ESTIMATION OF SURFACE RUNOFF AVAILABLE BY THRON MODEL FOR MAJOR CROPS OF KASKI DISTRICT, NEPAL

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Declaration and Copyright

Theresearch entitled "**Estimation of surface runoff available by thorn model for major crops of Kaski district, Nepal**" was carried out by me for the degree of Master of Hydrology and Meteorology under the guidance and supervision of Dr.Tirtha Raj Adhikari, Associate Professor, Central Department of Hydrology and Meteorology. I hereby declare that this research is my own original workand that it has not been presented and will not be presented by me to any other university for similar or any other degree award.

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LETTER OF RECOMMENDATION

This is to certify that works incorporated in this dissertation entitled "**Estimation of surface runoff available by thorn model for major crops of Kaski district, Nepal**" presented by Miss Ganga Nagarkoti for the partial fulfillment of the requirement for Master's Degree of Sciences in Hydrology and Meteorology of Central Department of Hydrology and Meteorology, Tribhuvan University which is the record of the candidates own work carried by her under my supervision and guidance. This dissertation has not been published or submitted for any other degree. There fore, this dissertation is recommended for final evaluation and acceptance.

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LETTER OF APPROVAL

The dissertation presented by **Miss. Ganga Nagarkoti** entitled "**Estimation of surface runoff available by thorn model for major crops of Kaski District, Nepal**" has been approved as a partial fulfilment of the requirement for the final year of the Master's Degree in Hydrology and Meteorology.

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LETTER OF ACCEPTENCE

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ABSTRACT

Variety of climatic conditions, topographic area, physiographic conditions, seasonal rain patterns, industrial areas, population affect water availability in those areas and the result directly appear on agriculture. It is well known that agriculture provides employment to about 80% of economically active population of Nepal, it increases GDP of country. The main cereal crops produced are used for food and fodders. So for maximum crop yield and systematic irrigation pattern, the availability of water should be known.

This study reviews calculation of amount of available surface runoff for major crops of Kaski district using Thronthwaite monthly water balance model. Kaski district is in center point of country with area of 2017 square kilometer. Its altitude ranges from 450 to 8091 masl and is covered mostly by forest, agriculture, snow, barren land, water resources. Paddy, maize, wheat and millet are major cereal crops cultivated in Kaski district. District receives maximum rainfall in July and minimum rainfall in November; Maximum temperature occurs in June and Minimum temperature occurs in January. The monthly surface runoff of Bhadaure, Ghandruk, Lamachour, Lumle, Pamdur, Pokhara Airport, Malepatan, Sikles and salyan is calculated using Thronthwaite monthly water balance model in millimeter. Blaney-Cridle climatic method is used for calculation of crop water need at different stages of crop growth. The surface water availability is calculated from difference of monthly surface runoff and monthly total crop water need. Spatial and temporal variation of water surplus and deficit is also analyzed.

Acronyms and Abbreviations

DHM	:	Department of Hydrology and Meteorology
ETo	:	Reference Crop Evapotranspiration
Etc	:	Evapotranspiration of crop under standard condition CWR:
Kc	:	Crop coefficient (constant)
FAO	:	Food and Agriculture Organization
GIS	:	Geographic Information System
GUI	:	Graphical User Interface
ICIMOD	:	International Center for Integrated Mountain Development
MoAD	:	Ministry of Agricultural development
GDP	:	Gross Domestic Product
HMG	:	His Majesty Government
PET	:	Potential Evapotranspiration
AET	:	Actual Evapotranspiration
ST	:	Soil-moisture Storage
SWT	:	Soil-moisture Storage Withdrawal
STC	:	Soil-moisture Storage Capacity
DRO	:	Direct Runoff
P	:	Precipitation
USGS	:	United States Geological Survey
Masl	:	Mean sea level pressure

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CHAPTER I: PRELIMINARY

1.1 Introduction

Water is available as fresh water (snow, glacier), surface water (such as lakes, rivers, reservoirs) and groundwater in the earth. Water is constantly moving on the Earth between the atmosphere, ocean, and different fresh water bodies. Climate, land use, local geology, physiographic condition, population, seasonal rainfall all affects the availability of water resources. One of the main and easily accessible water resources is surface runoff. It is a flow of water that occurs when rainfall, melt water or other sources of water that flows over earth surface exceeds a soil's maximum saturation level and all surface depression storage is filled. It is considered as major component of hydrological cycle.

Rainfall is the main source of surface runoff that varies both temporally and spatially. Nepal receives about 79.8% of the total annual rainfall during summer monsoon (June to September), 12.5% of the total annual rainfall in pre-monsoon (March to May), 4.2% of total annual rainfall in post monsoon (October to November) and 3.5% of total annual rainfall in winter (December to February) season(DHM, 2015).Nepal is mountainous country so the spatial feature of the rainfall is affected by the topography and altitudinal variations.

Water surplus or water deficit in agriculture is the factor to determine whether the surface runoff is sufficient or not for crop growth. Water surplus occurs where there is excess water available to the drainage system. This occurs when precipitation exceeds evapotranspiration and the excess is not being used by plants. Water deficit occurs where there is insufficient water to the drainage system. This occurs when evapotranspiration exceeds precipitation.

1.2 Rational of study

This study is based on agriculture and available water for irrigation. Since Nepal is agriculture based country, contributes about one third of GDP and provides employment to 80% of economically active population, research on agriculture is very important in context of Nepal. Food is important for human beings for survival. Water is necessary for agriculture and is utilized by crops through rainfall and irrigation. Nepal is rich in water resources such as river basin, snow, glaciers, monsoon rainfall, ground water etc. Agricultural water requirement is fulfilled through these resources of water. So it is very necessary to know the crop water requirement and availability of surface water for irrigation in certain area. If any area have water surplus then it can be utilized for another high water demand area and if any area have water deficit then the water demand can be fulfilled with many processes such as drainage systems, reservoirs, dams etc. These increases agricultural productivity as well as GDP of country and better utilization of water.

1.3 Topography of Nepal

Nepal is a land locked country that covers an area of 147,181 km2 between India and China. It covers 0.03% area of the world and 0.3% area of Asia. Geographically, Nepal is situated from 26°22’ to 30° North latitude and from 80°04’ to 88°12’ East longitudes. Its elevation varies from about 80 meters above sea level in low lying areas (Terai plain) to 8848 meters above sea level in the Himalaya (Mount Everest).

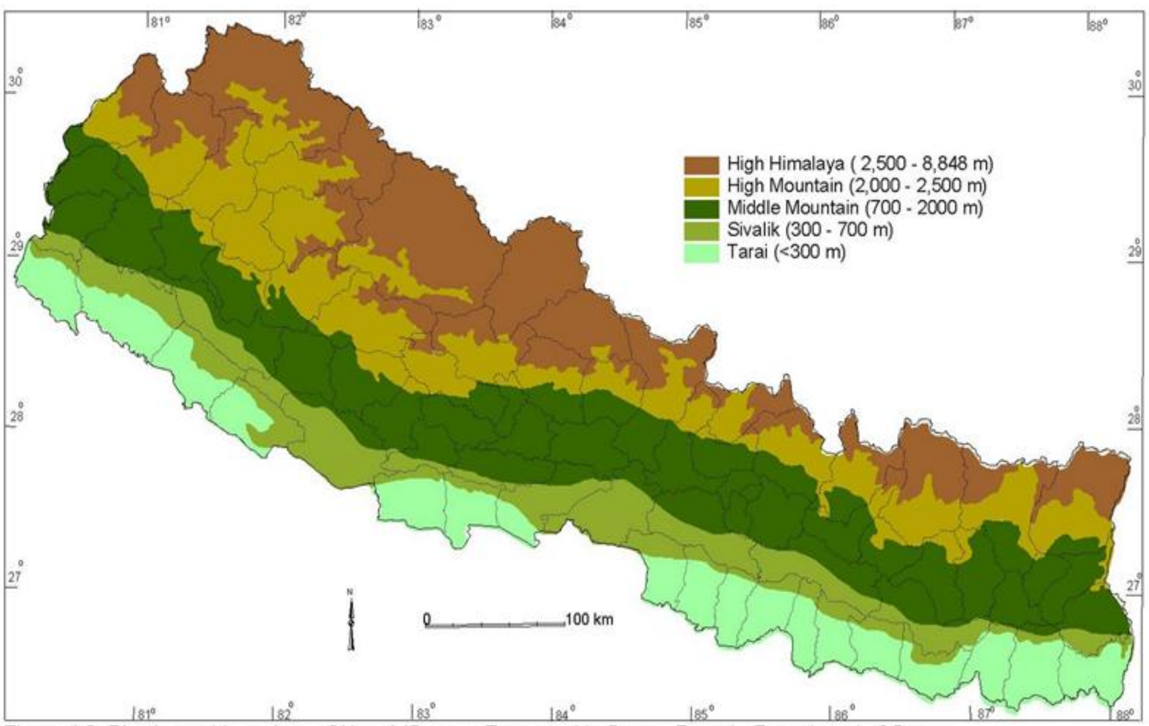


Figure 1 : Map of Topographic division of Nepal (Source: Topographic Survey Branch, Department of Survey, HMG, Nepal,1983)

Topographically, Nepal is divided into five physiographic regions: Terai, Siwalik range, Middle Mountains, High Mountains, High Himalayas and administratically, Nepal is divided into seven provinces.

1.4 Agriculture in Nepal

Agriculture, the major sector of Nepalese economy provides employment opportunities to 66 percent of the total population and contributes about 36 percent in the GDP.(MoAD). Nepalese agricultural sector highly depends on water availability and seasons especially monsoon season. Rice, wheat, maize, millet, barley and buck wheat are major growing cereal crops in Nepal.(FAO).

Nepal has three major agro-ecological zones terai plain, hilly region and mountainous region. Different geological, climatological and hydrological characteristics of these zones are responsible for distinct and varied agricultural land uses.

1.4.1 Terai region

This is most fertile zone of Nepal and occupies 23 percent of nation's land ranging from 59 to 700 meters elevation. Over 40 percent of available agricultural land is cultivated and due to the flat as well as low land surface irrigation is easily accessible. Flooding is common in these regions during monsoon season.

1.4.2 Hilly region

Hills are characterized by sloping lands and small valleys ranging from 700 to 3000 meters elevation. This region comprises 42 percent of nation's land mass but only 20 percent is cultivated. The area is characterized by high ridges and steep slopes around numerous streams giving rise to many microclimates.

1.4.3 Mountainous regions

This region is characterized by steep and rugged terrain lying between 3000 to 8848 meters. Only 5 percent of land in this region is suitable for cultivation.

1.5 Weather and Agriculture

Weather is an atmospheric condition that has an important impact on agriculture. Growth of crops highly depends on rainfall and temperature as these parameters are responsible for water availability and evapotranspiration. Agriculture is sensitive to short-term changes in weather that affect the production of crops. Insufficient rain and increasing temperature cause drought, whereas intense rain in short period reduces ground water recharge by accelerating runoff and causes floods. Both the situations induce negative effects in the agriculture.

1.6 Climate of Nepal

The climate in Nepal varies from sub-tropical to alpine within a short distance due to tremendous variation in topography and altitude (60 to 8,848 m). These factors along with direction of mountain slope have created numerous micro-environments. Alpine, cool temperate, warm temperate, subtropical and tropical climates prevail in Nepal. The snow line lies on around 2,500 m in winter and 4,000 m in summer. Snow rarely falls below 1,500 m altitude. On shaded north, snow remains considerably longer than on south facing slopes. The average annual rainfall is estimated as 1,600 mm, about 80% of which falls between June to September. The mean annual precipitation ranges from nearly 200 mm in rain shadow area near the Tibetan plateau to 4,600 mm along the southern slopes of Annapurna mountain range. Most of the winter rainfall occurs during December to February. Total number of rainy days varies from 24 to 181 days. Annual sunshine hours vary between 922 to 2,820 hours. The recorded maximum temperature during the summer varies from 25o C to 46o C and the recorded minimum temperature during the winter varies from - 26o C to nearly freezing point in the crop growing areas. Winter, spring, summer and autumn seasons prevails in the country.

1.7 Objectives of the study

Objective of this study is to estimate surface water availability for major crops of Kaski district and analyze temporal and spatial variation of water availability by calculating surface runoff and crop water need of major crops.

1.8 Limitations of the study

There are some limitations in accurate estimation from the study.

- Unavailability of data from remote places.
- Lack of reliable agricultural data.
- Insufficient Agro-meteorological data such as wind, Evapotranspiration.

CHAPTER II: LITERATURE REVIEW

2.1 Major cereal crops of Nepal

2.1.1 Paddy

Paddy is the first most important food crop in Nepal and among all cereal crops paddy occupies first position in terms of area (42.2%) and production (51.7%) (MoAD, 2015a). It is cultivated in many parts of the country. Rice crop is suited in regions with high humidity, prolonged sunshine with an assured supply of water. Rice needs relatively high temperature for their optimum growth and development. This crop is grown in wet (monsoon) season and also in spring season in two crop rice growing areas. The main season rice is planted from 3rd week of May to 3rd week of June depending on variety and rainfall. The rice is harvested from 3rd week of October to 2nd week of December and left for 4 to 6 days in field. On average total crop water need for paddy is 450 to 700mm depending upon type, sunshine duration, temperature, location, etc.(C. Brouwer, 1986). Rice area and production in eastern region are higher and decline from east to west due to large variation in rainfall and socio economic conditions in among the regions. However central region accounts for higher grain yield due to the fertile soil and higher use of chemical fertilizers and organic manures. For paddy growth, night temperature plays important role especially during reproductive phase. Low night temperature results in high productivity. High amount of solar radiation, after flowering in rice, gives more production and vice versa. (Basnet, 2008). Temperature increase is more harmful during day than during night. Heat susceptible variety of paddy may suffer from a high percentage of spikelet sterility induced by high temperature and this occurs largely on the day of flowering. Low temperature at night reduces expansion of leaves resulting in less photosynthesis and increasing specific leaf weight and thereby assimilate partitioned to the roots increases. Hence rising maximum temperature has negative impact on rice yield, lower temperature prolongs the growth duration of rice and reduces crop growth rate. (Yam K Rai, 2011). Rice is cultivated in mono-crop system.

2.1.2 Maize

Maize is the most important food crops in the hills. It comes second only to rice as in production and acres planted. The average upper limit of maize is considered 2,300 meters. At higher elevation maize is either single annual crop or is rotated with millet or barley. In terai it is grown both as summer and winter crop.(Khadka, 1987). Maize is a traditional food cultivated mainly in the rain fed upland hills for food, feed and fodder. It is grown under rain fed conditions in summer from April to August. (: Paudyal, 2001) In the terai and low lying river basin areas maize is also grown in winter and spring with irrigation. Maize is cultivated in both irrigated and non irrigated land across different agro-climatic condition of the country.(Paudyal, Ransom, Rajbhandari, Gerpacio, & Pingali, 2001). Maize requires 500 to 800 mm of water according to types and climatic conditions (C. Brouwer)(FAO). The optimum temperature range for germination is 20 to 30 degree Celsius while optimum soil moisture content should be approximately 60% of soil capacity. Maize is a warm weather crop and is not grown in areas with low mean daily temperature. Frost can damage maize at all growth stages and a frost free period of 120 to 140 days required to prevent damage. At maturity each maize plant have used 250 liter of water in absence of moisture stress. The most suitable soil for maize growth is sandy and clay-loam soils, the texture classes between these soils have air and moisture regimes that are optimal for healthy maize production (Plessis, 2003). Maize is cultivated in multi-crop system.

2.1.3 Wheat

Wheat is the third most important crop in Nepal after rice and maize comprising 0.6 m ha land of country. It is cultivated in wide range of environment ranging from terai to high hills as winter crop (Oct/Nov to Apr/May) and in the inner Himalayas as summer crop (Mar/Apr to Sept/Oct) (Bhandari H.S, 1997). In Nepal over 80 percent of wheat cultivation is under rice-wheat system. Due to the varied agro-ecological diversity of the country, it is possible to plant same cultivar in both winter and summer season. (Bal K. Joshi, 2006). Wheat sowing time varies from 3rd week of November to last week of December. Generally only one irrigation is practiced in wheat crop 30 days after sowing, because two irrigation in late sown delays maturity period. So the crop is affected by hot westerly wind and grains are shriveled. The crop is harvested between 2nd week of

March to 2nd week of April. The best climatic condition for wheat production is temperate climate. High temperature generally limits yield if wheat crop. (OYEWOLE, 2016). Temperature and humidity is considered as major yield limiting climatic factor. Under very dry condition, high soil temperature can negatively impact on yield, while humidity will favor incidence of pests and diseases. (Olugbemi, 1990). Temperature plays important role in wheat cultivation. Wheat thrives best in well drained fertile loam sand to medium textured clay loam and area of low night temperature.(OYEWOLE, THE WHEAT CROP, 2016). The wheat crop grown on sandy soil should be irrigated frequently than those cultivated on clayish soil. For, sandy loam irrigation interval of 5 to 7 days until booting stage is recommended and subsequent irrigation should be 7 days interval. Water stress at flowering will negatively affect yield by reducing grain number and weight. Irrigation should be terminated two weeks to crop harvest.

2.1.4 Millet

Finger millet is the fourth major cereal crop of Nepal according to area and production. Millet represents diverse group of small seeded grasses grown for food, feed or forage. (Lata, 2015). Six major types of millet are finger millet, foxtail millet, kodo millet, proso millet, barnyard millet and little millet (FAO). The varieties of species differ in their physical characteristics, quality, soil and climatic requirement as well as growth duration (FAO).The most common millet grown in Nepal is Finger millet and it is one of the important crops cultivated in hills and mountains. The average upper limit for crop cultivation is around 2,250 meters altitude. Below 1,000 meters altitude millet is transplanted after maize and from 1,000 meters to 1,500 meters considerable part of growing season overlaps with maize. Above 1,500 meters growing period of millet completely overlaps with maize.(Khadka, 1987). The majority of finger millet is mainly grown in relay with maize. (Baniya, 1990). Finger millet is planted after 55 days of maize seeding. (Tika Bahadur Karki, 2014). Harvesting and threshing of Finger millet is done mainly in October–November. (Rachana Devkota, 2016). Millet needs very little water for their production and can be cultivated in non irrigated conditions or in very low rainfall regimes. Finger millet can be grown in low fertility soil and is not dependent of use of chemical fertilizers. (Gull A., 2014). Millets are the mostly adaptable crop as they can withstand droughts and extreme heat, stress from moisture and temperature variation, heavy to sandy infertile soils with poor water holding capacity, degrees of soil acidity and alkalinity and precipitation variation so, millets can be cultivated in a wide range of variable environmental conditions. The high adaptability is due to the strong, deep root system which can be able to extract water from the soil. Millet is cultivated in multi-crop system.

2.2 Crop Water Need (ET crop)

Some amount of water is extracted from soil by plant root to grow. This amount of water escapes to the atmosphere from leaves and stem and the process is called Transpiration. Some amount of water on open soil surface and on plant's leaves, stem also escape as vapor and the process is called evaporation. So the crop water need is defined as the depth or amount of water needed to meet the water loss through evapotranspiration. The crop water need is usually expressed in mm/day, mm/month, and mm/season. The crop water need refers to crop grown under optimal conditions such as a uniform crop, actively growing, completely shading the ground, free of diseases and favorable soil condition. The crop water needs mainly depends on:

- Climate:
  Crop needs more water in sunny and hot climate than in cloudy and cool climate.
- Type of crop:
  Crops like maize or sugarcane needs more water than millet or sorghum.
- Growth stage of the crop:
  Fully grown crop needs more water than crop that have just been planted.

2.2.1 Influence on crop water need

2.2.1.1 Climatic influence on crop water need

The major climatic factors that influence crop water needs:

- Sunshine
- Temperature
- Humidity
- Wind speed

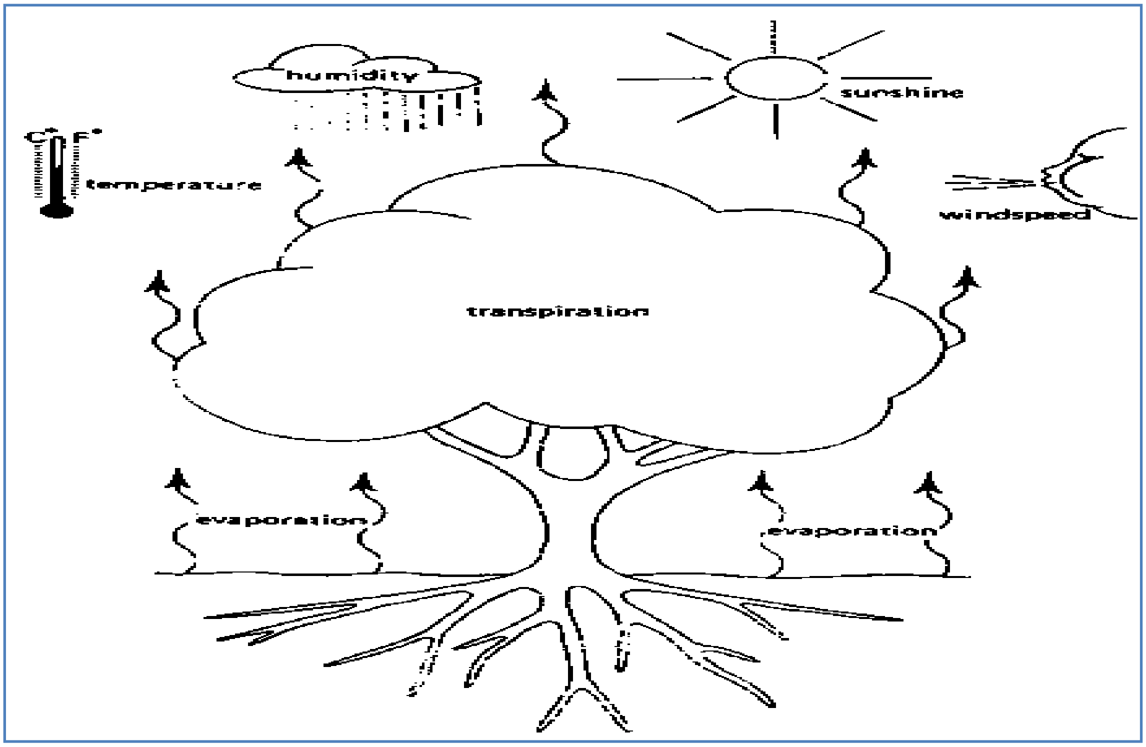


Figure 2 : major climatic factors that influence crop water needs

The highest crop water need is found in areas with hot, dry, windy and sunny climate whereas the lowest crop water need is found in areas with cool, humid, cloudy and little or no wind. Any one crop grown in different climatic zones will have different crop water need. So it is useful to take standard crop or reference crop and determine how much water the crop needs per day in various climatic regions. The influence of climate on crop water need is given by reference crop Evapotranspiration (ETo).

2.2.1.2 Influence of crop type on crop water need

1. Influence of crop type on daily water needs

On daily peak water need, different types of crops that is grown on same place, will have different crop water need. Forexample Maize and Radish

2. Influence of crop type on seasonal water needs

Crop type has influence on duration of the total growing season of the crop. So it effects on seasonal crop water need. For example there are many verities of rice with different growing cycle from 90 days to 150 days. Rice with 150 days growth cycle will need more water than rice with 90 days growth cycle. For these two types of rice crop daily peak water need may be same but seasonal water need, will be different. Certain crop grown in cooler months will need less water as compared to crop grown in hotter months.

2.2.1.3 Influence of growth stage of the crop on crop water need

A fully grown crop will need more water than a crop just has been planted. When the plants are small evaporation is more important than transpiration and when the plants are fully grown transpiration is more important than evaporation.

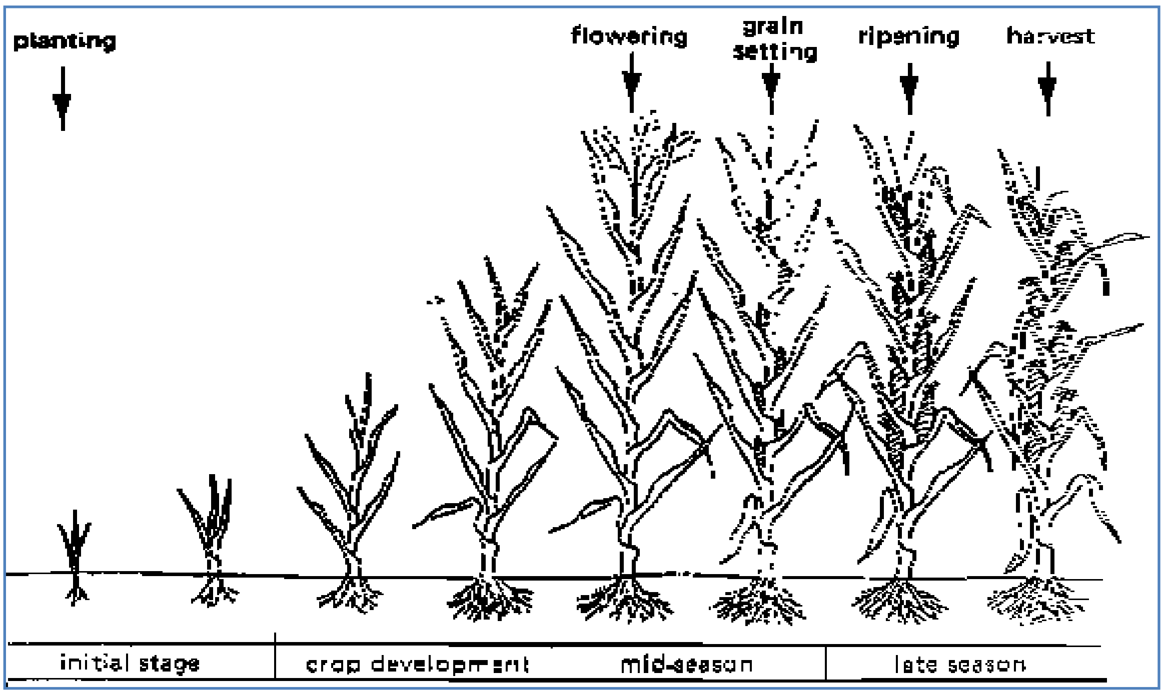


Figure 3 : Growth stage of a maize crop

At the initial stage crop water need is estimated at 50 percent of crop water need during the mid-season stage. In crop development stage crop water need gradually increases and reaches its maximum value at the beginning of mid-season stage. In late season stage , fresh harvesting crops needs same amount of water as in mid season stage and for dry harvesting crops no water is irrigated.

2.3 Surface runoff process

Rainfall firstly being intercepted by vegetation reaches the ground surface and infiltrates into the soil until the rainfall intensity reaches infiltration capacity of the soil and after filling depression storage surface runoff is generated. Runoff generates until the rainfall intensity exceeds actual infiltration capacity of the soil. (Rainfall-Runoff Analysis, FAO)

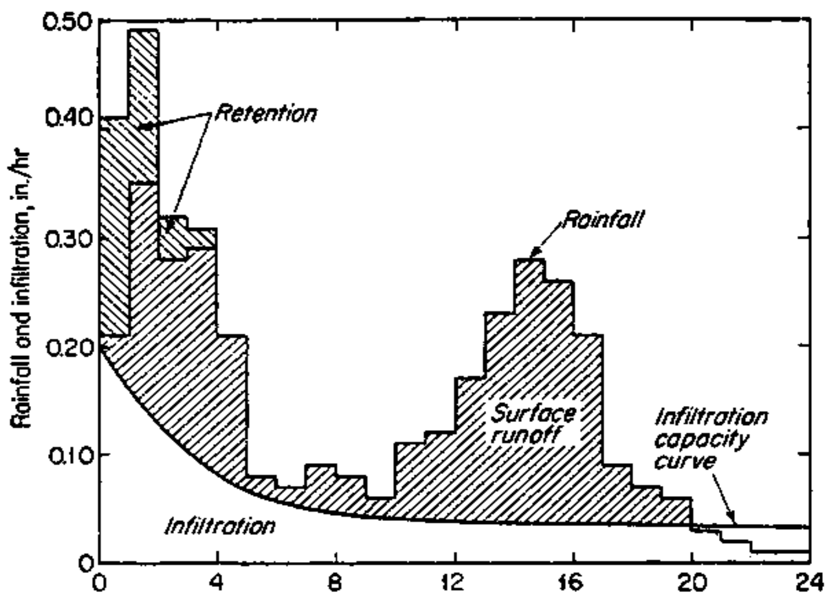


Figure 4: Schematic diagram of relationship between rainfall, infiltration and runoff (Linsley, 1958)

For water resource management and planning the runoff is most important hydrological parameter. The landscape of Nepal has unique pattern as flashy rivers and heavy rainfall-runoff. And due to the lack of knowledge of high altitude hydrology, it is challenging part to apply model in Nepal. So the regional modeling is helpful tool to predict hydrological variable at the ungauged stations in Nepal. (Jayandra Prasad Shrestha, 2014)

In case study of Rangoon watershed of Nepal, the mean annual rainfall and average annual temperature data series is in increasing trend whereas mean annual runoff data is in falling trend. The study area has cultivated land, urbanization, fragile ecosystem, unstable and fragile hill slopes so further study should be take to assess agricultural practice, land use patterns, sedimentation erosion rate and their impacts on watershed such as rainfall runoff etc. The analysis of these data gives identification of any serious events; hence assessment of trend of data set would be helpful to water resources managers to minimize the effects of vulnerable disasters. (Amar Bahadur Pal#1, 2017)

The research on estimation of surface runoff of Warasgaon dam catchment shows high surface runoff in the western part and most part is endowed by dense forest in medium slope and rich in floras. As these areas may prone to soil erosion due to high rainfall and runoff too, these areas can be developed as ecotourism destination by facilitating proper ecotourism infrastructure and services under policy guidelines. This will help to conserve and maintain the biological richness of the area as well as economic upliftment of the local people by providing employment and opportunities in the field of ecotourism management. Also, this runoff potential can be used for the Artificial Recharge by constructing the Nala Bundies and Farm ponds at suitable sites. Also, constructing the structures like check dams water can be stored and helpful for the dry summer days for drinking as well as agricultural purposes. (A. A. KULKARNI, 2018)

2.4 Factors affecting runoff

Runoff is affected by meteorological and physical factors:

Meteorological factors affecting runoff

- Type of precipitation(rain, snow, sleet, etc)
- Rainfall intensity
- Rainfall amount
- Rainfall duration
- Distribution of rainfall over basin
- Direction of storm movement
- Precipitation that occurred earlier and resulting soil moisture
- Other meteorological and climatic conditions (temperature, wind, relative humidity and season)

Physical factors affecting runoff

- Land use
- Vegetation
- Soil type
- Drainage area

- Basin area
- Elevation
- Slope of the land
- Drainage network pattern
- Ponds, lakes reservoirs, sinks, etc. in the basin, which prevent or delay runoff from continuing downstream

2.5 Runoff Coefficients

The runoff coefficient (Kc) is a dimensionless value that relates the amount of runoff (mm) to the amount of rainfall (mm) received.

Kc = Runoff / Rainfall

The value is larger for areas where there is low infiltration with high runoff and lower values for permeable, well vegetated areas.(waterboards.ca.gov)

CHAPTER III: DESCRIPTION OF MODELS AND METHODS

3.1 ArcGIS 10

ArcGIS is a geographic information system (GIS) that helps in working with maps and geographic information. It is used for: creating and using maps; compiling geographic data; analyzing mapped information; sharing and discovering geographic information; using maps and geographic information in a range of applications; and managing geographic information in a database. It is a computer based system that stores geographically referenced data, links it with non-graphic attributes allowing for a wide range of information processing including manipulation, analysis and modeling. ArcGIS Desktop 10 is the newest version of GIS software produced by ESRI. ArcGIS Desktop is comprised of a set of integrated applications, which are accessible from the start menu of computer. It is equipped with excellent Graphical User Interface (GUI), which enables visualization, exploring and the analysis of spatial data. The ArcGIS is capable of displaying, viewing, editing vector datasets called shape files. It has also the facility to display the tables, charts, layouts associated with the shape files. There are various extensions are incorporated in the ArcGIS to perform different tasks. The processing, modeling, visualization and interpretation of grid based raster data can be performed using the spatial analyst extension. Nowadays ArcGIS is widely used in various sectors like health, education, environment, defense etc.

3.2 Background of the Thronthwaite water balance model

Many researches have been done to examine various component of hydrologic cycle such as precipitation, evapotranspiration, and runoff; by using monthly water balance model (Gregory J. McCabe, 2007). Such models have been used to estimate the global water balance (Mather J. , 1969)(Legates, 1992)(Legates D. a., 2005); to develop climatic classification (Thornthwaite C. , 1948); to estimate soil moisture storage (Alley, 1984)(Mintz, 1992), Runoff (Alley, 1984)(Alley, 1985)(Yates, 1996)(Wolock, 1999) and irrigation demand (McCabe, 1999); and to evaluate the hydrologic effects of climate change (McCabe G. a., 1989);(Yates, 1996);(Strzepek, 1997);(Wolock, 1999). In this studyThronthwaite monthly water balance model is used for estimation of runoff. This water balance model is driven by graphical user interface (GUI) developed by the U.S.

Geological Survey. It is easy to modify water-balance parameters and estimate various water-balance components for a specified location. This model can be used as a research tool, an assessment tool, and as a tool for classroom instruction.

The water-balance model (Figure 5) analyses the allocation of water among various components of the hydrologic system using a monthly accounting procedure based on the A Monthly Water-Balance Model Driven By A Graphical User Interface By Gregory J. McCabe and Steven L. Markstrom methodology originally presented by Thornthwaite ((Thornthwaite, 1948), (Mather, 1978) (Mather J. , 1979) (McCabe, 1999). Inputs to the model are mean monthly temperature (T, in degrees Celsius), monthly total precipitation (P, in millimeters), and the latitude (in decimal degrees) of the location of interest. The latitude of the location is used for the computation of day length, which is needed for the computation of potential evapotranspiration (PET).

