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Evaluation of Precipitation distribution over Nepal using satellite data and its applications in Hydrological modeling

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Master's thesis

NTNU
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M.Sc. in Hydropower Development

Master Thesis

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Submitted by:

Bijay Tamrakar

June 2011

PREFACE

This report entitled "Evaluation of precipitation distribution over Nepal using satellite data and its applications in Hydrological Modeling" is submitted to Department of Hydraulics and Environmental Engineering, Norwegian University of Science and Technology, Trondheim, Norway. It is one of the partial requirements of the M.Sc. degree in Hydropower Development at NTNU in 2011.

The availability of temporal and spatial precipitation data is one of the major challenges in the country with mountainous topography like Nepal. This report includes the evaluation of TRMM satellite rainfall product regarding the ground based precipitation stations of Nepal, which gives vivid understanding of its usefulness in hydrological analysis for estimating of runoffs.

The thesis work has been very didactic and beneficial as it analyses the proficiency of estimation of precipitation using TRMM satellite products over all regions of Nepal.

Bijay Tamrakar
June 2011
Trondheim, Norway

ACKNOWLEDGEMENT

I would like to express my gratefulness to my supervisor, Prof. Knut Alfredsen for granting me the opportunity to work on this subject. I would heartily thank him for his encouragement, guidance and support from the initial to the final level that enabled me to develop an understanding of the subject. I am also greatly indebted to Mr. Emmanuel Jjunju, a PhD student, for his intensive support in providing the model of monthly water balance analysis.

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I am grateful to my father, mother and other family members who continuously encouraged me for study and hard work.

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Bijay Tamrakar

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M.Sc. THESIS IN HYDROPOWER DEVELOPMENT

Candidate: Bijay Tamrakar

Title: **Evaluation of precipitation distribution over Nepal using satellite data and its applications in Hydrological Modelling**

1 BACKGROUND

Access to high quality and representative precipitation data is crucial for the quality of rainfall-runoff modeling, and much effort is usually put into collecting and preparing such data. In the recent years a number of gridded precipitation products have been developed based on satellite and other remote sensing data. These have several promising features regarding areal coverage and access to precipitation in areas with few gauges. The accuracy of the data compared to gauges on a daily basis shows large differences (Sunil Ghaju, thesis 2010), but monthly/yearly data is yet to be tested. The main objective of the thesis is to collect satellite based precipitation data covering Nepal, develop maps of precipitation distribution on a monthly and yearly scale and evaluate the results. The data should also be applied to evaluate current scaling practices and for runoff generation.

2 MAIN QUESTIONS FOR THE THESIS

1. Study existing literature on precipitation distribution of precipitation in Nepal, and the application of satellite based precipitation in Nepal. Decide on which satellite products to use for the study.

2. Evaluate the collected precipitation data from the gauge networks. Find the gauges that overlap in time with the satellite, compute the daily/monthly/yearly and mean monthly precipitation and map the precipitation distribution over Nepal using observed data. Of particular interest here is the areal coverage and precipitation gradient.

3. Download and prepare the satellite data for Nepal. Accumulate the data, prepare the maps and compute the necessary data for comparison. Tools used for projection, clipping and rescaling should be clearly documented for future users, and new developments should be described and any source code included in an appendix of the thesis.

4. Compare the satellite and gauge based precipitation data from 2) and 3). Evaluations should be based on statistical measures and be clearly documented in the thesis.

5. Use the precipitation data on monthly basis to compute the monthly water balance using a water balance model running on a monthly time scale. Develop a runoff map for Nepal based on the satellite precipitation and the monthly model.

3 SUPERVISION, DATA AND INFORMATION INPUT

Professor Knut Alfredsen will supervise the thesis work.

Discussion with and input from colleagues and other research or engineering staff at NTNU, SINTEF, power companies or consultants are recommended. Significant inputs from others shall, however, be referenced in a convenient manner.

The research and engineering work carried out by the candidate in connection with this thesis shall remain within an educational context. The candidate and the supervisors are therefore free to introduce assumptions and limitations, which may be considered unrealistic or inappropriate in a contract research or a professional engineering context.

4 REPORT FORMAT AND REFERENCE STATEMENT

The thesis report shall be in the format A4. It shall be typed by a word processor and figures, tables, photos etc. shall be of good report quality. The report shall include a summary, a table of content, lists of figures and tables, a list of literature and other relevant references and a signed statement where the candidate states that the presented work is his own and that significant outside input is identified.

The report shall have a professional structure, assuming professional senior engineers (not in teaching or research) and decision makers as the main target group.

The summary shall not contain more than 450 words it shall be prepared for electronic reporting to SIU. The entire thesis may be published on the Internet as full text publishing through SIU. Reference is made to the full-text-publishing seminar during NORADS winter-seminar. The candidate shall provide a copy of the thesis (as complete as possible) on a CD in addition to the A4 paper report for printing.

The thesis shall be submitted no later than 15th of June 2011.

Trondheim 17th of January 2011

____

Knut Alfredsen
Professor

SUMMARY

Precipitation is a vital element of an atmosphere that has direct effect on Hydrology. Therefore, an accurate estimation of precipitation is obligatory to predict runoff through the catchment. Nepal has a high spatial variability of precipitation due to highly undulating surface terrain and complex relationships between land elevation and precipitation. This requires dense rain gauge network for the study of precipitation patterns in Nepal. However, it is difficult to arrange dense setup in the mountainous topography which is expensive and sometimes, even impossible for regular maintenance. The remedy for this problem could be the use of satellite based precipitation products with high temporal and spatial resolution.

In this study, TRMM data are employed to calculate rainfall over Nepal. TRMM rainfall product (that is precipitation data) can be obtained as: 3-hourly, daily, monthly and annually. These data are extracted and compared with 264 rain gauge stations in Nepal over the period of 8 years for their validation. A number of scripts are developed with python programming language to process raw satellite data which includes clipping to the region of interest, aggregation of day, month and annual values and extraction of rainfall on the gauging stations.

The day to day comparison showed that TRMM usually underestimates rainfall with some exception of overestimation at some regions. The CPOD_S value of 0.8 depicts that TRMM can detect precipitation in most of the days. Furthermore, in monthly comparison, TRMM estimated lower rainfall values but, the result still appeared to be acceptable (R^2 between 1 and 0.5) for use in other hydrological analysis. The comparison of annual precipitation as recorded by gauge and TRMM showed similar distribution patterns but the underestimation from monthly to yearly accumulate to form a huge difference in data sets. The correlation coefficient ranges from -0.86 to +0.8. The comparison of mean monthly precipitation data sets also derive same conclusion, but still possess a good R^2 efficiency. Though a fixed relation between altitude and intensity of rainfall could not be identified, it is observed that the efficiency of estimation decreases with increase in altitude.

The reliability of point to pixel (PO-PI) comparison method is also studied. This shows a wide spatial variability even within one pixel. The trend shows increasing precipitation on higher elevation. TRMM precipitation product estimates an average value falling over the pixel.

Since the comparison of monthly precipitation data showed good results, TRMM monthly precipitation data sets are also verified for use in discharge estimation from a catchment. A monthly water balance model developed by 'Thornthwaite' is simulated for four of the major river basins of Nepal including one sub-basin namely Karnali, Narayani, Bagmati, Saptakoshi and Sunkoshi. TRMM data without any bias correction factor is used for the estimation of discharge. The simulation results showed quiet an acceptable result although it is unable to catch up peak floods in some years.

Since TRMM is underestimating rainfall in most of the conditions, it will be wise to use an appropriate correction factor. Thus, a conclusion can be drawn from this study that TRMM rainfall products can be used in catchments with less or no rain gauge data, for estimating runoffs with a generalized bias adjustment factor.

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ACCRONYM

AET	Actual Evapotranspiration
ASCII	American Standard Code for International Interchange
CPC	Climate Prediction Center
CERES	Clouds and Earth's Radiant Energy System
CSV	Comma Separated Values
CPOD	Conditional Probability of Detection
UTC	Coordinated Universal Time
RR	Correlation Coefficient
CMORPH	CPC MORPHing Technique
DICS	Data and Information Services Center
DHM	Department of Hydrology and Meteorology
DRO	Direct Runoff
DAAC	Distributed Active Archive Center
ESRI	Environmental System Research Institute
EB	Estimation Bias
FEWS	Famine Early Warning System
GIS	Geographical Information System
GOES	Geostationary Operational Environmental Satellite
GPCP	Global Precipitation Climatology Project
GSMaP	Global Satellite Mapping of Precipitation
GES DISC	Goddard Earth Sciences Data and Information Service Center
GoN	Government of Nepal
HDF	Hierarchical Data Format
MAD	Mean Absolute Difference
MRAD	Mean Relative Absolute Difference
masl	meters above sea level
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NAD	Normalized Accumulated Difference
POES	Polar Operational Environmental Satellite
PET	Potential Evapotranspiration
PERSIANN	Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks
RMSD	Root Mean Squared Difference
TMI	TRMM Microwave Imager
TOVAS	TRMM Online Visualization and Analysis System
TRMM	Tropical Rainfall Measuring Mission
USAID	United States Agency for International Development
UTM	Universal Transverse Mercator
VIRS	Visible and Infrared Scanner
WB	Water Balance
WCRP	World Climate Research Program

CHAPTER I

INTRODUCTION

1.1 Background

Precipitation is one of the most important hydrological model inputs for planning, development and operation of water related projects. The study of spatial and temporal distribution of rainfall is first step for the development of water resources of the catchment [2] . The study of precipitation patterns is also an essential variable for the estimation of probability of floods and drought in an area. The precipitation is the key variable linking the atmosphere with hydrology. It is produced due to different atmospheric processes. Accurate high-resolution precipitation data are necessary for improving the understanding of climate, weather, and hydrology. They are characterized by spatial and temporal variability. There are different causes for the precipitation to occur and depend on landscape structure, areas with high elevation and slope. The field measurement of precipitation is done in a rain gauging station. These measurements give precipitation at a point. Different types of sophisticated instruments are developed for accurate point measurements but areal estimation still suffers from sampling error in representing average rainfall over an area. The spatial extent and temporal resolution of ground-based precipitation measurements are inadequate to support the creation of global precipitation data set that can help in detecting trends or in supporting process studies. At regional scales, the absence of adequate ground-based networks hampers effective usage of hydrological models in support of reliable flood and drought predictions.

Nepal has a wide variation in climate. The remarkable differences in climatic conditions are primarily due to the enormous range of altitude within a short north-south distance. This altitude difference also affects annual rainfall or precipitation patterns. Up to about 3,000 meters, total annual rainfall increase as the altitude increases; subsequently, the total diminishes with increasing altitude and latitude. So, the nature of precipitation varies drastically due to this orographic and rain shadow effects caused by high hills and mountains. The majority of precipitation studies of southern Asia have excluded the Himalayan belt due to the region’s extreme and complex topography and lack of adequate rain-gauge data [3]. Hence, there has been research in the regionalization of precipitation (i.e. determination of homogeneous areas) across Nepal to some extent only. So, it is important to understand the spatial patterns of precipitation across the country [3]. But, long term study showed no distinct trends over the 36 years.

For accurate estimation of precipitation over the area, precipitation stations should be placed close together. This demands high number of precipitation stations which is very costly for the developing countries like Nepal. Since the country doesn’t have a good network of ground based hydro meteorological stations, rainfall estimation in the given catchment is widely done by the method of interpolation. This could cause error in runoff estimation hence affecting the design of water related projects. One cost effective alternative is to estimate rainfall using data from combination with satellite sensors.

An alternative to ground based precipitation estimation is the use of radar based precipitation data. However, obtaining this data is difficult and usually not feasible in developing countries like Nepal in terms of cost and topography. During the last decade, satellite sensor technologies have been introduced for the estimation of global precipitation. Satellite precipitation maps have been derived from satellite observations of infrared [4, 5] [6], passive microwave [7] and space borne precipitation radar [8]. Substantial progress has been made in the past decade to generate precipitation estimates of high spatial and temporal resolution through combined use of infrared (IR) and passive microwave (PMW) observations from multiple satellites. Satellite based precipitation data have an advantage over the conventional method that they provide the areal distributed measurements instead of point measurement.

In the recent years, a number of gridded precipitation products have been developed. Some of them are be TRMM, GSMaP, PERSIANN, RFE, GPCD and CMORPH. These estimating products are based on following techniques.

- Visible and Infrared Techniques
- Bispectral Techniques
- Convective Stratiform Technique
- Passive Microwave Technique

1.2 Objective of Study

The main objective of the study is to evaluate the accuracy of satellite based precipitation data relative to the precipitation measured in gauges of Nepal and to investigate their applicability for monthly water balance of basins of Nepal.

The main tasks performed in the study are:

- Evaluation of TRMM satellite based rainfall estimate
- Preparation of 3- hourly, daily, monthly and yearly satellite based estimate in ASCII file format
- Clipping the satellite precipitation map to the map of Nepal
- Statistical comparison of ground measured precipitation with extracted satellite based precipitation for the region over Nepal.
- Observation of Precipitation patterns over the country
- Evaluate these satellite precipitation data by using them to compute monthly discharges and compare them with the measured data from four of the main river basins of Nepal

1.3 Scope of Study

TRMM satellite data has been compared with ground based precipitation stations. The following systematic tasks have been performed to meet the requirement of the study:

- Review of literature on the application of satellite based precipitation data in Nepal. Evaluate different sources of satellite precipitation data sets relevant for the study site and time period available.
- To be familiar with, modify and develop tools using python and other programming language to retrieve gridded data set, rotating, clipping them for study area and extracting data at gauge locations.
- Statistical comparison of ground measured gauge precipitation data with gridded satellite precipitation data at gauge locations.

- Evaluation of suitability of satellite precipitation data for runoff generation model. A monthly water balance model proposed by Thornthwaite is used to evaluate the suitability of satellite precipitation data.

1.4 Organization of the Thesis

The thesis report contains eight chapters organized as follows:

Chapter 2: This chapter includes a literature review of satellite precipitation products and discusses details of TRMM satellite data.

Chapter 3: This chapter deals with details of study area, its land features and hydrology.

Chapter 4: This chapter presents the sources of data used and discusses methodology of the study procedure. This chapter also presents details about the statistical comparison tools.

Chapter 5: This chapter deals with comparison of Satellite precipitation data with gauge station data. Daily, monthly, yearly and monthly average data are compared.

Chapter 6: This chapter discusses the literature behind the Monthly water balance model and presents the methodology of development of model.

Chapter 7: This chapter presents the input parameters used and how they are collected for the monthly balance model.

Chapter 8: This chapter presents the simulation results from the model.

Chapter 9: This chapter includes the conclusion of the study and recommendations proposed for further research with this study.

CHAPTER II

SATELLITE MAPPING

2.1 Introduction

The primary scope of satellite rainfall monitoring is to provide information on rainfall occurrence, amount and distribution over the globe for meteorology, climatology, hydrology, and environmental sciences. Estimates of precipitation have been derived from satellite observations of infrared, passive microwave and space borne precipitation radar.

2.2 Development History

The concept of using satellite techniques to analyze precipitation was devised in 1960. The techniques include use of Visual (VIS) and Infrared (IR) data to infer precipitation intensity based on the characteristics of cloud tops and its temperature [9]. These VIS and IR techniques provide data with continuous temporal coverage, but have relatively low degree of accuracy and stresses a particular aspect of the sensing of cloud physics properties and precipitation rather than the precipitation reaching the surface.

During 80s, passive microwave sensors (PMW) were developed that were deployed on polar orbiting spacecraft. These provide more accurate estimates of rainfall than that of VIS and IR but there was a limitation that this satellite could provide limited (only 1 or 2) samples in a day.

Recently developed remote sensored precipitation estimation techniques use both active and passive sensors. This utilizes advantage of both active PMW and IR sensors. An active sensor irradiates energy over a target and measures backscattered energy. Passive sensors measure the energy emitted by the earth's surface/atmospheric system after absorption and scattered during its propagation in the atmosphere. During this propagation, the interaction of energy with the medium (gases, aerosols and hydrometeors) is used to identify targets' characteristics, such as water vapor, ice, precipitation, or gas and particulate concentrations.

Substantial progress has been made in the past decade to generate precipitation estimates of high spatial and temporal resolution through combined use of infrared (IR) and passive microwave (PMW) observations from multiple satellites. Hsu et al. (1997) constructed a sophisticated system to convert the IR brightness temperatures observed by geostationary satellites into instantaneous rain rates through an artificial neural network trained carefully using concurrent IR and PMW-based precipitation estimates [10].

However, the accuracy of high resolution satellite precipitation products has uncertainties in representing spatial distribution, temporal variations and frequency of precipitation [11]. The conversion of the signal backscatter into rain-rates is not exact; surface effects and melting precipitation lead to anomalous signals, and low-level precipitation may be missed due to the upward-refraction of the radar beam through the atmosphere. Other issues include attenuation, beam blockage, beam-filling and beam overshoot [12]. Radar networks can still be usefully employed with cross-calibration and calibration from gauge data. Integrating information from multiple satellite sensors as well as gauge observations improves the quality and resolution of precipitation analysis.

2.3 Satellite Rainfall products

Presently, there are a number of satellite rainfall products that has been developed blending PMW and IR sensors. Some of them are presented in the Table: 2-1.

Table 2-1: Details of Satellite Precipitation Data

Product Name	Temporal Resolution	Spatial Resolution	Data extent	PMW data	IR data	Adjusted by gauge	Data format	One day Definition (UTC)
CMORPH	3-hourly	0.25 degree	2003 to present	Y	Y	N	GIS	00:00-23:50
PERSIANN	6-hourly	0.25 degree	2001 to present	Y	Y	N	ASCII	00:00-00:00
RFE-2	Daily	0.1 degree	2001 to present	Y	Y	Y	GIS	06:00-06:00
GPCP-1DD	Daily	1.0 degree	1996 to present	Nd	Y	Nd	Binary	22:30-22:30
TRMM-3B42	3-hourly	0.25 degree	1998 to present	Y	Y	Y	HDF	22:30-22:30
GSMaP MVK+	1-hourly	0.1 degree	2003 to 2006	Y	Y	Y	Binary	00:00-00:00

Note: Y – Yes, N – No, Nd – Not directly, PMW – Passive Microwave, IR – Infrared

2.3.1 PERSIANN Rainfall Estimate

PERSIANN system uses artificial neural network to estimate rainfall rates at each 0.25° x 0.25° pixel provided by geostationary satellites. The PERSIANN system uses both geostationary infrared imagery and infrared and daytime visible imagery. Rainfall product covers 50°S to 50°N globally. The PERSIANN system has tended to overestimate rainfall, with especially large errors for higher rainfall amounts [10] [13] [14] [15].

