84 | 5.07 | 6.54 | 3.64 | 8.31 | 7.08 | 9.67 | 9.27 | 7.18 | 8.74 | 6.57 | 6.33 | 9.6 | 5.22 | 4.36 | 6.98 |
| Dec. | 4.52 | 3.5 | 4.27 | 3.5 | 3.39 | 3.46 | 1.68 | 3.49 | 3 | 4.74 | 3.75 | 4.91 | 5.12 | 3.5 | 5.38 | 4.72 | 4.84 | 2.38 | 3.90 |
| Year | 14.2 | 12.2 | 12.3 | 12.3 | 11.9 | 14.6 | 9.31 | 16.9 | 18.7 | 18 | - | 18.9 | 23.2 | 17.4 | 13 | 22.1 | 11.2 | 12.5 | 15.52 |