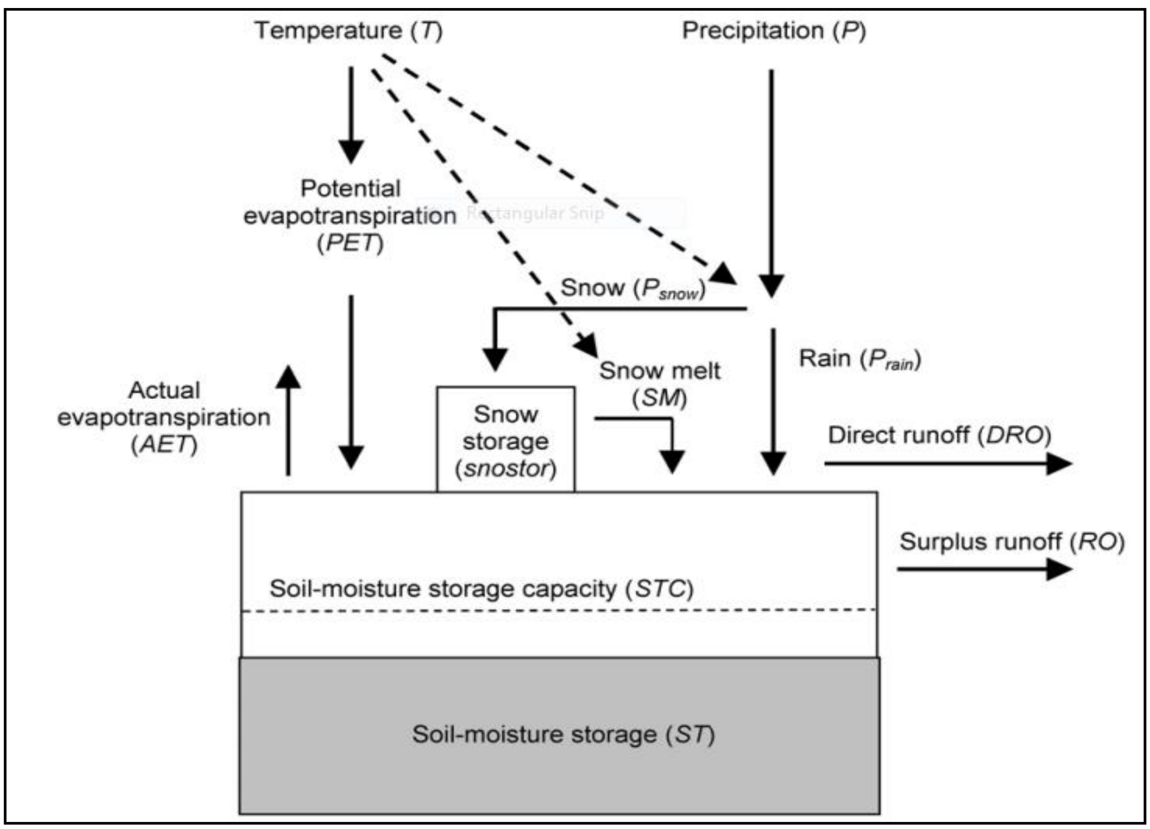


Figure5 : Diagram of the water balance model

Method of analysis

Snow Accumulation The first computation of the water-balance model is the estimation of the amount of monthly precipitation (P) that is rain (P_{rain}) or snow (P_{snow}), in millimeters. When mean monthly temperature (T) is below a specified threshold (T_{snow}), all precipitation is considered to be snow. If temperature is greater than an additional threshold (T_{rain}), then all precipitation is considered to be rain. Within the range defined by T_{snow} and T_{rain}, the amount of precipitation that is snow decreases linearly from 100 percent to 0 percent of total precipitation. This relation is expressed as:

$$P_{snow} = P \times \left[\frac{T_{rain} - T}{T_{rain} - T_{snow}} \right] . \qquad (1)$$

P_{rain} then is computed as:

$$P_{rain} = P - P_{snow} . \qquad (2)$$

Direct Runoff

Direct runoff (DRO) is runoff, in millimeters, from impervious surfaces or runoff resulting from infiltration-excess overflow. The fraction (drofrac) of P_{rain} that becomes DRO is specified; based on previous water-balance analyses, 5 percent is a typical value to use (McCabe, 1999). The expression for DRO is:

$DRO = P_{rain} \times drofrac$ ……………….(3)

Direct runoff (DRO) is subtracted from Prain to compute the amount of remaining precipitation (P_{remain}):

$P_{remain} = P_{rain} - DRO$ ……………….(4)

Evapotranspiration and Soil-Moisture Storage

Actual evapotranspiration (AET) is derived from potential evapotranspiration (PET), P_{total}, soil-moisture storage (ST), and soil-moisture storage withdrawal (STW). Monthly PET is estimated from mean monthly temperature (T) and is defined as the water loss from a large, homogeneous, vegetation-covered area that never lacks water (Thornthwaite C. , 1948) (Mather J. 1., 1978). Thus, PET represents the climatic demand for water relative to the available energy. In this water balance, PET is calculated by using the Hamon equation (Hamon, 1961):

$PET_{hamon} = 13.97 \times d \times D^2 \times W_t$ ……………..(5)

WherePET_{Hamon} is PET in millimeters per month, d is the number of days in a month, D is the mean monthly hours of daylight in units of 12 hrs, and Wt is a saturated water vapor density term, in grams per cubic meter, calculated by:

$W_t = (4.95 \times e^{0.062 \times T})/100$ ……………….(6)

Where'T' is the mean monthly temperature in degrees Celsius. (Hamon, 1961).

When P_{total}(total liquid water input to the soil i.e. Premain plus melted snow to the soil) for a month is less then PET, then AET is equal to P_{total} plus the amount of soil moisture that can be withdrawn from storage in the soil. Soil-moisture storage withdrawal linearly decreases with decreasing ST such that as the soil becomes drier, water becomes more difficult to remove from the soil and less is available for AET.

STW is computed as follows:

$SWT = ST_{i-1}-[abs\ (P_{total}–PET) \times (ST_{i-1}/STC)]$ …………(7)

Where ST_{i-1} is the soil-moisture storage for the previous month and STC is the soil-moisture storage capacity. An STC of 150 mm works for most locations (McCabe, 1999) (Wolock, 1999).

If the sum of P_{total} and STW is less than PET, then a water deficit is calculated as PET–AET. If P_{total}exceeds PET, then AET is equal to PET and the water in excess of PET replenishes ST. When ST is greater than STC, the excess water becomes surplus (S) and is eventually available for runoff.

Runoff Generation

Runoff (RO) is generated from the surplus, S, at a specified rate (rfactor). An rfactor value of 0.5 is commonly used (Wolock, 1999). The rfactor parameter determines the fraction of surplus that becomes runoff in a month. The remaining surplus is carried over to the following month to compute total S for that month. Direct runoff (DRO), in millimeters, is added directly to the runoff generated from surplus (RO) to compute total monthly runoff (RO_{total}), in millimeters.

Running the Water-Balance Program

The window for the Thornthwaite monthly water-balance program will behave like any other window on the desktop. Resize, iconify, or close it like any other application by dragging the borders and clicking on the window controllers in the upper corners of the frame. Figure 6 is a screen image of the program's graphical user interface.

The water-balance model has seven input parameters (runoff factor, direct runoff factor, soil-moisture storage capacity,latitude of location, rain temperature threshold, snow temperature threshold, and maximum snow-melt rate of the snow storage) that are modified through the graphical user interface (Figure 6). The range and default values for these parameters are set by the model. These values are changed by clicking on the corresponding slider bar and dragging the value. The system will not allow invalid values to be entered. Latitude for all station is 28 degrees used; default value is used for rain-temperature threshold. Runoff factor is calculated from Table 3-1, for which slope is calculated reference with Pokhara Airport shown in Appendix L and land cover is assumed farmland. Soil moisture storage capacity is taken 140mm/meter as for loamy soil, it is (100 to 175) mm/meter(FAO).

Table 3-1: Runoff coefficient for different soil and slope areas (McCuen, 1998)

	Runoff Coefficient, C					
	Soil Group A			Soil Group B		
Slope :	< 2%	2-6%	> 6%	< 2%	2-6%	> 6%
Forest	0.08	0.11	0.14	0.10	0.14	0.18
Meadow	0.14	0.22	0.30	0.20	0.28	0.37
Pasture	0.15	0.25	0.37	0.23	0.34	0.45
Farmland	0.14	0.18	0.22	0.16	0.21	0.28
Res. 1 acre	0.22	0.26	0.29	0.24	0.28	0.34
Res. 1/2 acre	0.25	0.29	0.32	0.28	0.32	0.36
Res. 1/3 acre	0.28	0.32	0.35	0.30	0.35	0.39
Res. 1/4 acre	0.30	0.34	0.37	0.33	0.37	0.42
Res. 1/8 acre	0.33	0.37	0.40	0.35	0.39	0.44
Industrial	0.85	0.85	0.86	0.85	0.86	0.86
Commercial	0.88	0.88	0.89	0.89	0.89	0.89
Streets: ROW	0.76	0.77	0.79	0.80	0.82	0.84
Parking	0.95	0.96	0.97	0.95	0.96	0.97
Disturbed Area	0.65	0.67	0.69	0.66	0.68	0.70

Rational Method Runoff Coefficients - Part I

The model requires a simple input data file. To select the input file, click on the button corresponding to the file ("Input file") and a file browser will appear. The input file must be a file on the user's local file system that contains monthly water balance input data. A sample data file (input.file) is provided with the model and is located in the USGS Thornthwaite installation folder. The data file must be organized into four columns with one or more space characters between the columns. The first column is the year, the second is the numeric month of the year, the third is mean monthly temperature in degrees Celsius, and the last is monthly total precipitation in millimeters. When the model runs, tabular output is written to a popup window (Figure7). The columns of the output are date, PET, P, P–PET, soil-moisture storage, AET, PET–AET (also known as moisture deficit), snow storage, surplus, and RO_{total}. The contents of this window can be saved to a file by clicking on the Save button at the bottom of the window and specifying the name (and directory) of an output file in the file browser. At the bottom of the main program window (Figure 6), the user can select the specific variables to be plotted by clicking on the corresponding circle. After the model runs, a window will open with the plotted time series (Figure 8). The model can be run any number of times, each time selecting a different set of variables to plot.

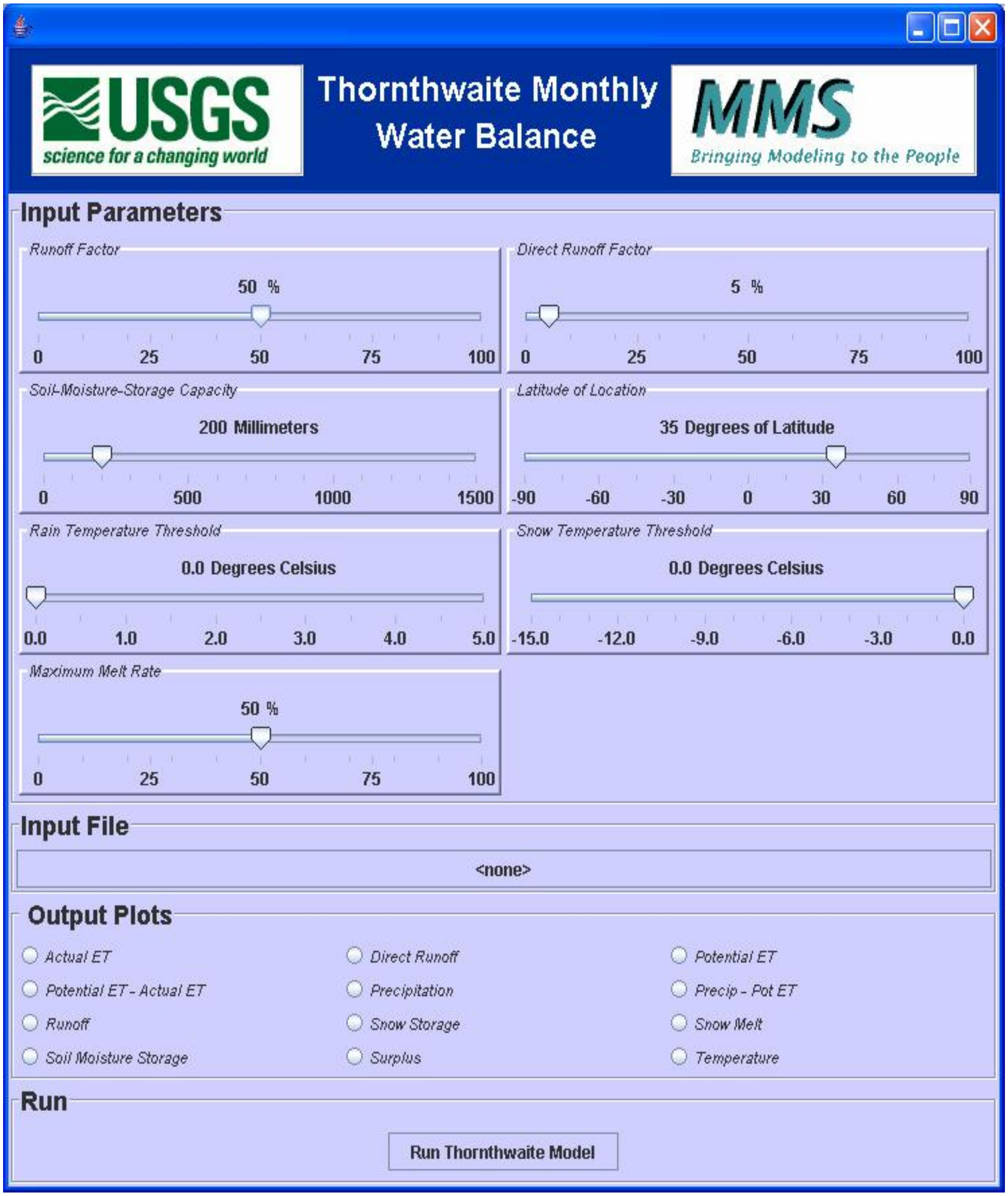


Figure 6 : Thronthwaite monthly water balance model

Date	PET	P	P-PET	Soil Moisture	AET	PET-AET	Snow Storage	Surplus	ROtotal
Jan-1960	18.0	44.1	23.9	173.9	18.0	0.0	0.0	0.0	14.9
Feb-1960	18.2	62.9	41.6	200.0	18.2	0.0	0.0	15.5	17.2
Mar-1960	28.5	32.8	2.7	200.0	28.5	0.0	0.0	2.7	10.0
Apr-1960	70.1	48.5	-24.1	175.9	70.1	-0.0	0.0	0.0	6.6
May-1960	98.0	150.6	45.1	200.0	98.0	0.0	0.0	21.0	20.1
Jun-1960	147.5	74.7	-76.6	123.4	147.5	0.0	0.0	0.0	10.0
Jul-1960	156.7	151.8	-12.5	115.7	151.9	4.8	0.0	0.0	10.7
Aug-1960	142.1	88.1	-58.4	81.9	117.5	24.6	0.0	0.0	6.0
Sep-1960	96.2	60.6	-38.6	66.1	73.4	22.8	0.0	0.0	3.8
Oct-1960	56.8	115.6	53.0	119.1	56.8	0.0	0.0	0.0	6.2
Nov-1960	29.6	13.4	-16.8	109.1	22.8	6.8	0.0	0.0	0.9
Dec-1960	17.6	84.5	62.6	171.7	17.6	0.0	0.0	0.0	4.3
Jan-1961	17.5	10.0	-8.0	164.9	16.4	1.1	0.0	0.0	0.6
Feb-1961	24.0	43.5	17.4	182.3	24.0	0.0	0.0	0.0	2.2
Mar-1961	41.9	90.0	43.6	200.0	41.9	0.0	0.0	25.9	17.4
Apr-1961	60.7	27.0	-35.1	164.9	60.7	0.0	0.0	0.0	7.8
May-1961	100.5	123.5	16.9	181.8	100.5	0.0	0.0	0.0	9.4
Jun-1961	131.7	111.6	-25.6	158.5	129.3	2.3	0.0	0.0	7.2
Jul-1961	155.5	133.5	-28.7	135.8	149.6	5.9	0.0	0.0	7.5
Aug-1961	132.1	84.4	-51.9	100.6	115.4	16.7	0.0	0.0	4.6
Sep-1961	83.5	140.8	50.3	150.8	83.5	0.0	0.0	0.0	7.2
Oct-1961	53.6	66.5	9.5	160.3	53.6	0.0	0.0	0.0	3.4

Figure 7 : Screen image of example output from the water-balance model.

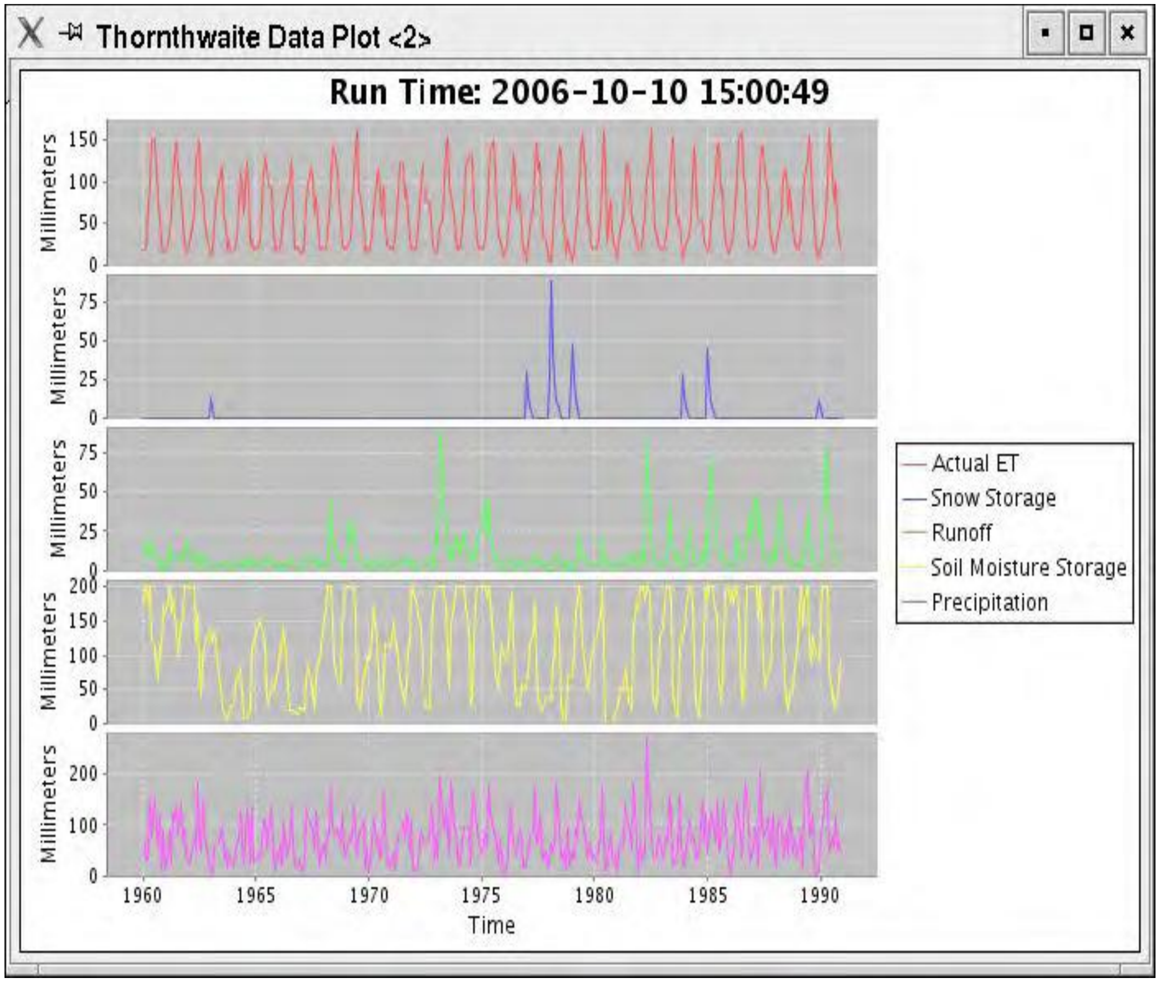


Figure 8 : Screen image of example time series plotted by the water-balance model.

3.3 Estimation of crop water need

Crop water need is the calculation of evapotranspiration of the crop. Since there is influence of climate on crop water needs, reference crop evapotranspiration (ETo) is calculated.ETo is the rate of evapotranspiration from a large area, covered by green grass, 8 to 15 cm tall, which grows actively, completely shades the ground and which is not short of water. Grass has been taken as reference crop. In order to obtain the crop water need (ETcrop) the reference crop evapotranspiration, ETo, must be multiplied by the crop factor, Kc. The crop factor (or "crop coefficient") varies according to the growth stage of the crop. There are four growth stages to distinguish:

- the initial stage: when the crop uses little water;
- the crop development stage, when the water consumption increases;
- the mid-season stage, when water consumption reaches a peak;
- the late-season stage, when the maturing crop once again requires less water. (FAO)

$$ET_{crop} = ET_o \times k_c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

with ET crop = crop evapotranspiration or crop water need (mm/day)

Kc = crop factor

ETo = reference evapotranspiration (mm/day)

Both ET crop and ETo are expressed in the same unit: usually in mm/day (as an average for a period of one month) or in mm/month.

Table 3-2: Crop Factor (kc) at different stages of growth for cereal crops (FAO)

Crops/Growth stage	Initial stage	Crop dev stage	Mid season stage	late season stage
Paddy	1.05	1.2	1.2	0.9
Maize	0.4	0.8	1.15	0.7
millet	0.3	0.7	1.1	0.65
wheat	0.35	0.75	1.15	0.45

Table 3-3 : Growing days at different stages for cereal crops (FAO)

Crops/Growth stage	Initial stage	Crop dev stage	Mid season stage	late season stage	total days	duration
Paddy	30	30	60	30	150	June 15 to Nov 15
Maize	20	35	40	30	125	Apr 15 to Aug 20
millet	15	25	40	25	105	June 20 to Oct 5
wheat	15	30	65	40	150	Nov01 to Mar 30

Methods to calculate reference crop Evapotranspiration (ETo)

1. Blaney-Cridle method
2. Radiation method
3. Penman method
4. Pan-evaporation method

Concerning accuracy, only approximate possible errors can be given since no base-line type of climate exists. The modified Penman method would offer the best results with minimum possible error of plus or minus 10 percent in summer, and -up to 20 percent under low evaporative conditions. The Pan method can be graded next with possible error of 15 percent, depending on the location of the pan. The Radiation method, in extreme conditions, involves a possible error of up to 20 percent in summer. The Blaney-Criddle method should only be applied for periods of one month or longer; in humid, windy, mid-latitude winter condition; an over and under prediction of up to 25 percent has been noted. (Doorenbos, 1997)

In this research, Blaney-cridle method is used to determine reference crop evapotranspiration. If no measured data on pan evaporation are available locally, a theoretical method (Blaney-Criddle method) to calculate the reference crop evapotranspiration ETo has to be used. This method use measured data on temperature only. It should be noted, however, that this method is not very accurate; it provides a rough estimate or "order of magnitude" only. Especially under "extreme" climatic conditions the Blaney-Criddle method is inaccurate: in windy, dry, sunny areas, the ETo is underestimated (up to some 60 percent), while in calm, humid, clouded areas, the ETo is overestimated (up to some 40 percent).

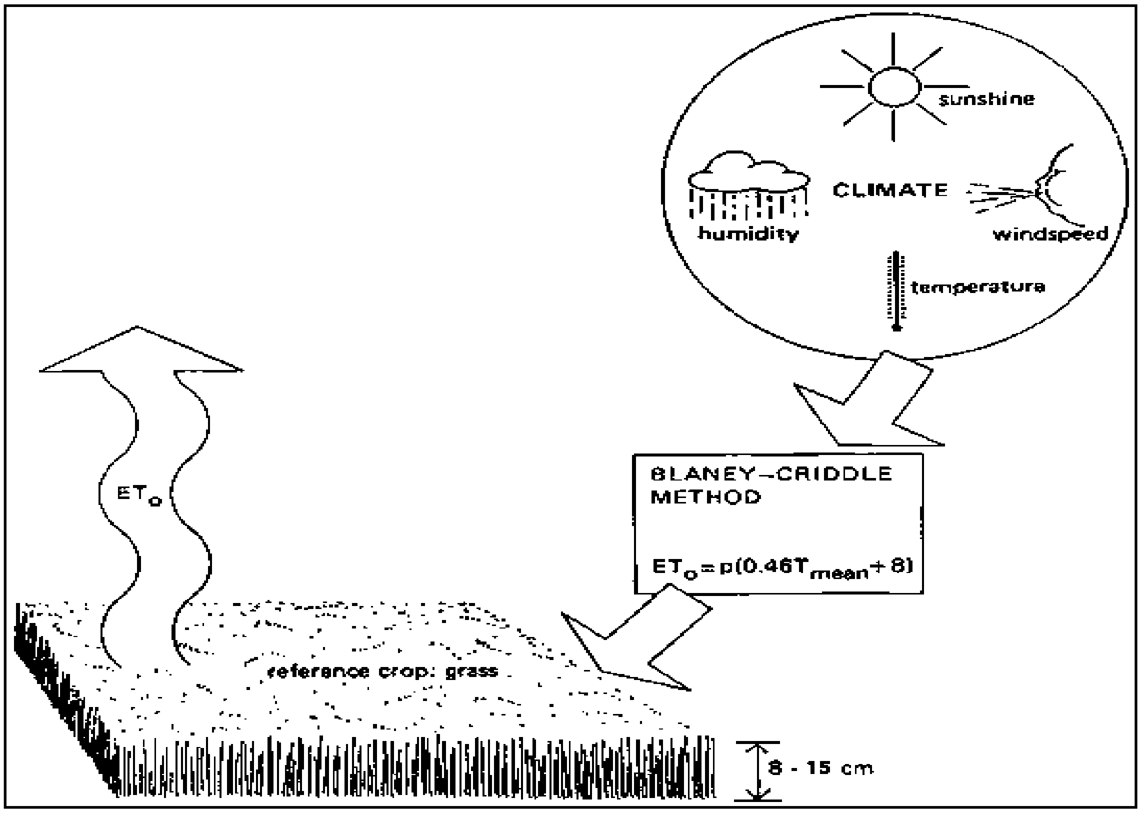


Figure 9 : Blaney-Cridle method

The Blaney-Criddle formula:

ETo = p (0.46 T mean +8)

ETo = Reference crop evapotranspiration (mm/day) as an average for a period of 1 month
T mean = mean daily temperature (°C)
p = mean daily percentage of annual daytime hours

The Blaney-Criddle method always refers to mean monthly values, both for the temperature and the ETo.

To determine the value of p. Table 3-4 is used. To be able to determine the p value it is essential to know the approximate latitude of the area: the number of degrees north or south of the equator

Table 3-4: Mean daily percentage (p) of annual daytime hours for different latitudes

Latitude	North	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
	South	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
60^0		0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.3	0.3	0.2	0.2	0.1
55^0		0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.3	0.3	0.2	0.2	0.2
50^0		0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.3	0.3	0.2	0.2	0.2
45^0		0.2	0.2	0.3	0.3	0.3	0.4	0.3	0.3	0.3	0.2	0.2	0.2
40^0		0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
35^0		0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
30^0		0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
25^0		0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2
20^0		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
15^0		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
10^0		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
5^0		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
0		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

CHAPTERIV: DATA AND METHODOLOGY

4.1 Description of study area

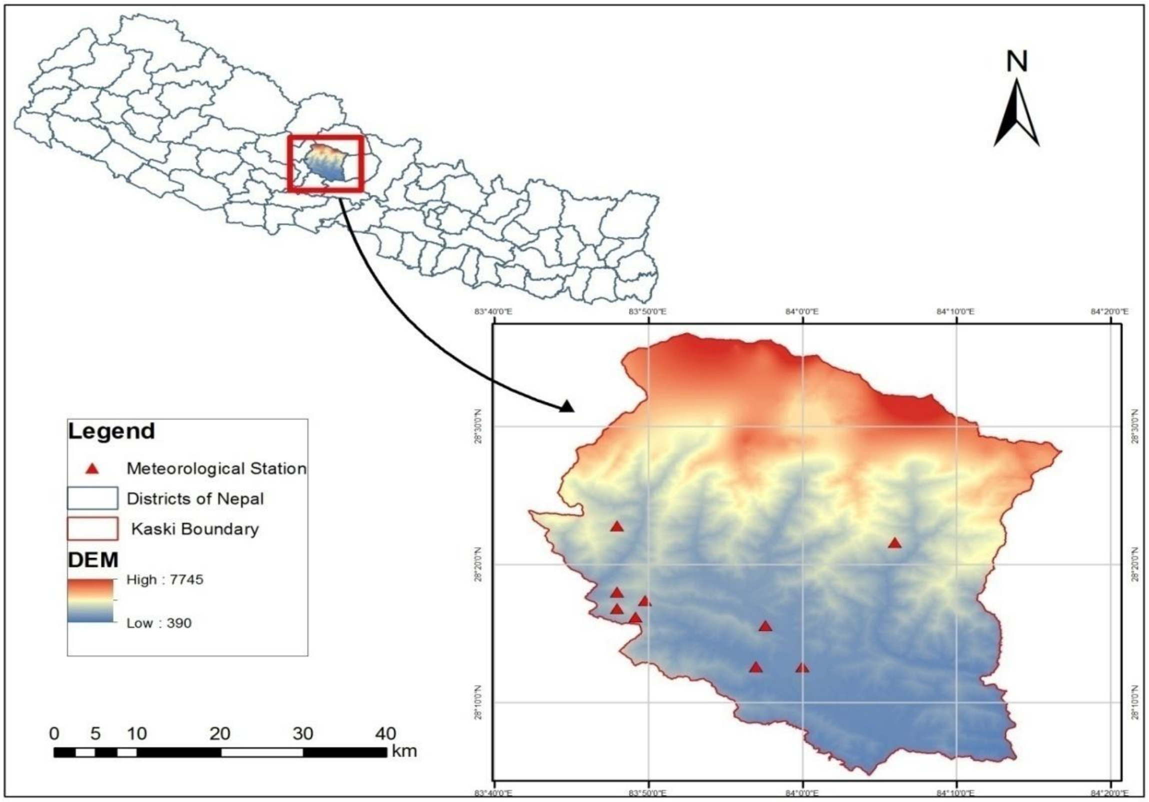


Figure 10 : Map showing location of study area

Kaski District a part of Province No 4 is one of the seventy-five districts of Nepal. Geographically the district lies on 83°40' east to 84°12' East longitude and 28°06' north to 28°36' North latitude. It is adjacent to the neighboring districts with Lamjung and Tanahun districts in the East; Syangja and Parbat districts in the West; Manang and Myagdi districts in the North; and Syangja and Tanahu districts in the South. The district covers an area of 2,017 square km. This district lies at the centroid point of the country. The altitude of Kaski district ranges from 450 to 8091 masl. The district covers parts of the Annapurna mountain range, and the picturesque scene of the mountains can be observed from most parts of the district. It is one of the best tourist destinations of Nepal. The district is full of rivers such as SetiGandaki, Modi and Madi along with other rivulets. The district is famous for the Himalayan range with about 11 Himalayas with height greater than 7000 m.

4.1.1 Geography and Climate

Consistent to the national topographical variation, the district has also the diversity of weather and climate according to the elevation of the district. As the altitude of the district varies greatly, climate of the district can be found different in different altitudes, the classification of which is given as under:

Five types of climate are found in this district, sub-tropical, temperate, temperate cold, alpine and tundra climate.

Mountainous climate: This type of climate is found above 5,000 masl, the area of which is well known for its trekking routes and eye-catching view of the Himalayas.

Alpine climate: This type of climate is found at altitudes of 2,500 to 5,000 masl. The topography is composed of large sloping land areas, which remain covered with frost and snow in the winter. In the rainy season, these areas turn into grazing land for the yaks and sheep.

Temperate climate: This type of climate is found at altitudes of 1,500 to 2,500 masl, where frost is common and sometimes snowfall occurs when the temperature is very low in the winter. Apple, pear, walnut, and peach are the common fruits and buckwheat, barley, cardamom, and potatoes are the main crops.

Mild-temperate climate: This type of climate is present at altitudes of 800 to 1,500 masl, where winter is cold and summer is warm. Peach, persimmon, orange, litchi, lime, and banana are the main fruits cultivated in this type of climate. Millet, maize, buckwheat, rice, mustard, cardamom, zinger and different types of vegetables are the main crops.

Sub-tropical: Areas located at altitudes of 300 to 800 masl consisted of this type of climate, where summer is hot and winter is cool. Plenty of agricultural land is available in this area. Hence, crops like rice, maize, wheat, millet, sugarcane, and black gram are produced. Different type of vegetables and fruits like mango, litchi, pineapple, jackfruit, and banana etc. are commonly cultivated.