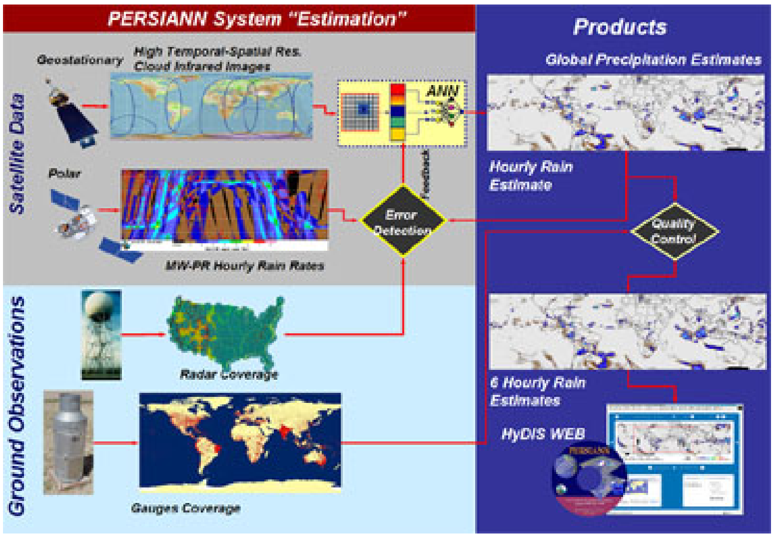

Figure 2-1: Flowchart of the PERSIANN system of Rainfall Estimate[16]

2.3.2 CMORPH

CMORPH is one of the products of National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC). CMORPH produces global precipitation analysis at very high spatial and temporal resolution. This technique uses precipitation estimates that have been derived from microwave observations obtained entirely from geostationary satellite IR data. This technique is not a precipitation estimation algorithm but a means by which estimates from existing microwave rainfall algorithms can be combined. Therefore, this method is extremely flexible such that any precipitation estimates from any microwave satellite source can be incorporated. Data covers from 60°N to 60°S.

2.3.3 African Rainfall Estimate (RFE-2)

African Rainfall Estimate (RFE-2) is also a product of National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC) which is produced specifically for USAID, FEWS to assist in drought monitoring activities over Africa, southern Asia, and Afghanistan area domains [17].

RFE 2.0 uses four types of input data, including three satellite sources, to create the final rainfall estimates. Inputs include satellite IR temperature data, microwave precipitation estimates and gauge fields. The final output is minimally biased and greatly improved spatial resolution.

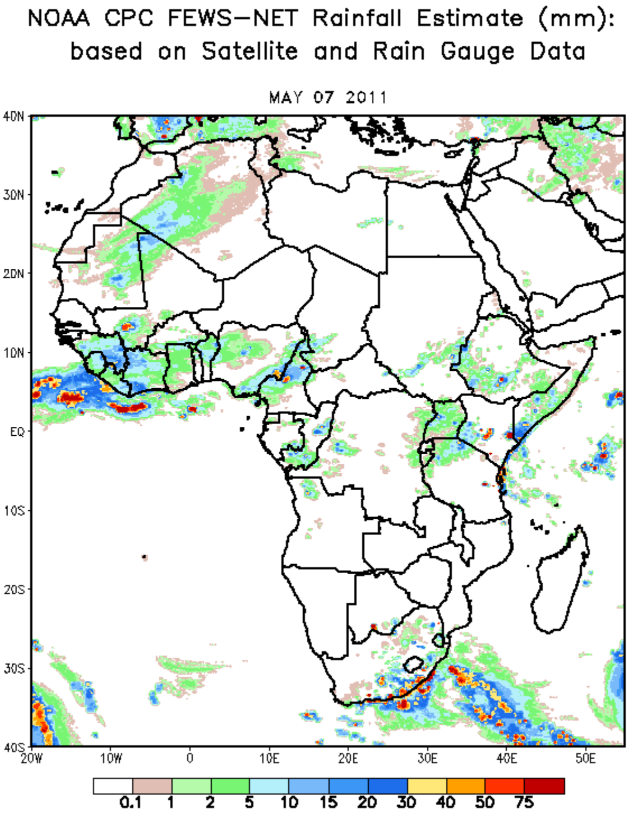

Figure 2-2: African Rainfall Estimate (RFE-2) [17]

2.3.4 GPCP-1DD

The Global Precipitation Climatology Project (GPCP) is established by the World Climate Research Program (WCRP) to address the problem of quantifying the distribution of precipitation around the globe over many years. The general approach is to combine the precipitation information available from each of several sources into a final merged product. Data covers from 40°N to 40°S.

GPCP Version 2 monthly Satellite-Gauge (SG), Pentad, and One-Degree Daily (1DD) are newer versions that combine precipitation data sets. The 1DD product provides precipitation estimates on a 1-degree grid over the entire globe at 1-day (daily) for the period October 1996 - present. These precipitation products are produced by optimally merging estimates computed from microwave, infrared, and sounder data observed by the international constellation of precipitation-related satellites and precipitation gauge analysis [18].

2.3.5 GSMaP MVK+

The GSMaP project is introduced for studying the production of a high-precision, high-resolution global precipitation map using satellite data using PMW and GEO IR radiometers. The project is sponsored by Japan Science and Technology Agency (JST). GSMaP estimates are achieved by temporal interpolation of PMW retrievals using blended PMW-IR algorithm composed of a morphed technique [19] and kalman filter [20] using IR information.

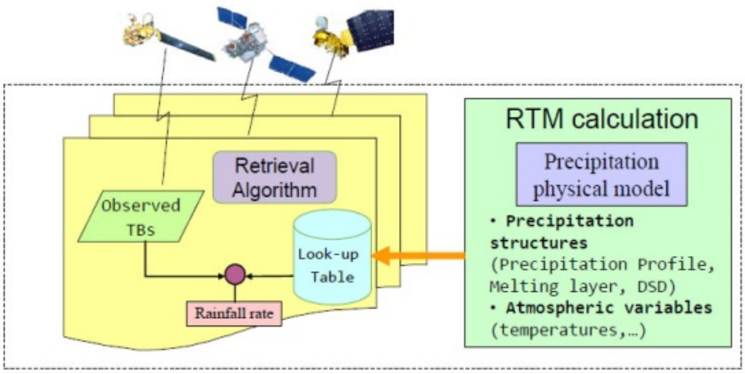

Figure 2-3: GSMaP Algorithm

The spatial resolution of GSMaP data is 0.1 x 0.1 degree latitude and longitude covering globe from 60°N to 60°S with temporal resolution of 1 hour.

2.3.6 TRMM 3B42

The Tropical Rainfall Measuring Mission (TRMM) is a joint mission between the National Aeronautics and Space Administration (NASA) of the United States and the National Space Development Agency (NASDA) of Japan. The objectives of TRMM are to measure rainfall and energy exchange of tropical and subtropical regions of the world.

The purpose of the TRMM 3B42 algorithm is to produce TRMM-adjusted merged-infrared (IR) precipitation and root-mean-square (RMS) precipitation-error estimates. The precipitation estimates have a 3-hourly temporal resolution and a 0.25-degree by 0.25-degree spatial resolution. Spatial coverage extends from 50 degrees south to 50 degrees north latitude.

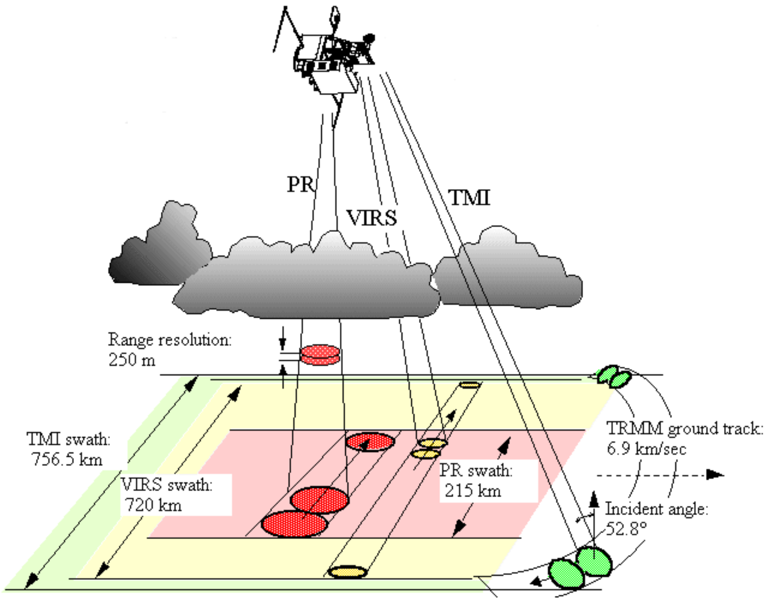

Figure 2-4: Working mechanism of TRMM Satellite [21]

The daily accumulated (beginning at 00:00 UTC and ending at 21:00 UTC; unit: mm/hr.) rainfall can be derived from this 3-hourly product.

2.4 Selection of Precipitation product

Department of Hydrology and Meteorology, Ministry of Environment, Science and Technology, Government of Nepal, defines one day duration as 03:00 UTC to 03:00 UTC of next day (i.e. 08:45 am to 08:45 am local time). Coordinated Universal Time (abbreviated UTC) is the time standard based on International Atomic Time (TAI) with leap seconds added at irregular intervals to compensate for the Earth's slowing rotation [22]. Nepalese standard time (NST) is 5:45 hours ahead of UTC.

It is necessary that the time of recording of rainfall at gauge station should be same as that recorded by rainfall products. Otherwise the data recorded for a day by rainfall product and gauge for the same day will not match.

Of these various rainfall products, TRMM 3-hourly data is selected for further analysis. This data can be collected according to the day definition of Nepal. Data are also available for the whole study period. It is illustrated in the next section. The other products are not selected for analysis due to following reasons:

- CMORPH: The CMORPH data starts from 2003. Since data for CMORPH are available only from 2003, data can be evaluated only for 6 years. So, this product is not used for evaluation.
- PERSIANN and GPCP-1DD: These rainfall products were not selected for evaluation because the data cannot be accumulated according to day definition of Nepal. Also, they provide a huge overestimated precipitation data [23]
- RFE-2: Since RFE is designed to estimate rainfall in African countries, it is not applicable to be used in study area. So, this product is not used for evaluation.
- GSMaP MVK+: The satellite data is available only from 2003 to 2006. The data were evaluated for one of the basin of Nepal by Mr. Sunil Ghaju [24] as a part of his Master thesis and concluded that it is heavily underestimating precipitation.

2.4.1 TRMM

The Tropical Rainfall Measuring Mission (TRMM) is a joint mission between the National Aeronautics and Space Administration (NASA) of the United States and the National Space Development Agency (NASDA) of Japan. The objectives of TRMM are to measure rainfall and energy (i.e., latent heat of condensation) exchange of tropical and subtropical regions of the world. The satellite was launched on November 27, 1997 from the Tanegashima Space Center in Tanegashima, Japan.

The TRMM satellite includes TRMM Microwave Imager (TMI), the precipitation radar (PR), and the Visible and Infrared Radiometer System (VIRS). Additionally, the TRMM satellite has Earth Observing System (EOS) instruments in the Clouds and Earth's Radiant Energy System (CERES) and the Lightning Imaging System (LIS). The space segment of TRMM is a satellite in a 350-km circular orbit with a 35 degree inclination angle [8].

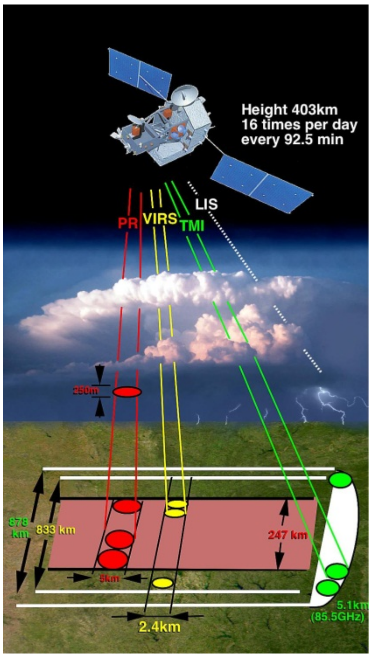

Figure 2-5: Components of TRMM Satellite

i. Precipitation Radar (PR)

Among the three primary instruments on TRMM, the most innovative is the Precipitation Radar. It is the first space borne instrument designed to provide three-dimensional maps of storm structure. These measurements yield invaluable information on the intensity and distribution of the rain; on the rain type, on the storm depth and on the height at which the snow melts into rain.

The Precipitation Radar has a horizontal resolution at the ground of about 3.1 miles (five kilometers) and a swath width of 154 miles (247 kilometers). One of its most important features is its ability to provide vertical profiles of the rain and snow from the surface up to a height of about 12 miles (20 kilometers).

The Precipitation Radar is able to detect fairly light rain rates down to about 0.027 inches (0.7 millimeters) per hour. It carries out all these measurements while using only 224 watts of electric power. The Precipitation Radar is built by the National Space Development Agency, JAXA of Japan as part of its contribution to the joint US/Japan Tropical Rainfall Measuring Mission (TRMM).

ii. TRMM Microwave Imager (TMI)

The Tropical Rainfall Measuring Mission's Microwave Imager is a passive microwave sensor designed to provide quantitative rainfall information over a wide band under the TRMM satellite. It is based on the design of the highly successful Special Sensor Microwave/Imager (SSM/I). By carefully measuring the minute amounts of microwave energy emitted by the Earth and its atmosphere, TMI is able to quantify the water vapor, the cloud water, and the rainfall intensity in the atmosphere. It is a relatively small instrument that consumes little power. This combined with the wide swath and the good, quantitative information regarding rainfall make TMI the "workhorse" of the rain-measuring package on Tropical Rainfall Measuring Mission.

iii. Visible and Infrared Scanner (VIRS)

The Visible and Infrared Scanner is one of the primary instruments of the Tropical Rainfall Measuring Mission (TRMM) observatory. VIRS is one of the three instruments in the rain-measuring package and serves as a very indirect indicator of rainfall. It also ties with TRMM measurements with other measurements that are made routinely using the meteorological Polar Orbiting Environmental Satellites (POES) and those that are made using the Geostationary Operational Environmental Satellites (GOES) operated by the United States.

VIRS, as its name implies, senses radiation coming up from the Earth in five spectral regions, ranging from visible to infrared i.e. 0.63 to 12 micrometers. The intensity of the radiation in the various spectral regions (or bands) can be used to determine the brightness (visible and near infrared) or temperature (infrared) of the source. If the sky is clear, the temperature will correspond to that of the surface of the Earth, and if there are clouds, the temperature will tend to be that of the cloud tops. Cold temperatures will produce greater intensities in the shorter wavelength bands and warm temperatures will produce greater intensities in the longer wavelength bands. Since colder clouds occur at higher altitudes the measured temperatures are useful as indicators of cloud heights, and the highest clouds can be associated with the presence of rain.

iv. Clouds and the Earth's Radiant Energy System (CERES)

The data from Clouds and the Earth’s Radiant Energy System instrument will be used to study the energy exchanged between the Sun; Earth’s atmosphere, surface and clouds; and space. The Earth’s daily weather and climate are controlled by the balance between the amount of solar energy received by the Earth and the amount of energy emitted by the Earth into space.

CERES will measure the energy at the top of the atmosphere, as well as estimate energy levels within the atmosphere and at the Earth’s surface. Using information from very high resolution cloud imaging instruments, CERES also will determine cloud properties, including cloud-amount, altitude, thickness, and size of the cloud particles. All of these measurements are critical for advancing the understanding of the Earth’s total climate system and further improving climate prediction models.

v. Lightning Imaging Sensor

The Lightning Imaging Sensor is a small, highly sophisticated instrument that detects and locates lightning over the tropical region.

The lightning detector is a compact combination of optical and electronic elements including a staring imager capable of locating and detecting lightning within individual storms. A high-speed, charge-coupled device detection array behaves similarly to the retina of the human eye by creating an image of the lightning event and the background scene. A real-time event processor then extracts the signal, thus determining when a lightning flash occurs.

vi. Use as a Satellite Precipitation data

The purpose of the TRMM 3B42 algorithm is to produce TRMM-adjusted merged infrared (IR) precipitation and root-mean-square (RMS) precipitation-error estimates. The algorithm consists of two separate steps. The first step uses the TRMM VIRS and TMI orbit data (TRMM products 1B01 and 2A12) and the monthly TMI/TRMM Combined Instrument (TCI) calibration parameters (from

TRMM product 3B31) to produce monthly IR calibration parameters. The second step uses these derived monthly IR calibration parameters to adjust the merged-IR precipitation data, which consists of GMS, GOES-E, GOES-W, and Meteosat-7, Meteosat-5, and NOAA-12 data. The final gridded, adjusted merged-IR precipitation (mm/hr.) and RMS precipitation-error estimates have a 3-hourly temporal resolution and a 0.25-degree by 0.25-degree spatial resolution.

CHAPTER III

STUDY AREA

3.1 Location

Nepal is preponderantly a mountainous country and lies in the South-eastern part of Asia and extends between 26°22' and 30°27' North latitude and 80°04' and 88°12' East longitude. It is located in the Himalayas and bordered to the north by the People's Republic of China, and to the south, east, and west by the Republic of India. The total area of the country is 147,181 sq. km with average north-south width of 193 km and east-west length of 885 km.