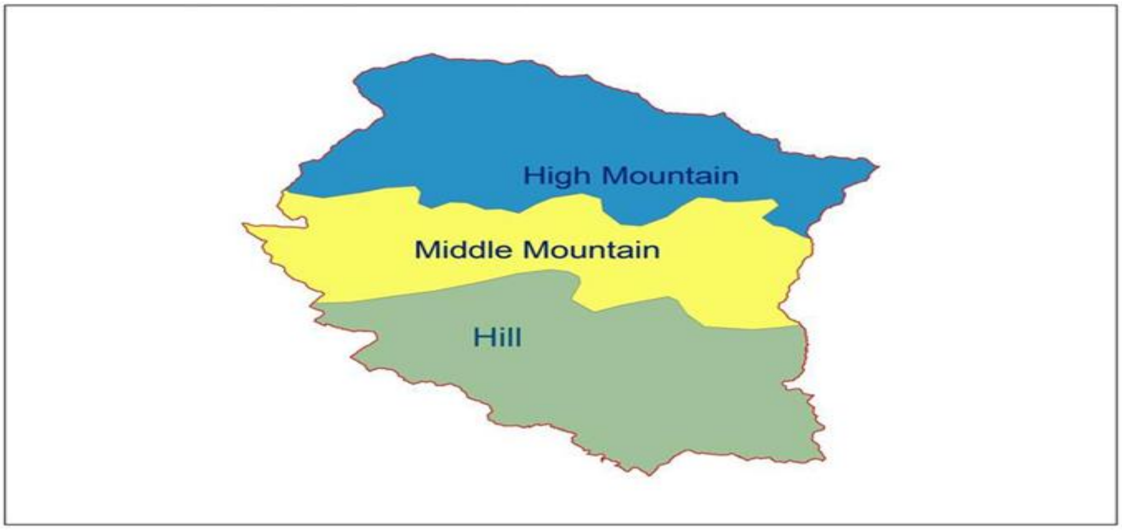


Figure 11 : Physiographic map of Kaski (Maharjan, 2017)

Kaski district contains three physiographic zones namely: High Mountains, Middle Mountains and Hills. High mountains usually have trans- Himalayan and alpine type climate; upper parts of middle mountains have sub-alpine where as lower part has temperate type of climate. Similarly Hills have sub-tropical type of climate. The hill region located at the south west part of the district receives the highest annual rainfall of above 4000 mm. The middle mountains and High Mountain receives less than hilly regions.(Maharjan, 2017)

4.1.2 Major cereal crop cultivated land in Kaski district

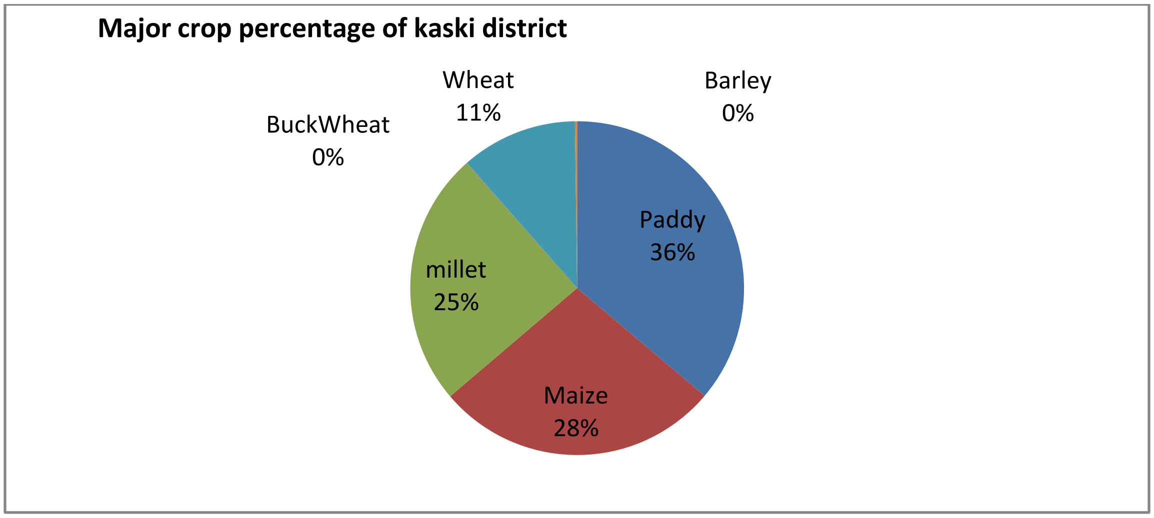


Figure 12 : Major cereal crop cultivated area in percentage (National Sample Census of Agriculture)

4.1.3 Land use map of Kaski district

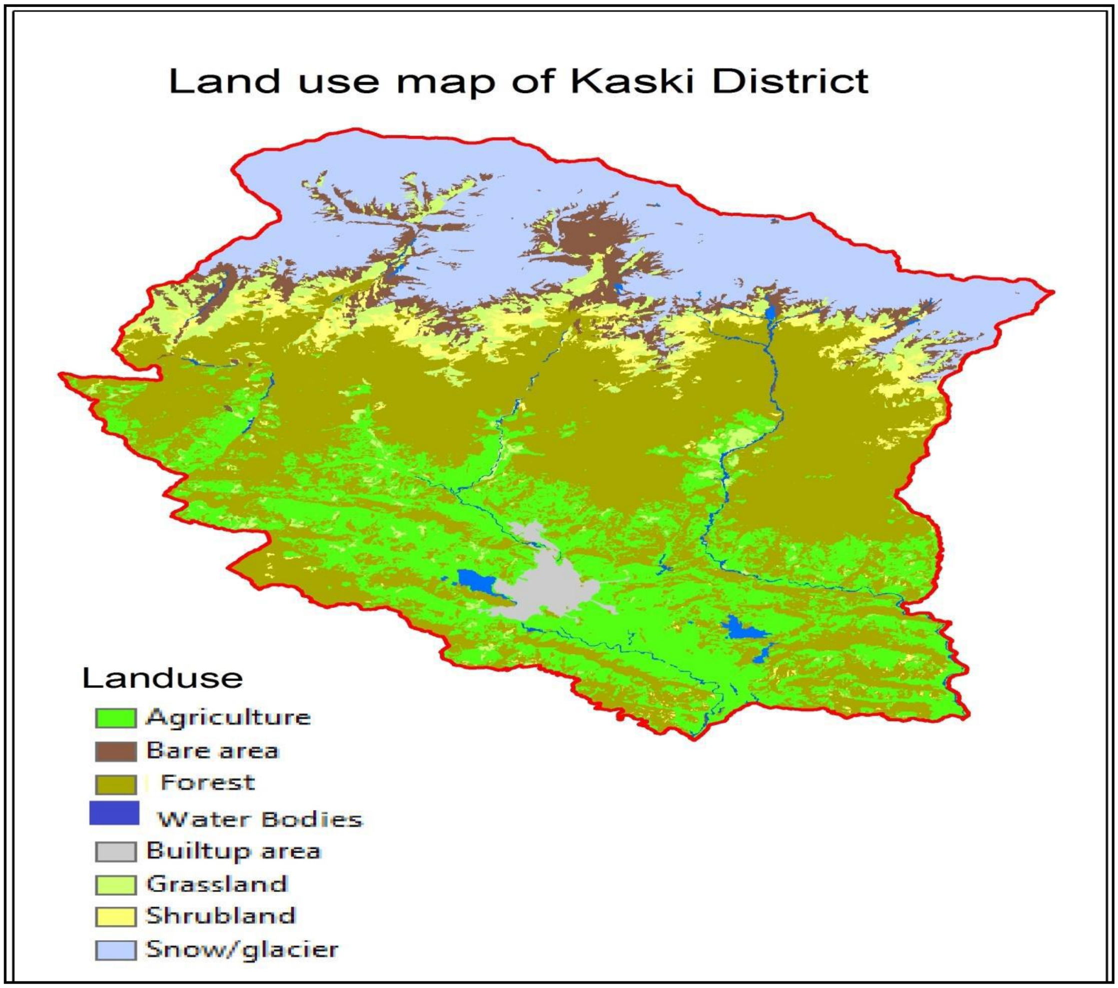


Figure 13 : Map showing land use distribution of Kaski (Maharjan, 2017)

The required Land Cover Data was taken from International Centre for Integrated Mountain Development's (ICIMOD) geoportal. The land use patterns of Kaski are Agriculture, bare area, forest, water bodies, built-up area, grassland, shrub land and snow/glacier, agriculture land, pasture and water bodies.

4.2 Data collection

The climatic data such as rainfall and temperature of Kaski district from 9 different stations were collected from Department of Hydrology and Meteorology (DHM).

Table 4-1 : Selected meteorological stations for data analysis:

S. No	Index No.	Station	Type	lat	Long	Elevation	collected data	Collected period
				N	E	m		
1	804	Pokhara Airport	Aeronautical	28.20	83.98	827	1.Rainfall 2.Temperature	1. 1985-2016 2.1985-2016
2	811	Malepatan	Agro meteorological	28.22	83.97	858	1.Rainfall 2.Temperature	1. 1985-2016 2.1985-2016
3	813	BhadaureDeurali	Precipitation	28.27	83.82	1629	Rainfall	1985-2016
4	814	Lumle	Agro meteorological	28.30	83.82	1740	1.Rainfall 2.Temperature	1. 1985-2016 2.1985-2016
5	818	Lamachaur	Precipitation	28.27	83.97	1070	Rainfall	1985-2016
6	821	Ghandruk	Precipitation	28.38	83.80	1960	Rainfall	1985-2016
7	824	Siklesh	Precipitation	28.37	84.10	1820	Rainfall	1985-2016
8	829	Sallyan	Precipitation	28.28	83.80	1600	Rainfall	1992(4)-2016
9	830	Pamdur	Precipitation	28.29	83.83	1713	Rainfall	1992(4)-2016

4.3 Methodology

Thronthwaite water balance model needs input file of temperature and rainfall with year and month in Notepad++. Lapse rate method is used for calculation of missing temperature data of climatic stations and for precipitation stations.

Lapse rate method Regression formula:

Temperature=Reference temperature of lowest elevation station+ (elevation of station to calculate temperature-Elevation of reference station)*(-0.006)

Input parameter to run thronthwaite water balance model are runoff factor, direct runoff factor, soil-moisture storage capacity, latitude of location, rain temperature threshold, snow temperature threshold, and maximum snow-melt rate of the snow storage that are modified through the graphical user interface. Latitude is used 28 degrees for all stations; soil moisture storage capacity is used 140mm/m, runoff factor is taken from Table 3-1. Rest of the parameter is taken as default values. The output monthly surface runoff is plotted on ArcGIS 10.

Blaney-Cridle method is used for calculation of crop water need. Reference crop water need is calculated from Blaneycridle formula. Mean daily percentage of annual day time hours (Table 3-4) and monthly mean temperature is used as parameter. Crop factor for different crops is used from Table 3-2 and growth stages and duration of crop growth is taken as from Table 3-3.

The crop water availability is calculated by subtracting crop water need to monthly surface runoff.

CHAPTERV: RESULT AND DISCUSSION

5.1 Observed monthly Average Precipitation and temperature of Kaski District

In the analysis of monthly average precipitation of Kaski district, the average highest rainfall of about 1116.7 mm in month of July and average lowest rainfall of only 19.1 mm in November. District receives about 3547.8mm i.e. 83% of rain in the monsoon season. In pre-monsoon season average rainfall is 465.8mm i.e. 11% of annual rainfall. 181mm of rainfall i.e. 4% of average annual rainfall occurs in post-monsoon season and nearly 2% of rainfall occurs in winter season. The table of average rainfall calculation is shown in Appendix A.

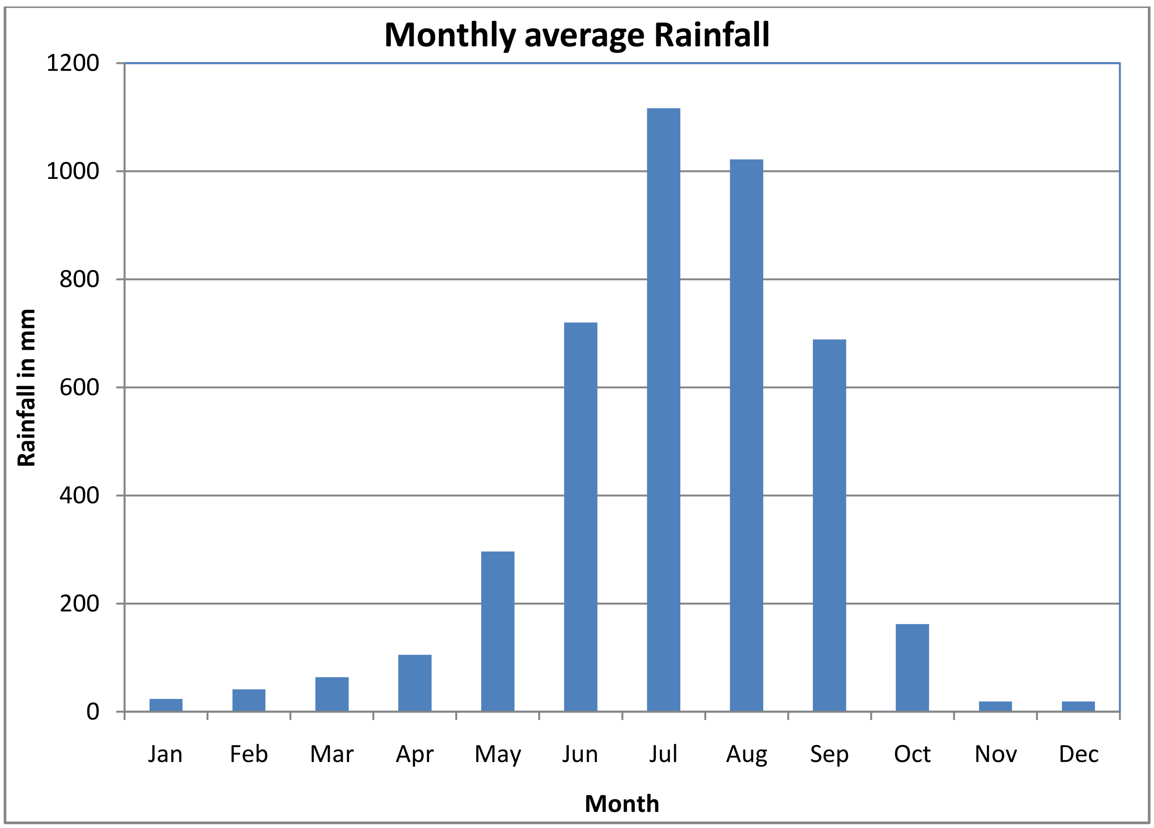


Figure 14: Monthly average precipitation of Kaski district

The highest average maximum temperature is observed to be 26.7 °C in month of June while average minimum temperature is experienced in month of January which is 3.6 °C. The calculation of average temperature of Kaski District is given in Appendix B.

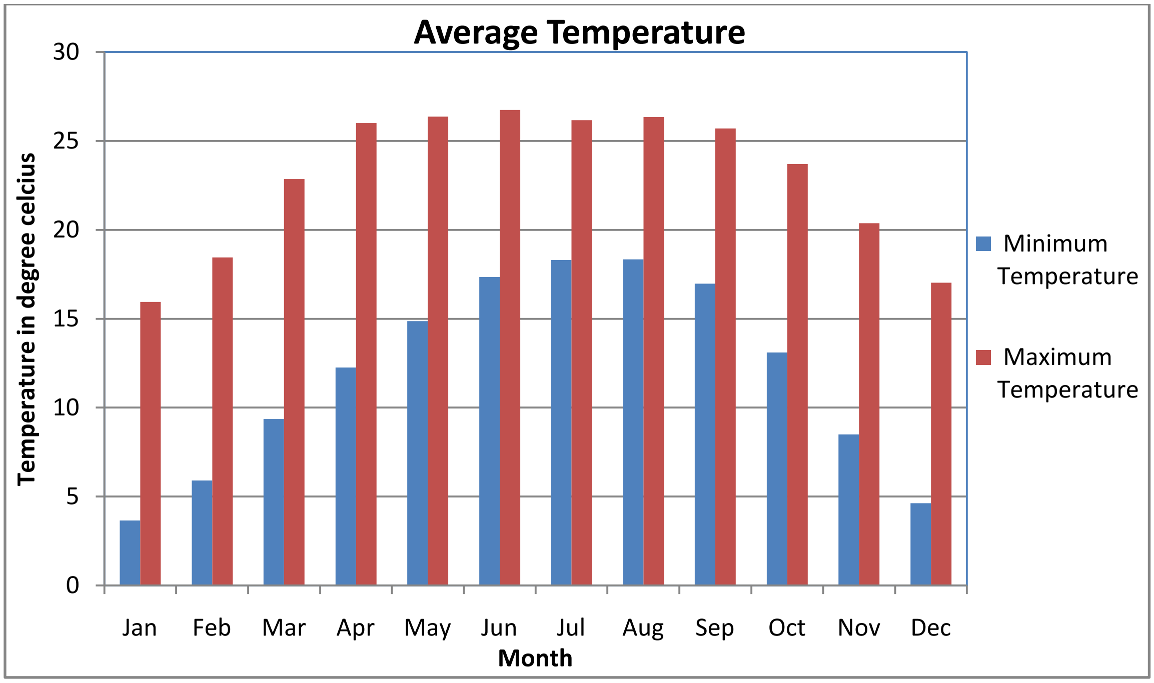
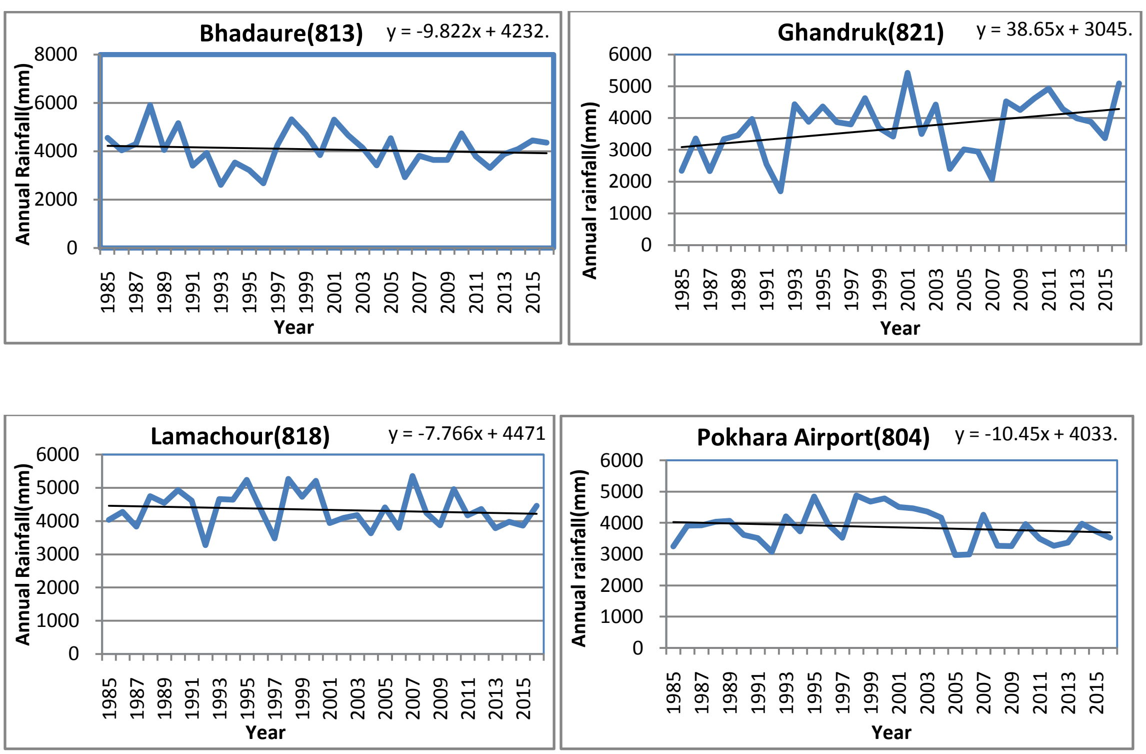


Figure 15 : Monthly average temperature of Kaski District

5.2 Observed annual precipitation Trend



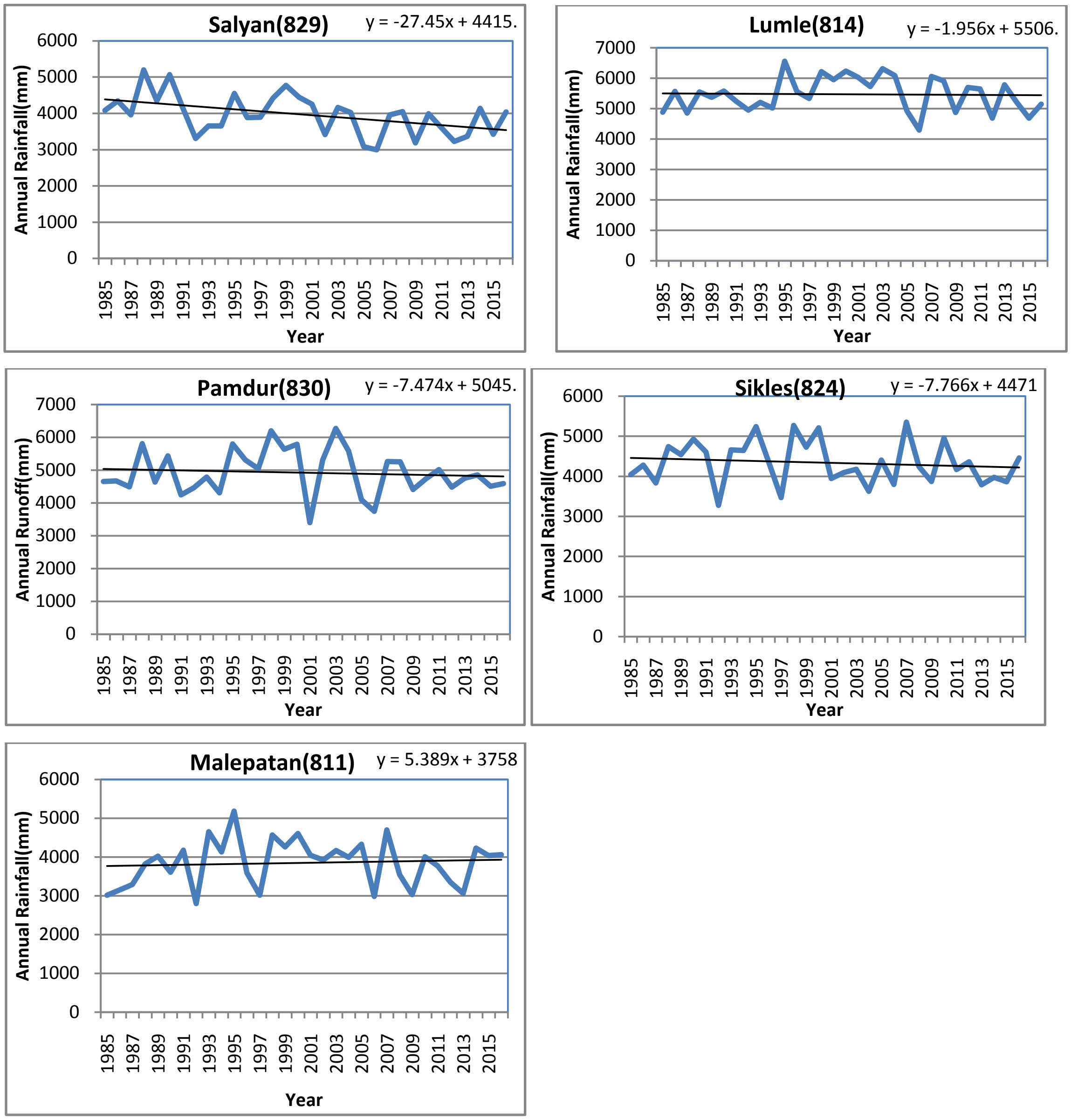


Figure 16 : Average annual precipitation trend for bhadaure, ghandruk, lamachour, malepatan, pokhara airport, lumle, pamdur, salyan and sikles.

The observed annual precipitation trend analysis is done using excel chart. The stations Bhadaure(813), Lamachour(818), Pokhara Airport(804), Lumle(814), Pamdur(830) and Sikles(824) shows decreasing trend in annual precipitation as 9.8mm/year, 7.7mm/year, 10.5mm/year, 27.4mm/year, 1.9mm/year, 7.4mm/year and 7.7mm/year respectively. The stations Ghandruk(821) and Malepatan(811) shows increasing trend in annual precipitation as 38.6mm/year and 5.3mm/year respectively. Drastic annual rainfall increase is in Ghandruk whereas rainfall decrease is in Salyan.

5.3 Average annual rainfall and maximum temperature at different stations of Kaski district

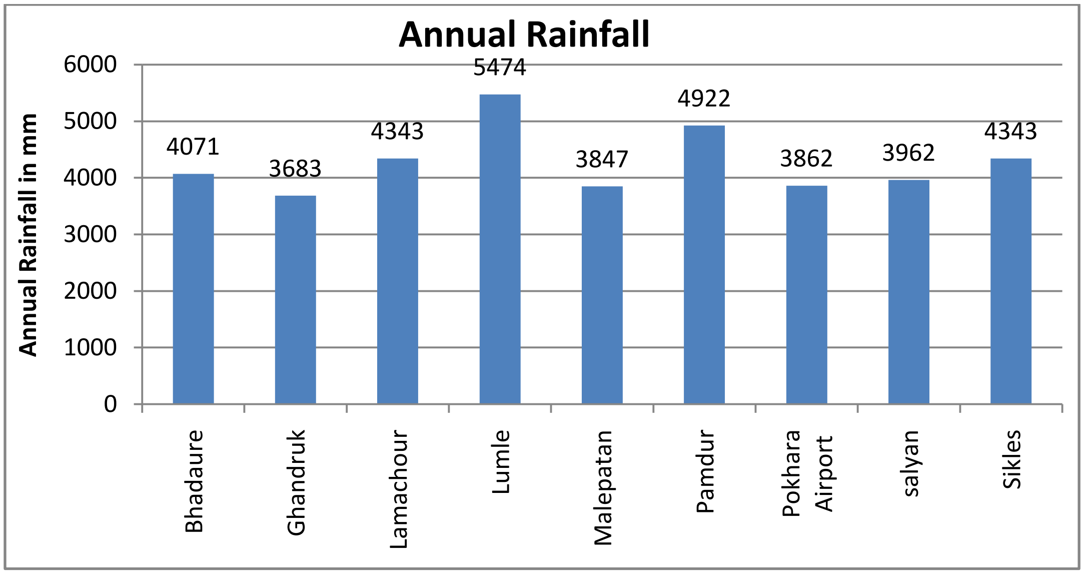


Figure 17 : Annual rainfall at different stations of Kaski district

The maximum annual rainfall is observed in Lumle and Pamdur i.e. 5474mm and 4922mm respectively whereas minimum rainfall is observed in Ghandruk i.e. 3686mm

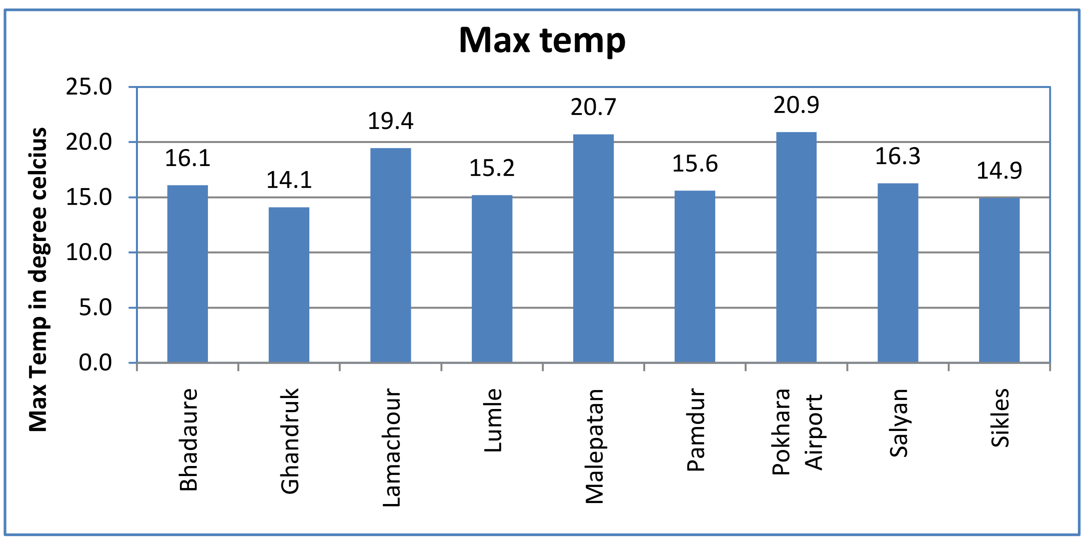


Figure 18 : Average maximum temperature at different stations of Kaski district

The highest maximum temperature is observed in Pokhara Airport and Malepatan i.e. 20.9 and 20.7 respectively whereas lowest maximum temperature is observed in Ghandruk i.e. 14.1

5.4 Monthly runoff analysis of Kaski District with mean temperature

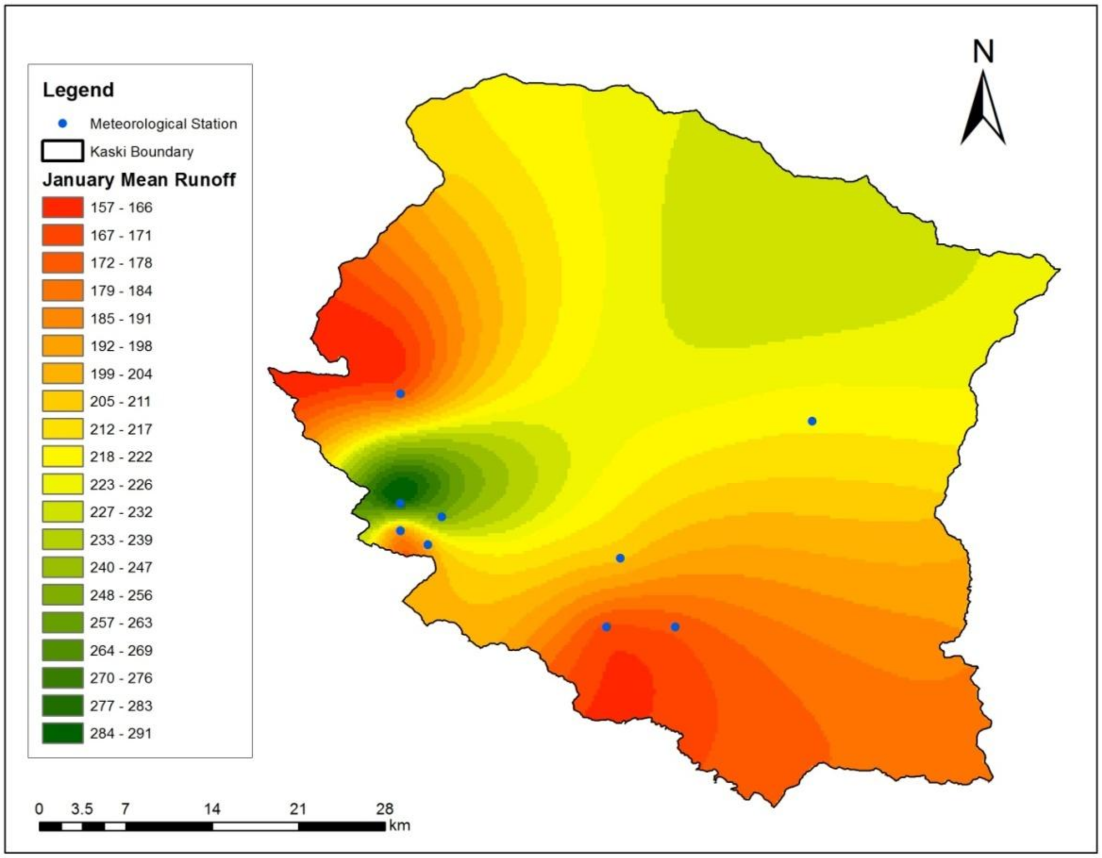


Figure 19 : Runoff distribution of Kaski in January

The figure shows average runoff distribution of Kaski district in January. Runoff is above 240mm in the south west part of Middle Mountain and northwest part of hill where as surface runoff is less than 172mm in northwest Middle Mountain and southern Hill. According to altitudinal map of district this maximum surface runoff area is steep slope area between hills.

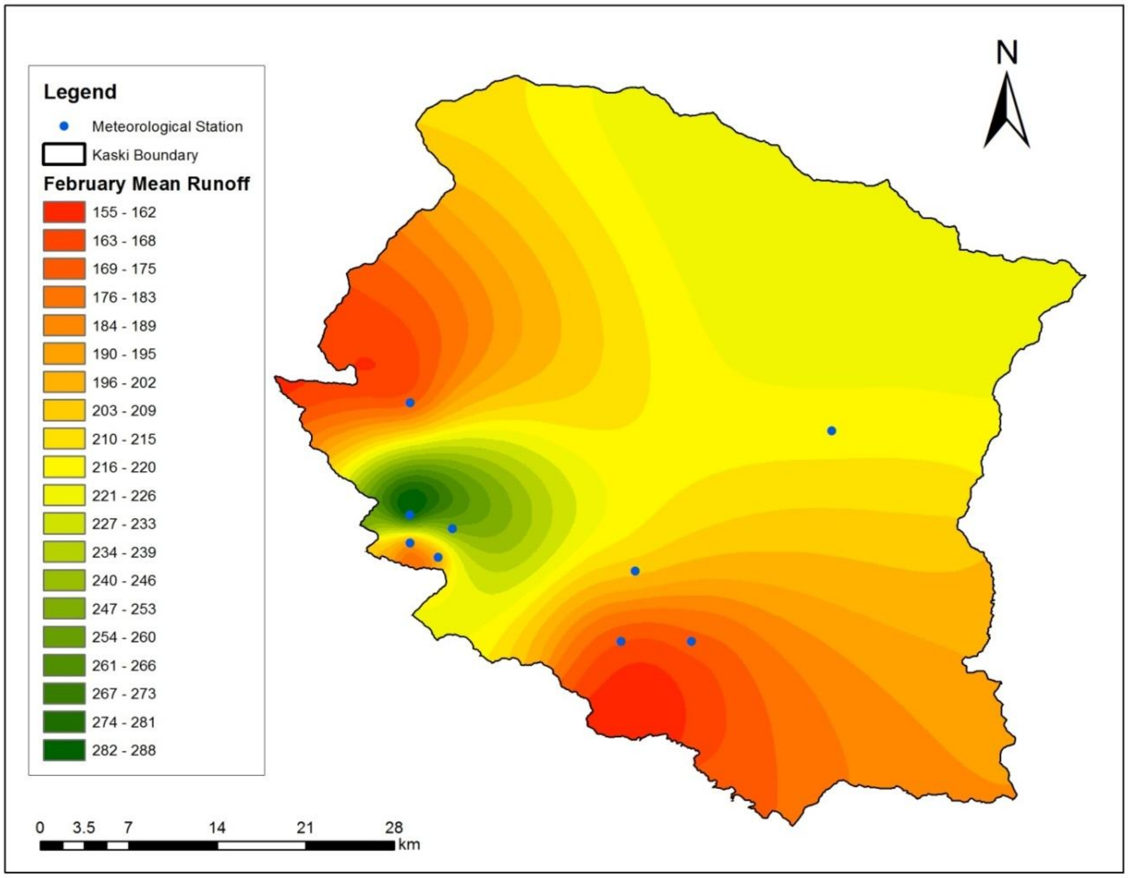


Figure 20 : Runoff distribution of Kaski in February

February is last month of winter season with less rainfall. Surface runoff above 240 mm is in the south east part of Middle mountain and northwest part of Hill. Rest of the part has relatively less runoff. Surface runoff above 240 mm is in the south western part of middle hills and north western part of hill.

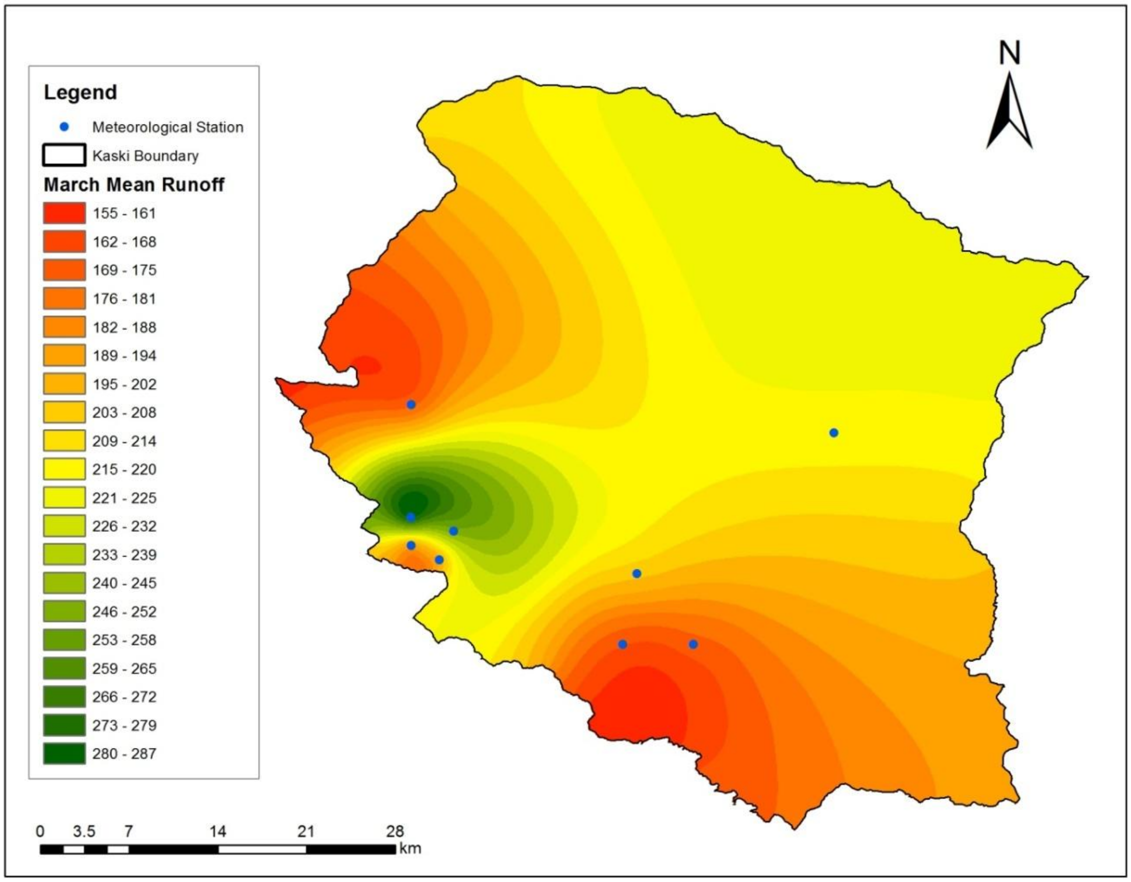


Figure 21 : Runoff distribution of Kaski district in March

March is the starting of pre monsoon season accompanied with isolated local systems for development of clouds and precipitation. Parts of southern hill, north western Middle mountain, south western High Mountain, areas including salyan and bhadaure stations accompanied with less surface runoff.

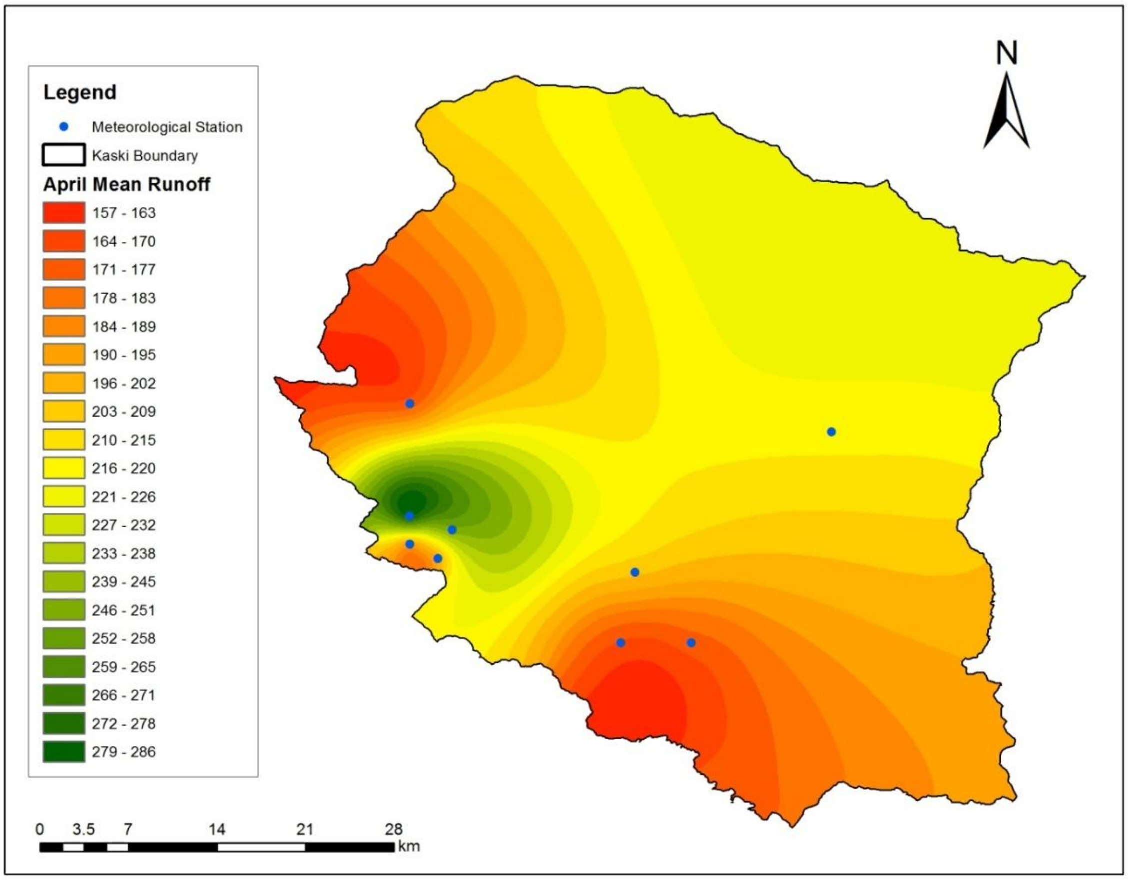


Figure 22 : Runoff distribution of Kaski district in April

The figure shows average runoff distribution of Kaski district in April. Runoff is above 240mm in the south west part of Middle mountain and northwest part of hill where as surface runoff is less than 180mm in northwest Middle mountain and southern hill.

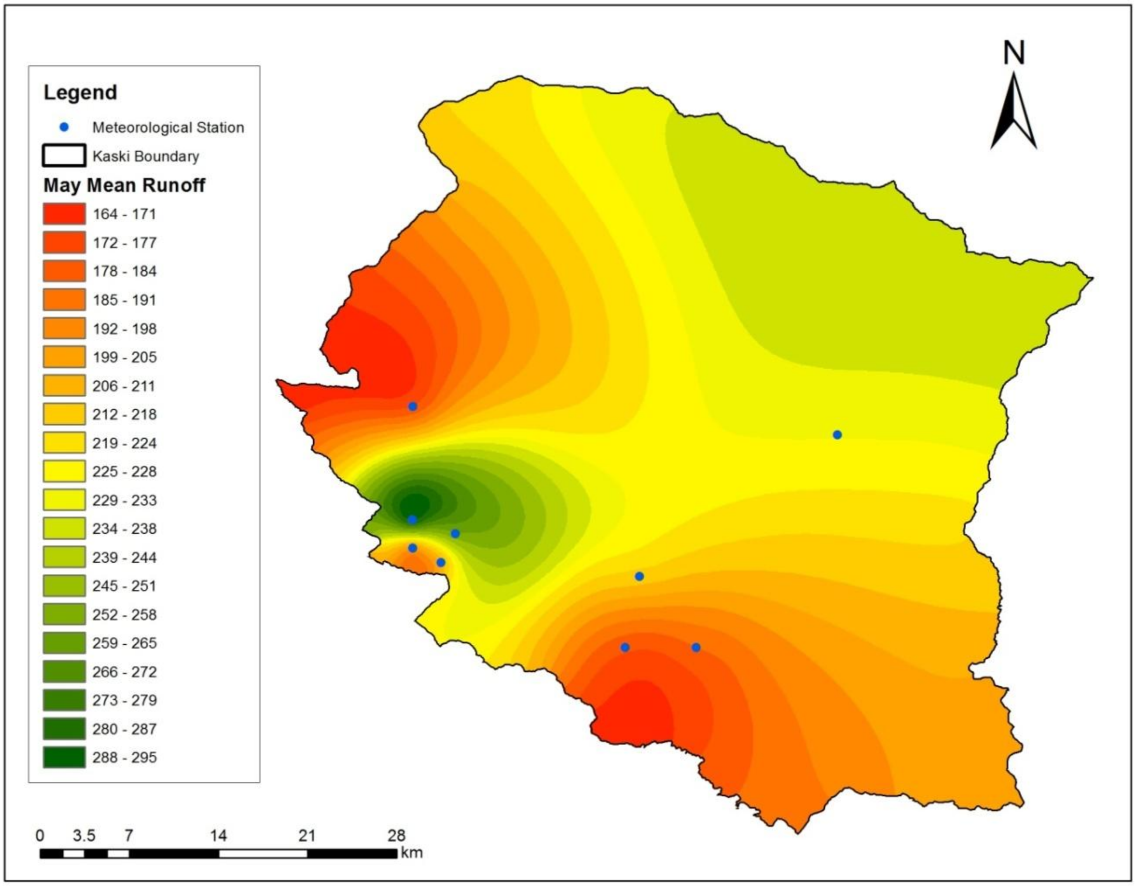


Figure 23 : Runoff distribution of Kaski district in May

The figure shows average runoff distribution of Kaski district in May. Runoff is above 245mm in the south west part of Middle mountain and northwest part of hill where as surface runoff is less than 192mm in northwest Middle mountain and southern Hill.

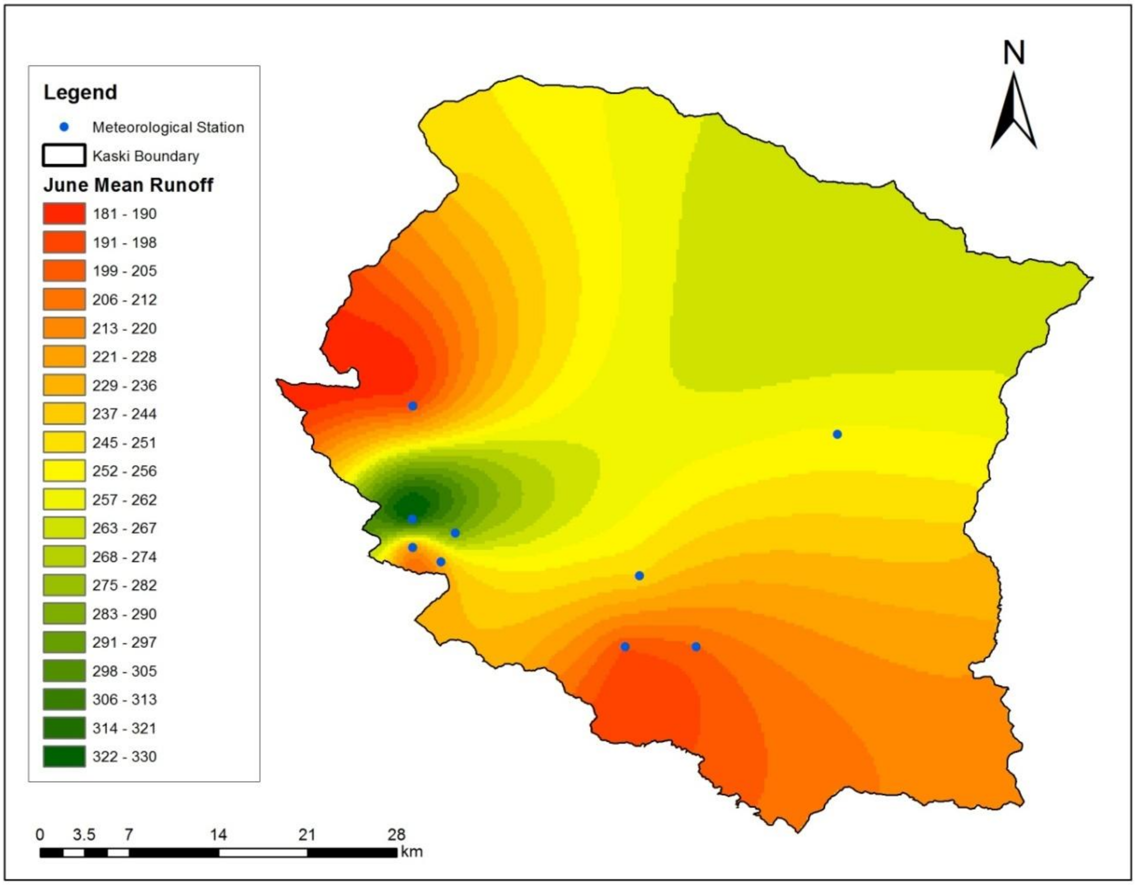


Figure 24 : Runoff distribution of Kaski district in June

The figure shows average runoff distribution of Kaski district in June. This month is starting of monsoon season. Runoff is above 275mm in the south west part of Middle mountain and northwest part of hill where as surface runoff is less than 220mm in northwest Middle mountain and southern hill.

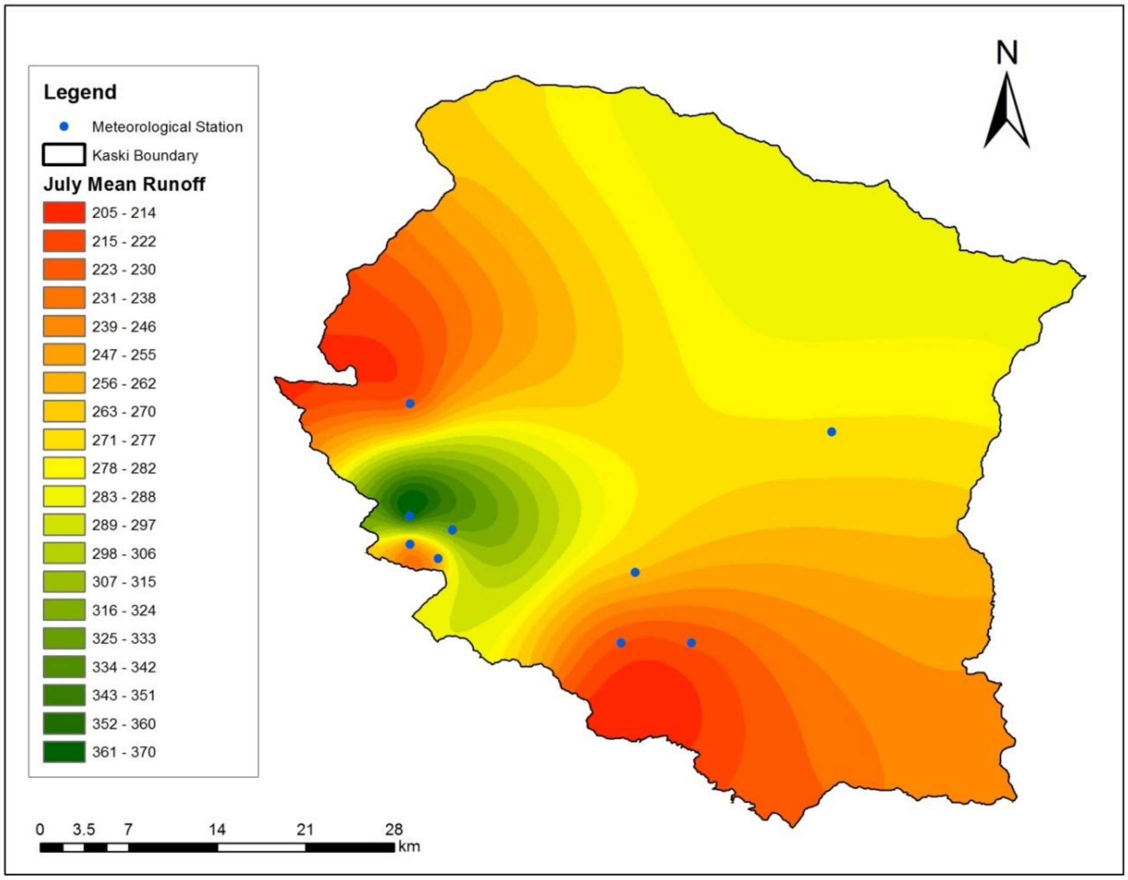


Figure 25 : Runoff distribution of Kaski district in July

The figure shows average runoff distribution of Kaski district in July. Normally peak rainfall occurs in this month. Runoff is above 300mm in the south west part of Middle mountain and northwest part of hill where as surface runoff is less than 250mm in northwest Middle mountain and southern hill.

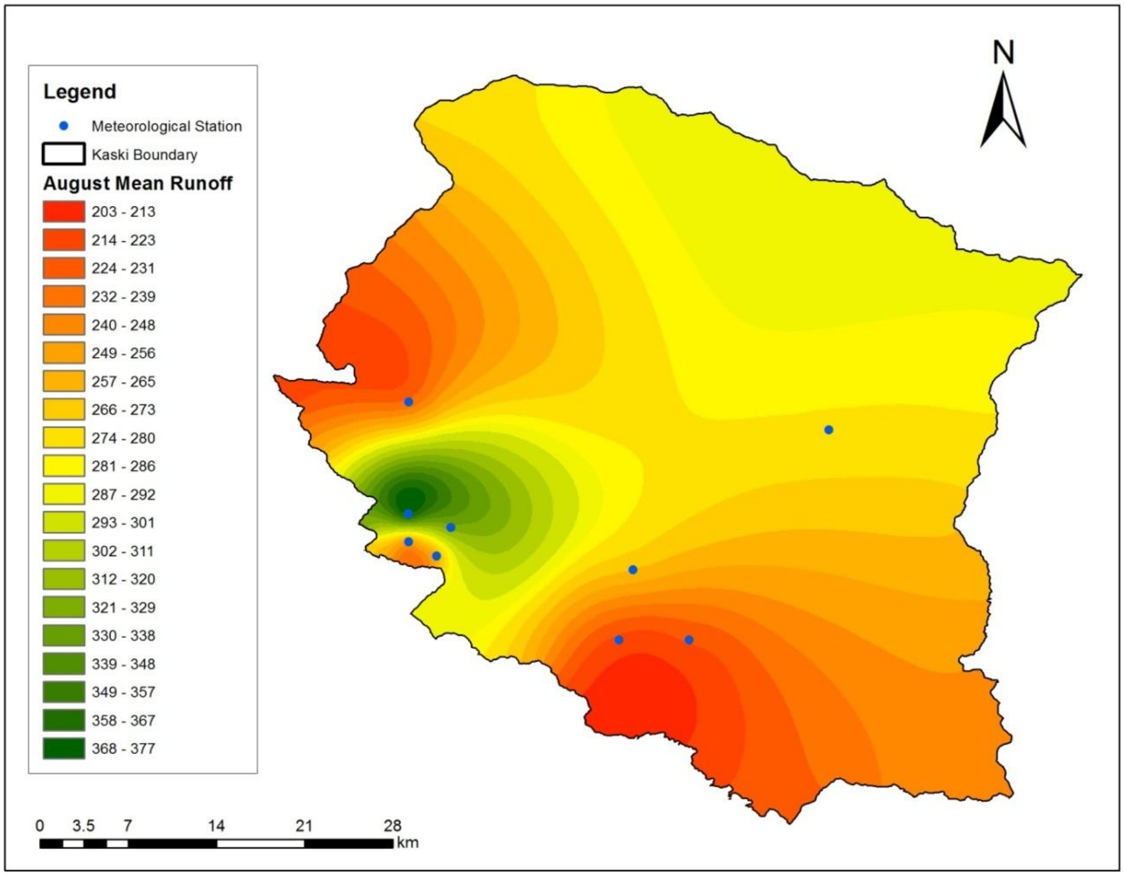


Figure 26 : Runoff distribution of Kaski district in August

The figure shows average runoff distribution of Kaski district in August. Runoff is above 300mm in the south west part of Middle mountain and northwest part of hill where as surface runoff is less than 250mm in northwest Middle mountain and southern hill.

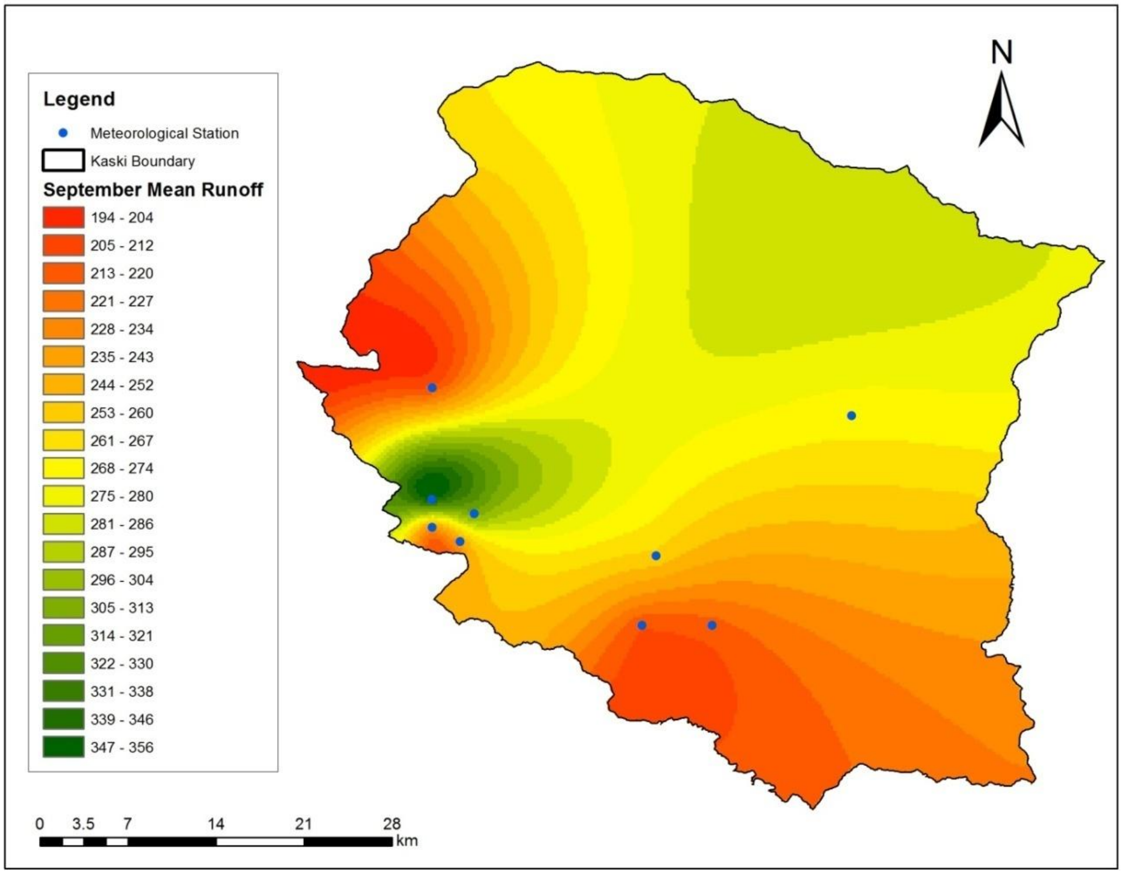


Figure 27 : Runoff distribution of Kaski district on September

The figure shows average runoff distribution of Kaski district in September. It is the end month of monsoon season.Runoff is above 296mm in the southwest part of Middle mountain and northwest part of hill where as surface runoff is less than 235mm in northwest Middle mountain and southern hill.

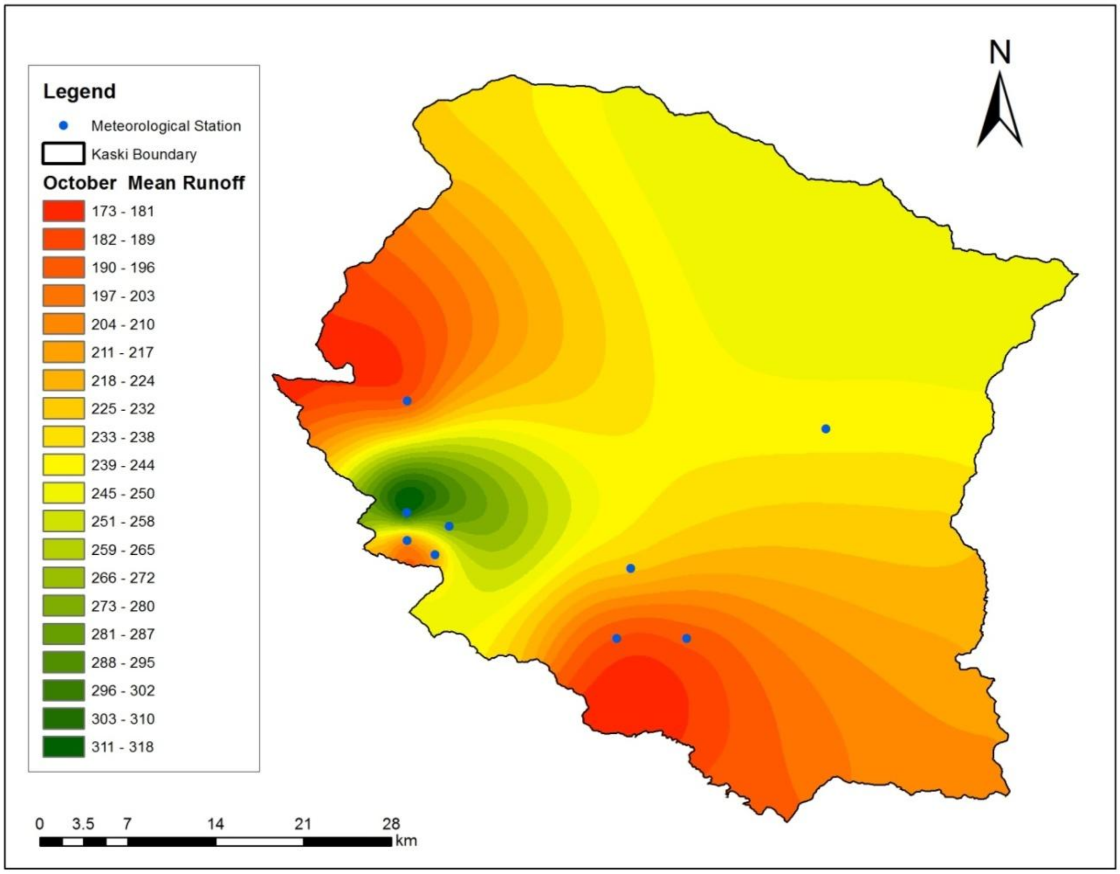


Figure 28 : Runoff distribution of Kaski district on October

The figure shows average runoff distribution of Kaski district in October. It is the starting of post monsoon season. Runoff is above 266mm in the southwest part of Middle mountain and northwest part of hill where as surface runoff is less than 211mm in northwest Middle mountain and southern hill.

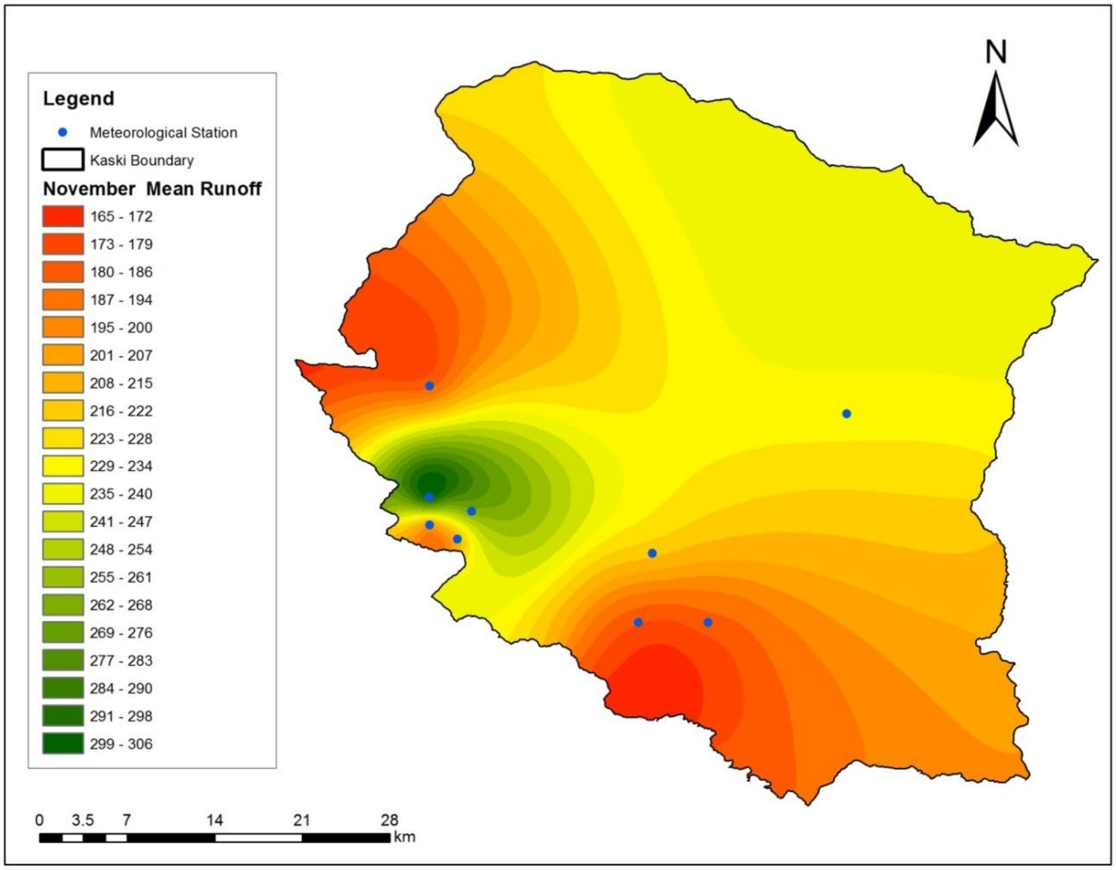


Figure 29 : Runoff distribution of Kaski district on November

The figure shows average runoff distribution of Kaski district in November. Runoff is above 255mm in the south west part of Middle mountain and northwest part of hill where as surface runoff is less than 201mm in northwest Middle mountain and southern hill.

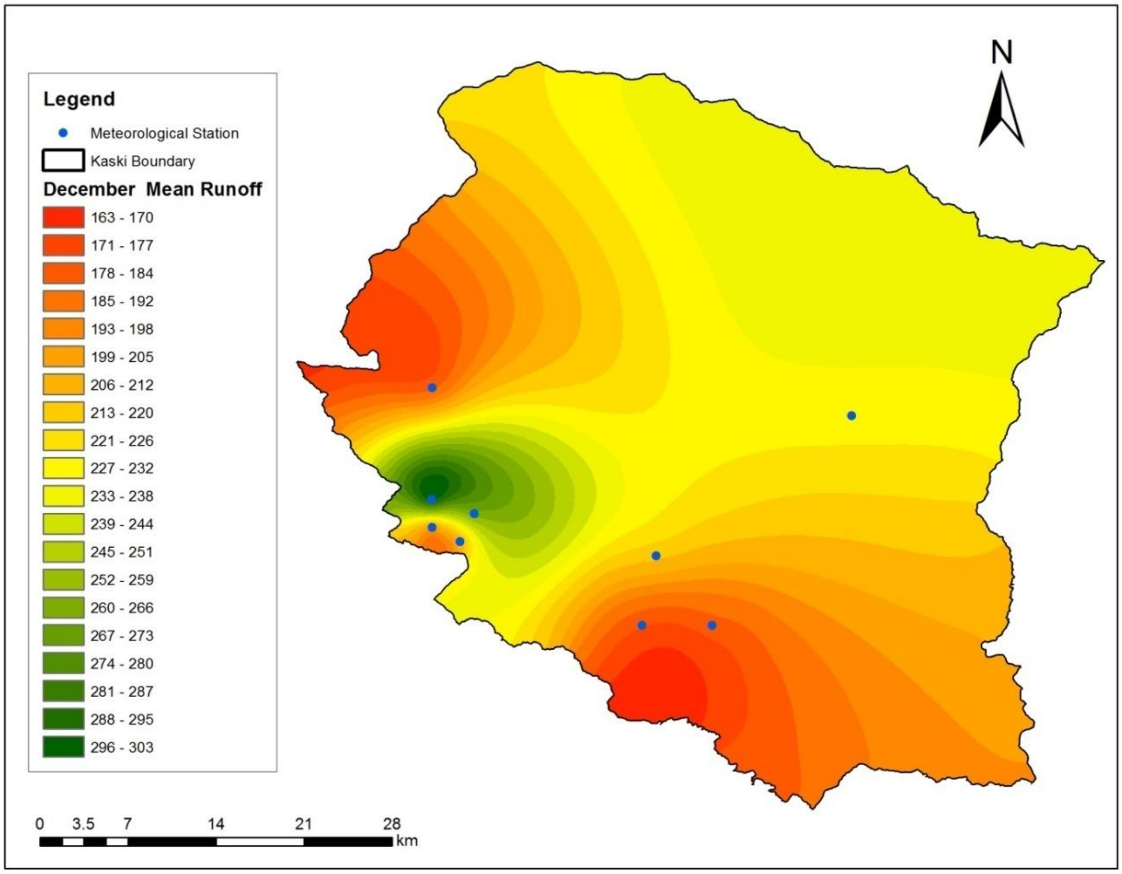
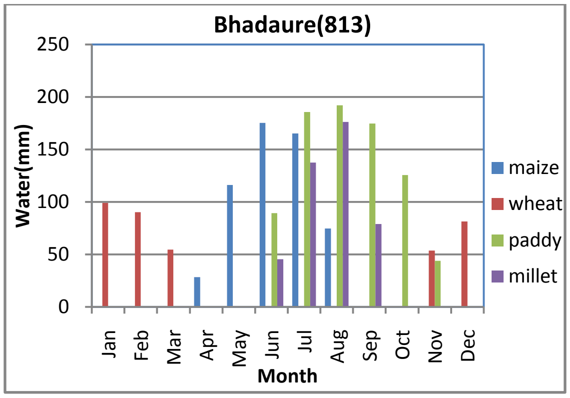


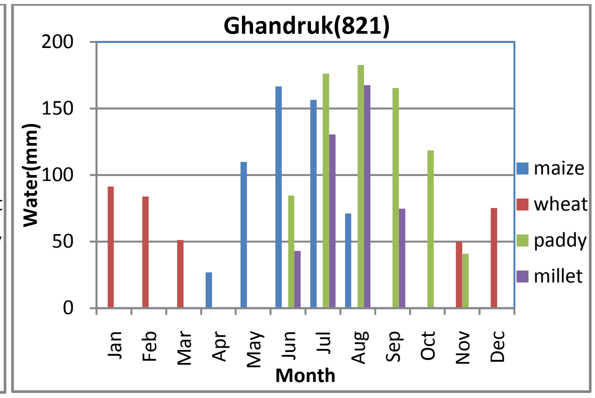
Figure 30 : Runoff distribution of Kaski district on December

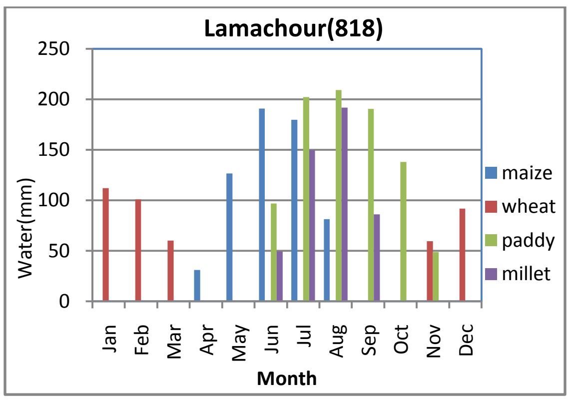
The figure shows average runoff distribution of Kaski district in December. It is the starting of winter season. Runoff is above 252mm in the south west part of Middle mountain and northwest part of hill where as surface runoff is less than 193mm in northwest Middle mountain and southern hill.

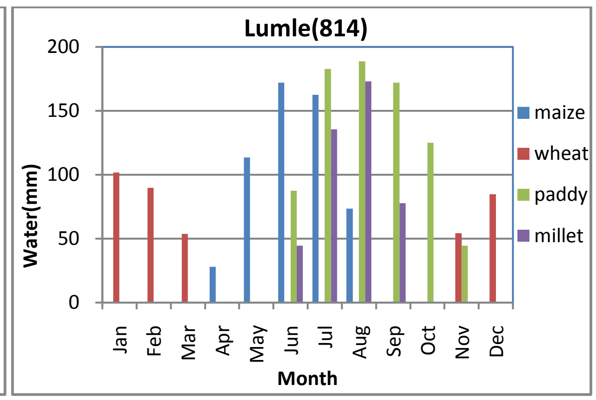
The surface runoff with average maximum and average minimum temperature is also calculated and the output map is shown in Appendix J. Relatively high surface runoff is calculated with minimum temperature and relatively less surface runoff is calculated with maximum temperature. The less surface runoff is due to high Evapotranspiration in maximum temperature.