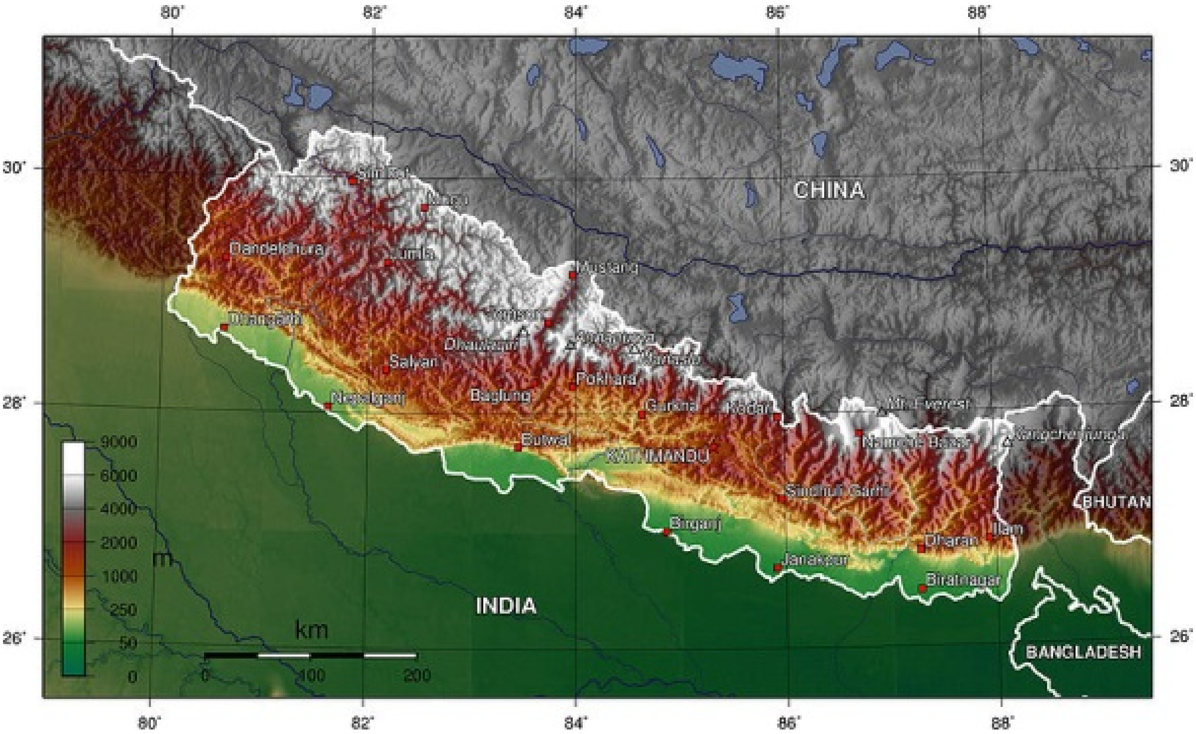

Figure 3-1: Physical Map of Nepal

3.2 Physical Features

The major part of the country is of high mountains and rolling hills. Over three-fourths of the total area is taken up by mountains. The country can be divided into three physiographic regions: Northern Himalayas, hills and southern lowlands. Mahabharat, Churia and Himalayan mountain ranges extend from east to west along the country and are geologically the youngest mountain chain of the Himalayas. The mountains are geologically fragile. Lowlands comprises of both cultivable land and dense forests. Altitude varies from 90 meters above the sea level in the south to 8848 meters in the North Himalayas with an average rise of elevation of 45 meters for every one kilometer [2]. Many valleys exist along the hill regions. An illustrative section of the country along the North-South direction is presented in Figure 3-2.

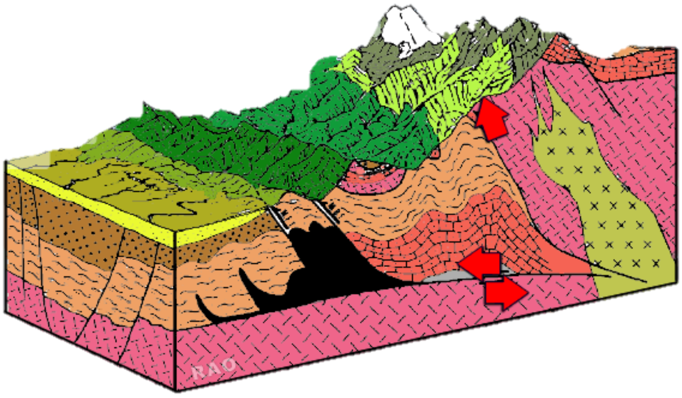

Figure 3-2: Section along North-South of the country

3.3 Hydro-Meteorology

Hydro-meteorology is the study the transfer of water and energy between the land and atmosphere. It deals with problems involving the hydrologic cycle, the water budget and the rainfall statistics. Water-based weather patterns can be predicted and studied using the latest Hydro-meteorological methods.

3.3.1 Climate

Nepal has very pleasant climate. The country lies in the monsoon climatic regime [2]. There is a seasonal variation in the amount of rainfall, depending on the monsoon cycle. The pre-monsoon season generally occurs during April and May. The monsoon lasts from June to September and involves a large amount of precipitation. The post-monsoon season begins with a slow withdrawal of the monsoon and moistness disappears completely by mid-October. The post-monsoon season lasts until December.

Furthermore, there is a tremendous variation in climate of the country due to extreme variation in topography. During pre-monsoon season, the highest temperature during the day in lowlands reaches around 40°C however; the hills and mountains remain cool. The presence of the east-west-Himalayan range in the north and the monsoonal alteration of wet and dry seasons also greatly contribute to local variations in climate. The Himalaya blocks cold winds from Central Asia in winter, and forms the northern limit of the monsoon wind patterns.

Nepal can be divided into five characteristic climate zones showing a trend from east to west.

- Hot, tropical zone of below 500 meters in altitude
- Subtropical zone extending up to 1200 meters in altitude
- Warm temperate zone of 1,200 to 2,400 meters in altitude
- Cold zone of 2400 to 3600 meters in altitude
- Subarctic or alpine climatic zone of 3,600 to 4,400 meters in altitude
- Arctic zone above 4,400 meters in altitude

Precipitation, air temperature, evaporation, and relative humidity play an important role in building the climate of a particular place. Characteristics of these parameters in the context of Nepal are discussed in the following paragraphs.

3.3.2 Precipitation

Precipitation in Nepal is mainly due to summer monsoon. It starts from mid of June and lasts till September. During summer, Indian subcontinent heats up considerably causing a low pressure area over the northern and central Indian subcontinent. This draws in moisture rich air from the Indian Ocean that moves north. The Himalayas act as a high barrier preventing them to rise further up across the mountain ridge. With gain in altitude, temperature drops down and precipitation occurs. Summer monsoon is characterized by intense rainfall lasting for shorter period of time with violent lightening and responsible for almost 80 percentage of the annual precipitation in Nepal [25]. Within this monsoon itself, the total amount of rain comes within just 20% of its duration and exhibits considerable macro, meso, and micro scale variations [26]. In general the precipitation above 5000 to 6000 meters falls as snow during summer monsoon period [27]. The effect of summer monsoon is higher in southeastern part of the country than the northwestern part. Rains diminish in September and generally end by mid-October.

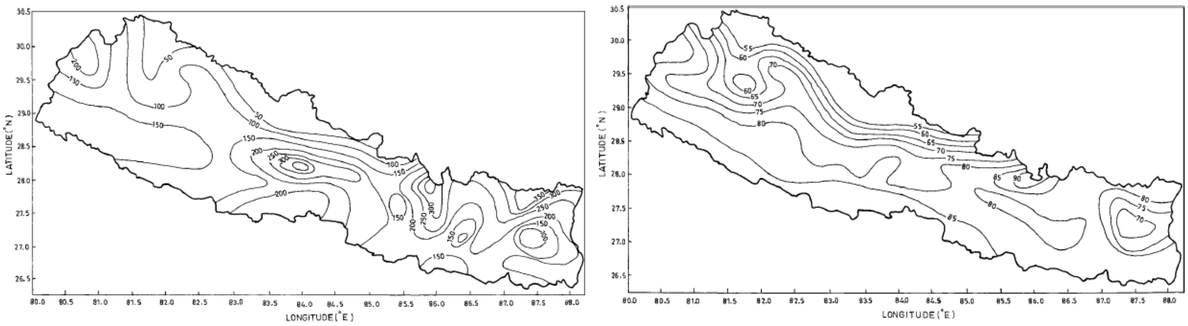

Figure 3-3: Annual precipitation and Percentage of monsoon rainfall compared to annual over Nepal [25]

The winter monsoon is marked by occasional, short rainfalls in the lowlands and plains and snowfalls in the high-altitude areas. The amount of precipitation resulting from the northeast land varies year to year but increases markedly with elevation. The secondary winter precipitation in the form of snowfalls in the Himalayas is important for generating a sufficient volume of spring and summer melt waters. Almost all the precipitation above 3000 m in this period falls as snow [27].

The overall annual precipitation is governed by the precipitation in summer monsoon. As the country has high mountains in the north, there is high variability of rainfall distribution due to orographic and rain shadow effects.

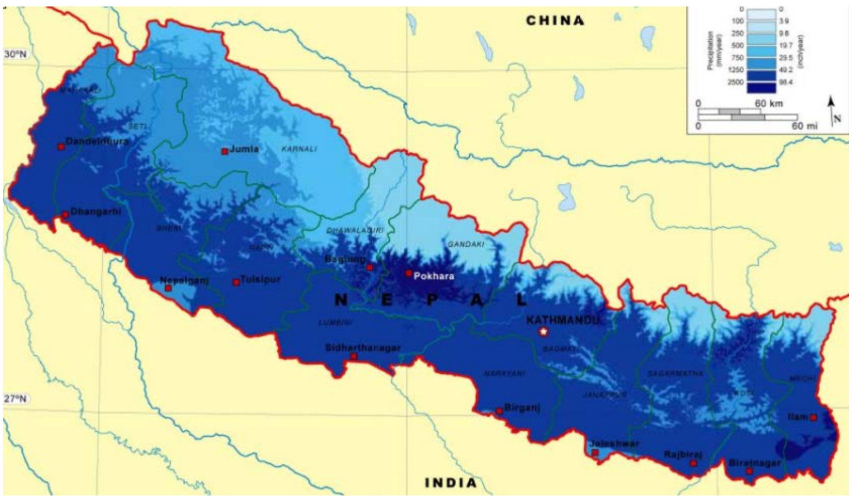

Figure 3-4: Annual precipitation Map of Nepal [28]

3.3.3 Air temperature

Air temperature is very important input parameter in hydro-meteorological analysis. It is a parameter with both temporal and spatial dependence and depends on the solar radiation, topography and atmospheric cycle in the area. Figure 3-5 represents the mean annual air temperature over Nepal. The air temperatures at high altitude are relatively lower than those at low altitude. Such phenomenon is defined by the parameter Lapse Rate. According to Barry (1992) the average temperature decrease with height (environmental lapse rate) is about 6°C/km in the free atmosphere. The dry adiabatic lapse rate (DALR) is 9.8°C/km [29].

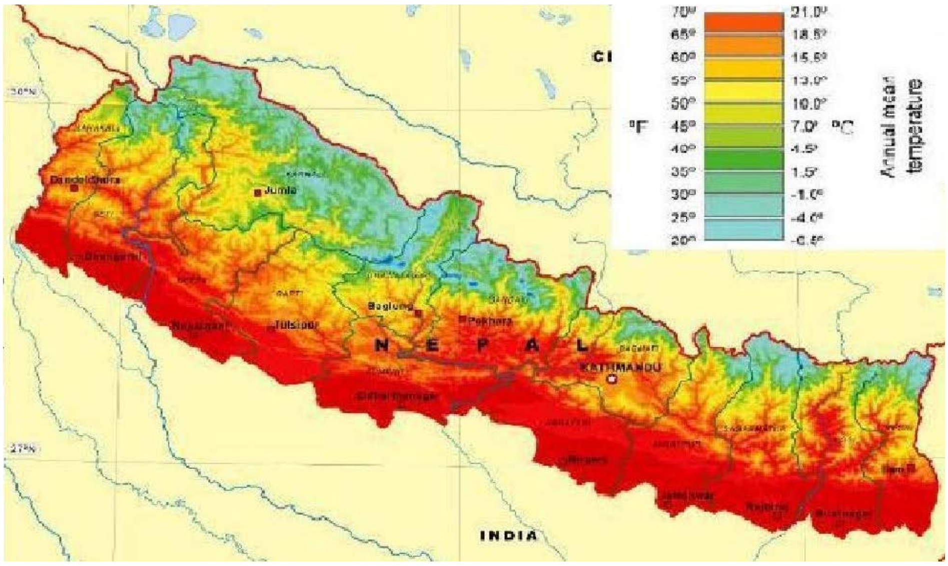

Figure 3-5: Annual Mean Temperature Map of Nepal [28]

Air temperature is the most important parameter for evaluating the climatic fluctuation of a location. An analysis of records from 49 stations distributed throughout Nepal shows that there is a clear increase in temperature after the mid-1970s [30]. The trends are high in higher altitude regions of the country. This result is in agreement with global temperature trends [30] [31].

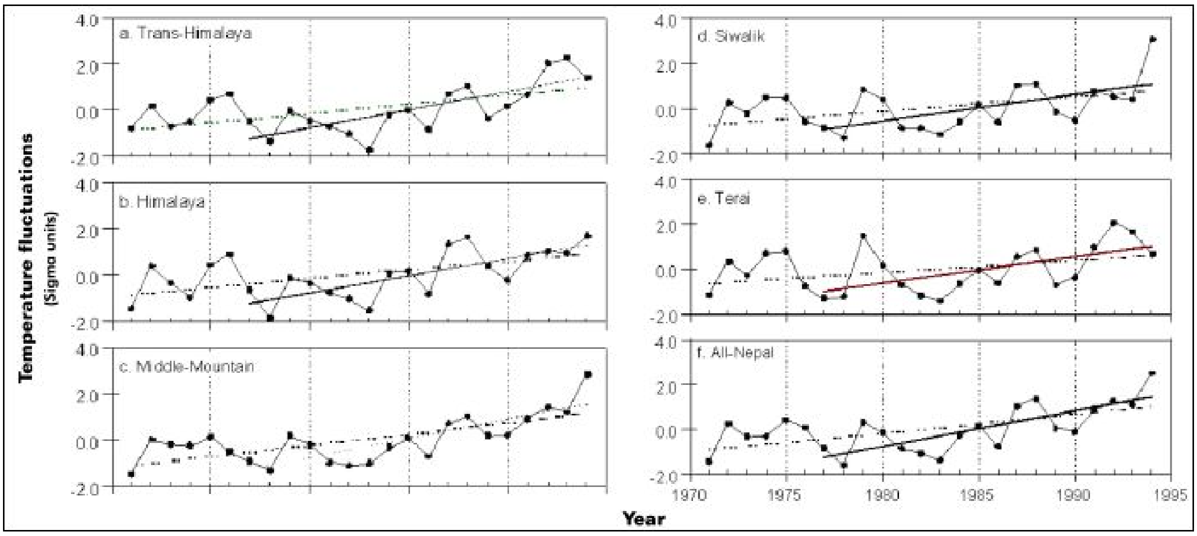

Figure 3-6: Annual temperature trends for different physiographic regions of the country [30]

3.3.4 Evaporation

Loss of water due to vaporization is termed as evaporation and particularly, evaporation loss from the plant leaves is termed as transpiration. The balance between precipitation and evaporation determines the stream flow. Evaporation is a function of temperature, humidity, solar radiation, and wind speed. There are a limited number of stations measuring evaporation in Nepal. This has also been derived using the methods of Penman (1956), Thornthwaite (1948) and Morton (1983). Both measured and derived values are adequate to characterize the spatial variation of evaporation in Nepal.

The term evapotranspiration is used to define the combined loss of water from plant surface and other surfaces like water bodies, soil etc. Potential evapotranspiration (PET) is the evapotranspiration rate of a short green crop, completely shading the ground, of uniform height and with adequate water status in the soil profile. In Nepal, a decreasing trend for potential evapotranspiration is observed with increasing elevation [1]. This is also shown in Figure 3-7.

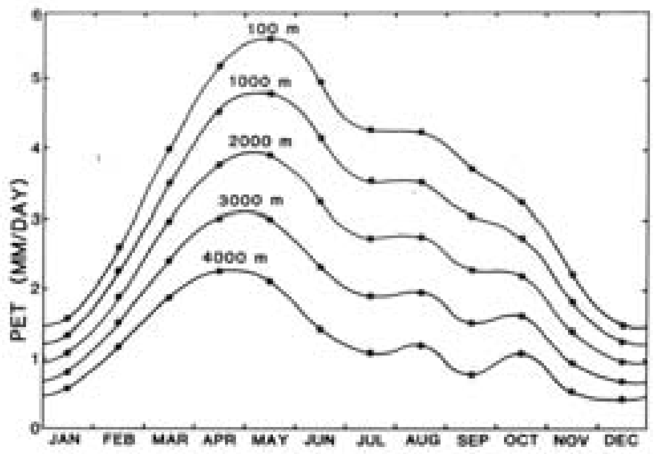

Figure 3-7: Seasonal trends in Potential Evapotranspiration at different Elevations [1]

3.3.5 Land use

It is the term used to define the extent of human modification to the natural land [22]. The natural land may be converted to a city area, agricultural land, pastures etc. Land use type has direct effect on drainage capacity of the catchment. Fast drainage or slow drainage also depends on type of vegetation cover in the catchment. As Nepal has different types of climatic condition, vegetation cover ranges from tropical to alpine forests.