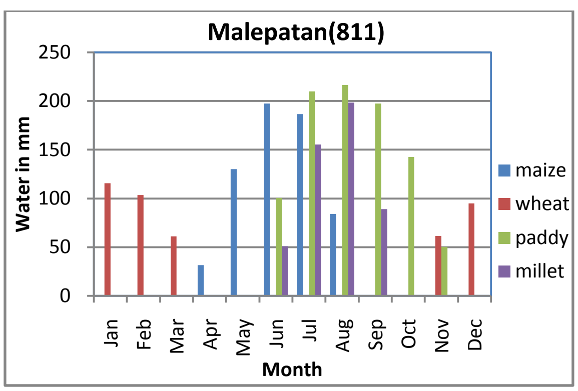
5.5 Analysis of Crop water need for major crops (Paddy, Maize, Wheat, Millet) of Kaski district at 9 meteorological stations

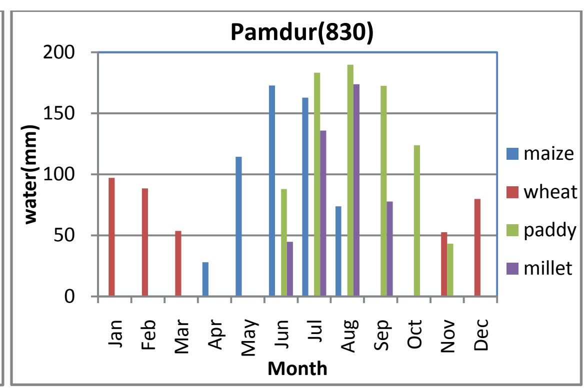












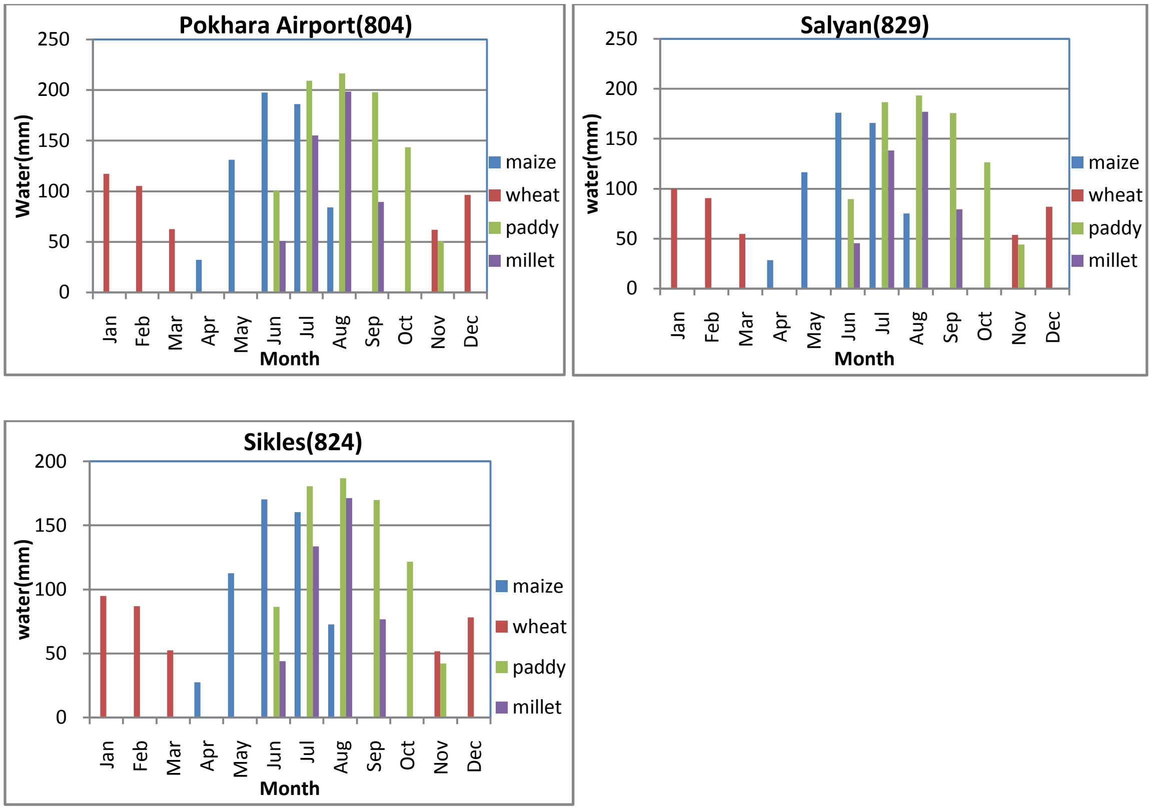
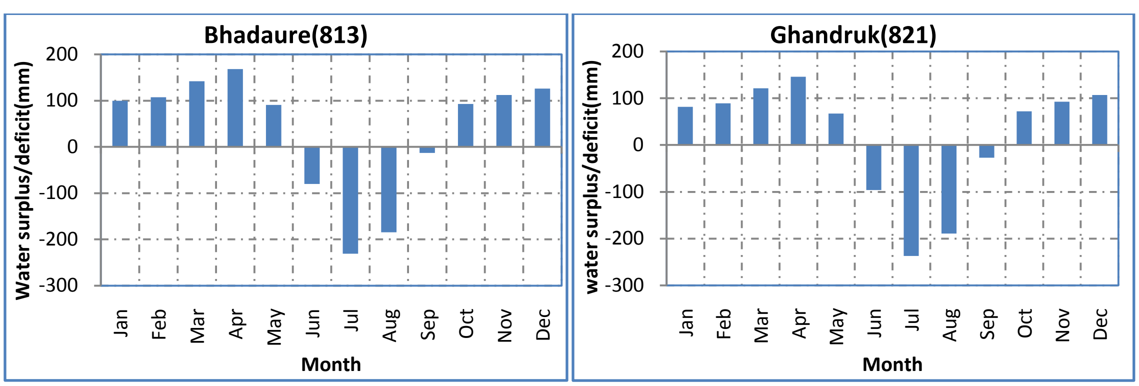


Figure 31: Graph of Cropwater need for major crops of Kaski district at different stations

There is more water need in the months of June, July, August and September. These months are accompanied with growth season of three major crops i.e. paddy, maize and millet. Calculation of crop water need of major crops in each station is shown in Appendix C.

5.6 Analysis of Water surplus/Water deficit



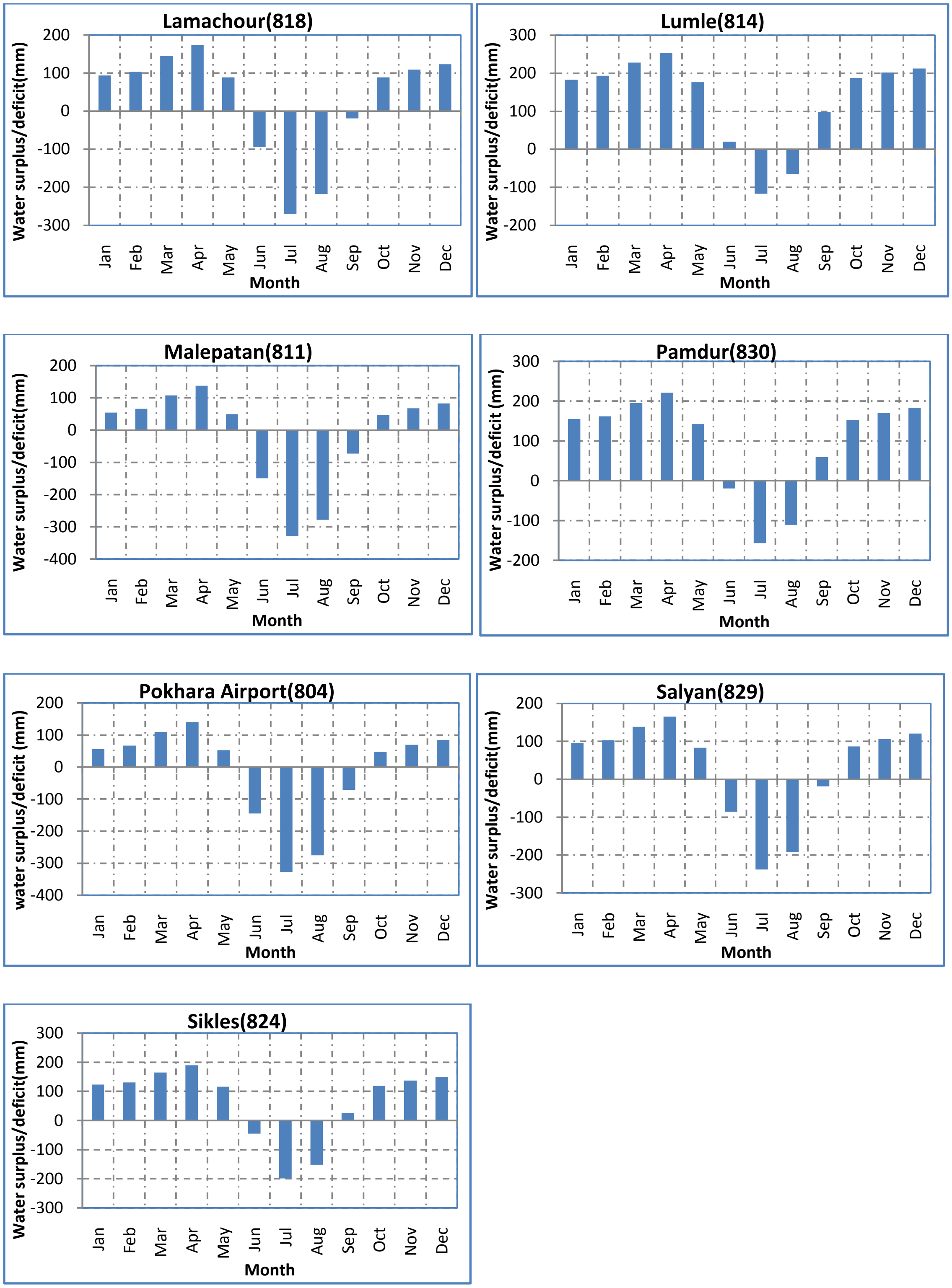


Figure 32: Graph of Average monthly water surplus/deficit of Pokhara airport(804), Bhadaure(813), Gandruk(821), Lamachour(818), Lumle(814), Malepatan(811), Pamdur(830), Salyan(829) and Sikles(824).

The average water surplus or water deficit is calculated by subtracting monthly total crop water need to monthly total runoff on each station. Where, total crop water need is calculated using Blaney Cridle method and monthly runoff using thronthwaite water balance method. The calculation of average monthly water surplus of nine meteorological stations of Kaski district is shown in Appendix B. In January, there is water surplus in every station with maximum surplus in Lumle i.e.183.1mm to minimum surplus in Pokhara Airport and Malepatan i.e.55.7mm and 54.3mm respectively. In the month of February, there is surplus in every station with maximum surplus in Lumle i.e. 193.4mm and minimum surplus in Pokhara Airport and Malepatan i.e. 66.85mm and 65.64mm. In March, there is surplus in every station with maximum surplus in Lumle i.e. 227.8mm whereas minimum surplus in Pokhara Airport and Malepatan i.e. 109.2mm and 107.7mm each. In April, there is surplus in all station with maximum surplus in Lumle i.e. 252.6mm and minimum surplus in Malepatan i.e.137.7mm. In May, there is surplus in all stations with maximum surplus in Lumle i.e. 176.6mm and minimum surplus in Malepatan i.e. 49.1mm. In June , there is water surplus of 20.33mm in Lumle and water deficit in rest of the stations with maximum deficit in Malepatan i.e 149mm. July is month with water deficit in all station with maximum deficit in Malepatan and Pokhara Airport i.e.329.2mm and 327.2mm respectively. In August, there is water deficit in all stations, with maximum deficit in Malepatan and Pokhara Airport and Malepatan and Pokhara Airport i.e 278.5mm and 275.3mmrespectively whereas minimum deficit in Lumle i.e. 65.34mm. In September, there is surplus in Lumle, Pamdur and sikles i.e. 98.45mm, 59.15mm and 24.81mm respectively. There is deficit in rest of the stations with maximum deficit in Malepatan i.e. 72.66mm. In October, there is water surplus in all stations with maximum surplus in Lumle i.e. 187.6mm and minimum surplus in Pokhara Airport and Malepatan i.e.47.72mm and 45.74mm respectively. In November, there is surplus in all stations with maximum surplus in Lumle i.e. 201.7mm and minimum surplus in Pokhara Airport and Malepatan i.e. 69.86mm and 67.91 respectively. In December, there is surplus in all stations with maximum surplus in Lumle i.e. 212.6mm and minimum surplus in Pokhara Airport and Malepatan i.e. 84.14mm and 82.83mm respectively.

5.7 Analysis of Annual surplus/deficit at all stations

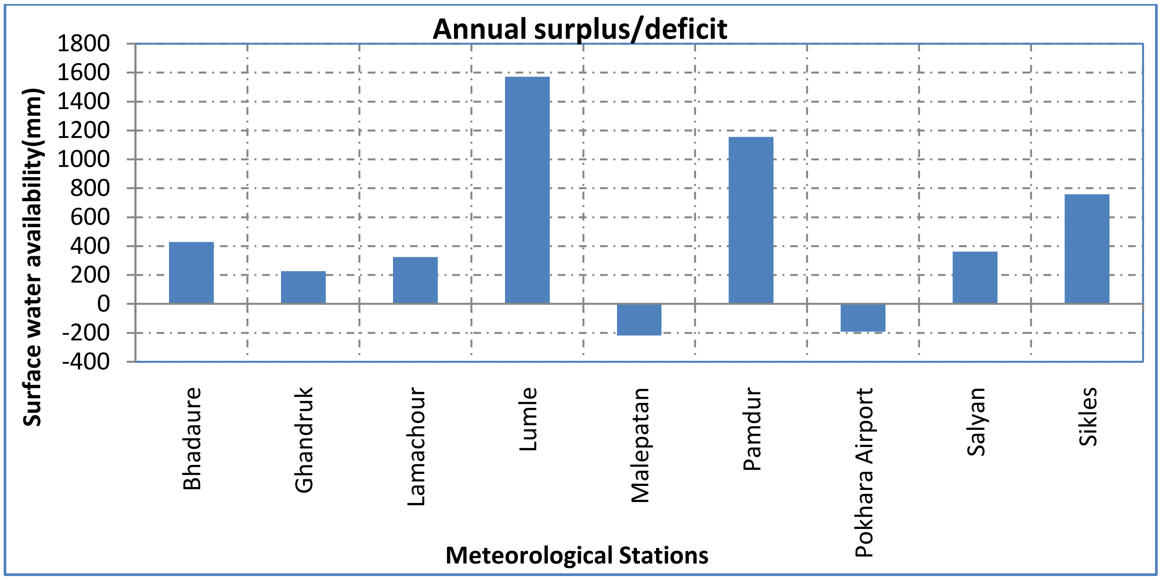


Figure 33 : Graph of Annual water surplus/deficit at different meteorological stations of Kaski District

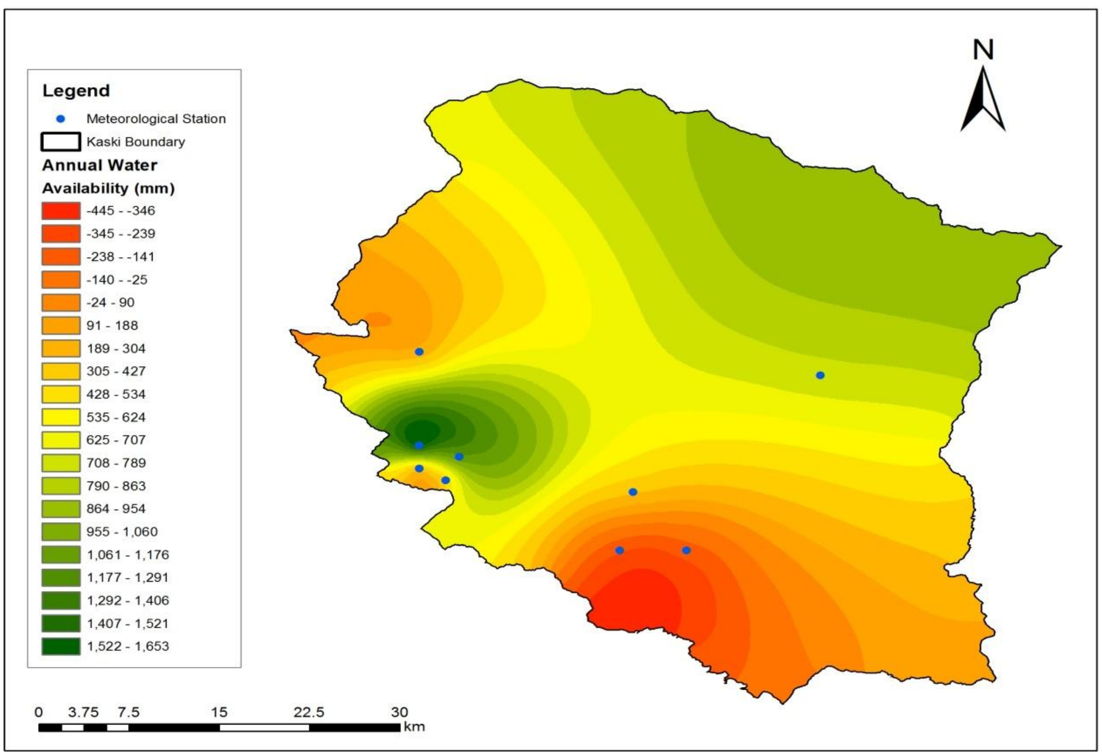


Figure 34 : Spatial variation of annual water availability for major crops of kaski district

The annual surplus/deficit is calculated from annual runoff and annual crop water need. Malepatan and Pokhara Airport are with water deficit of 218.53mm and 191.12mm. Rest of the stations have water surplus with maximum in lumle i.e.1571.75mm and Pamdur i.e.1156.20mm. InLumle and Pamdur there is high rainfall and low temperatures that result in high surplus. Deficit in Malepatan and Pokhara Airport is due to the high temperature.

CHAPTER VI: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The major findings of this study are summarized as below:

- From the analysis of Monthly average rainfall, Kaski district receives maximum rainfall in July as it is peak period of monsoon season and minimum rainfall in November as it is end of post monsoon season with relatively dry weather.
- From the analysis of average temperature, average maximum temperature occurs in June as it is ending of pre-monsoon season and starting of monsoon season. Normally, temperature increases in pre-monsoon season until onset of monsoon. The average minimum temperature occurs in January as it is in winter season where cold and dry northwesterly wind prevails in the country.
- In the spatial analysis of average annual rainfall and average maximum temperature, the annual rainfall is maximum in Lumle as compared to other stations. In case of maximum temperatures, the highest values are observed in Pokhara Airport and Malepatan.
- Thronthwaite water balance model calculated monthly surface runoff of Kaski district. Maximum surface runoff is in southwest part of middle-mountain and northwest part of hill with maximum runoff in August in Lumle and Pamdur i.e.369.8mm and 326.4mm respectively. Minimum surface runoff is in southwest part of high-mountain, northwest part of middle-mountain, southern part of hill and little part of western hill including Salyan and Bhadaure. The month of minimum runoff calculated is March in Malepatan and Pokhara airport i.e. 168.7mm and 171.7mm respectively.
- Crop water need is calculated maximum in the month June to September because it is growing season of paddy, millet and crop development season of maize. Less crop water need is in November as it contains only harvesting season of paddy. From December to April only wheat is grown, so crop water need is less as compared to June, July, August and September.
- Monthly water availability (surplus /deficit) for major crops calculated from difference of monthly surface runoff and monthly crop water need. There is large

water deficit in July and August in all stations. This large deficit is due to the high value of crop water need. There is little amount of deficit in all stations in June and September. There is water surplus in October, November, December, January, February, March, April and May due to less crop water requirement.

- Annual rainfall trend of each station is calculated from excel trend analysis. There is maximum rainfall decrease of 27.4mm/year in Salyan and minimum rainfall increase of 38.6mm/year in Ghandruk.
- The annual water availability (surplus/deficit) is calculated from annual runoff and annual crop water need. There is Water deficit of 218.53mm and 191.12mm in Malepatan and Pokhara Airport which is result of high evaporation because of relatively high temperature. Rest of the stations have water surplus with maximum in lumle i.e.1571.75mm and Pamdur i.e.1156.20mm which is due to the high rainfall and low temperature.

6.2 Recommendations

After result and discussions made in previous chapter, following recommendations are prescribed.

- Study of water surplus/deficit for another pilot district with less annual rainfall can be done for comparison of result.
- Study on rain temperature threshold and snow temperature threshold of Nepal should be done for better result of model output.
- Study on geographic conditions should be done for establishment of meteorological stations that can cover best range of climatic conditions.
- Computing crop water need of other cereal crops, leguminous grains, tubers and bulb crops, oil seeds, cash crops, spices and vegetables can be taken into account to improve irrigation practices and irrigation schedules.
- Since there is temporal and spatial variation of water surplus and deficit, the study on utilization of surplus water can be done for crop harvesting in water deficient months and places.
- Study on soil type and spatial variation of major crops growing area can be done to know actual crop water need as well as for better irrigation practice.

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APPENDIX

AppendixA

Table 0-1 : Average Monthly rainfall data of meteorological stations in mm

Sation/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bhadaure	21.72	37.35	51.95	93.07	304.93	691.66	1097.69	994.78	584.15	156.48	17.83	19.11
Ghandruk	25.07	57.54	73.42	106.14	208.57	565.80	978.41	974.64	538.59	114.16	20.70	20.45
Lamachour	18.91	37.00	68.27	103.43	337.92	788.06	1053.24	978.04	757.70	167.01	16.58	16.71
Lumle	32.08	52.59	70.28	104.23	309.06	886.75	1485.12	1396.44	886.33	209.05	22.28	19.97
Malepatan	22.35	35.13	61.35	106.12	308.75	648.46	983.33	840.48	648.22	158.16	17.33	17.23
Pamdur	28.49	37.53	61.37	101.51	279.44	777.55	1371.83	1221.69	808.98	188.48	23.43	21.77
Pokhara Airport	19.76	36.17	62.26	120.23	339.59	666.12	937.55	845.10	640.39	157.54	19.88	17.57
salyan	25.67	43.31	59.30	107.68	243.57	668.22	1090.41	969.11	578.28	138.98	17.47	20.12
Sikles	18.91	37.00	68.27	103.43	337.92	788.06	1053.24	978.04	757.70	167.01	16.58	16.71

Appendix B

Table 0-2 : Average monthly water surplus or deficit (mm) of meteorological stations

station/month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bhadaure	99.52	107.3	141.8	168.1	90.79	-79.84	-231.1	-184.3	-13.25	92.5	112	126
Ghandruk	81.42	89.19	121.2	145.7	67.25	-95.88	-237	-189.1	-27.4	71.98	92.77	106.7
Lamachour	93.67	103.7	144.1	173	88.92	-94.43	-269.4	-217.3	-19.16	88.72	108.8	123.2
Lumle	183.1	193.4	227.8	252.6	176.6	20.329	-117.1	-65.34	98.447	187.6	201.7	212.6
Malepatan	54.3	65.64	107.7	137.7	49.1	-149.2	-329.2	-278.5	-72.66	45.74	67.91	82.83
Pamdur	155.4	162	195.8	221.2	142.6	-19.43	-156.7	-111	59.152	153.1	170.5	183.7
Pokhara Airport	55.7	66.85	109.2	141	52.77	-144.9	-327.2	-275.3	-70.99	47.72	69.86	84.14
Salyan	95.13	103.2	138.1	165.1	83.03	-86.42	-238.1	-192.2	-19.18	86.41	106.8	120.9
Sikles	123.7	130.3	164.4	189.4	116.1	-44.88	-199	-152.2	24.806	118.7	136.7	150.3

Appendix C

Table 0-3 : Monthly crop water need of major crops of Kaski district

Bhadaure

Crop/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Crop water need
Maize	×	×	×	28.41	116.05	175.19	165.09	74.75	×	×	×	×	559.49
Wheat	99.00	90.10	54.48	×	×	×	×	×	×	×	53.58	81.39	378.54
Paddy	×	×	×	×	×	89.22	185.73	192.22	174.77	125.67	43.84	×	811.44
Millet	×	×	×	×	×	45.32	137.58	176.20	78.89	×	×	×	437.98
Monthly total crop water need	99.00	90.10	54.48	28.41	116.05	309.72	488.40	443.17	253.65	125.67	97.41	81.39	2187.45

Ghandruk

Crop/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total crop water need
Maize	×	×	×	26.81	109.77	166.52	156.54	71.08	×	×	×	×	530.72
Wheat	91.38	83.78	51.12	×	×	×	×	×	×	×	50.09	75.36	351.72
Paddy	×	×	×	×	×	84.60	176.10	182.78	165.49	118.42	40.98	×	768.38
Millet	×	×	×	×	×	42.97	130.45	167.55	74.70	×	×	×	415.67
Monthly total crop water need	91.38	83.78	51.12	26.81	109.77	294.09	463.09	421.41	240.20	118.42	91.07	75.36	2066.49

Lamachour

Crop/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total crop water need
Maize	×	×	×	31.05	126.72	190.70	179.64	81.32	×	×	×	×	609.43
Wheat	111.95	100.86	60.01	×	×	×	×	×	×	×	59.51	91.64	423.97
Paddy	×	×	×	×	×	96.89	202.09	209.11	190.53	137.99	48.69	×	885.30
Millet	×	×	×	×	×	49.21	149.70	191.68	86.00	×	×	×	476.60
Monthly total crop water need	111.95	100.86	60.01	31.05	126.72	336.80	531.43	482.11	276.54	137.99	108.21	91.64	2395.29

Lumle

Crop/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total crop water need
Maize	×	×	×	28.09	113.54	171.99	162.53	73.40	×	×	×	×	549.55
Wheat	101.66	89.79	53.64	×	×	×	×	×	×	×	54.28	84.70	384.07
Paddy	×	×	×	×	×	87.38	182.84	188.74	171.98	124.94	44.41	×	800.30
Millet	×	×	×	×	×	44.39	135.44	173.01	77.63	×	×	×	430.47
monthly totalcrop water need	101.66	89.79	53.64	28.09	113.54	303.76	480.81	435.15	249.62	124.94	98.68	84.70	2164.39

Malepatan

Crop/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total crop water need
Maize	×	×	×	31.69	130.17	197.55	186.48	84.22	×	×	×	×	630.10
Wheat	115.75	103.39	61.02	×	×	×	×	×	×	×	61.43	94.96	436.55
Paddy	×	×	×	×	×	100.37	209.79	216.56	197.49	142.70	50.26	×	917.17
Millet	×	×	×	×	×	50.98	155.40	198.51	89.14	×	×	×	494.04
Monthly total crop water need	115.75	103.39	61.02	31.69	130.17	348.89	551.68	499.29	286.63	142.70	111.70	94.96	2477.86

Pamdur

Crop/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total crop water need
Maize	×	×	×	28.01	114.48	172.91	162.95	73.79	×	×	×	×	552.13
Wheat	97.09	88.52	53.64	×	×	×	×	×	×	×	52.70	79.88	371.84
Paddy	×	×	×	×	×	88.06	183.32	189.73	172.45	123.86	43.12	×	800.54
Millet	×	×	×	×	×	44.73	135.80	173.92	77.84	×	×	×	432.29
Monthly totalcrop water need	97.09	88.52	53.64	28.01	114.48	305.69	482.07	437.44	250.29	123.86	95.83	79.88	2156.80

Pokhara

Crop/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total crop water need
Maize	×	×	×	32.25	131.11	197.55	186.06	84.22	×	×	×	×	631.18
Wheat	117.28	105.28	62.53	×	×	×	×	×	×	×	61.96	96.46	443.51
Paddy	×	×	×	×	×	100.39	209.31	216.56	197.95	143.42	50.69	×	918.33
Millet	×	×	×	×	×	50.99	155.05	198.51	89.35	×	×	×	493.91
Monthly total crop water need	117.28	105.28	62.53	32.25	131.11	348.93	550.42	499.29	287.30	143.42	112.65	96.46	2486.92

Salyan

Crop/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total crop water need
Maize	×	×	×	28.57	116.68	176.10	165.95	75.14	×	×	×	×	562.43
Wheat	99.76	90.74	54.81	×	×	×	×	×	×	×	53.93	81.99	381.22
Paddy	×	×	×	×	×	89.47	186.69	193.21	175.69	126.39	44.12	×	815.59
Millet	×	×	×	×	×	45.45	138.29	177.11	79.31	×	×	×	440.15
Monthly totalcrop water need	99.76	90.74	54.81	28.57	116.68	311.02	490.93	445.46	255.00	126.39	98.05	81.99	2199.39

Sikles

Crop/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total crop water need
Maize	×	×	×	27.45	112.60	170.17	160.39	72.63	×	×	×	×	543.23
Wheat	94.81	86.94	52.47	×	×	×	×	×	×	×	51.66	78.07	363.94
Paddy	×	×	×	×	×	86.46	180.44	186.75	169.67	121.68	42.27	×	787.26
Millet	×	×	×	×	×	43.91	133.66	171.19	76.59	×	×	×	425.35
Monthly total crop water need	94.81	86.94	52.47	27.45	112.60	300.54	474.48	430.57	246.25	121.68	93.92	78.07	2119.78

Appendix D

Table 0-4 : Average monthly runoff with mean temperature at all stations

Index No./ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
813	198.5	197.4	196.3	196.5	206.8	229.9	257.3	258.9	240.4	218.2	209.4	207.4
821	172.8	173.0	172.3	172.5	177.0	198.2	226.1	232.3	212.8	190.4	183.8	182.0
818	205.6	204.5	204.1	204.1	215.6	242.4	262.1	264.8	257.4	226.7	217.0	214.9
814	284.8	283.2	281.4	280.7	290.1	324.1	363.7	369.8	348.1	312.6	300.4	297.3
811	170.1	169.0	168.7	169.4	179.3	199.7	222.5	220.8	214.0	188.4	179.6	177.8
830	252.5	250.5	249.4	249.2	257.1	286.3	325.4	326.4	309.4	277.0	266.3	263.6
804	173.0	172.1	171.8	173.2	183.9	204.1	223.2	224.0	216.3	191.1	182.5	180.6
829	194.9	193.9	192.9	193.7	199.7	224.6	252.9	253.2	235.8	212.8	204.8	202.9
824	218.5	217.3	216.8	216.8	228.7	255.7	275.5	278.4	271.1	240.4	230.6	228.3

Appendix E

Table 0-5 : Average monthly runoff with maximum temperature at all stations

Index No./ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bhadaure(813)	183.4	182.4	181.4	181.6	191.5	214.1	241.4	242.9	224.3	202.1	193.5	191.6
Ghandruk(821)	158.6	158.8	158.2	158.3	162.5	183.4	211.1	217.2	197.6	175.3	168.9	167.2
Lamachour(818)	187.9	187.0	186.7	186.7	197.7	224.0	243.5	246.1	238.5	207.8	198.3	196.3
Lumle(814)	273.1	271.5	269.7	269.0	278.0	311.8	351.3	357.4	335.6	300.1	288.0	285.0
Malepatan(811)	150.7	149.9	149.8	150.6	159.9	179.7	202.3	200.3	193.4	167.9	159.2	157.6
Pamdur(830)	236.9	235.1	234.0	233.8	241.2	270.1	309.1	310.0	292.9	260.5	249.9	247.3
Pokhara Airport(804)	154.6	153.9	153.7	155.1	165.3	184.9	203.9	204.5	196.7	171.5	163.0	161.3
Salyan(829)	179.0	178.2	177.3	178.0	183.5	208.0	236.2	236.4	218.9	195.9	188.1	186.3
Sikles(824)	203.5	202.4	202.0	201.9	213.2	240.0	259.7	262.5	255.1	224.4	214.8	212.6

Appendix F

Table 0-6 : Average monthly runoff with minimum temperature at all stations

Index No./ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
813	210.6	209.4	208.2	208.6	219.3	242.5	270.0	271.7	253.2	231.0	222.1	220.0
821	183.5	184.1	183.5	183.8	188.5	209.9	237.8	244.1	224.6	202.2	195.5	193.4
818	207.5	206.5	205.5	206.4	212.7	237.8	266.2	266.6	249.3	226.2	218.2	216.2
814	294.4	292.8	291.0	290.4	300.1	334.1	373.8	380.0	358.3	322.8	310.6	307.4
811	186.3	185.2	184.8	185.6	196.0	216.7	239.7	238.1	231.3	205.8	196.8	194.9
830	264.7	262.7	261.5	261.4	269.7	299.0	338.2	339.3	322.4	290.0	279.2	276.2
804	188.7	187.7	187.3	188.9	200.1	220.5	239.8	240.7	233.1	207.9	199.1	197.1
829	207.5	206.5	205.5	206.4	212.7	237.8	266.2	266.6	249.3	226.2	218.2	216.2
824	230.1	228.9	228.4	228.6	240.8	267.8	287.8	290.7	283.5	252.8	242.9	240.5

Appendix G

Table 0-7 : Average Monthly Minimum temperature of all stations

Index No./ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
813	2.3	4.7	8.2	11.1	13.8	16.3	17.2	17.3	15.9	12.0	7.2	3.3
821	0.3	2.7	6.2	9.1	11.8	14.3	15.2	15.3	13.9	10.0	5.3	1.3
818	5.7	8.0	11.5	14.4	17.1	19.6	20.6	20.6	19.2	15.3	10.6	6.6
814	4.9	6.4	9.6	12.5	14.3	16.7	17.6	17.5	16.4	12.9	9.3	6.2
811	7.0	9.3	12.8	15.7	18.4	20.9	21.8	21.9	20.5	16.6	11.9	7.9
830	1.8	4.2	7.7	10.6	13.3	15.8	16.7	16.8	15.4	11.5	6.7	2.8
804	7.1	9.5	13.0	15.9	18.6	21.1	22.0	22.1	20.7	16.8	12.1	8.1
829	2.5	4.8	8.3	11.2	13.9	16.4	17.4	17.5	16.1	12.1	7.4	3.4
824	1.2	3.5	7.0	9.9	12.6	15.1	16.1	16.1	14.7	10.8	6.1	2.1

Appendix H

Table 0-8 : Average Monthly Maximum temperature of all stations

Index No./ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
813	15.0	17.6	22.1	25.2	25.6	25.9	25.3	25.5	24.9	22.8	19.5	16.1
821	13.1	15.6	20.1	23.2	23.6	23.9	23.3	23.5	22.9	20.8	17.5	14.1
818	18.4	21.0	25.4	28.6	28.9	29.3	28.7	28.9	28.2	26.2	22.8	19.4
814	13.8	15.6	19.7	22.9	23.5	24.0	23.6	23.7	23.1	21.4	18.3	15.2
811	19.7	22.3	26.7	29.9	30.2	30.5	29.9	30.1	29.5	27.4	24.1	20.7
830	14.5	17.1	21.6	24.7	25.1	25.4	24.8	25.0	24.4	22.3	19.0	15.6
804	19.9	22.4	26.9	30.0	30.4	30.7	30.1	30.3	29.7	27.6	24.3	20.9
829	15.2	17.8	22.3	25.4	25.7	26.1	25.5	25.7	25.0	23.0	19.6	16.3
824	13.9	16.5	20.9	24.1	24.4	24.8	24.2	24.4	23.7	21.7	18.3	14.9

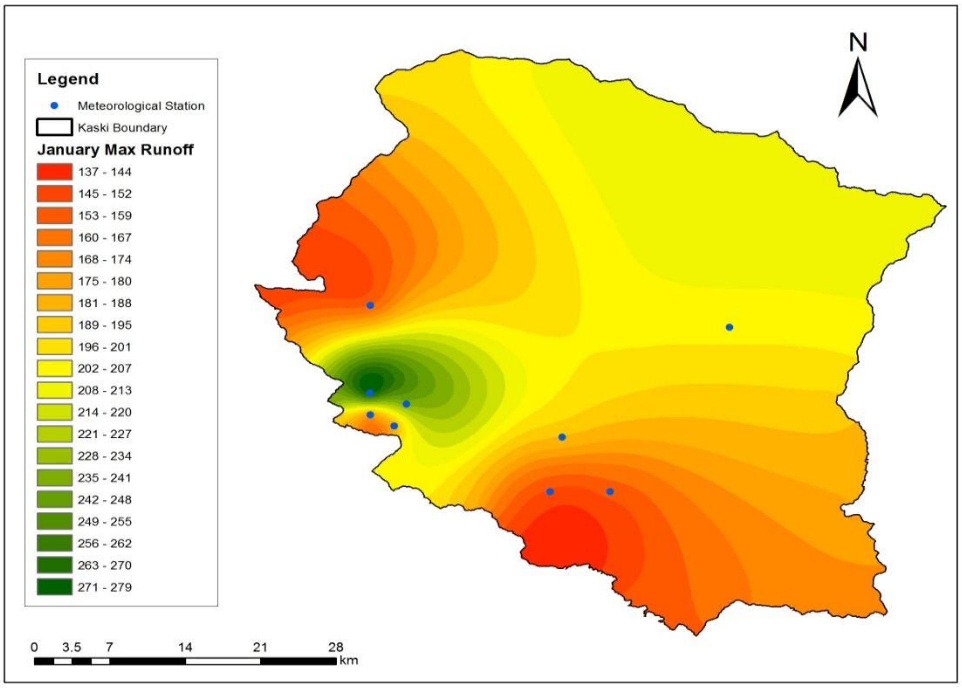
Appendex I

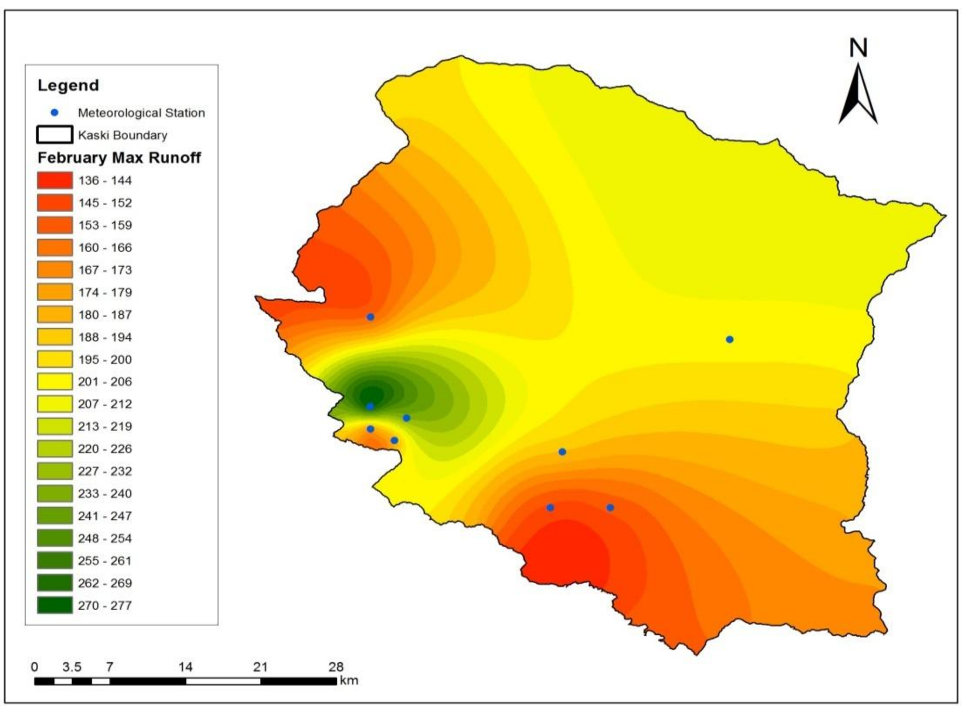
Table 0-9 : Average Monthly Minimum and Maximum Temperature of Kaski district

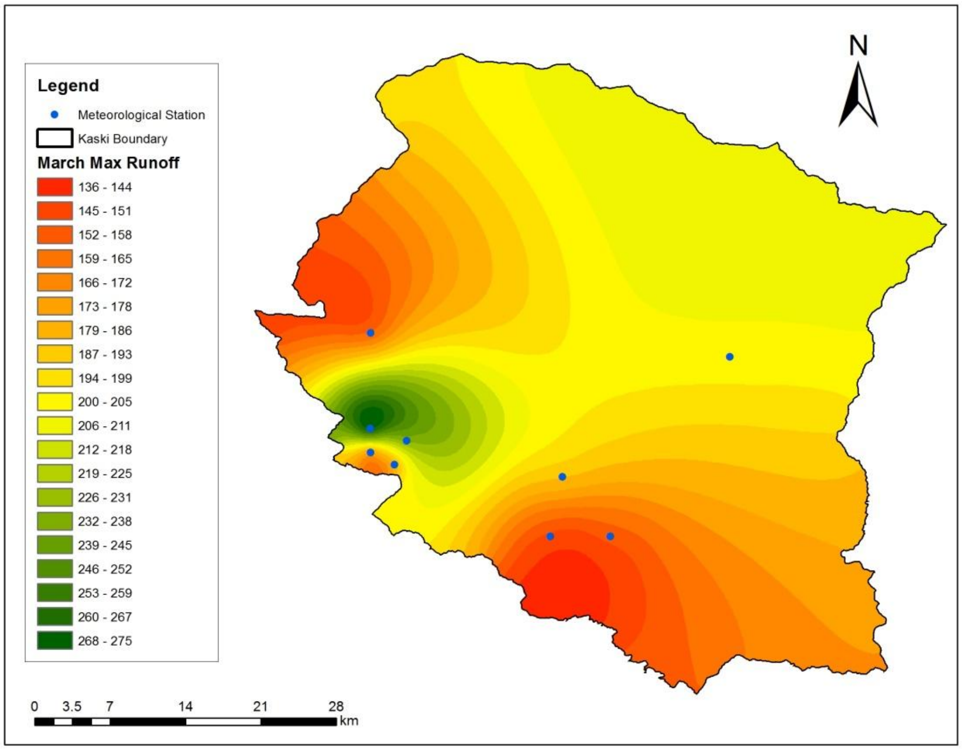
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Minimum Temperature	3.6	5.9	9.4	12.3	14.9	17.4	18.3	18.3	17.0	13.1	8.5	4.6
Average Maximum Temperature	15.9	18.4	22.9	26.0	26.4	26.7	26.2	26.4	25.7	23.7	20.4	17.0

Appendix J

Figure 35 : Monthly runoff map of Kaski district calculated by Thronthwaite model using maximum and minimum temperatures



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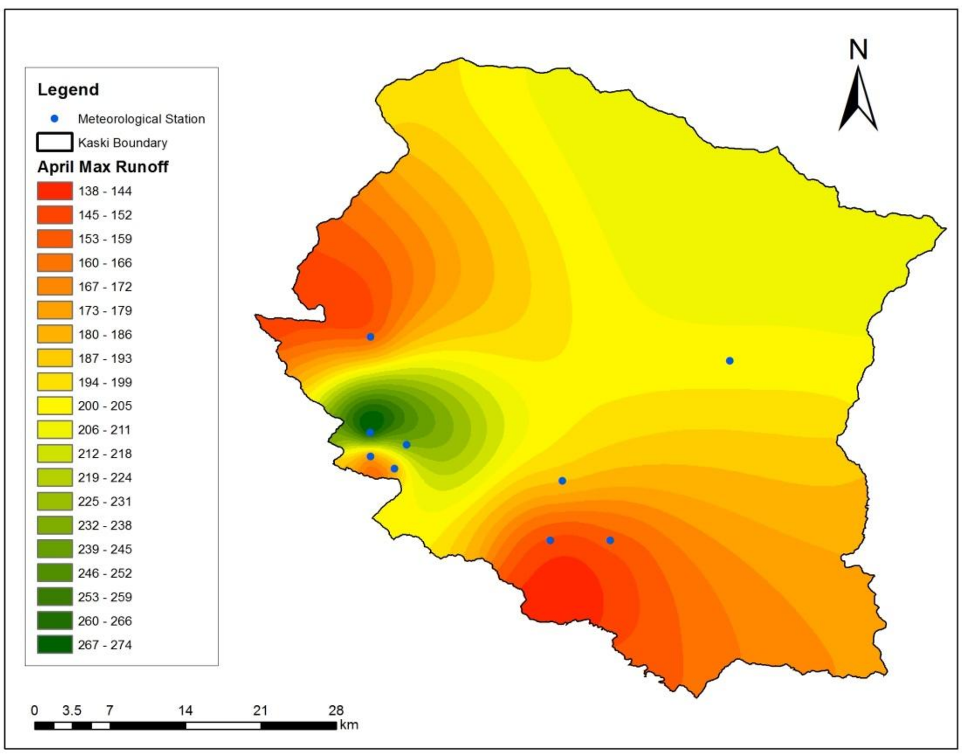
Meteorological Station
Kaski Boundary
March Max Runoff
136 - 144
145 - 151
152 - 158
159 - 165
166 - 172
173 - 178
179 - 186
187 - 193
194 - 199
200 - 205
206 - 211
212 - 218
219 - 225
226 - 231
232 - 238
239 - 245
246 - 252
253 - 259
260 - 267
268 - 275
N
0 3.5 7 14 21 28
km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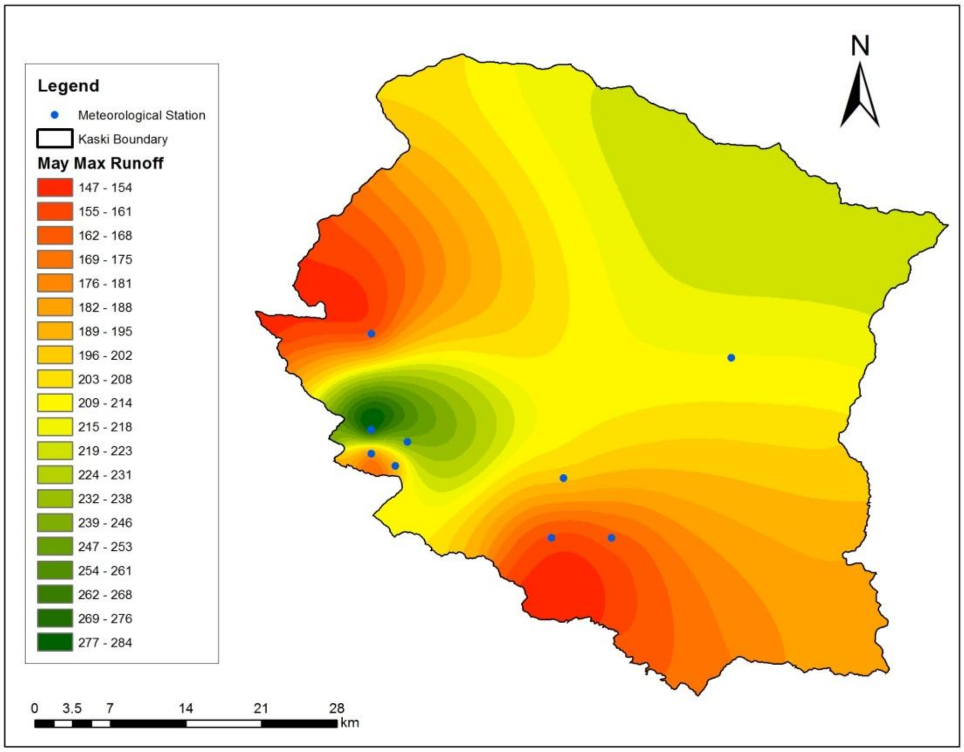
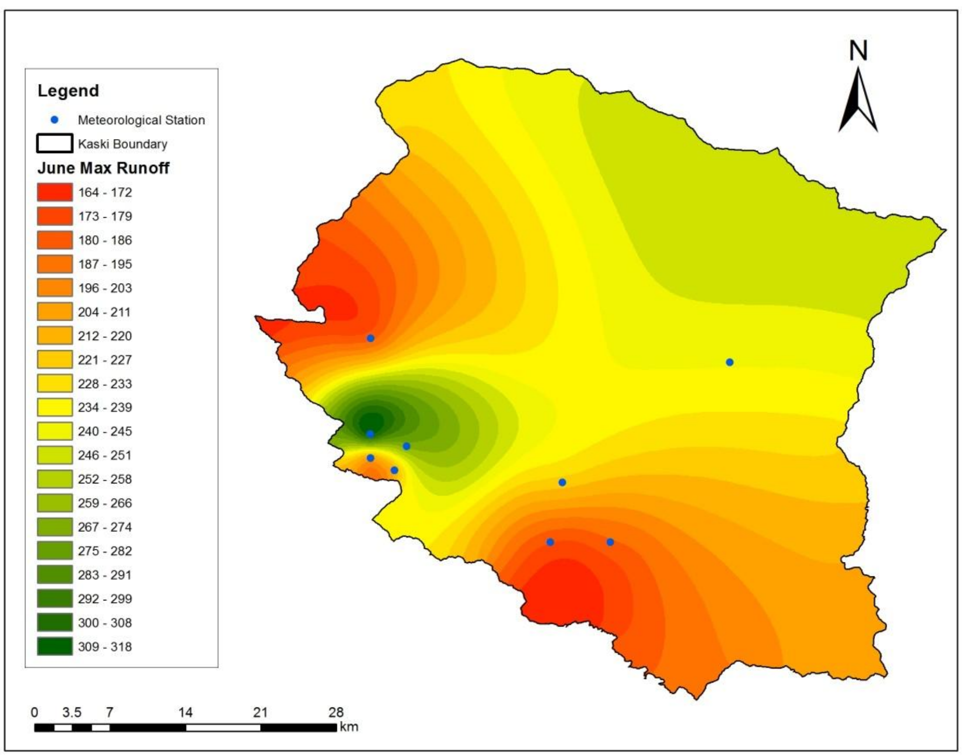
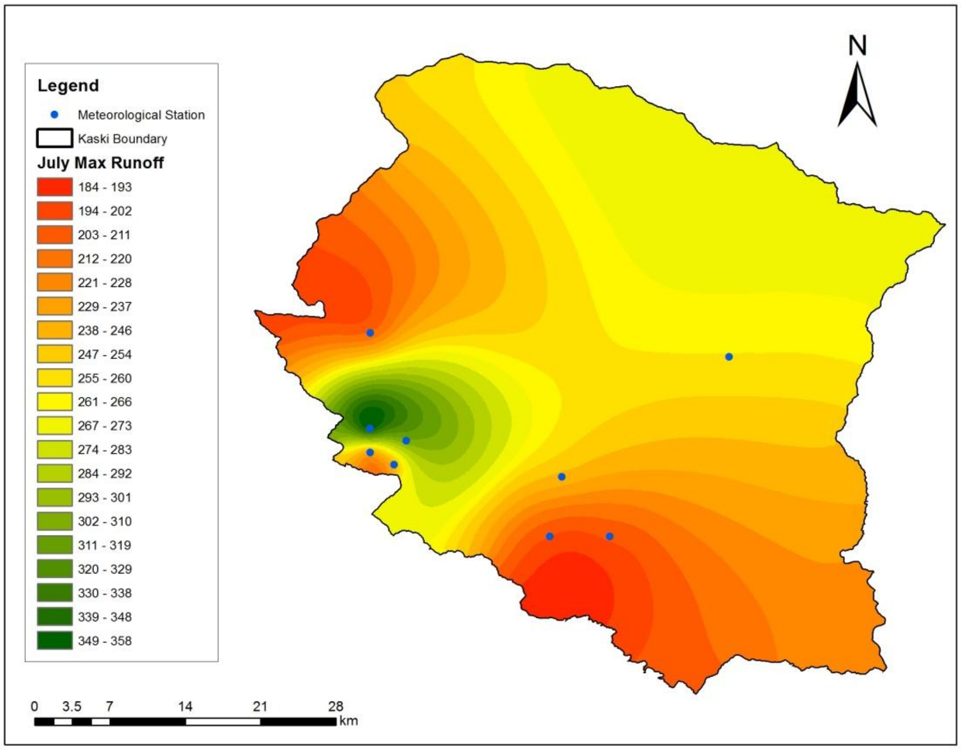
Meteorological Station
Kaski Boundary
April Max Runoff
138 - 144
145 - 152
153 - 159
160 - 166
167 - 172
173 - 179
180 - 186
187 - 193
194 - 199
200 - 205
206 - 211
212 - 218
219 - 224
225 - 231
232 - 238
239 - 245
246 - 252
253 - 259
260 - 266
267 - 274
N
0 3.5 7 14 21 28
km



Legend
Meteorological Station
Kaski Boundary
May Max Runoff
147 - 154
155 - 161
162 - 168
169 - 175
176 - 181
182 - 188
189 - 195
196 - 202
203 - 208
209 - 214
215 - 218
219 - 223
224 - 231
232 - 238
239 - 246
247 - 253
254 - 261
262 - 268
269 - 276
277 - 284
N
0 3.5 7 14 21 28 km



Legend
Meteorological Station
Kaski Boundary
June Max Runoff
164 - 172
173 - 179
180 - 186
187 - 195
196 - 203
204 - 211
212 - 220
221 - 227
228 - 233
234 - 239
240 - 245
246 - 251
252 - 258
259 - 266
267 - 274
275 - 282
283 - 291
292 - 299
300 - 308
309 - 318
N
0 3.5 7 14 21 28 km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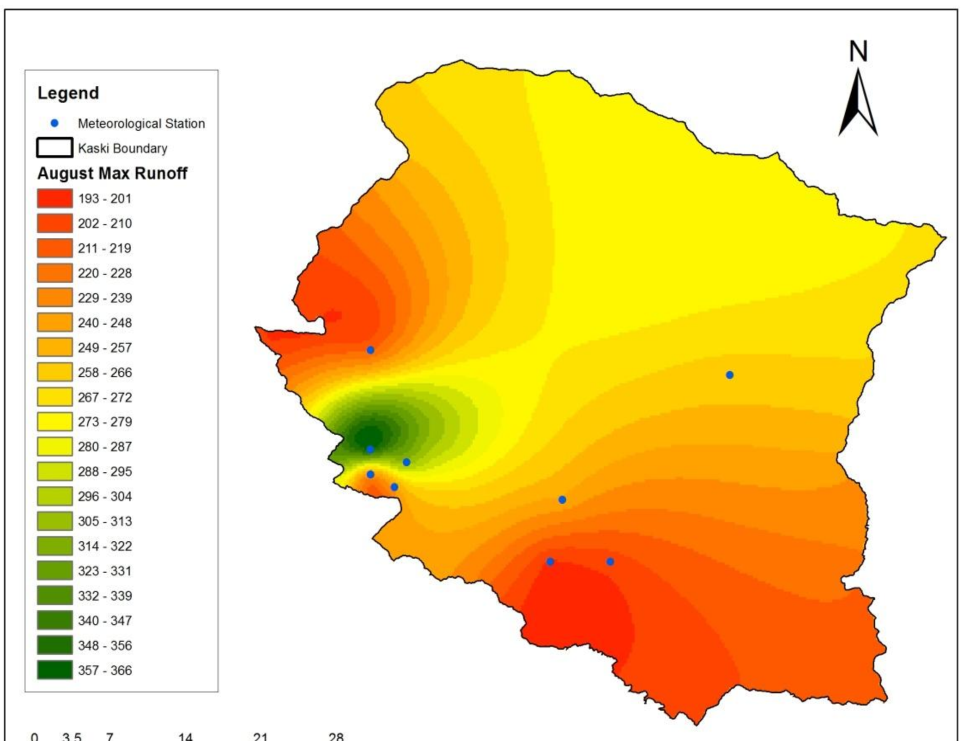
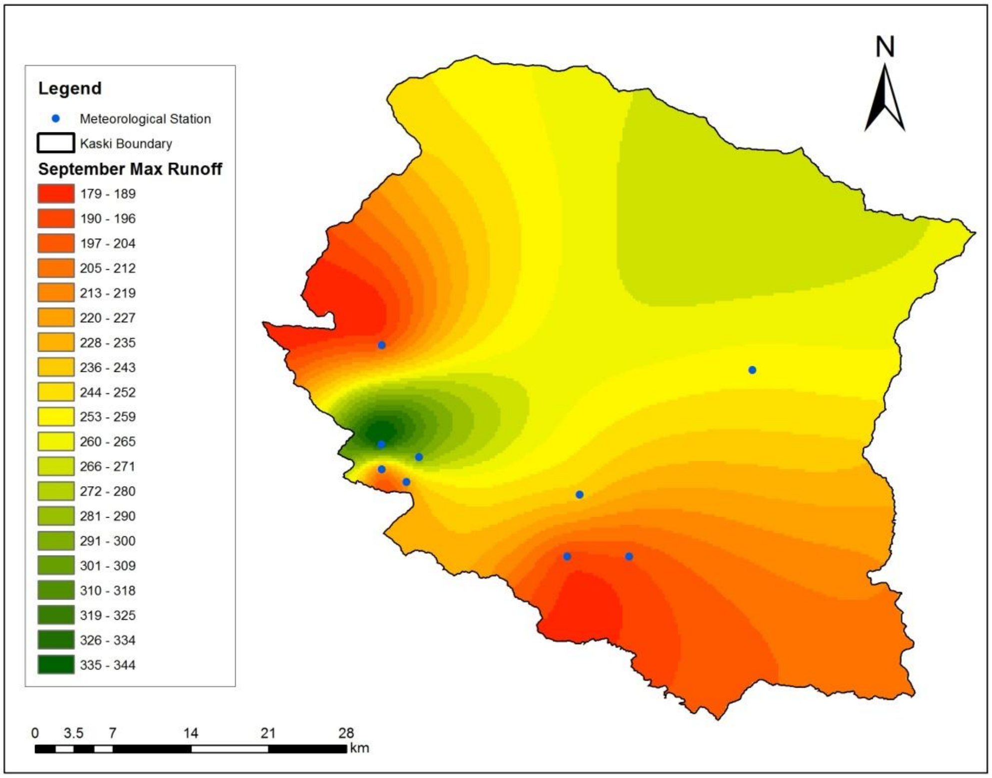
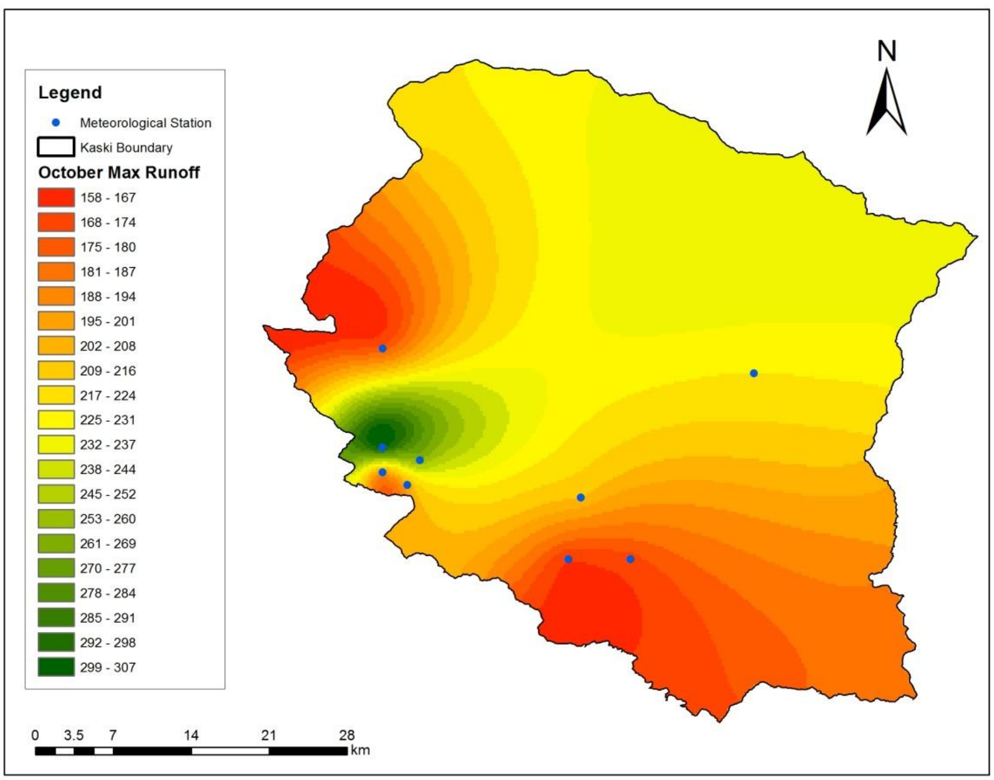
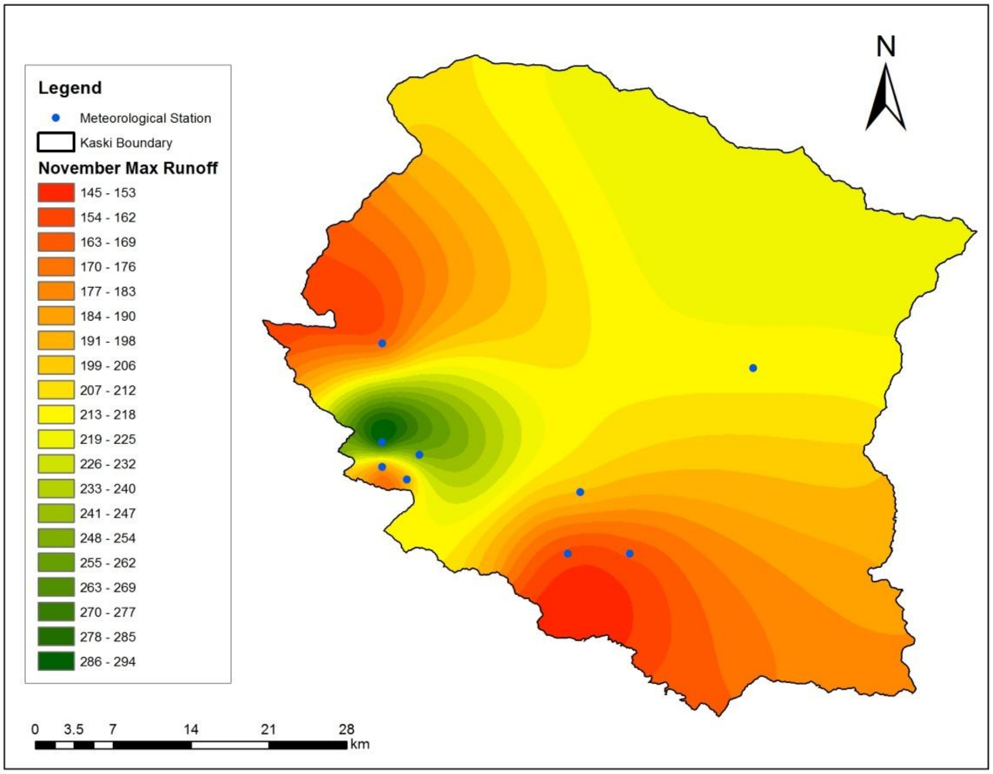
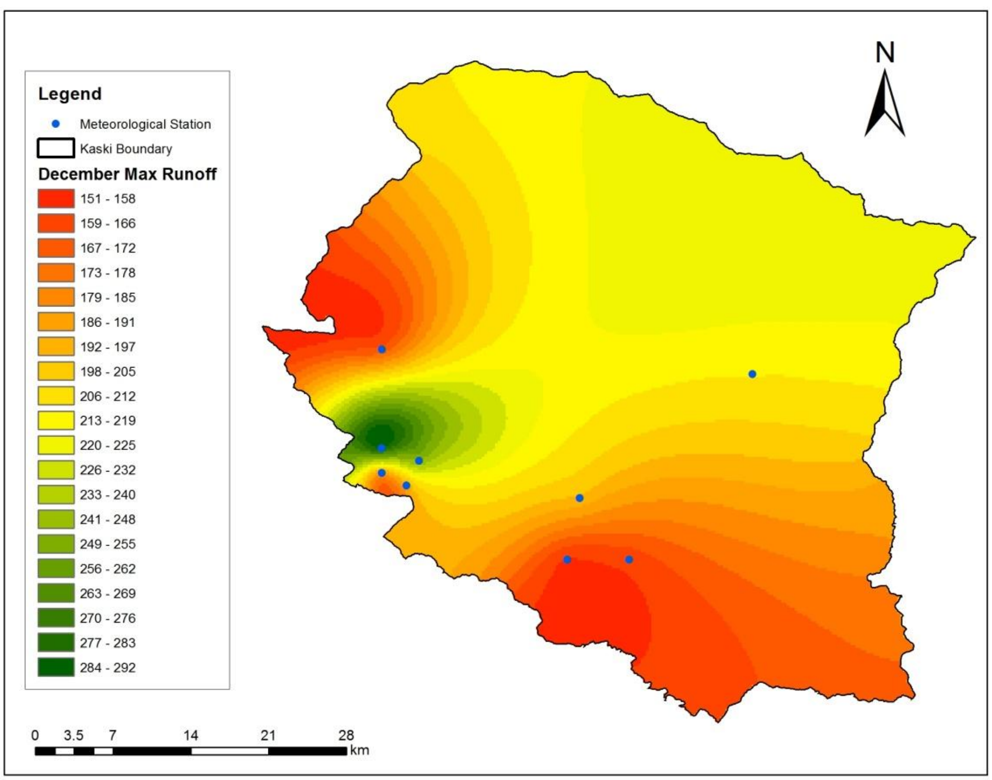
Legend
Meteorological Station
Kaski Boundary
July Max Runoff
184 - 193
194 - 202
203 - 211
212 - 220
221 - 228
229 - 237
238 - 246
247 - 254
255 - 260
261 - 266
267 - 273
274 - 283
284 - 292
293 - 301
302 - 310
311 - 319
320 - 329
330 - 338
339 - 348
349 - 358
0 3.5 7 14 21 28
km

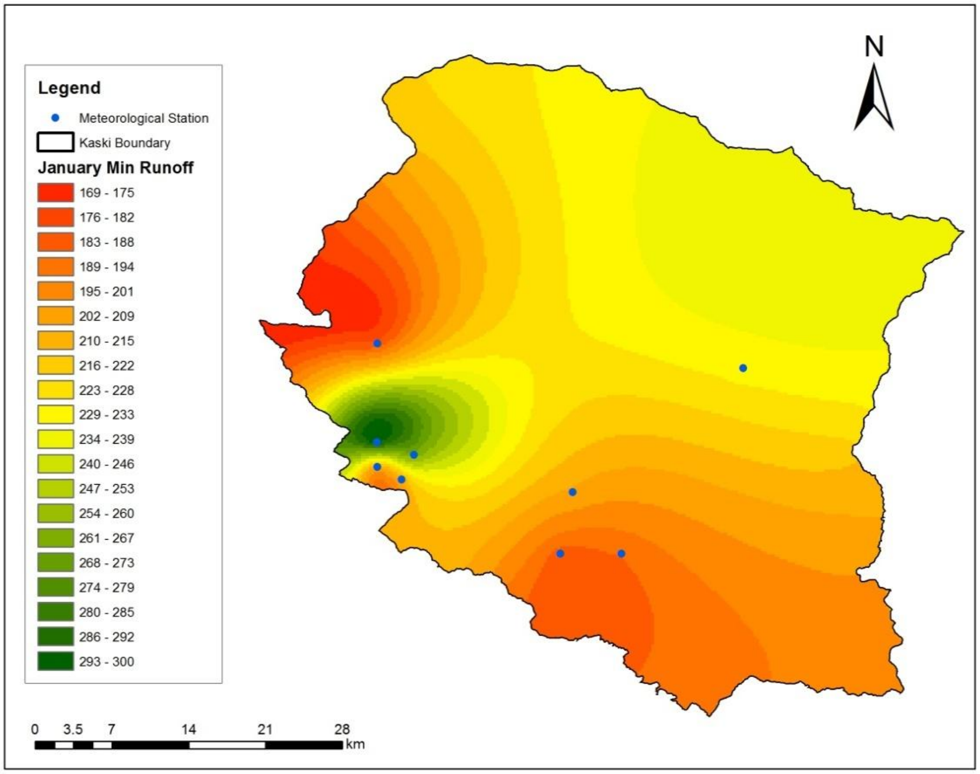

N
Legend
Meteorological Station
Kaski Boundary
August Max Runoff
193 - 201
202 - 210
211 - 219
220 - 228
229 - 239
240 - 248
249 - 257
258 - 266
267 - 272
273 - 279
280 - 287
288 - 295
296 - 304
305 - 313
314 - 322
323 - 331
332 - 339
340 - 347
348 - 356
357 - 366
0 3.5 7 14 21 28
km