The latest physiographic data indicate that Nepal comprises around 4.27 million hectares of forest (29% of total land area), 1.56 million hectares of scrubland (10.6%) and degraded forest, 1.7 million hectares of grassland (12%), 3.0 million hectares of farmland (21%), and about 1.0 million hectares of uncultivated lands (7%). It has been reported that forest cover in the Terai and hill areas decreased at an annual rate of 1.3%, and 2.3% between 1978/79 and 1990/91, respectively [32]. On average, forested areas have decreased at an annual rate of 1.7%, and scrublands have decreased at an annual rate of 0.5%. In terms of total land area, the Terai occupies only 23.1%, the hills, occupy 41.7%, and mountains 35.2% of Nepal's total land area. [33]

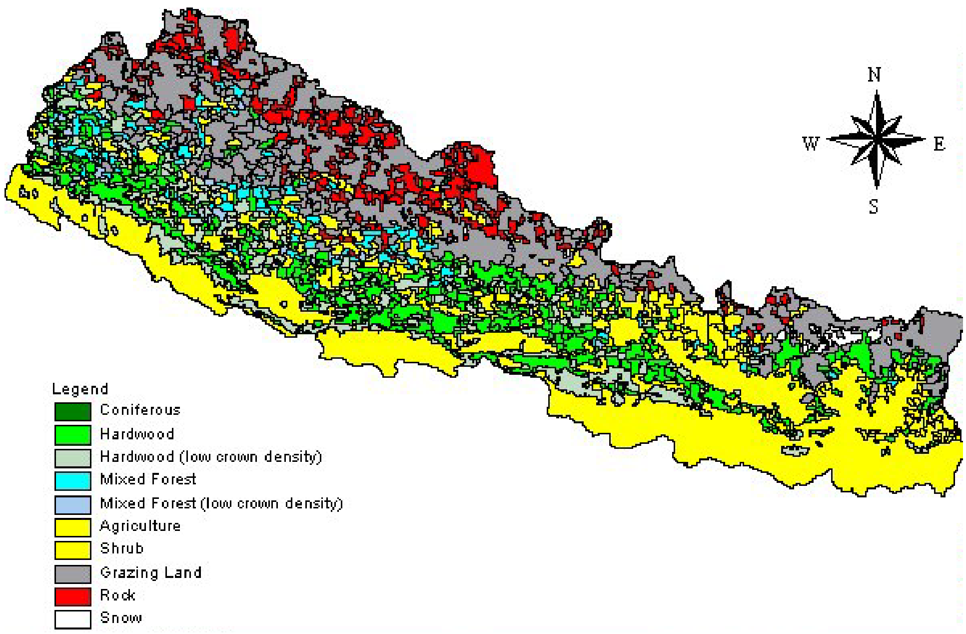

Figure 3-8: Classified Land Cover Map of Nepal 1992/1993 [34]

3.4 Major Rivers of Nepal

For hydrological studies, the country can be divided into six major drainage basins: Koshi River Basin, Bagmati River Basin, Narayani River Basin, Rapti River Basin, Karnali River Basin and Mahakali River Basin. Among them, Karnali, Narayani and Koshi are major snow fed rivers in Nepal. Most of these rivers receive flow from numerous tributaries originating in the high mountainous areas with glaciers and snow covers. The Karnali basin has the least monsoonal effect.

Table 3-1: River basins of Nepal

S.No.	River Basin	Drainage area (km^2)	Average annual yield (m^3/s)	Average Rainfall (mm)	Major rivers
1	Koshi River Basin	61000	1409	1600	Arun, Sunkoshi, Bhotekoshi
2	Karnali River basin	41000	1400	1775	Seti, Bheri
3	Mahakali River basin	15260		947	Chamelia, Surnagad
4	Narayani River basin	29600	1600	2000	Trishuli, Marsyandi, Seti, Gandaki
5	Bagmati River basin	3750	-	2000	Manohara, Bishnumati, Kulekhani
6	Rapti River basin	23900	140		Jhimruk, Rohini

The snowfalls below the elevation of 3000 m are usually considered to be less significant as its contribution to the stream flow may persist for a few days only. Upper air observations made in Nepal indicate the annual variation of freezing level from about 3000 to 6000 m. Hence this range of altitude plays an important role in the contribution of melt water to the rivers downstream. The areas within the altitude range of 3000 m and 6000 m are about 53 %, 45 % and 61 % in the Karnali, Narayani and Koshi basins respectively.

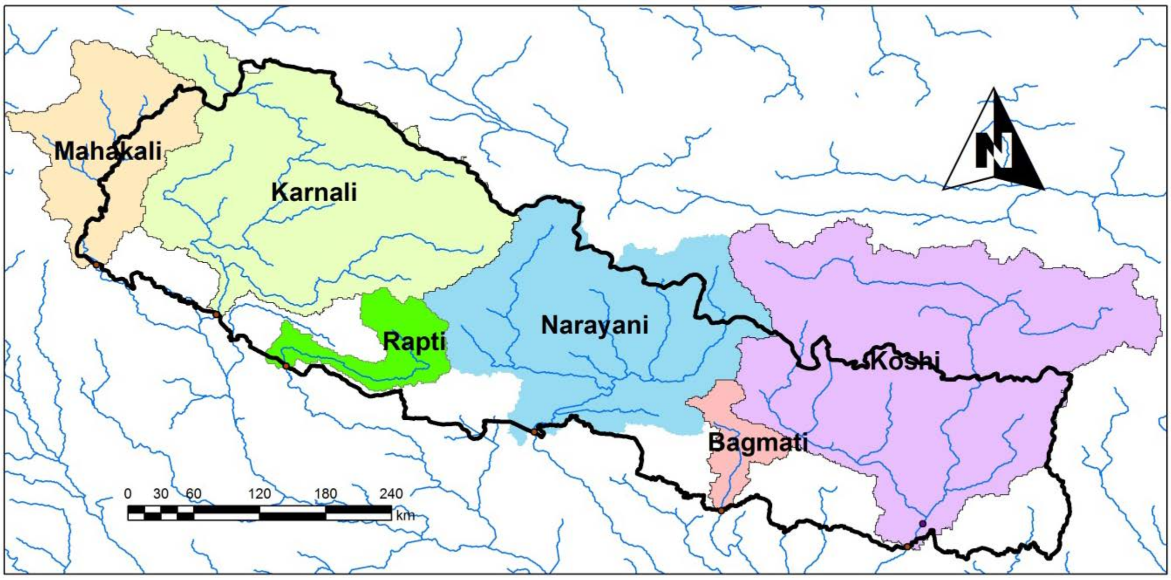

Figure 3-9: Major River basins of Nepal

CHAPTER IV

DATA SOURCE AND METHODOLOGY

4.1 Introduction

Main data collected for the study purpose are recorded rainfall data from the gauge station and TRMM satellite precipitation data. Data from 2001 to 2008 are used for the comparison. Other data used for simulating monthly water balance are discharge data at outlet of each basin and temperature data in the catchment of those river basins.

4.2 Rain gauge data

Rain gauge stations collect precipitation data at particular point during specified interval of time. In Nepal, measurement is done at 03:00 UTC i.e. 08:45 am local time. The rain gauge data are collected from Department of Hydrology and Meteorology, Ministry of Environment, Science and Technology, Government of Nepal.

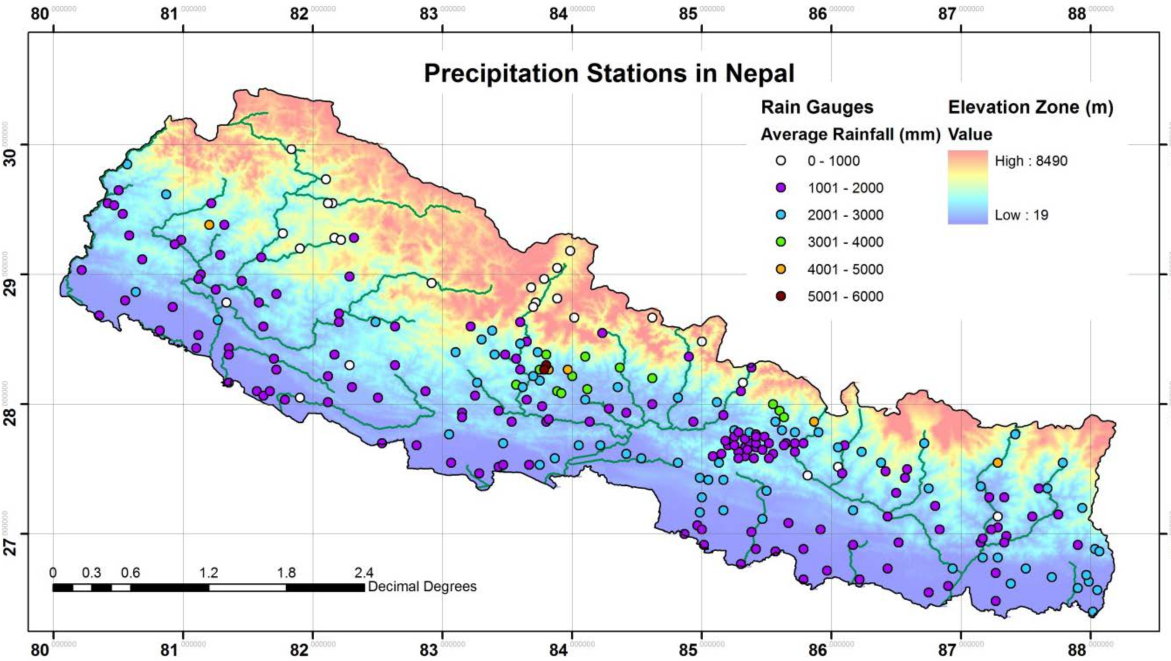

Figure 4-1: Precipitation stations in Nepal

There are around 272 precipitation stations around the country. Out of which 6 are Aeronautical station, 9 are synoptic station, 20 are agro-meteorological station, 70 are climatological station and 167 are just precipitation station. Some gauge stations have some missing data over a long duration. Stations that have missing data over 3 years are rejected for analysis. But stations at higher elevation are still selected to compare data of high altitudes.

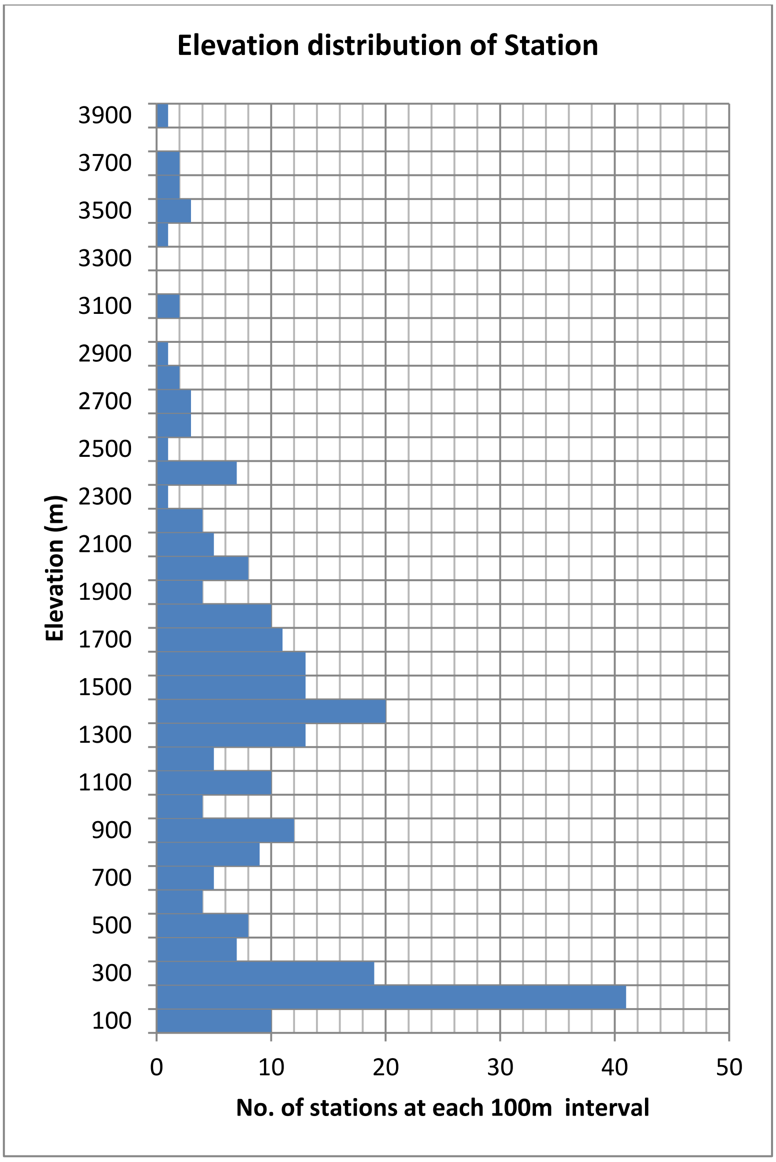

Figure 4-2: Elevation Distribution of Station in Nepal

Data are collected from 2001 to 2008 for 264 different stations. The data quality is also checked for individual stations. The name, station ID, geographic location and elevations of the stations are presented in Appendix 1. The stations names marked with red color are excluded from comparison as they have more than 3 years of missing data. The lists of missing data are presented in Appendix 3.

4.3 Satellite Precipitation data

There are various types of global satellite data available released by different organizations which can be downloaded freely from the internet. Among them, TRMM-3B42 version 6 data has been selected for comparison and analysis. The reason for choosing the product has already been discussed.

4.3.1 TRMM Precipitation data

TRMM Satellite is designed to monitor and study tropical rainfall and the associated release of energy that helps to power the global atmospheric circulation, shaping both global weather and climate. The operation and distribution of all TRMM products is done by the Goddard Distributed Active Archive Center (GES DISC DAAC). There are various types of gridded products available. All of the products have different objectives and produced in different levels of processing.

Level 1 products are the VIRS calibrated radiances, TMI brightness temperatures, and the PR return power and reflectivity measurements. Level 2 products are derived geophysical parameters at the same resolution and location as those of the Level 1 source data. Level 3 products are the time-averaged parameters mapped onto a uniform space-time grid.

Different products archived and distributed by GES DISC DAAC is present in Table 4-1.

Of these various data sets, TRMM 3B42 version 6.0 is used for further comparison. 3B42 version 6 provides precipitation for a 3 hours interval that can be converted to daily, monthly and annual accumulations. The TRMM 3B42 rainfall products are prepared by merging High quality Infrared precipitation and root mean square precipitation error estimates. This involves following stages:

i. Calibrate of microwave precipitation estimates
ii. Prepare of infrared precipitation estimates using the calibrated microwave precipitation
iii. Combine microwave and IR estimates
iv. Integrate with rain gauge data

The overview of data processing during the preparation of TRMM 3B42 is presented in Figure 4-3.

The TRMM 3B42 version 6 blended data is available through direct ftp server of NASA: ftp://disc2.nascom.nasa.gov/data/opendap/TRMM_3Hourly_3B42/

The characteristics and key features of TRMM precipitation product is presented in Table 4-1.

Table 4-1: Data Characteristics of TRMM-3B42 V6

Temporal Resolution:	1998 to present
Geographic Coverage:	Latitude: 50° S to 50°N Longitude: 180°W to 180° E
Temporal Resolution:	3 – Hourly
Spatial Resolution	0.25° x 0.25°
Grid Size	400 x 1440 pixels
Average File Size	Compressed: ~285 KB; Original: ~4.5 MB
Projection :	Geographic WGS 1984
File Type:	HDF
Precipitation measurement:	mm/hr.
Missing value	-999.9

Table 4-2: Gridded data products from TRMM [21]

Data Set	Description	Temporal Resolution	Spatial Resolution	Sensor	Parameters	Date Range
3A11 Gridded Oceanic Rainfall Product	Latitude band from 40°N to 40°S	Monthly	5° x 5°	TMI	Precipitation amount, Conditional rain rate, Rain	1997-12-01 to Present
3A12 Level 3 profile and surface rainfall Product	Comprised of mean 2A12 data and calculated vertical hydrometeor profiles as well as mean surface rainfall	Monthly	0.5° x 0.5°	TMI	Temperature profiles, Water vapor profiles, Rain, Precipitation rate, Convection, Cloud liquid Water/ice, cloud Precipitable water, Atmospheric heating	1997-12-01 to Present
3A25 Gridded Rainfall Product	Total and conditional rain rate and snow-ice layer depth for a latitude band from 40°N to 40°S	Monthly	0.5° x 0.5°	PR	Precipitation rate	1997-12-01 to Present
3A26 Gridded Surface Rainfall Product	Rain rate probability distribution for a latitude band from 40°N to 40°S	Monthly	5° x 5°	TMI	Precipitation rate	1997-12-01 to Present
3A46: Gridded Rainfall Product	Global rain rate	Monthly	1° x 1°	Special Sensor Microwave/ Imager	Rain, Precipitation rate, Precipitation amount	1998-01-01 to 2009-09-01
3B31 Gridded Rainfall Product	Latitude band from 40°N to 40°S	Monthly	5° x 5°	PR, TMI	Cloud liquid water/ice, Precipitation amount, Rain	1997-12-01 to Present
3B42 Merged and calibrated satellite estimate	Calibrated IR merged with TRMM and other satellite data	3-hourly	0.25° x 0.25°	PR, TMI, VIRS	Precipitation rate	1997-12-31 to Present
3B43 Merged TRMM and other sources estimates	Merged 3B-42 and rain gauge estimates	Monthly	0.25° x 0.25°	PR, TMI, VIRS	Precipitation rate	1998-01-01 to Present
CSH Level 3 Convective/ Stratiform Heating	Convective/Stratiform Heating	Monthly	0.5° x 0.5°	TMI	Atmospheric heating, Convection, Convection	1997-12-01 to Present
TRMM_3B42_daily	3B42 V6 derived	Daily	0.25° x 0.25°	PR, TMI, VIRS	Precipitation rate	1997-12-31 to Present

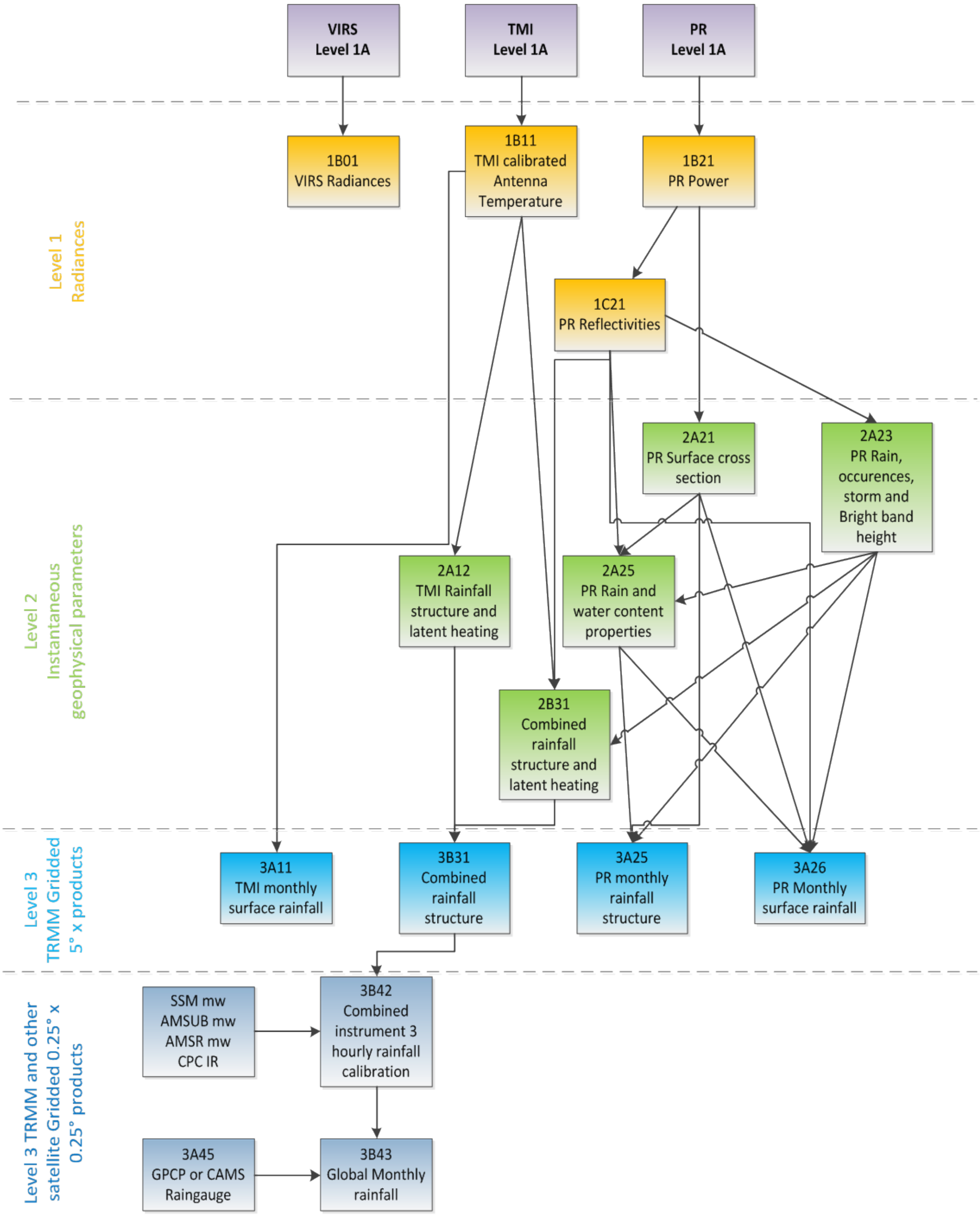

Figure 4-3: TRMM V6 data processing overview [21]

The observation time for TRMM 3B42 3-hourly data are 00:00, 03:00, 06:00, 09:00, 12:00, 15:00, 18:00 and 21:00 UTC. The time denotes the mid of 3-hour interval. For example, the time 00:00 UTC denotes that the rainfall is averaged over the period 22:30 UTC of previous day to 01:30 UTC of the next day.

TRMM data can also be visualized online on TRMM Online Visualization and Analysis System (TOVAS). This is developed by GES DAAC. It is a web based interface for visualization and analysis of TRMM gridded rainfall products [35]. Different maps can be generated for average area (Lat-Lon map) and Time series. Besides rainfall study and monitoring, it is also applicable to variety of other research and applications, such as climate study and monitoring, weather events study and monitoring, agricultural crop monitoring and data products comparison. TOVAS is also available for real-time monitoring and different rainfall archives. These can be accessed through the link; http://disc2.nascom.nasa.gov/Giovanni/tovas/.

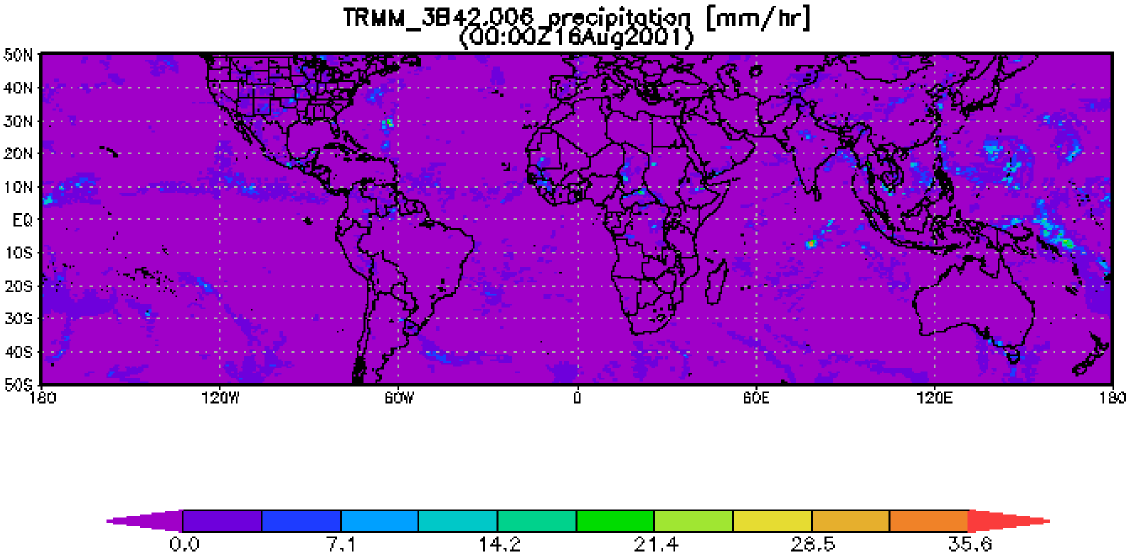

Figure 4-4: TOVAS generated TRMM 3B42 3- hourly estimate for 2001-08-16 00:00 UTC over the globe [35]

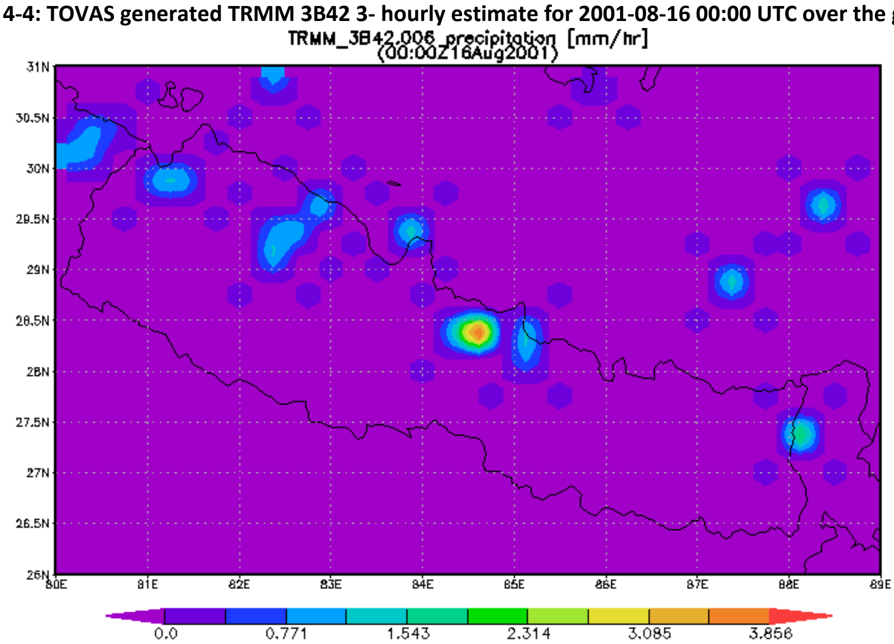

Figure 4-5: TOVAS generated TRMM 3B42 3- hourly estimate for 2001-08-16 00:00 UTC focused over Nepal [35]

4.4 Data Processing

There is difficulty in comparing data from gauges with those from satellite products in that they provide two different kinds of information. Satellite estimates provide an average precipitation over an area of the satellite pixel while the Gauge provides measurements at a point. Hence, one of them should be transformed to the format of other to make them comparable. There are commonly two approaches used for the comparison of these data.

- Point to Pixel (PO-PI) comparison
- Pixel to pixel (PI-PI) comparison

4.4.1 Point to Pixel (PO-PI) comparison

In this approach, point measurement at ground based gauge station is compared with satellite derived precipitation pixel value at the same location. The detailed steps for the comparison process for TRMM 3B42 data with observed gauge rainfall are shown in Figure 4-6. For the data processing and comparison procedure, different scripts are developed, some of which are developed as a part of the thesis work and some of them are developed by the previous researchers. Most of the program is based on P*ython* programming language.

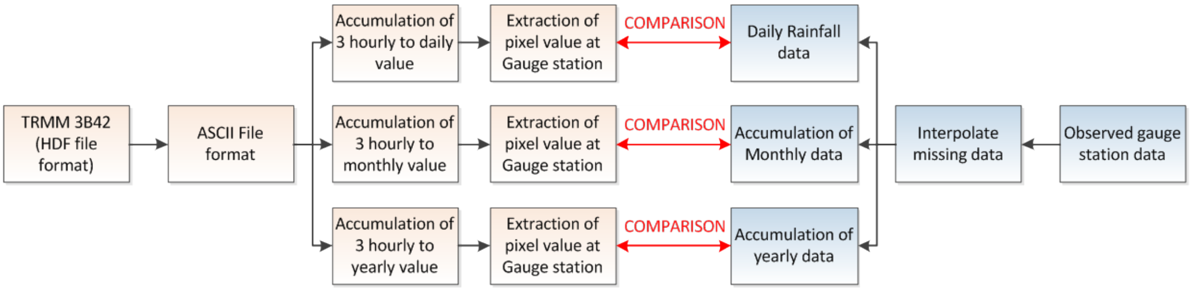

Figure 4-6: Sequence of data processing in PO-PI

i. Script Programming

The processing of data to prepare them in a comparable format is done by a series of scripts that have been developed in python programming language. Python is a powerful high-level programming language. *Python v2.6.1* is used for developing scripts. Some of its key distinguishing features [36] include:

- very clear, readable syntax
- strong introspection capabilities
- exception-based error handling
- very high level dynamic data types
- extensive standard libraries

Python also has an open source license and is free to use. Different packages can be used along with python. Python with *GDAL (Geospatial Data Abstraction Library)* library allows access to raster data and makes conversion possible between different formats of raster and vector geospatial data. Numpy package enables n-dimensional array manipulation. Matplotllib is a 2D plotting library that produces interactive figures.

The Python programming language can be downloaded freely from the Python official website: http://www.python.org/ftp/python/2.6/python-2.6.msi. The major scripts developed to extract and compare the data sets are presented in figure 4-4 and the scripts coding are listed in Appendix 2.

The raw TRMM 3B42 data is in HDF file format. It is the standard data format for all NASA Earth Observing System (EOS). HDF (Hierarchical Data Format) is the name of a set of file formats and libraries designed to store and organize large amounts of numerical data [22]. The data in HDF file format is converted to ASCII file format using a python script (*Hdf_to _ascii.py*). The script is originally developed for a research activity.

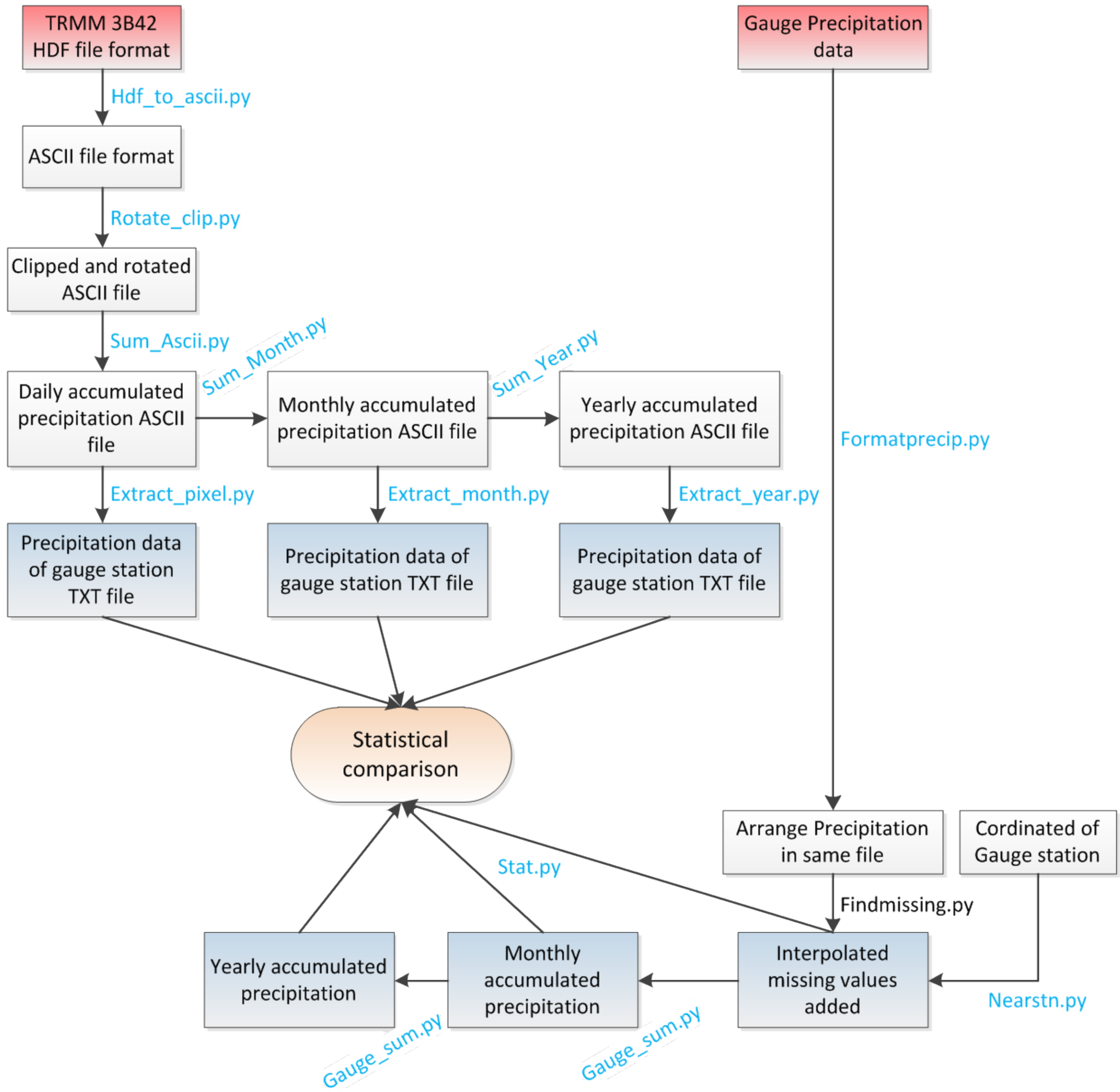

Figure 4-7: Processes and Python scripts used for Point to pixel comparison

The converted ASCII file is rotated by 90° clockwise. So, the ASCII maps should be rotated by 90° anticlockwise to get it in exact grid. A python script (*rotate_clip.py*) is developed for this rotation and shifting. The script is also programmed to crop the ASCII map to the study area. Cropping is done at the initial level of data processing so as to make the further processing easy and less time consuming. There are 23376 number of 3-hourly TRMM data for the period from 2001 to 2008 each having 576000 pixels. Hence, this will need a lot of time for further processing if the clipping is not done at this level. ASCII precipitation maps are clipped from 80°E to 89°E latitude and 26°N to 31°N longitude thus creating maps of 36 by 20 cells. Random rotated and clipped data are compared and verified with TOVAS. The converted ASCII maps are presented in Figure 4-8, Figure 4-9 and Figure 4-10.