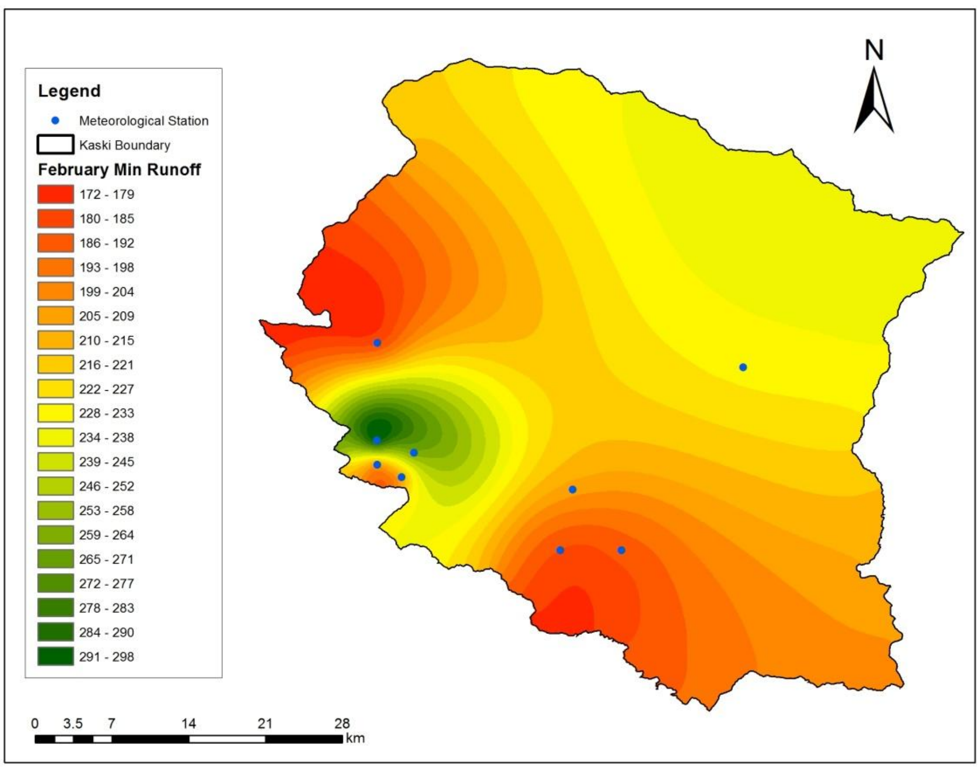

N
Legend
Meteorological Station
Kaski Boundary
September Max Runoff
179 - 189
190 - 196
197 - 204
205 - 212
213 - 219
220 - 227
228 - 235
236 - 243
244 - 252
253 - 259
260 - 265
266 - 271
272 - 280
281 - 290
291 - 300
301 - 309
310 - 318
319 - 325
326 - 334
335 - 344
0 3.5 7 14 21 28
km


N
Legend
Meteorological Station
Kaski Boundary
October Max Runoff
158 - 167
168 - 174
175 - 180
181 - 187
188 - 194
195 - 201
202 - 208
209 - 216
217 - 224
225 - 231
232 - 237
238 - 244
245 - 252
253 - 260
261 - 269
270 - 277
278 - 284
285 - 291
292 - 298
299 - 307
0 3.5 7 14 21 28
km


Legend
Meteorological Station
Kaski Boundary
November Max Runoff
145 - 153
154 - 162
163 - 169
170 - 176
177 - 183
184 - 190
191 - 198
199 - 206
207 - 212
213 - 218
219 - 225
226 - 232
233 - 240
241 - 247
248 - 254
255 - 262
263 - 269
270 - 277
278 - 285
286 - 294
N
0 3.5 7 14 21 28 km


Legend
Meteorological Station
Kaski Boundary
December Max Runoff
151 - 158
159 - 166
167 - 172
173 - 178
179 - 185
186 - 191
192 - 197
198 - 205
206 - 212
213 - 219
220 - 225
226 - 232
233 - 240
241 - 248
249 - 255
256 - 262
263 - 269
270 - 276
277 - 283
284 - 292
N
0 3.5 7 14 21 28 km


N
Legend
Meteorological Station
Kaski Boundary
January Min Runoff
169 - 175
176 - 182
183 - 188
189 - 194
195 - 201
202 - 209
210 - 215
216 - 222
223 - 228
229 - 233
234 - 239
240 - 246
247 - 253
254 - 260
261 - 267
268 - 273
274 - 279
280 - 285
286 - 292
293 - 300
0 3.5 7 14 21 28
km


N
Legend
Meteorological Station
Kaski Boundary
February Min Runoff
172 - 179
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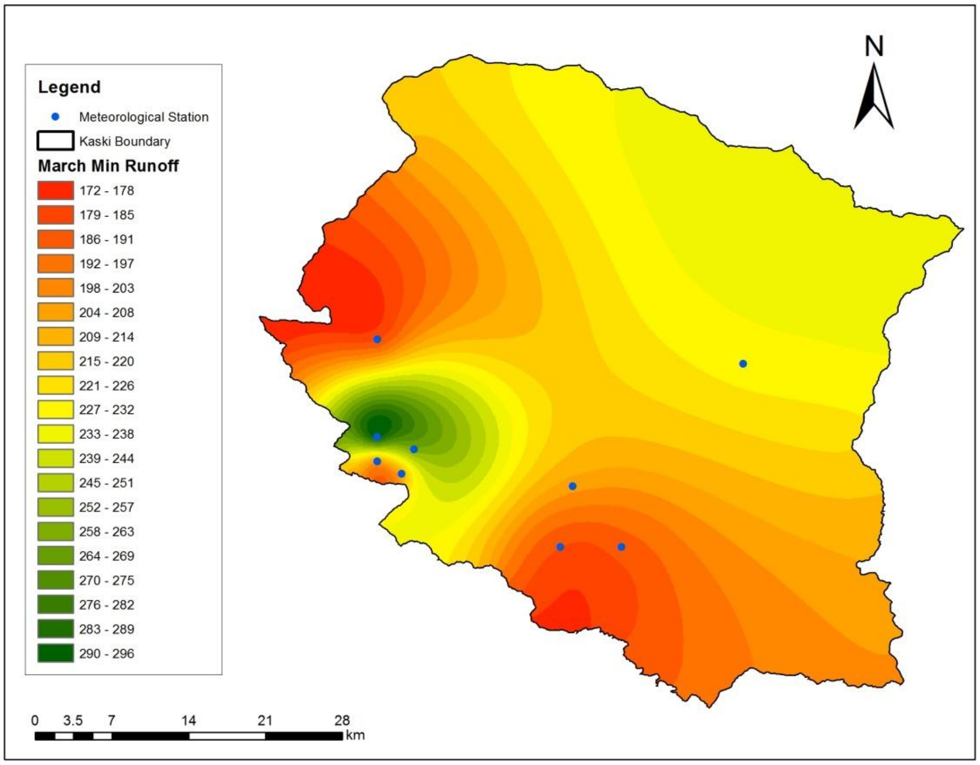
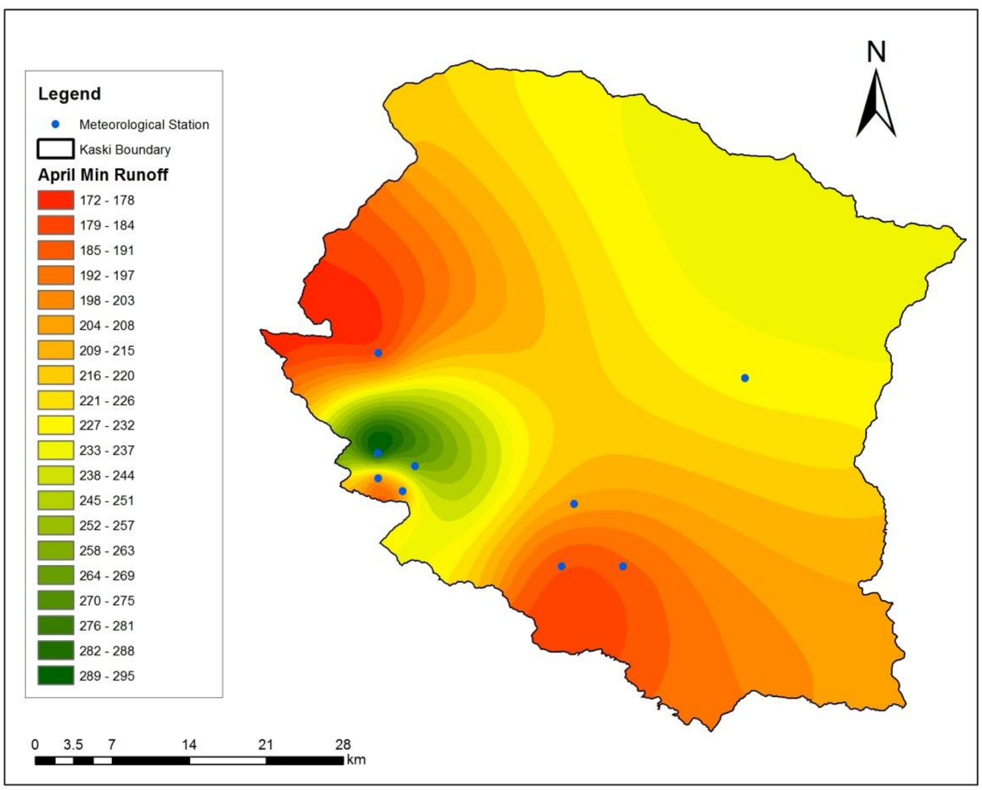
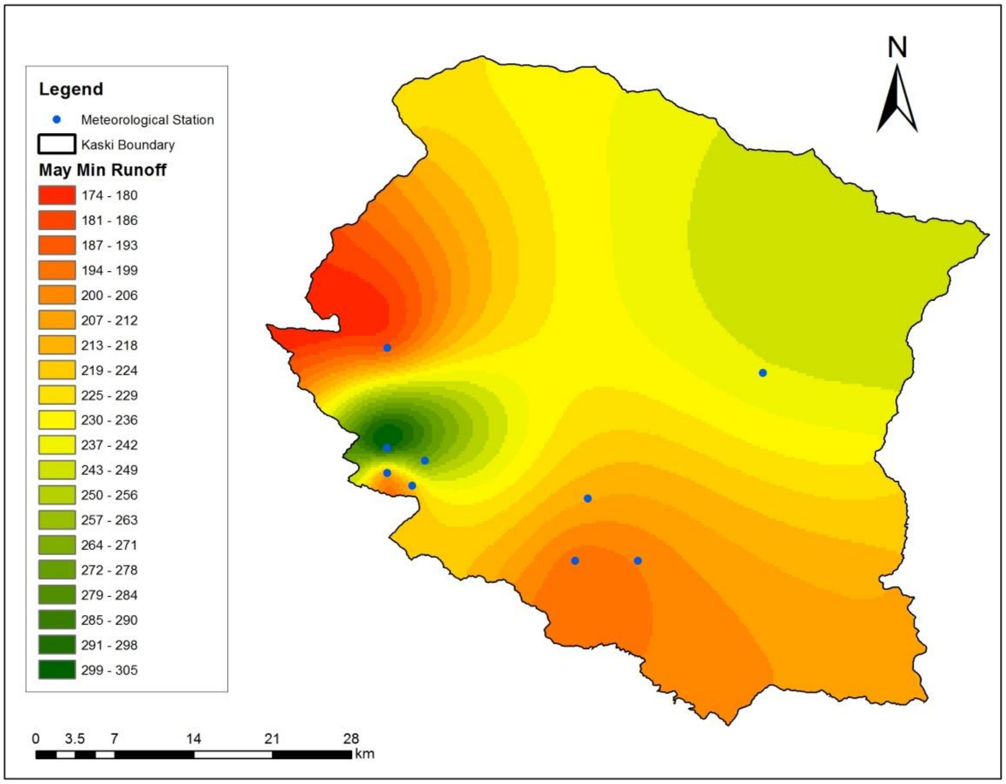
186 - 192
193 - 198
199 - 204
205 - 209
210 - 215
216 - 221
222 - 227
228 - 233
234 - 238
239 - 245
246 - 252
253 - 258
259 - 264
265 - 271
272 - 277
278 - 283
284 - 290
291 - 298
0 3.5 7 14 21 28
km


N
Legend
Meteorological Station
Kaski Boundary
March Min Runoff
172 - 178
179 - 185
186 - 191
192 - 197
198 - 203
204 - 208
209 - 214
215 - 220
221 - 226
227 - 232
233 - 238
239 - 244
245 - 251
252 - 257
258 - 263
264 - 269
270 - 275
276 - 282
283 - 289
290 - 296
0 3.5 7 14 21 28
km


N
Legend
Meteorological Station
Kaski Boundary
April Min Runoff
172 - 178
179 - 184
185 - 191
192 - 197
198 - 203
204 - 208
209 - 215
216 - 220
221 - 226
227 - 232
233 - 237
238 - 244
245 - 251
252 - 257
258 - 263
264 - 269
270 - 275
276 - 281
282 - 288
289 - 295
0 3.5 7 14 21 28
km


N
Legend
Meteorological Station
Kaski Boundary
May Min Runoff
174 - 180
181 - 186
187 - 193
194 - 199
200 - 206
207 - 212
213 - 218
219 - 224
225 - 229
230 - 236
237 - 242
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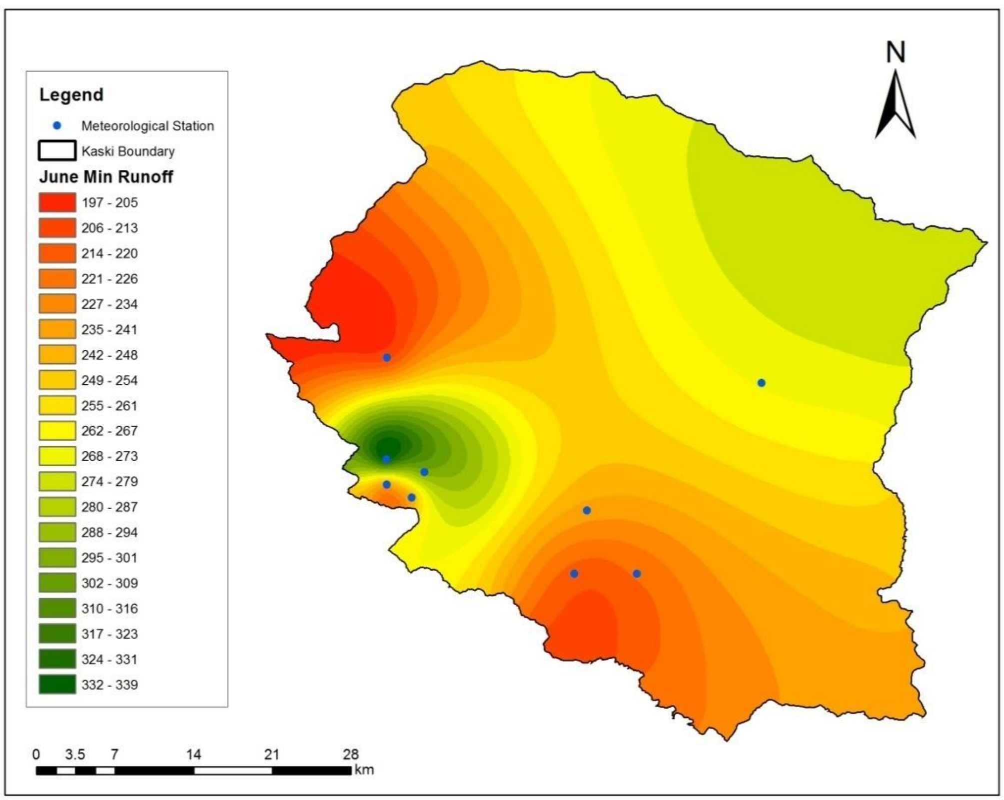
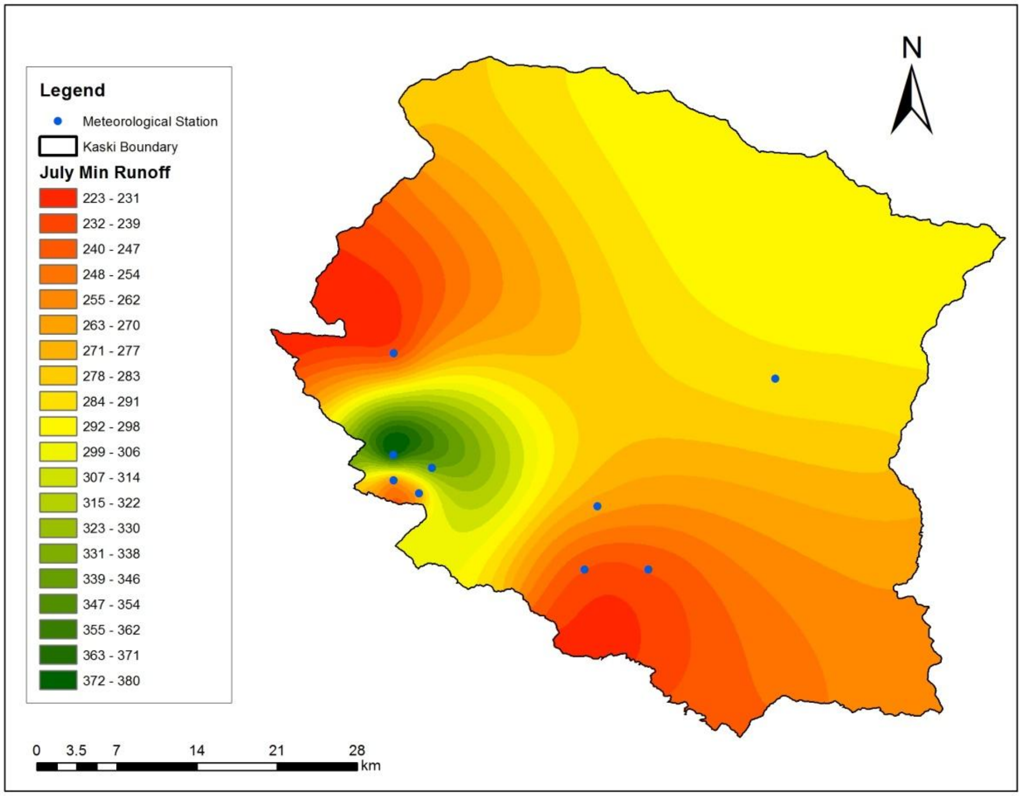
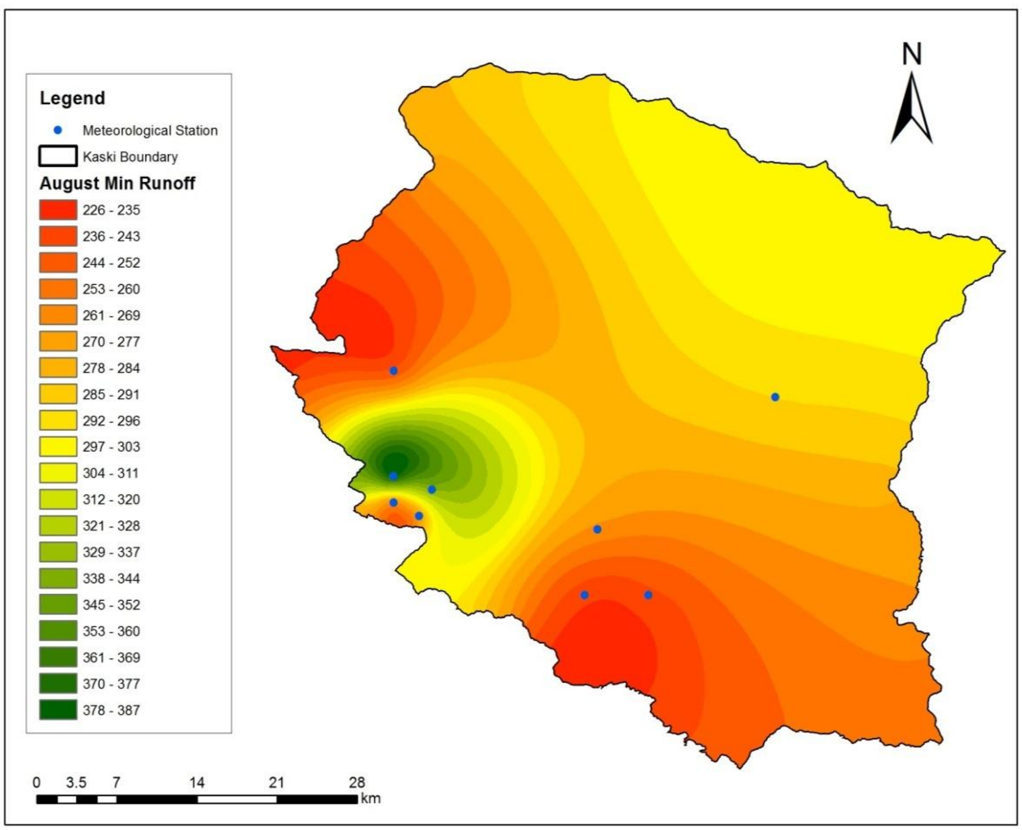
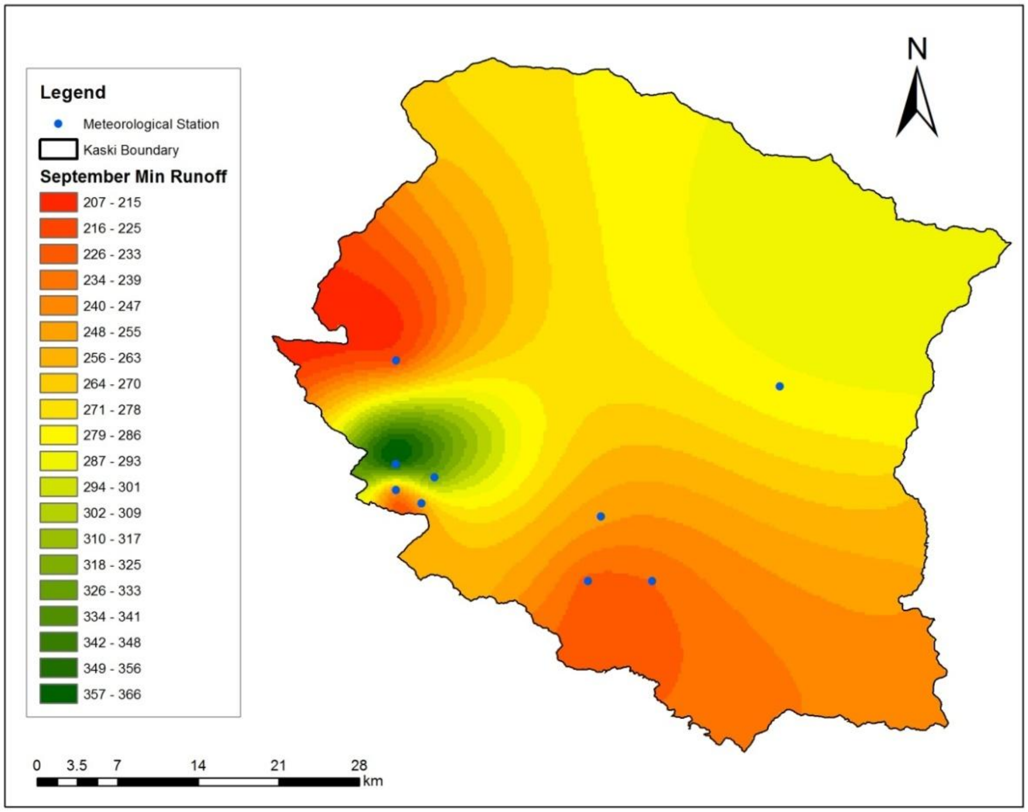
250 - 256
257 - 263
264 - 271
272 - 278
279 - 284
285 - 290
291 - 298
299 - 305
0 3.5 7 14 21 28
km


N
Legend
Meteorological Station
Kaski Boundary
June Min Runoff
197 - 205
206 - 213
214 - 220
221 - 226
227 - 234
235 - 241
242 - 248
249 - 254
255 - 261
262 - 267
268 - 273
274 - 279
280 - 287
288 - 294
295 - 301
302 - 309
310 - 316
317 - 323
324 - 331
332 - 339
0 3.5 7 14 21 28
km


N
Legend
Meteorological Station
Kaski Boundary
July Min Runoff
223 - 231
232 - 239
240 - 247
248 - 254
255 - 262
263 - 270
271 - 277
278 - 283
284 - 291
292 - 298
299 - 306
307 - 314
315 - 322
323 - 330
331 - 338
339 - 346
347 - 354
355 - 362
363 - 371
372 - 380
0 3.5 7 14 21 28
km


N
Legend
Meteorological Station
Kaski Boundary
August Min Runoff
226 - 235
236 - 243
244 - 252
253 - 260
261 - 269
270 - 277
278 - 284
285 - 291
292 - 296
297 - 303
304 - 311
312 - 320
321 - 328
329 - 337
338 - 344
345 - 352
353 - 360
361 - 369
370 - 377
378 - 387
0 3.5 7 14 21 28
km


N
Legend
Meteorological Station
Kaski Boundary
September Min Runoff
207 - 215
216 - 225
226 - 233
234 - 239
240 - 247
248 - 255
256 - 263
264 - 270
271 - 278
279 - 286
287 - 293
294 - 301
302 - 309
310 - 317
318 - 325
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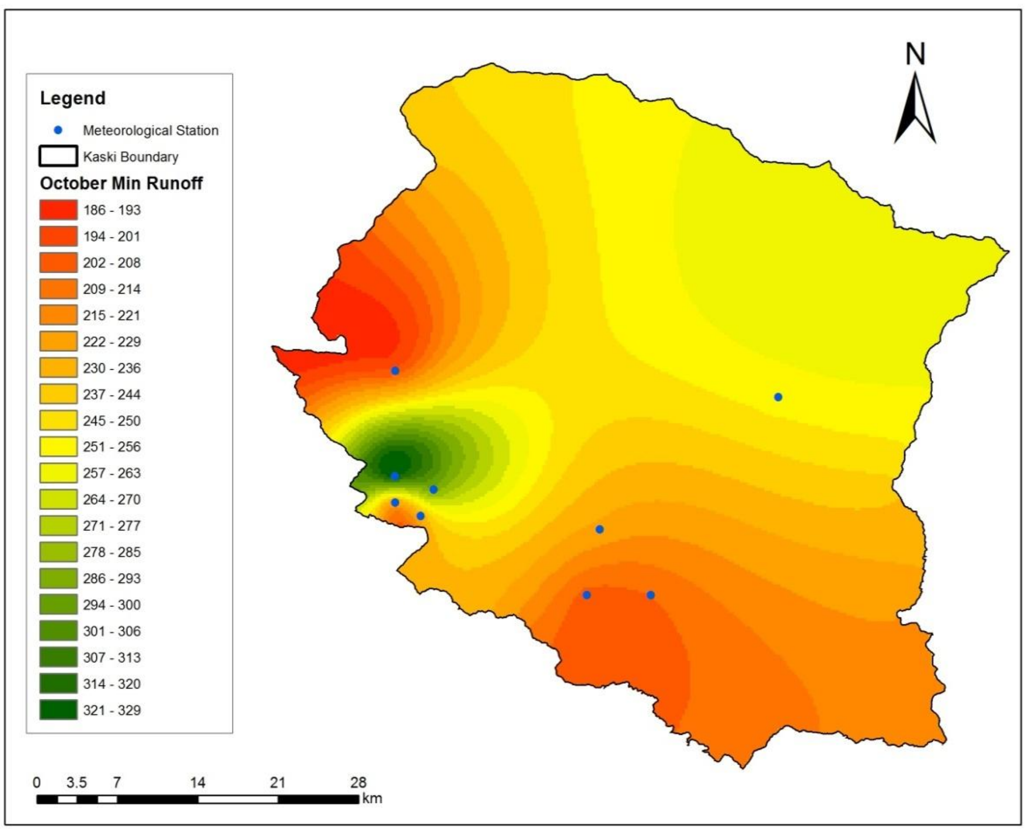
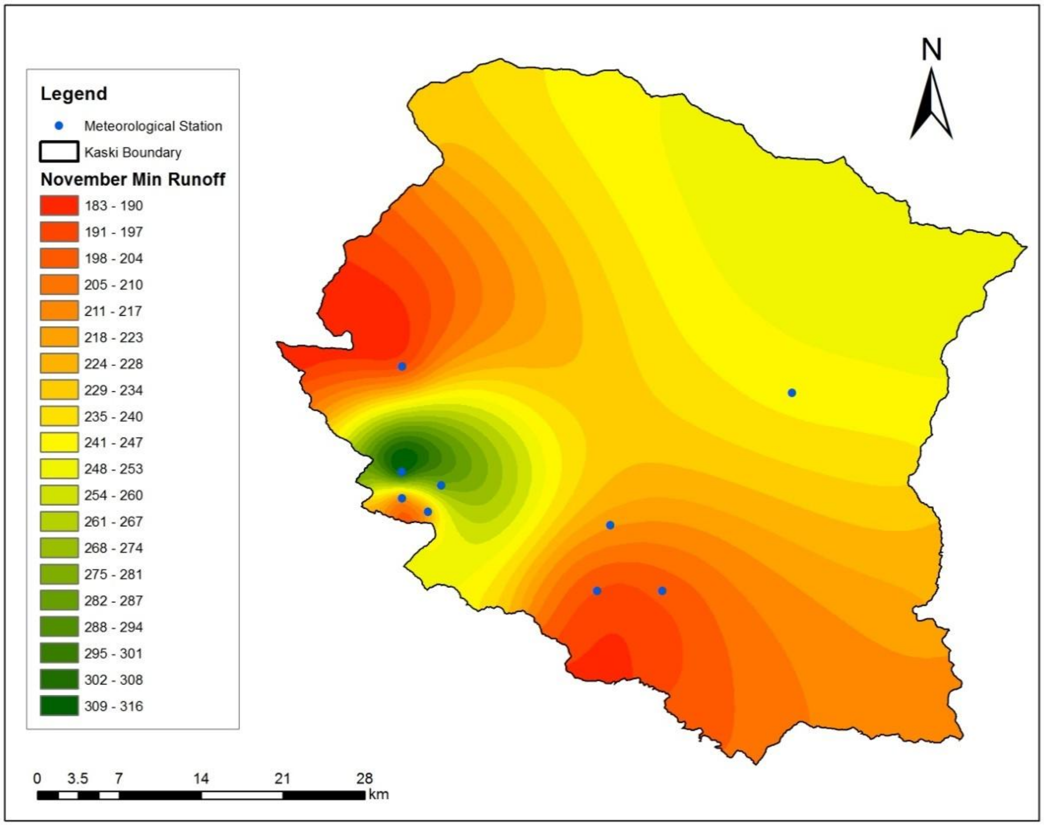
349 - 356
357 - 366
0 3.5 7 14 21 28
km


N
Legend
Meteorological Station
Kaski Boundary
October Min Runoff
186 - 193
194 - 201
202 - 208
209 - 214
215 - 221
222 - 229
230 - 236
237 - 244
245 - 250
251 - 256
257 - 263
264 - 270
271 - 277
278 - 285
286 - 293
294 - 300
301 - 306
307 - 313
314 - 320
321 - 329
0 3.5 7 14 21 28
km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Meteorological Station
Kaski Boundary
November Min Runoff
183 - 190
191 - 197
198 - 204
205 - 210
211 - 217
218 - 223
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229 - 234
235 - 240
241 - 247
248 - 253
254 - 260
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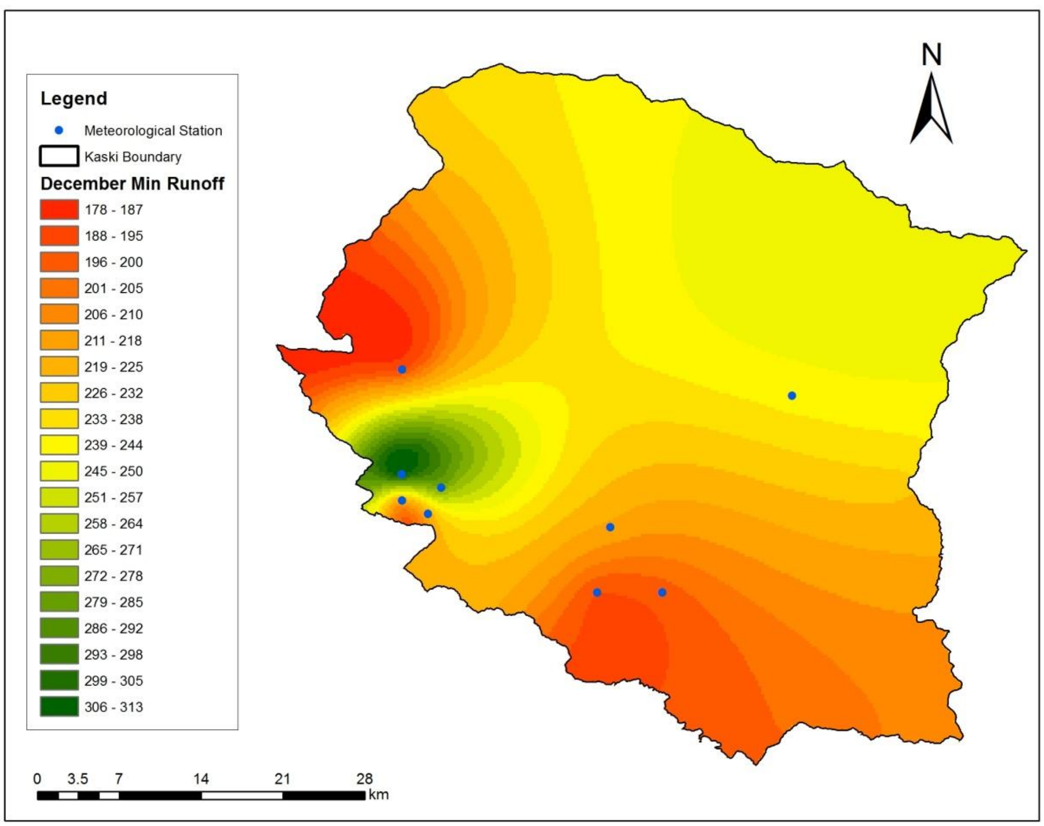
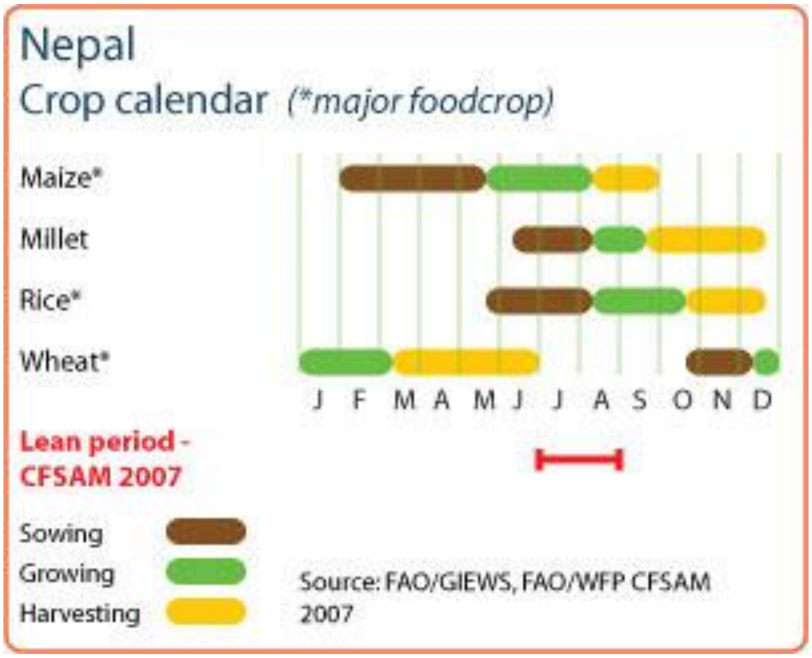
0 3.5 7 14 21 28
km


N
Legend
Meteorological Station
Kaski Boundary
December Min Runoff
178 - 187
188 - 195
196 - 200
201 - 205
206 - 210
211 - 218
219 - 225
226 - 232
233 - 238
239 - 244
245 - 250
251 - 257
258 - 264
265 - 271
272 - 278
279 - 285
286 - 292
293 - 298
299 - 305
306 - 313
0 3.5 7 14 21 28
km