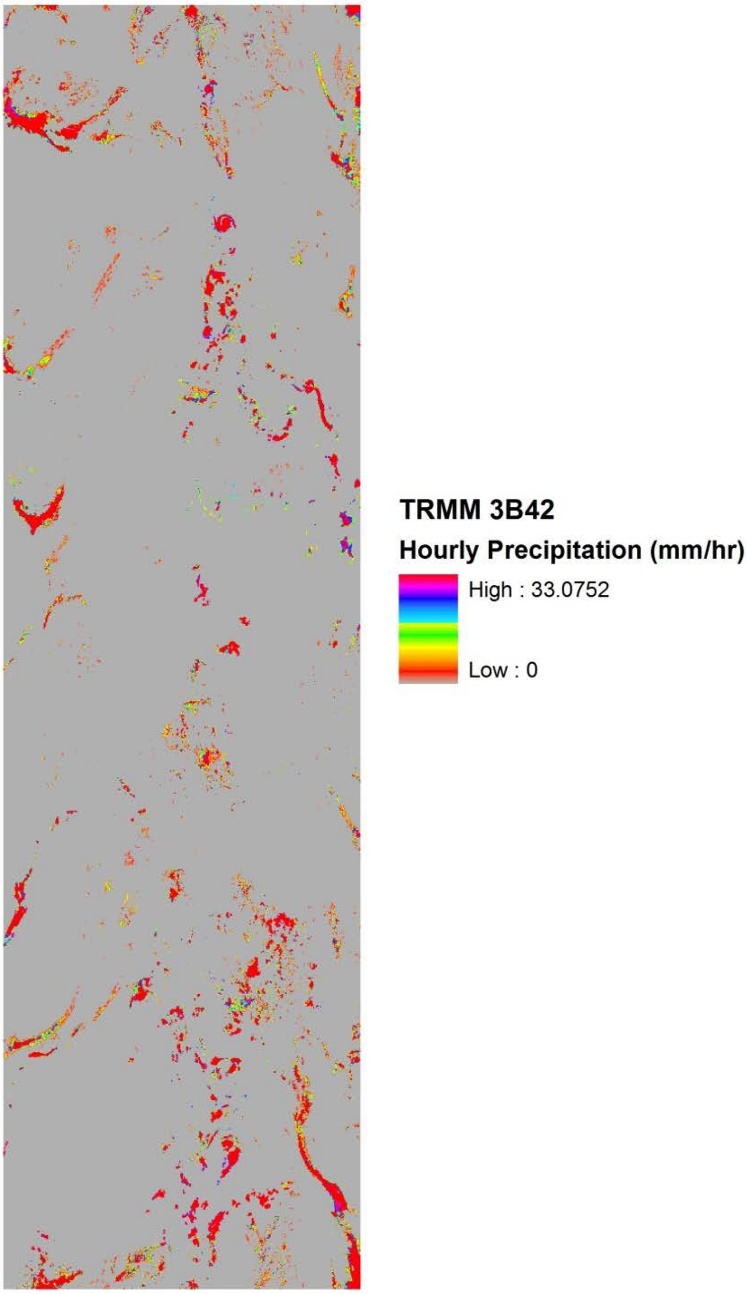

Figure 4-8: TRMM 3B42 - 0.25° x 0.25° (after corverting from HDF to ASCII) for 2001-08-16 00:00 UTC

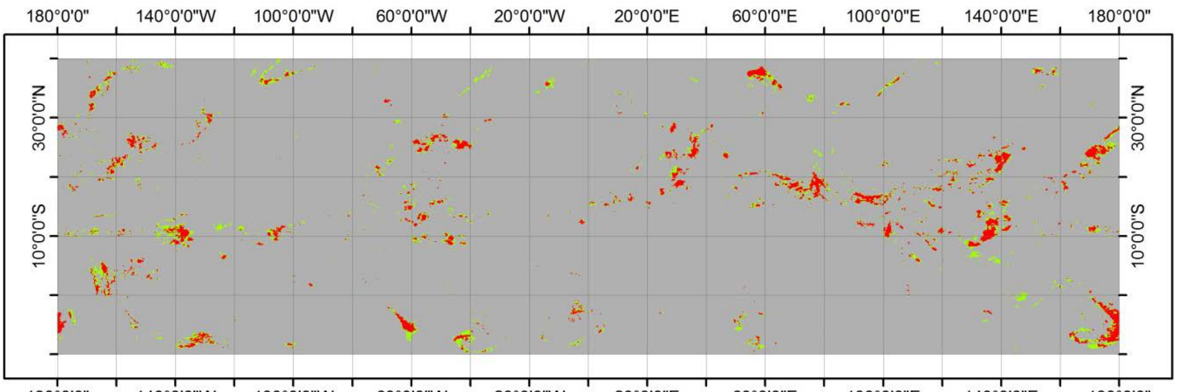

Figure 4-9: ASCII Image after rotation for 2001-08-16 00:00 UTC

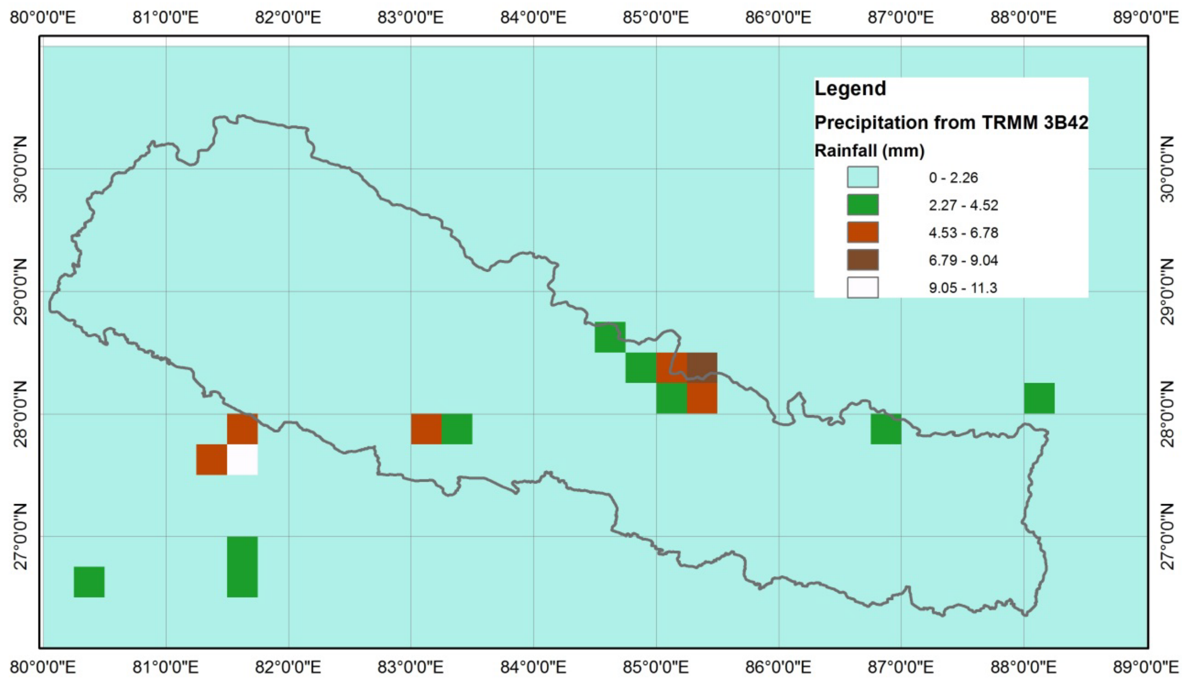

Figure 4-10: Image clipped to country's boundary for 2001-08-16 00:00 UTC

After rotating and clipping the 3-hourly precipitation map of the study area, these maps should be summed up to accumulate the daily precipitation. A 3 hourly precipitation data represents an average precipitation value over a 3 hour's period (measured in mm/hr.). For example, precipitation data recorded for 03:00 UTC represents and average precipitation value from 00:00 to 03:00. So, this data should be multiplied by '3' to get a 3-hourly precipitation value. Also, the accumulation for a day is done according to day definition for Nepal. The accumulation time for gauge stations of Nepal is from 03:00 UTC to 03:00 UTC (08:45 am to 08:45 am) of next day. So, 8 TRMM 3 hourly precipitation ASCII maps for the time 03, 06, 09, 12, 15, 18, 21, 00 of the next day are summed up and multiplied by 3 to get the 24 hourly precipitation maps. A python script (*Sum_Ascii.py*) is developed to prepare daily precipitation maps. A one day precipitation map for 2001-08-16 is shown in Figure 4-11.

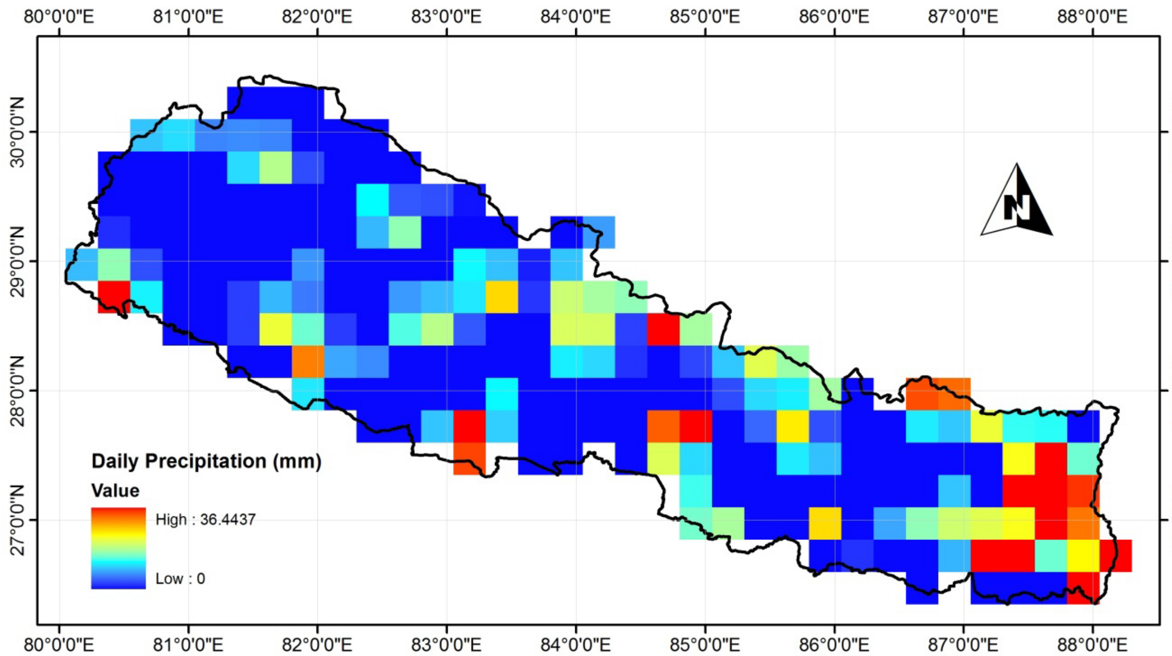

Figure 4-11: ASCII Precipitation map clipped for basin of Nepal for a day at 2001-08-16

Similarly, monthly and yearly precipitation maps are prepared accumulating these daily precipitation maps using the scripts "*Sum_month.py*" and "*Sum_Year.py*" respectively.

Now, the pixel value for the gauge station should be extracted from these daily, monthly and yearly ASCII precipitation maps to make them comparable with Ground based precipitation stations. A python script (*Extract_point.py*) is developed for this purpose. The script is programmed such that any station falling within the grid will have that grid value. Also, any two or more stations falling in the same grid will have same grid values.

The number of data extracted for each station from 2001 to 2008 for daily, monthly and yearly precipitation are 2922, 96 and 8 respectively.

4.4.2 Pixel to Pixel (PI-PI) comparison

In this method, one should compute pixel areal averages from the point rain gauge data and compare each of the pixels with the pixels of Satellite map. The areal average can be estimated using Inverse Distance Weighing Method (IDW) or kriging method. IDW is a simple interpolation method based on distance to the interpolation location and weighted average of the observations. If one pixel contains two or more gauge stations, average rainfall of those two values will be allocated to the pixel. Kriging method uses known precipitations from the nearly stations and a semivariogram to determine unknown value for a pixel.

This method of data preparation is good if the precipitation stations are uniformly distributed over an area. If the points are scattered and the distance between points are more, there is less influence on the output value of the cell. Nepal has very less precipitation stations on higher elevation. So, this method would provide precipitation value for a pixel with higher error.

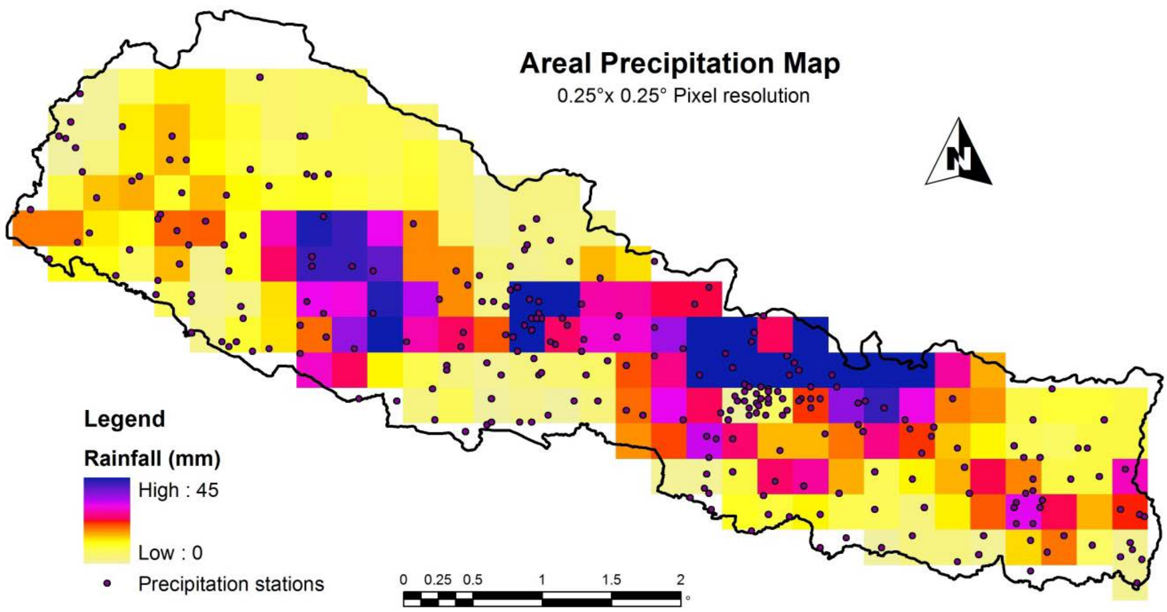

Figure 4-12: Areal precipitation map for 16-08-2001 using IDW method

In the Figure 4-12, the areal average is computed for the pixel size of 0.25°x0.25° using kriging method of interpolation from the gauge rainfall data at a point for a day 16-08-2001 in ArcGIS. It can be seen that the upper left part of the country doesn't have much stations and the precipitation values for those pixels are computed for distant stations. This gives error in precipitation estimation. This method is not adopted for data preparation.

4.5 Comparison Methods

Different visual and statistical methods are used to compare satellite precipitation with gauge precipitation; the comparison has been done from 2001 to 2008. Python script (*Stat.py*) is used to make a statistical comparison of data set. The script could compare data on each day/ month /year and find the coefficients of statistical measures. The script could also omit some of the data and station that have more missing data.

The comparison is done with data of days having recorded precipitation on both ground and radar. Gauging stations with no recorded precipitations on either satellite or gauge or lots of missing data on gauge are omitted for analysis. The limit for number of missing data for the gauge station is calculated as,

$$Analysis\ days = \frac{Radar\ and\ Gauge\ data\ recorded\ days}{Radar\ data\ recorded\ days}$$

If the value of 'Analysis days' falls behind 0.8, then the data of the gauge station is not used for comparison. The number of gauge stations that could be compared on daily monthly and yearly data is 248, 242, and 175 respectively. The comparison measures used are as follows:

4.5.1 Scatter Plot

A scatter plot is a visual method of comparing two data sets. In this method, the observed gauge data are plotted against radar data for each day. If the plot is concentrated around 45 degree diagonal line, we can conclude that the data is well correlated without any bias. One can distinguish the biasness of data sets at a glance.

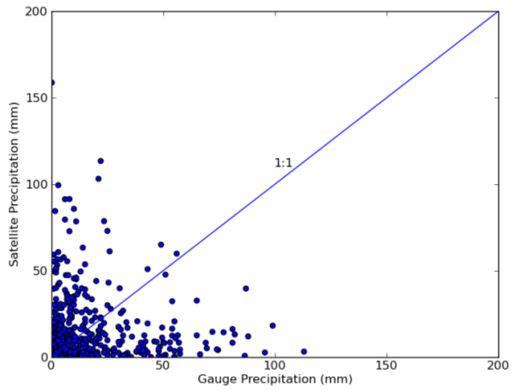

Figure 4-13: Scatter plot between gauge and radar data sets

4.5.2 Nash-Sutcliffe Coefficient of Efficiency (R^2)

The Nash–Sutcliffe Coefficient of efficiency (R^2) is a dimensionless indicator widely used to evaluate hydrological simulation models [37]. It is defined as:

$$R^2 = 1 - \frac{\sum_1^N (SP_i - GP_i)^2}{\sum_1^N (GP_i - Avg.GP)^2}$$

Where, *SP* is satellite derived precipitation value
GP is measured precipitation in gauges
Avg.GP is Average precipitation value in gauges
N is total number of precipitation data sets

Nash-Sutcliffe Coefficient of Efficiency (R^2) value ranges from negative infinity to one ($-\infty \leq R^2 \leq 1$). An efficiency of one ($R^2 = 1$) means the perfect match of satellite derived rainfall data to the observed raifall data while efficiency value of zero ($R^2 = 0$) means the difference between observed rainfall data and satellite derived rainfall values is as large as the variability in the observed rainfall data. The negative efficiency ($-\infty < R^2 < 0$) indicates observed mean is a better predictor than the satellite derived rainfall [22].

4.5.3 Normalized Accumulated Difference (NAD)

It gives the percentile deviation of satellite precipitation with respect to gauge precipitation. NAD can be calculated using the following equation:

$$NAD = \frac{\sum_1^N (SP_i - GP_i)}{\sum_1^N GP_i} \times 100$$

Where SP and GP are satellite and gauge precipitation.

For the calculation, only those days are used when precipitation is recorded on both satellite and gauge. Positive NAD means satellite is over estimating precipitation value and negative NAD means the satellite is under estimating precipitation value [22].

4.5.4 Root Mean Squared Difference (RMSD)

The root mean square difference (RMSD), also known as root mean square error (RMSE) is a measure of the differences between satellite precipitation and observed gauge precipitation. RMSD is a good measure of precision. Root Mean Square Difference is given by,

$$RMSD = \sqrt{\frac{\sum_i^N (SP_i - GP_i)^2}{N}}$$

Where, N is the number of precipitation days.

The value of RMSD is always greater than zero to infinity. Lower RMSD value represents that the satellite is better correlated with gauge data and vice versa. The RMSD value equal to zero means the perfect match of satellite derived rainfall data to the observed rainfall data. This doesn't measure whether the data are over or under estimated.

4.5.5 Mean Absolute Difference (MAD)

Mean absolute difference (MAD) is used to evaluate the average magnitude of error. MAD can be calculated as:

$$MAD = \frac{\sum_1^N |SP_i - GP_i|}{N}$$

MAD is expressed in mm. It can range from zero to infinity. Zero MAD means there is a perfect match between two data sets. It cannot express the direction of deviation.

4.5.6 Mean Relative Absolute Difference (MRAD)

Mean relative absolute difference evaluates the average magnitude of error in satellite precipitation with respect to gauge precipitation [24]. It can be estimated as:

$$MRAD = \frac{\sum_1^N \frac{|SP_i - GP_i|}{GP_i}}{N}$$

The value ranges from zero to infinity. Lower MRAD value suggests good estimation of satellite data.

4.5.7 Correlation coefficient (RR)

The correlation coefficient is a measure of linear dependence between satellite and gauge precipitation data sets [22]. Correlation coefficient (RR) can be calculated using following equation:

$$RR = \frac{cov(SP, GP)}{\sigma_{SP} * \sigma_{SG}}$$

where RR is coefficient of correlation,

cov (SP,GP) is the covariance of satellite and gauge precipitation respectively,

σ_{SP} and σ_{SG} are standard deviations of satellite and gauge precipitation data.

The correlation coefficient ranges from −1 to 1. A value equal to 1 implies a good correlation between satellite and gauge precipitation data sets. A value of −1 implies that there is an opposite relation between two data sets i.e. one variable is increased, the other will be decreased. A value equal to 0 implies that there is no linear correlation between the variables.

4.5.8 Estimation Bias (EB)

Estimation bias is the normalized difference between the satellite and gauge precipitation data sets evaluated over a long period of time. It is calculated in percentage and is defined as:

$$EB = \frac{\sum_1^N SP_i - \sum_1^N GP_i}{\sum_1^N GP_i} \times 100$$

where SP and GP are satellite and gauge precipitation

For the calculation of estimation bias, days with missing data either on Satellite or gauge are excluded. An estimator is said to be unbiased if its bias is equal to zero. The negative EB shows underestimation of satellite data and positive EB shows over estimation of satellite data.

4.5.9 Satellite Conditional Probability of Detection (CPOD_S)

Satellite conditional probability of detection (CPOD_S) is the measure of probability that precipitation recorded by a gauge is detected by the satellite [38]. The following equation is used to compute this probability:

$$CPOD\_S = \frac{No.of\ days\ when\ (GP > 0.1\ and\ SP > 0)}{No.of\ days\ when\ (GP > 0.1\ and\ SP \geq 0)}$$

where GP represents gauge precipitation and
SP represents the satellite precipitation.

The CPOD_S value is always less than or equal to one. If CPOD_S value is equal to 1, it is understood that every observed precipitation is detected by the satellite.

4.5.10 Gauge Conditional Probability of Detection (CPOD_G)

Gauge conditional probability of detection (CPOD_G) is the measure of probability that precipitation recorded in a satellite is recorded in a gauge [39]. The following equation is used to find this probability:

$$CPOD\_G = \frac{No. of\ days\ when\ (SP > 0.1\ and\ GP > 0)}{No. of\ days\ when\ (SP > 0.1\ and\ GP \geq 0)}$$

where GP represents gauge precipitation and
SP represents the satellite precipitation.

The CPOD_G value is less or equals to one. The CPOD_G value equal to 1 dictates that all precipitation detected by satellite is recorded in the ground. These measures can be used for determining the probability of precipitation in the future.

CHAPTER V

RESULTS OF COMPARISON

This section deals with results of comparison of data sets between satellite and observed precipitation based on Point to Pixel comparison.

The satellite and Gauge precipitation data sets are compared for daily, monthly and yearly precipitation. The methods for comparing two sets of satellite data are discussed in section 4.5. Days, with missing data either in satellite or in gauging station, are excluded from the comparison. Additionally, days, with zero recorded precipitation on both satellite and gauge, are also excluded from comparison. Inclusion of these data in the analysis will obviously increase the sample size and the resulting R^2, NAD, RMSD, RR, MRAD and EB may become favorable to the satellite rainfall because of increased sample size [40].

5.1 Point to Pixel Comparison

Point to pixel comparison is the comparison of point measurement in gauge station with pixel value of TRMM precipitation estimate for that coordinate. So the better result can be expected if the pixel size is small. The gauge stations with many missing data are excluded from statistical comparison. The stations with ratio of gauge precipitation days and satellite precipitation days less than 0.8 are excluded. The number of excluded stations during the comparison of daily, monthly, yearly and mean monthly data sets is different. The list of excluded stations from comparison is attached in Appendix 3.

Table 5-1: Excluded Gauge stations

Comparison type	No. of data compared	No. of Excluded stations
Daily comparison	2922	16
Monthly comparison	96	22
Yearly comparison	8	89
Monthly average	12	0

The TRMM data at remaining stations are compared using different statistical tools like Nash-Sutcliffe efficiency (R^2), Correlation coefficient (RR), Normalized Accumulated Difference (NAD), Root Mean Squared Difference (RMSD), Mean Absolute Difference (MAD), Mean Relative Absolute Difference (MRAD), Estimation Bias (EB), Satellite Conditional Probability of Detection (CPOD_S) and Gauge Conditional Probability of Detection (CPOD_G) for day, month and year accumulated precipitation. The details of results are shown in Appendix 4.

5.1.1 Daily Precipitation

Precipitation maps prepared from TRMM satellite data for a day accumulation is compared with daily gauge precipitation data at different stations. Nash Sutcliffe efficiency is computed for all stations and the summary of the results are shown in Table 5-2.

Table 5-2: R^2 comparison for Daily precipitation

R2	No. of Station
1 – 0.5	0
0.5 – 0	7
-1 – 0	212
-3 – 1	24
-30 – 3	3
-40 – -30	2
Total Stations	**248**

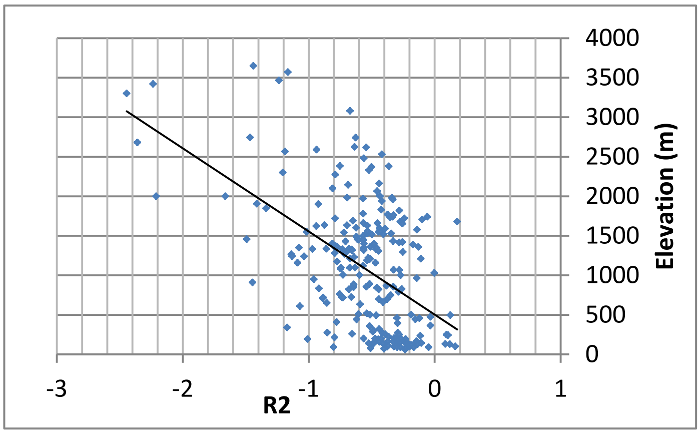

Figure 5-1: Variation of Nash Sutcliffe with elevation

Table 5-2 depicts that most of the stations have the R^2 value in the range of 0 and -1. The extreme R^2 value for Station Melung, Dolakha (Station ID 1104) is cross checked for extracted satellite precipitation value with TRMM Online Visualization and Analysis System (TOVAS) for random dates and extracted precipitation values appeared to be acceptable. The low and negative R^2 indicate that the satellite precipitation products are underestimating rainfall. The R^2 value for the TRMM product seems decreasing with elevation. Figure 5-1 shows the variation of Nash-Sutcliffe efficiency with the elevation. The trend has been calculated excluding extreme events less than -3. The spatial variability of Nash-Sutcliffe efficiency over the study basin is show in Figure 5-2.

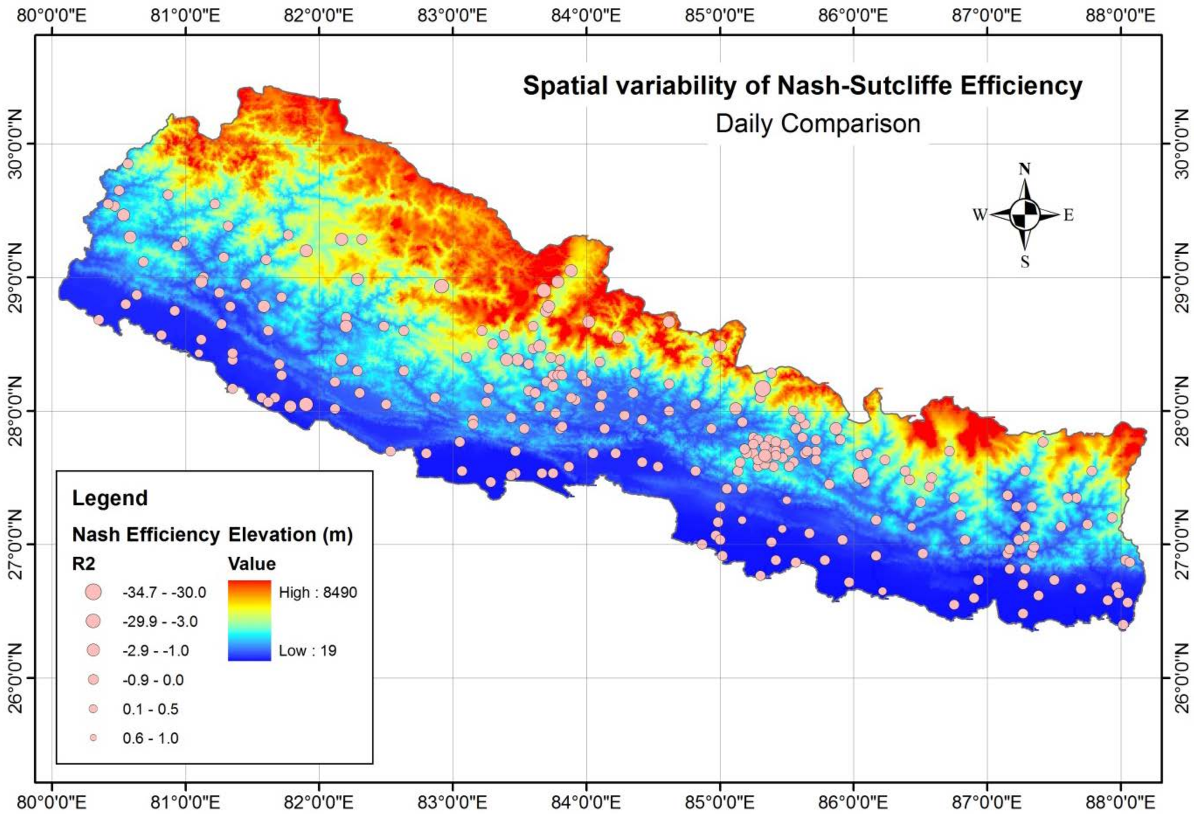

Figure 5-2: Spatial distribution of Nash Sutcliffe efficiency for daily precipitation comparison

Sample scatter plots for two stations with maximum and minimum Nash-Sutcliffe efficiency is shown in Figure 5-3. The scatter plots also indicate the poor correlation of TRMM data with gauge data. The figure at LHS shows over estimated TRMM rainfall where most of points are located above 1:1 line while figure at RHS shows under estimated precipitation where most of data are located under the 1:1 line.

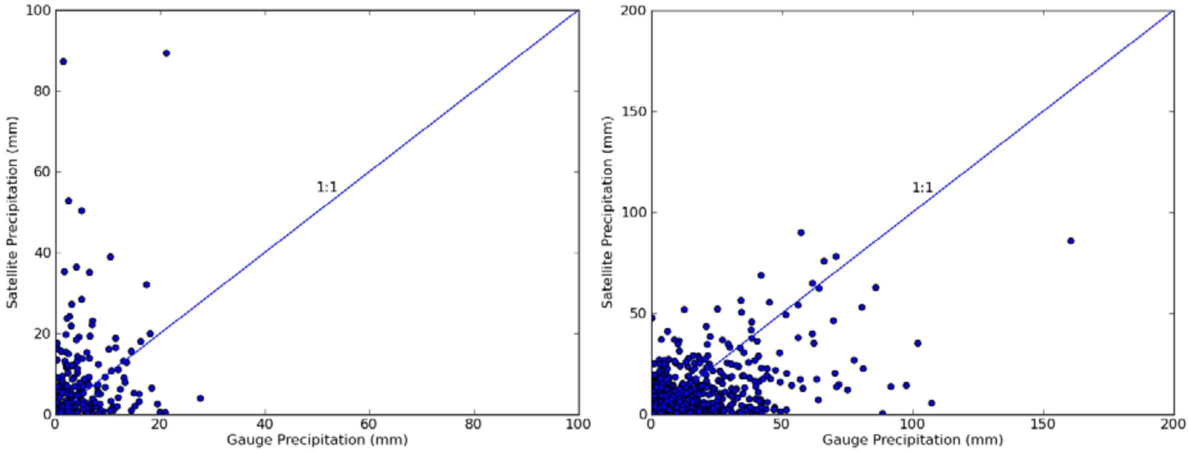

Figure 5-3: Scatter plots for Daily rainfall showing overestimate [Station 625(L)] and underestimate [Station 1034 (R)]

The calculation of Normalized Accumulated Difference (NAD) also illustrates that TRMM satellite data is underestimating precipitation. The comparison shows that 224 out of 248 stations have negative NAD value. But, stations at higher elevation show positive NAD value. This might have caused because those stations lie in the rain shadow region and TRMM is unavailable to take account of this region.

Root Mean Square difference (RMSD) is computed for daily precipitation comparison for each station. Most of the stations have value ranging from 20 to 40.

Table 5-3: RMSD comparison for Daily precipitation

RMSD	No. of Station
0-1	0
1-5	0
5-10	4
10-20	49
20-40	173
40-60	22
Total no of stations	**248**

The mean relative error of TRMM data is analyzed by calculating Mean Absolute Difference (MAD). The MAD ranged from maximum (32.83 mm) for station Dumkibas, Nawalparasi (Station ID 710) to minimum (4.85 mm) for Samargaon, Mustang [Station ID 624]. The average MAD for all stations is 17.76 mm per precipitation day.

Mean Relative Absolute Difference (MRAD) is also computed for daily precipitation comparison for each station. The result is shown in Table 5-4.

Table 5-4: MRAD comparison for daily precipitation

MRAD value	No. of Station
0-1	6
1-2	71
2-3	70
3-5	61
5-10	36
10-15	4
Total stations	**248**

Estimation Bias (EB) is one of the next major parameter for evaluating satellite rainfall product. It is an accumulated difference of satellite and gauge precipitation over the entire study period. Estimation bias range from -78.44 % for station Dhankuta, Dhankuta (Station ID 1317) to 332.03 % for station Samargaon, Mustang (Station ID 624). There are 56 stations with positive estimation bias indicating over estimation in the area while remaining 192 stations have negative estimation bias indicating under estimation of rainfall. An average of -9.95 % of Estimation Bias is obtained for all stations of the country.

TRMM data are also checked for Probability of Detection of precipitation when precipitation is recorded in gauging stations. The threshold of 0.1 mm is used to evaluate Satellite Conditional Probability of Detection (CPOD_S). The probability of precipitation is maximum (0.89) for station Muna, Myagdi (Station ID 628) and is minimum (0.47) for the station Chepuwa, Sankuwasava (Station ID 1317). The overall average of CPOD_S equal to 0.70 reflects that TRMM detection of precipitation is good. Similarly, TRMM daily precipitation data are also checked for Gauge Conditional Probability of Detection (CPOD_G). The minimum probability is 0.14 for station Ghami, Mustang (Station ID 610) and the maximum probability is 0.89 station Memeng jagat, Panchthar (Station ID 1406) with overall average of 0.57. It means that the TRMM product is detecting precipitation for many days even when there are no precipitations recorded in gauge. The comparison illustrating number of stations lying in the range for CPOD_G and CPOD_S is shown in Figure 5-4.

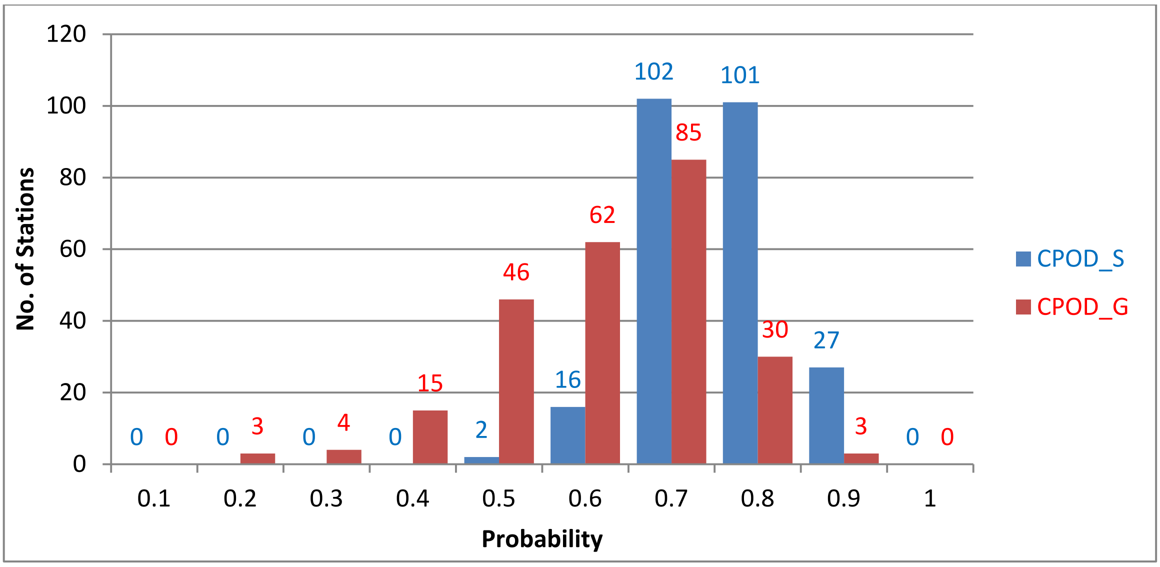

Figure 5-4: CPOD_S and CPOD_G for Daily precipitation

TRMM satellite data is also checked for their linear dependence with gauge data using correlation coefficient (RR). From the result of correlation coefficient (RR) values, the linear association of TRMM data is not so good. The correlation coefficient ranges from negative correlation of -0.06 for station Gam Shreenagar, Mugu (Station ID 306) to positive correlation of 0.60 for the station Pakhribas, Dhankuta (Station ID 1304).

5.1.2 Monthly Precipitation

Monthly precipitation maps are prepared by accumulating daily precipitation maps. These monthly maps are compared with monthly precipitation data sets of gauge station. There are 96 data for comparison from 8 years. The comparison of monthly precipitation data sets yield some different results than that from daily comparisons. Different statistical parameters are used for comparison between these two data sets.

As for daily precipitation data sets, Nash Sutcliffe efficiency is also computed for each station with monthly precipitation data sets. The range of R^2 value is shown in Table 5-5.