Appendix K

Figure 36 : Crop calendar of Nepal for major food crop (FAO)



Appendix L

Table 0-10 : Slope calculation for all stations

Index No.	LAT_	LONG_	ELEV_m	From_To	Distance (m)	Difference of elevation between stations	Rise/run	Slope%	Slope in degrees
821	28.38	83.80	1960	Pokhara Airport_Ghandruk	27220	1133	0.041623806	4.162381	2.383493
824	28.36	84.10	1820	Pokhara Airport_Siklesh	19315	993	0.051410821	5.141082	2.943032
814	28.30	83.80	1740	Pokhara Airport_Lumle	22031	913	0.041441605	4.144161	2.373071
830	28.29	83.83	1713	Pokhara Airport_Pamdur	18906	886	0.04686343	4.686343	2.683114
813	28.27	83.82	1629	Pokhara Airport_Bhadaure	18890	802	0.042456326	4.245633	2.431108
829	28.28	83.80	1600	Pokhara Airport_Sallyan	21121	773	0.036598646	3.659865	2.096012
818	28.26	83.96	1070	Pokhara Airport_Lamachaur	6796	243	0.035756327	3.575633	2.047814
811	28.21	83.95	856	Pokhara Airport_Malepatan	4912	29	0.005903909	0.590391	0.338265
804	28.21	84.00	827						

Appendix M

Table 0-11: Calculation of annual surplus/deficit at all stations

Index No.	Total annual runoff	Total annual crop water need	Annual surplus/deficit
813	2616.95	2187.45	429.50
821	2293.27	2066.49	226.78
818	2719.17	2395.29	323.88
814	3736.14	2164.39	1571.75
811	2259.33	2477.86	-218.53
830	3313.00	2156.80	1156.20
804	2295.80	2486.92	-191.12
829	2562.21	2199.39	362.82
824	2878.10	2119.78	758.33

Appendix N

Table 0-12 : Output from Thronthwaite water balance model of Pokhara Airport

Year	Month	PET	P	P-PET	soil Moisture	AET	PET-AET	snow Storage	Surplus	ROtotal
1985	1	36.9	22.3	-15.7	133.2	38	-1.1	0	0	1.4
1985	2	43.4	25.8	-18.9	115.2	42.5	0.9	0	0	1.5
1985	3	80.7	26.6	-55.5	69.5	70.9	9.8	0	0	1.6
1985	4	105.1	63.4	-44.8	47.3	82.5	22.6	0	0	3.4
1985	5	117.2	298.8	166.7	140	117.2	0	0	74	15.9
1985	6	134.9	372.7	219.2	140	134.9	0	0	219.2	21.8
1985	7	129.4	904.9	730.2	140	129.4	0	0	730.2	55.7
1985	8	127.4	525	371.4	140	127.4	0	0	371.4	40.3
1985	9	97.4	696.4	564.2	140	97.4	0	0	564.2	54.4
1985	10	71.5	203.5	121.8	140	71.5	0	0	121.8	30.7
1985	11	46.8	50.8	1.4	140	46.8	0	0	1.4	22.9
1985	12	38.5	58.1	16.7	140	38.5	0	0	16.7	23.2
1986	1	37	0.6	-36.4	103.6	37	0	0	0	20.2
1986	2	42.4	46.8	2.1	105.7	42.4	0	0	0	22.3
1986	3	68.5	64	-7.7	99.8	66.6	1.9	0	0	22.9
1986	4	87	191	94.5	140	87	0	0	54.3	29.6
1986	5	109.1	158.9	41.8	140	109.1	0	0	41.8	28.2
1986	6	135.3	726.2	554.6	140	135.3	0	0	554.6	62

Year	Month	PET	P	P-PET	soil Moisture	AET	PET-AET	snow Storage	Surplus	ROtotal
1986	7	136	768.2	593.8	140	136	0	0	593.8	69.7
1986	8	126.6	574.2	418.9	140	126.6	0	0	418.9	63.9
1986	9	94.7	1164.2	1011.3	140	94.7	0	0	1011.3	103.2
1986	10	70.4	130.3	53.3	140	70.4	0	0	53.3	51.6
1986	11	49.5	14.2	-36	104	49.5	0	0	0	45.3
1986	12	36	69	29.6	133.5	36	0	0	0	47.6
1987	1	38.2	3	-35.3	99.9	36.5	1.6	0	0	43.9
1987	2	44.3	62.9	15.5	115.4	44.3	0	0	0	46.4
1987	3	67.7	85.9	13.9	129.3	67.7	0	0	0	47.1
1987	4	90.5	117.3	20.9	140	90.5	0	0	10.2	48.4
1987	5	116.5	110.6	-11.4	128.6	116.5	0	0	0	47.6
1987	6	137	655.7	485.9	140	137	0	0	474.5	79.2
1987	7	131.4	1212.8	1020.7	140	131.4	0	0	1020.7	116.8
1987	8	121.2	741.6	583.3	140	121.2	0	0	583.3	98.5
1987	9	102	728.1	589.7	140	102	0	0	589.7	103.1
1987	10	73.1	167.2	85.7	140	73.1	0	0	85.7	75.3
1987	11	49.7	5	-44.9	95.1	49.7	0	0	0	66.5
1987	12	39.5	28.3	-12.6	86.5	35.4	4	0	0	67
1988	1	39.4	1.6	-37.8	63.1	24.9	14.5	0	0	65
1988	2	45.1	26.1	-20.3	54	33.9	11.1	0	0	65.6
1988	3	67.7	73.4	2.1	56	67.7	0	0	0	67.3
1988	4	96.9	135.6	31.9	87.9	96.9	0	0	0	69.8
1988	5	123.1	241.4	106.2	140	123.1	0	0	54.1	75
1988	6	134.5	782.6	609	140	134.5	0	0	609	107.5
1988	7	138.1	1093.5	900.7	140	138.1	0	0	900.7	131.4
1988	8	123.9	810.5	646.1	140	123.9	0	0	646.1	122.9
1988	9	102.3	793.9	651.9	140	102.3	0	0	651.9	127.8
1988	10	75.9	15	-61.6	78.4	75.9	0	0	0	87.9
1988	11	48.4	3.6	-45	53.2	28.6	19.8	0	0	86.5
1988	12	40.5	55	11.8	64.9	40.5	0	0	0	88.2
1989	1	35.3	68	29.3	94.2	35.3	0	0	0	88
1989	2	39.5	14.2	-26	76.7	31	8.5	0	0	84.5
1989	3	67	65.5	-4.8	74.1	64.9	2.2	0	0	86.2
1989	4	94.8	11.7	-83.7	29.8	55.4	39.4	0	0	82.7
1989	5	127	518.3	365.4	140	127	0	0	255.2	109.7
1989	6	132	594.1	432.4	140	132	0	0	432.4	117
1989	7	127.8	973.9	797.4	140	127.8	0	0	797.4	143.1
1989	8	121.2	871.6	706.8	140	121.2	0	0	706.8	144.1
1989	9	99.8	807.2	667	140	99.8	0	0	667	146.6
1989	10	74	58.4	-18.6	121.4	74	0	0	0	108
1989	11	47	44.4	-4.8	117.3	46.3	0.6	0	0	106.3
1989	12	35.9	42.9	4.9	122.2	35.9	0	0	0	105.2
1990	1	41	0	-41	86.4	35.8	5.2	0	0	102
1990	2	42	59.6	14.6	101	42	0	0	0	104
1990	3	60.3	114.7	48.6	140	60.3	0	0	9.7	105.8
1990	4	88.9	44.8	-46.3	93.7	88.9	0	0	0	101.3
1990	5	117.2	361.1	225.9	140	117.2	0	0	179.6	117.9

Year	Month	PET	P	P-PET	soil Moisture	AET	PET-AET	snow Storage	Surplus	ROtotal
1990	6	137	931.5	747.9	140	137	0	0	747.9	152.9
1990	7	135.2	732.5	560.7	140	135.2	0	0	560.7	147.5
1990	8	123.1	742.5	582.3	140	123.1	0	0	582.3	152.7
1990	9	100.1	530.2	403.6	140	100.1	0	0	403.6	145
1990	10	71.5	99.7	23.2	140	71.5	0	0	23.2	122.5
1990	11	50.1	0	-50.1	89.9	50.1	0	0	0	116.4
1990	12	38.5	2.9	-35.8	66.9	25.7	12.8	0	0	115.3
1991	1	36	9.9	-26.6	54.2	22.1	13.9	0	0	114.5
1991	2	45.4	22.4	-24.1	44.9	30.6	14.8	0	0	114
1991	3	70.9	77.6	2.8	47.7	70.9	0	0	0	115.7
1991	4	92.8	64.2	-31.8	36.9	71.8	21	0	0	113.9
1991	5	122	358.3	218.4	140	122	0	0	115.3	128.6
1991	6	132.4	497.5	340.2	140	132.4	0	0	340.2	137.9
1991	7	140.7	797.7	617.1	140	140.7	0	0	617.1	157.9
1991	8	125.4	602.9	447.3	140	125.4	0	0	447.3	151.5
1991	9	101.4	994.1	843	140	101.4	0	0	843	178.3
1991	10	75.4	53	-25.1	114.9	75.4	0	0	0	129.9
1991	11	46.1	0.8	-45.3	77.7	38	8.1	0	0	126
1991	12	36.3	35.2	-2.9	76.1	35	1.3	0	0	126.5
1992	1	36.3	10.5	-26.3	61.8	24.3	12	0	0	124
1992	2	38.6	24.7	-15.1	55.1	30.2	8.5	0	0	123.5
1992	3	74.5	0.5	-74	26	29.6	44.9	0	0	121.1
1992	4	104.4	53.9	-53.2	16.1	61.1	43.3	0	0	122.5
1992	5	114	247	120.7	136.8	114	0	0	0	131
1992	6	134.9	469.1	310.8	140	134.9	0	0	307.6	144
1992	7	135.6	793.6	618.3	140	135.6	0	0	618.3	165.2
1992	8	125	798.7	633.7	140	125	0	0	633.7	170.5
1992	9	101.4	396.5	275.3	140	101.4	0	0	275.3	151.8
1992	10	73.1	246.5	161.1	140	73.1	0	0	161.1	144.6
1992	11	48.4	2.4	-46.2	93.8	48.4	0	0	0	131.1
1992	12	36.3	26.2	-11.4	86.2	32.6	3.8	0	0	131
1993	1	37.3	9.7	-28.1	68.9	26.5	10.8	0	0	128.9
1993	2	45.4	20.2	-26.2	56	32.1	13.3	0	0	128.1
1993	3	62	55.7	-9.1	52.3	56.6	5.5	0	0	128.6
1993	4	88.9	205.2	106.1	140	88.9	0	0	18.4	135
1993	5	116.5	358.4	224	140	116.5	0	0	224	143.7
1993	6	134.9	652.1	484.6	140	134.9	0	0	484.6	161.9
1993	7	141.6	965.6	775.7	140	141.6	0	0	775.7	184.1
1993	8	123.1	1168.5	987	140	123.1	0	0	987	202.7
1993	9	95.6	478.5	359	140	95.6	0	0	359	170.4
1993	10	75.2	294.7	204.8	140	75.2	0	0	204.8	161.8
1993	11	50.6	0.6	-50	90	50.6	0	0	0	145.6
1993	12	40	0	-40	64.3	25.7	14.3	0	0	144.1
1994	1	37.8	34.7	-4.8	62.1	35.2	2.6	0	0	144.4
1994	2	40.1	49.5	6.9	69	40.1	0	0	0	143.7
1994	3	72.2	73.2	-2.7	67.7	70.9	1.4	0	0	143.5
1994	4	90.8	59.6	-34.2	51.1	73.1	17.7	0	0	141.4

Year	Month	PET	P	P-PET	soil Moisture	AET	PET-AET	snow Storage	Surplus	ROtotal
1994	5	125.1	380.7	236.6	140	125.1	0	0	147.8	157.6
1994	6	134.5	686.9	518.1	140	134.5	0	0	518.1	176.7
1994	7	140.7	1020.3	828.6	140	140.7	0	0	828.6	200.2
1994	8	128.2	794.4	626.5	140	128.2	0	0	626.5	193.7
1994	9	100.4	523.8	397.2	140	100.4	0	0	397.2	182.6
1994	10	71.1	97.8	21.8	140	71.1	0	0	21.8	159.9
1994	11	45.5	1.8	-43.8	96.2	45.5	0	0	0	153.6
1994	12	36.2	0	-36.2	71.3	24.9	11.3	0	0	152
1995	1	34.3	16	-19.1	61.6	24.9	9.4	0	0	151.2
1995	2	41.2	43.4	0	61.6	41.2	0	0	0	151.1
1995	3	68.1	72.5	0.8	62.4	68.1	0	0	0	151.1
1995	4	94.8	75.8	-22.8	52.2	82.2	12.7	0	0	149.8
1995	5	134.7	282.4	133.6	140	134.7	0	0	45.7	159.1
1995	6	132	1391.3	1189.7	140	132	0	0	1189.7	225
1995	7	135.2	1372.1	1168.3	140	135.2	0	0	1168.3	234.2
1995	8	125.8	745.5	582.4	140	125.8	0	0	582.4	207
1995	9	101.7	560	430.3	140	101.7	0	0	430.3	200.3
1995	10	77.1	202.8	115.6	140	77.1	0	0	115.6	181.9
1995	11	48.9	80.8	27.9	140	48.9	0	0	27.9	174.4
1995	12	37.9	3.9	-34.2	105.8	37.9	0	0	0	168.8
1996	1	36	59.7	20.7	126.5	36	0	0	0	169.9
1996	2	42.5	75.4	29.1	140	42.5	0	0	15.6	169.2
1996	3	74	94.6	15.8	140	74	0	0	15.8	168.6
1996	4	97.2	38.5	-60.6	79.4	97.2	0	0	0	164.2
1996	5	122.8	371.9	230.5	140	122.8	0	0	169.9	180.9
1996	6	129.2	687.5	524	140	129.2	0	0	524	200.3
1996	7	137.7	936.8	752.3	140	137.7	0	0	752.3	218.7
1996	8	124.7	857.4	689.9	140	124.7	0	0	689.9	219.9
1996	9	99.8	703.4	568.4	140	99.8	0	0	568.4	216.1
1996	10	71.1	131.7	54	140	71.1	0	0	54	186.2
1996	11	50.6	0	-50.6	89.4	50.6	0	0	0	177.9
1996	12	38.4	0	-38.4	64.9	24.5	13.9	0	0	176.1
1997	1	35.3	62.5	24.1	88.9	35.3	0	0	0	177.4
1997	2	39.1	11.8	-27.9	71.2	28.9	10.2	0	0	173.2
1997	3	69.6	45.6	-26.3	57.9	56.7	12.9	0	0	173.1
1997	4	82.7	224.6	130.6	140	82.7	0	0	48.5	180.9
1997	5	114.7	308.7	178.6	140	114.7	0	0	178.6	185.2
1997	6	130	545.8	388.6	140	130	0	0	388.6	199.2
1997	7	141.1	1113.5	916.7	140	141.1	0	0	916.7	235
1997	8	126.2	604.1	447.7	140	126.2	0	0	447.7	212.2
1997	9	99.2	327.4	211.8	140	99.2	0	0	211.8	198.7
1997	10	65	115.8	45	140	65	0	0	45	186.8
1997	11	47.3	30	-18.8	121.2	47.3	0	0	0	180.7
1997	12	35	133.9	92.2	140	35	0	0	73.4	184.8
1998	1	35.4	0	-35.4	104.6	35.4	0	0	0	176.3
1998	2	44	24.8	-20.4	89.3	38.8	5.2	0	0	175.8
1998	3	63.8	107.6	38.4	127.7	63.8	0	0	0	178.2

Year	Month	PET	P	P-PET	soil Moisture	AET	PET-AET	snow Storage	Surplus	ROtotal
1998	4	94	238.9	133	140	94	0	0	120.7	184.2
1998	5	126.2	415.3	268.3	140	126.2	0	0	268.3	194
1998	6	144	769.7	587.3	140	144	0	0	587.3	215.9
1998	7	139.4	917.2	731.9	140	139.4	0	0	731.9	228.8
1998	8	124.7	1493.5	1294.2	140	124.7	0	0	1294.2	268.7
1998	9	103.9	740.3	599.4	140	103.9	0	0	599.4	235.1
1998	10	83.8	158.7	67	140	83.8	0	0	67	204.7
1998	11	52.7	9.6	-43.6	96.4	52.7	0	0	0	195.3
1998	12	39.3	3.4	-36	71.6	28	11.2	0	0	193
1999	1	37.6	7.5	-30.4	56.1	22.7	14.9	0	0	191.3
1999	2	50.1	22.6	-28.6	44.6	32.9	17.2	0	0	190.2
1999	3	78	0	-78	19.7	24.9	53.2	0	0	187.1
1999	4	117.1	20.6	-97.5	6	33.3	83.8	0	0	186.3
1999	5	122.4	899.7	732.3	140	122.4	0	0	598.3	234.4
1999	6	132	979.6	798.6	140	132	0	0	798.6	244.5
1999	7	133.5	950.5	769.5	140	133.5	0	0	769.5	248.8
1999	8	119.7	899.7	735	140	119.7	0	0	735	251.6
1999	9	103.9	730.7	590.2	140	103.9	0	0	590.2	246.9
1999	10	76.6	176.4	91	140	76.6	0	0	91	218
1999	11	50.8	0	-50.8	89.2	50.8	0	0	0	207.1
1999	12	40.5	0.8	-39.7	63.9	26.1	14.4	0	0	205.1
2000	1	38.4	10.6	-28.3	51	23	15.4	0	0	203.5
2000	2	39.3	13.3	-26.7	41.3	22.4	17	0	0	201.6
2000	3	65.6	51.5	-16.7	36.3	53.8	11.8	0	0	201.5
2000	4	87.5	199.5	102	138.4	87.5	0	0	0	206.9
2000	5	109.1	682.9	539.6	140	109.1	0	0	538	234.5
2000	6	114.4	875.7	717.5	140	114.4	0	0	717.5	249.3
2000	7	128.6	1032	851.8	140	128.6	0	0	851.8	263.6
2000	8	123.9	1192.4	1008.9	140	123.9	0	0	1008.9	279.6
2000	9	97.4	572.7	446.7	140	97.4	0	0	446.7	250.9
2000	10	77.1	136	52.1	140	77.1	0	0	52.1	227.3
2000	11	51.9	18.4	-34.4	105.6	51.9	0	0	0	219.3
2000	12	38.3	0	-38.3	76.7	28.9	9.4	0	0	216.2
2001	1	37.6	3	-34.7	57.7	21.9	15.7	0	0	214.1
2001	2	46.1	25	-22.3	48.5	33	13.1	0	0	213.1
2001	3	72.4	15.3	-57.9	28.4	34.6	37.8	0	0	210.5
2001	4	97.2	111.7	8.9	37.3	97.2	0	0	0	213.2
2001	5	121.2	359.2	220	140	121.2	0	0	117.3	224.7
2001	6	137.8	711.5	538.1	140	137.8	0	0	538.1	245.6
2001	7	142.9	856.4	670.7	140	142.9	0	0	670.7	257.5
2001	8	127.8	1521.9	1318	140	127.8	0	0	1318	301.8
2001	9	101.7	716.1	578.6	140	101.7	0	0	578.6	265
2001	10	80.2	115.3	29.3	140	80.2	0	0	29.3	233
2001	11	53.5	77.1	19.7	140	53.5	0	0	19.7	229
2001	12	39.5	0	-39.5	100.5	39.5	0	0	0	222.9
2002	1	37.7	44.4	4.5	105	37.7	0	0	0	222.9
2002	2	46.1	54	5.2	110.2	46.1	0	0	0	221.2

Year	Month	PET	P	P-PET	soil Moisture	AET	PET-AET	snow Storage	Surplus	ROtotal
2002	3	73.8	61.9	-15	98.4	70.6	3.2	0	0	219.4
2002	4	95.7	202.1	96.3	140	95.7	0	0	54.7	224.8
2002	5	122.4	437.1	292.9	140	122.4	0	0	292.9	237.3
2002	6	140.9	703.4	527.4	140	140.9	0	0	527.4	253.7
2002	7	140.3	1815.1	1584.1	140	140.3	0	0	1584.1	323
2002	8	127	693.3	531.6	140	127	0	0	531.6	269.9
2002	9	101.1	335.4	217.6	140	101.1	0	0	217.6	251.8
2002	10	76.4	95.8	14.6	140	76.4	0	0	14.6	237.6
2002	11	50.8	23.5	-28.4	111.6	50.8	0	0	0	231.7
2002	12	39.4	0	-39.4	80.2	31.4	8	0	0	228.2
2003	1	37	36.6	-2.2	78.9	36	1	0	0	227.7
2003	2	43.6	84.6	36.8	115.7	43.6	0	0	0	227.9
2003	3	68.7	100.1	26.4	140	68.7	0	0	2.1	226.4
2003	4	99.7	202.6	92.8	140	99.7	0	0	92.8	230.3
2003	5	117.5	246	116.2	140	117.5	0	0	116.2	231.4
2003	6	136.1	785.4	610	140	136.1	0	0	610	262.3
2003	7	140.3	1291.8	1086.9	140	140.3	0	0	1086.9	296.3
2003	8	133	586	423.7	140	133	0	0	423.7	262.9
2003	9	103.3	953	802.1	140	103.3	0	0	802.1	286.9
2003	10	80.5	17.2	-64.2	75.8	80.5	0	0	0	237.7
2003	11	52.4	16.9	-36.3	56.2	35.7	16.6	0	0	235.3
2003	12	39	42.1	1	57.2	39	0	0	0	234.3
2004	1	37.8	31.2	-8.2	53.8	33	4.8	0	0	231.4
2004	2	46.7	10.9	-36.3	39.9	24.3	22.3	0	0	228.1
2004	3	84.6	28.4	-57.6	23.5	43.4	41.2	0	0	226.7
2004	4	95.1	268.7	160.1	140	95.1	0	0	43.6	236.9
2004	5	125.5	372.5	228.4	140	125.5	0	0	228.4	242.1
2004	6	136.6	772	596.8	140	136.6	0	0	596.8	265.8
2004	7	137.7	816.9	638.4	140	137.7	0	0	638.4	272.2
2004	8	133.5	788.7	615.8	140	133.5	0	0	615.8	274.6
2004	9	101.4	867	722.3	140	101.4	0	0	722.3	283.4
2004	10	73.1	184.2	101.9	140	73.1	0	0	101.9	247.9
2004	11	47.1	33	-15.8	124.2	47.1	0	0	0	237.9
2004	12	39.4	0	-39.4	89.3	34.9	4.4	0	0	233.9
2005	1	37.6	58	17.5	106.8	37.6	0	0	0	234.5
2005	2	44.9	11.4	-34.1	80.8	36.9	8.1	0	0	229.8
2005	3	74.5	85	6.3	87	74.5	0	0	0	231.2
2005	4	94.8	104.6	4.5	91.6	94.8	0	0	0	229.9
2005	5	117.5	309.5	176.5	140	117.5	0	0	128.1	239.2
2005	6	140	282.2	128.1	140	140	0	0	128.1	236.9
2005	7	143.4	548.8	378	140	143.4	0	0	378	251.8
2005	8	128.2	924.5	750.1	140	128.2	0	0	750.1	275.8
2005	9	107.5	313.5	190.3	140	107.5	0	0	190.3	244.9
2005	10	73.6	325.7	235.8	140	73.6	0	0	235.8	245.6
2005	11	48.3	3.6	-44.9	95.1	48.3	0	0	0	227.2
2005	12	37.5	0	-37.5	69.7	25.5	12	0	0	224.7
2006	1	39.4	0	-39.4	50.1	19.6	19.8	0	0	222.5

Year	Month	PET	P	P-PET	soil Moisture	AET	PET-AET	snow Storage	Surplus	ROtotal
2006	2	54.6	5.3	-49.6	32.3	22.8	31.9	0	0	220.5
2006	3	72.4	83.5	6.9	39.2	72.4	0	0	0	222.2
2006	4	93.7	147	46	85.2	93.7	0	0	0	223.2
2006	5	125.8	586.7	431.5	140	125.8	0	0	376.7	246.8
2006	6	136.1	493.8	333	140	136.1	0	0	333	243.3
2006	7	148.3	433.5	263.5	140	148.3	0	0	263.5	240.7
2006	8	132.2	529.8	371.1	140	132.2	0	0	371.1	247.1
2006	9	103.3	409.4	285.6	140	103.3	0	0	285.6	241.7
2006	10	76.8	275	184.4	140	76.8	0	0	184.4	234.6
2006	11	50.9	3.3	-47.8	92.2	50.9	0	0	0	218.8
2006	12	40.9	17.1	-24.6	76	32.5	8.4	0	0	217.3
2007	1	37.5	0	-37.5	55.7	20.3	17.1	0	0	214.3
2007	2	42	159.5	109.5	140	42	0	0	25.2	220.4
2007	3	69.2	59.2	-12.9	127.1	69.2	0	0	0	213.3
2007	4	98.7	219.7	110	140	98.7	0	0	97.1	220.1
2007	5	129.4	307.8	163	140	129.4	0	0	163	224.1
2007	6	139.6	616.1	445.7	140	139.6	0	0	445.7	241.9
2007	7	139	931.4	745.9	140	139	0	0	745.9	263
2007	8	129.4	676.1	512.9	140	129.4	0	0	512.9	253.2
2007	9	100.4	1186.2	1026.4	140	100.4	0	0	1026.4	286.8
2007	10	80.2	72.6	-11.3	128.7	80.2	0	0	0	228.8
2007	11	49.8	25	-26.1	104.8	47.7	2.1	0	0	224.2
2007	12	37.4	12.2	-25.8	85.5	30.9	6.5	0	0	221.3
2008	1	37	17.1	-20.8	72.8	28.9	8.1	0	0	219.3
2008	2	41.2	1.6	-39.7	52.2	22.2	19	0	0	216.4
2008	3	74.7	29.3	-46.9	34.7	45.3	29.4	0	0	215.6
2008	4	96	113.6	11.9	46.6	96	0	0	0	217.7
2008	5	118.6	332.8	197.5	140	118.6	0	0	104.1	227.6
2008	6	136.1	604.3	437.9	140	136.1	0	0	437.9	243.4
2008	7	143.4	487.4	319.7	140	143.4	0	0	319.7	238.6
2008	8	126.2	1208.7	1022.1	140	126.2	0	0	1022.1	282.8
2008	9	98.3	365.1	248.6	140	98.3	0	0	248.6	240.9
2008	10	74.7	102.8	22.9	140	74.7	0	0	22.9	225.7
2008	11	51.4	0	-51.4	88.6	51.4	0	0	0	218.4
2008	12	41.9	0	-41.9	62.1	26.5	15.4	0	0	216.2
2009	1	41.6	0	-41.6	43.6	18.5	23.2	0	0	214
2009	2	50.7	0	-50.7	27.8	15.8	34.9	0	0	211.9
2009	3	74.7	25.3	-50.7	17.8	34.1	40.6	0	0	211.1
2009	4	107.4	45.6	-64	9.6	51.4	55.9	0	0	210
2009	5	125.5	260.2	121.7	131.4	125.5	0	0	0	218.6
2009	6	140.4	609.3	438.4	140	140.4	0	0	429.8	238.3
2009	7	146.9	762.7	577.6	140	146.9	0	0	577.6	249.7
2009	8	130.6	1026.2	844.3	140	130.6	0	0	844.3	269.2
2009	9	103.9	302.5	183.4	140	103.9	0	0	183.4	232.7
2009	10	76.6	220.2	132.6	140	76.6	0	0	132.6	227.7
2009	11	49.8	0	-49.8	90.2	49.8	0	0	0	214.5
2009	12	41	4.4	-36.8	66.5	27.9	13.1	0	0	212.6

Year	Month	PET	P	P-PET	soil Moisture	AET	PET-AET	snow Storage	Surplus	ROtotal
2010	1	40.5	0.1	-40.4	47.3	19.3	21.2	0	0	210.3
2010	2	44.8	55.1	7.5	54.8	44.8	0	0	0	210.9
2010	3	82.5	72.9	-13.3	49.6	74.4	8.1	0	0	209.7
2010	4	109	74.9	-37.9	36.2	84.6	24.5	0	0	207.8
2010	5	126.2	271.6	131.8	140	126.2	0	0	28	215.8
2010	6	141.3	539.2	370.9	140	141.3	0	0	370.9	230.9
2010	7	140.7	1083.9	889	140	140.7	0	0	889	265
2010	8	128.2	1187.8	1000.2	140	128.2	0	0	1000.2	278.1
2010	9	101.4	595.6	464.4	140	101.4	0	0	464.4	250.9
2010	10	78.3	76.6	-5.5	134.5	78.3	0	0	0	222.8
2010	11	52.8	9	-44.3	91.9	51.1	1.7	0	0	217.2
2010	12	37.2	0	-37.2	67.5	24.5	12.8	0	0	214.6
2011	1	35.1	19.2	-16.9	59.4	26.4	8.7	0	0	213.4
2011	2	44.9	32.3	-14.3	53.3	36.7	8.2	0	0	211.9
2011	3	72.9	27.9	-46.4	35.6	44.2	28.7	0	0	209.6
2011	4	93.4	161.9	60.4	96.1	93.4	0	0	0	214.2
2011	5	122.4	284.4	147.8	140	122.4	0	0	103.9	219.3
2011	6	132.4	474.9	318.8	140	132.4	0	0	318.8	230
2011	7	135.6	1041.2	853.6	140	135.6	0	0	853.6	264.8
2011	8	124.3	690.4	531.6	140	124.3	0	0	531.6	250.4
2011	9	104.3	549.1	417.4	140	104.3	0	0	417.4	245.4
2011	10	76.8	71.5	-8.9	131.1	76.8	0	0	0	219.3
2011	11	47	133.7	80	140	47	0	0	71.1	221
2011	12	35.7	0	-35.7	104.3	35.7	0	0	0	212.1
2012	1	34.8	12.4	-23	87.2	28.9	5.9	0	0	210.6
2012	2	44.3	53.8	6.9	94.1	44.3	0	0	0	210.6
2012	3	72.7	16.2	-57.3	55.6	53.9	18.8	0	0	206.6
2012	4	97.2	137.3	33.2	88.8	97.2	0	0	0	210.6
2012	5	127	186.2	49.9	138.7	127	0	0	0	211
2012	6	141.7	499.3	332.6	140	141.7	0	0	331.3	228
2012	7	140.7	877.6	693	140	140.7	0	0	693	251.8
2012	8	129.8	711.9	546.5	140	129.8	0	0	546.5	246.9
2012	9	104.6	538.5	407	140	104.6	0	0	407	240.2
2012	10	74.3	232.7	146.8	140	74.3	0	0	146.8	224.2
2012	11	47.6	0	-47.6	92.4	47.6	0	0	0	210.5
2012	12	39.4	0	-39.4	66.4	26	13.4	0	0	208.4
2013	1	36.9	17.6	-20.2	56.9	26.3	10.6	0	0	207.2
2013	2	44.7	68.7	20.6	77.5	44.7	0	0	0	207.7
2013	3	77.1	30.1	-48.5	50.6	55.4	21.7	0	0	203.7
2013	4	97.5	114.1	10.9	61.5	97.5	0	0	0	205.9
2013	5	123.5	277.3	139.9	140	123.5	0	0	61.4	212.6
2013	6	138.3	823.1	643.7	140	138.3	0	0	643.7	244.4
2013	7	144.7	973.9	780.5	140	144.7	0	0	780.5	257.7
2013	8	131.8	490.6	334.3	140	131.8	0	0	334.3	234.8
2013	9	106.2	319.2	197	140	106.2	0	0	197	226.1
2013	10	77.8	233	143.6	140	77.8	0	0	143.6	221.1
2013	11	49.2	22.3	-28	112	49.2	0	0	0	208.5

Year	Month	PET	P	P-PET	soil Moisture	AET	PET-AET	snow Storage	Surplus	ROtotal
2013	12	38.3	0	-38.3	81.4	30.6	7.7	0	0	205.3
2014	1	38.4	17.5	-21.8	68.7	29.3	9.1	0	0	204.1
2014	2	43.7	17.8	-26.8	55.6	30.1	13.6	0	0	202.1
2014	3	71.1	74	-0.8	55.2	70.6	0.5	0	0	202.9
2014	4	100.3	48.2	-54.5	33.7	67.3	33	0	0	199.6
2014	5	128.6	125.5	-9.4	31.5	121.5	7.1	0	0	201.5
2014	6	144	687.8	509.5	140	144	0	0	400.9	231.7
2014	7	147.4	800.4	613	140	147.4	0	0	613	241.5
2014	8	129	1421.7	1221.6	140	129	0	0	1221.6	282.7
2014	9	105.2	581.2	446.9	140	105.2	0	0	446.9	243.1
2014	10	75.2	158.9	75.8	140	75.2	0	0	75.8	220.6
2014	11	53.3	10.1	-43.7	96.3	53.3	0	0	0	211
2014	12	50.7	26.9	-25.1	79	42.8	7.9	0	0	209.7
2015	1	40	54.3	11.6	90.6	40	0	0	0	209
2015	2	47.1	30.3	-18.3	78.7	40.6	6.5	0	0	205.8
2015	3	72.4	167.9	87.1	140	72.4	0	0	25.8	210.8
2015	4	91.4	128.2	30.4	140	91.4	0	0	30.4	207.1
2015	5	129	213.8	74.1	140	129	0	0	74.1	210.2
2015	6	141.3	506.9	340.3	140	141.3	0	0	340.3	226.2
2015	7	145.1	923	731.7	140	145.1	0	0	731.7	252.3
2015	8	130.6	781.8	612.1	140	130.6	0	0	612.1	249.3
2015	9	109.6	702.9	558.2	140	109.6	0	0	558.2	248.9
2015	10	78.5	215.2	125.9	140	78.5	0	0	125.9	223.6
2015	11	53.2	2.9	-50.4	89.6	53.2	0	0	0	210.9
2015	12	38.2	0	-38.2	65.2	24.4	13.7	0	0	208.6
2016	1	38.6	2.3	-36.5	48.2	19.2	19.5	0	0	206.6
2016	2	49.8	0.1	-49.7	31.1	17.2	32.6	0	0	204.5
2016	3	76.6	93.5	12.2	43.3	76.6	0	0	0	207.1
2016	4	109	24.6	-85.7	16.8	49.9	59.2	0	0	201.6
2016	5	123.9	241.9	105.9	122.7	123.9	0	0	0	210.5
2016	6	140.4	589	419.1	140	140.4	0	0	401.8	229.9
2016	7	139.4	877.5	694.2	140	139.4	0	0	694.2	249.2
2016	8	136.8	381.6	225.7	140	136.8	0	0	225.7	224.6
2016	9	104.9	972	818.5	140	104.9	0	0	818.5	260.3
2016	10	82	335.4	236.6	140	82	0	0	236.6	228.7
2016	11	51.4	0	-51.4	88.6	51.4	0	0	0	209.8
2016	12	43.2	0	-43.2	61.3	27.3	15.9	0	0	207.7