Table 5-5: R^2 comparison for monthly precipitation

R2	No. of Station
1 - 0.5	171
0.5 - 0	52
-1 - 0	8
-3 - 1	3
-20 - 3	8
	242

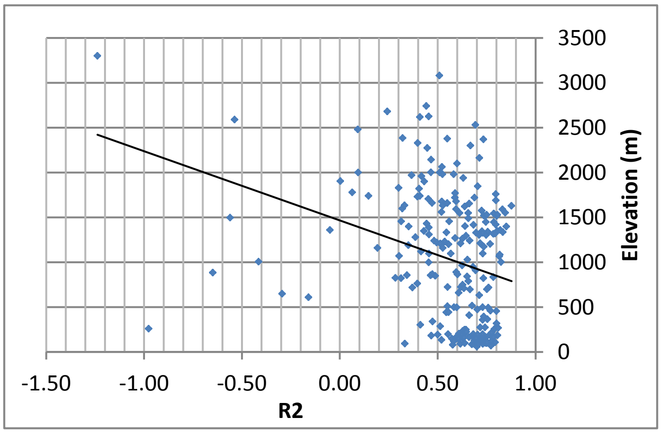

Figure 5-5: Variation of R^2 with elevation in Monthly data sets

Table 5-5 shows that most of the stations have R^2 value lying between 0.5 and 1. Other 19 stations have R^2 value below -3. It can also be observed that most of the stations with lower R^2 values are from higher elevations greater than 2500 masl. This can also be observed from Figure 5-6. The lower R^2 values indicate that TRMM is underestimating rainfall as the value of R^2 decreases with elevation. Figure 5-6 also illustrates the same fact. Station at Thankot, Kathmandu (station ID 1015) has maximum R^2 value of 0.88. This shows a very good estimation of monthly precipitation data by TRMM. The scatter plot of monthly observed vs. satellite precipitation data set is presented in Figure 5-8.

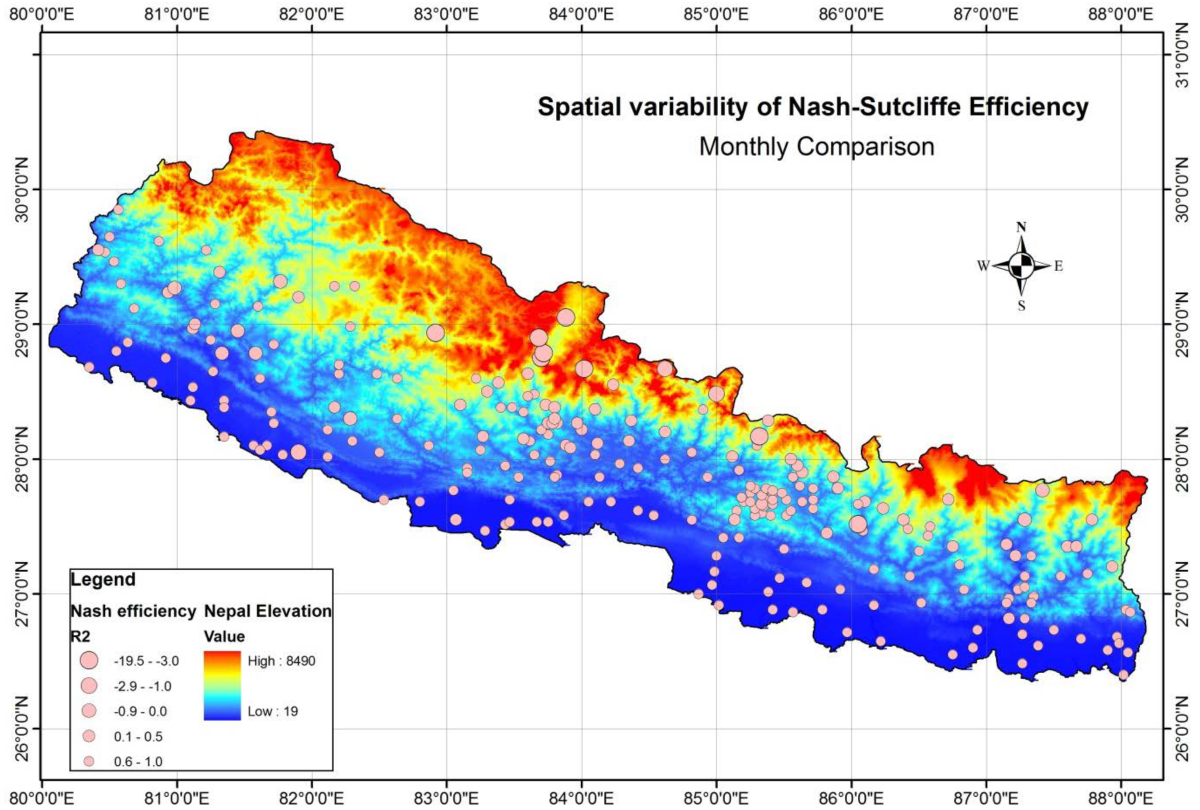

Figure 5-6: Spatial distribution of Nash Sutcliffe efficiency for monthly precipitation

Stations, with Nash Sutcliffe efficiency greater than 0.8, are plotted in a map as shown in Figure 5-7. It is observed that all eight stations with higher R^2 value are close to each other and have elevations ranging from 1000 to 1500 masl. This shows that TRMM satellite has a good capture of precipitation in these pixels.

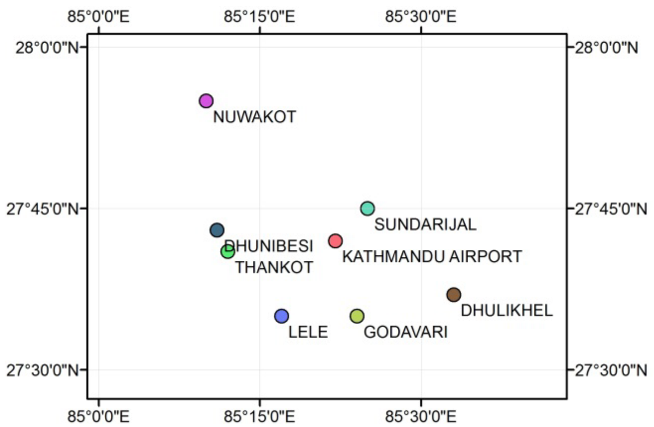

Figure 5-7: Stations with R^2>0.8

Scatter plots are prepared for each station from the monthly precipitation data sets of gauge and satellite. Scatter plot is a visual comparison method of two data sets. Overestimate or underestimate of TRMM rainfall can be observed as the points deviate from the 1:1 line. Scatter plots of most of the stations show a good correlation of data sets. Figures below show an overestimated and good estimated TRMM satellite data.

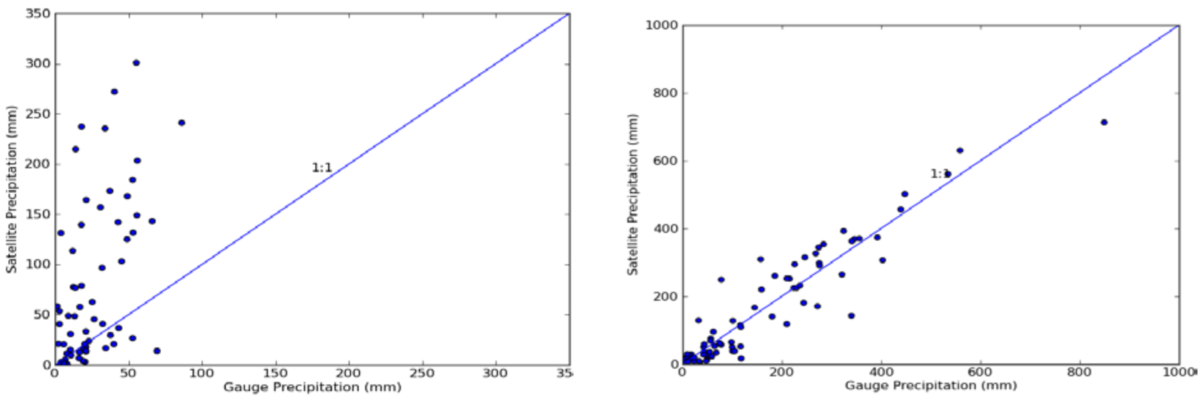

Figure 5-8: Scatter plots for monthly rainfall showing overestimate [Station 625(L)] and well estimate [Station 1015 (R)]

Normalized Accumulated Difference (NAD) measures over or under estimation of satellite data. NAD value expresses under-estimation of precipitation as the average NAD for all stations over Nepal is negative. NAD value ranges from -78 to +270. RMSD value is also computed for each for the comparison of monthly gauge and satellite precipitation data sets. RMSD value close to zero represents a good estimate of satellite data. The value ranged from 100 to 200 for most of the gauge stations.

Table 5-6: RMSD comparison for monthly precipitation

RMSD	No. of Station
0 - 10	0
10 - 50	2
50 - 100	91
100 - 200	120
200 - 400	25
400 - 600	4
	242

The Mean Absolute Difference (MAD) is obtained to be ranging from 30mm to 346 mm. Lower value of MAD represents minimal error in estimation of Satellite data. Similarly, MRAD value also represents error in estimation but with relative to observed data. We can see from Table 5-7 that most of the stations have MRAD value between 0 and 1. This shows there is less relative error in data of most of the stations.

Table 5-7: MRAD comparison for monthly precipitation

MRAD	No. of Station
0 - 1	186
1 - 2	32
2 - 3	9
3 - 5	10
5 - 10	4
10 - 15	1
	242

Estimation bias (EB) varies from -78.5 % for stations with most underestimated data sets to +308 % for stations with overestimated data sets. An average of -11.3 % of Estimation bias, expresses that TRMM satellite data underestimates precipitation for most of the locations in the country.

Satellite Conditional Probability of Detection (CPOD_S) of precipitation for all the stations is above 0.9. This means precipitation occurring on every month is detected by the satellite. However, not all precipitations detected in TRMM satellite are recorded in Gauge. This means TRMM Satellite data have more number of precipitation months than that in a Gauge recording. The comparison of CPOD_S and CPOD_G is presented in Figure 5-9.

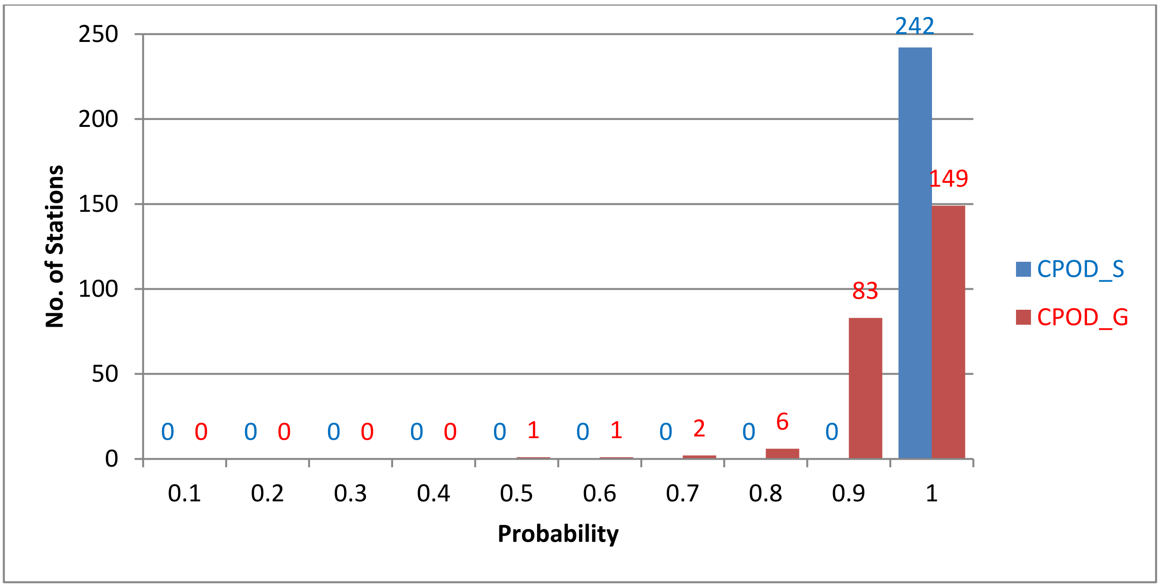

Figure 5-9: CPOD_S and CPOD_G for monthly precipitation

The coefficient of correlation between satellite and gauge precipitation data sets is positive for all stations. The value stretch from 0.95 for Station Siklesh, Kaski (Station ID824) to a minimum of 0.13 for station Simikot, Humla (Station ID 311) with an average RR value of 0.81. These results state that there is a good correlation of Satellite data with Gauge precipitation data sets.

5.1.3 Yearly Precipitation

Yearly precipitation maps are prepared by accumulating monthly precipitation maps for 12 months of each year. The comparison showed that the yearly accumulated satellite precipitation data is not so much reliable as there is huge biasness in data sets. This irregularity in data probably have occurred due to accumulation of errors from daily to monthly and then monthly to yearly.

Table 5-8: R^2 comparison for yearly precipitation

R2	No. of Stations
1 - 0.5	0
0.5 - 0	9
-1 - 0	40
-10 - 1	87
-30 - 10	32
-200 - 30	7
	175

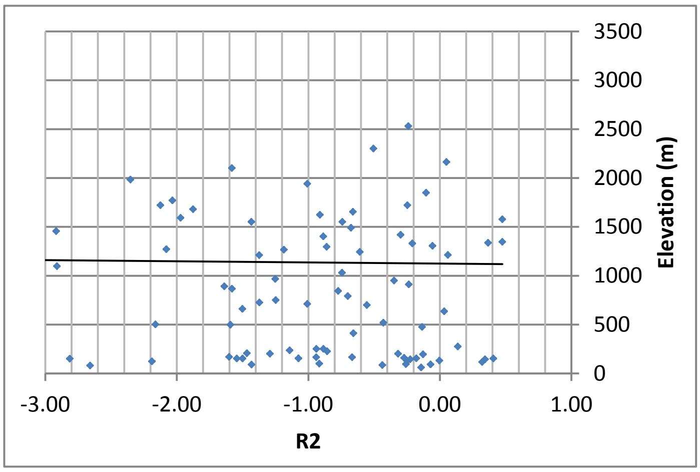

Figure 5-10: Variation of R^2 with elevation in Yearly data sets

The comparison of data with Nash Sutcliffe efficiency parameter shows that yearly estimation of precipitation from satellite precipitation is not so good. R^2 value for most of the station is negative. This is because we can see from the data that accumulated yearly precipitation from TRMM satellite data is lesser than that of gauge. Since from monthly comparison of data, it is concluded that satellite data set underestimates precipitation for most of the stations, it is obvious that accumulation of this underestimated data leads to accumulation of error and this caused huge difference in data sets. Figure 5-11 shows the map with R2 values on different station over the country.

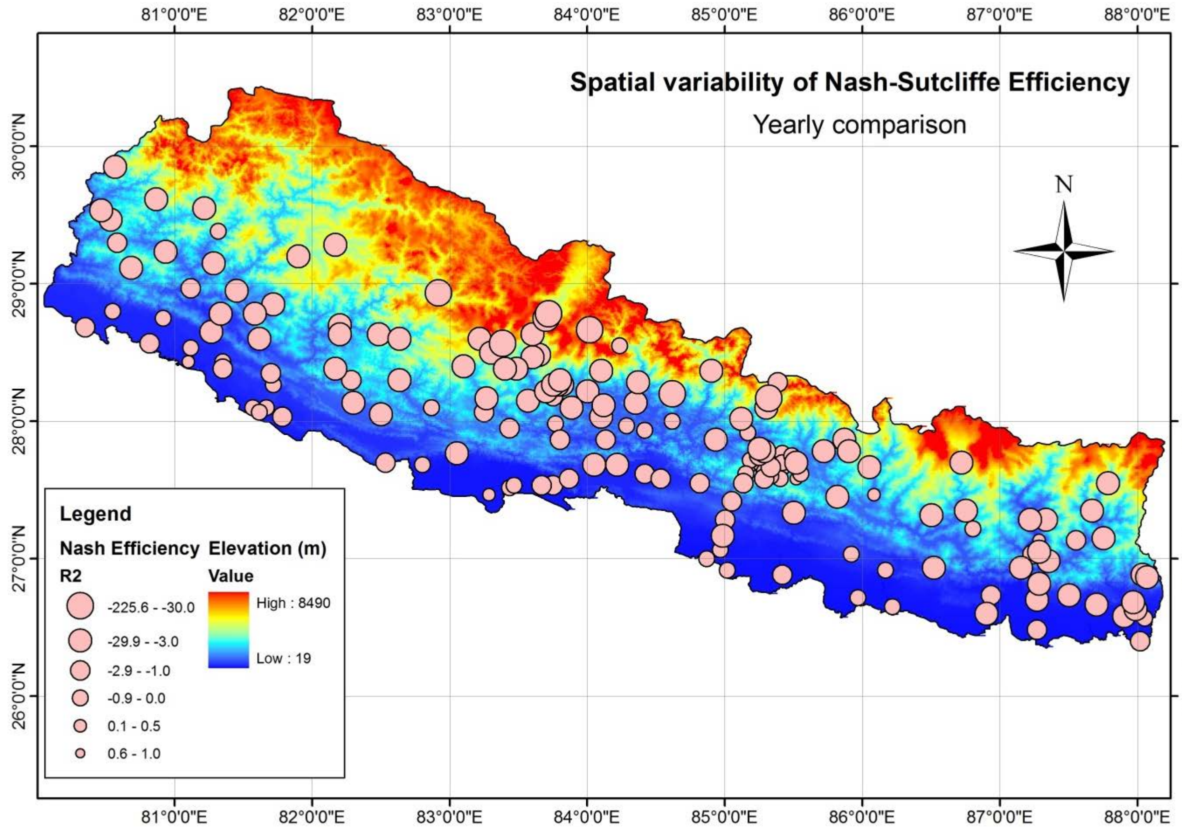

Figure 5-11: Spatial distribution of Nash Sutcliffe efficiency for yearly precipitation comparison

Scatter plots of Figure 5-12 and Figure 5-13 show poorly estimated and well estimated data sets. Both stations receive less yearly satellite precipitation, but difference of yearly precipitation between observed and satellite is high on former station.

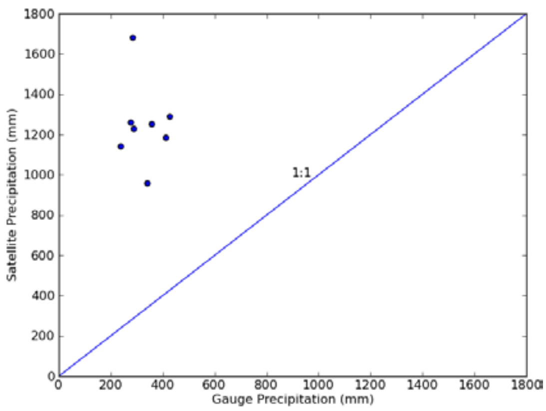

Figure 5-12: Scatter plot showing overestimated yearly precipitation by TRMM for station 1054

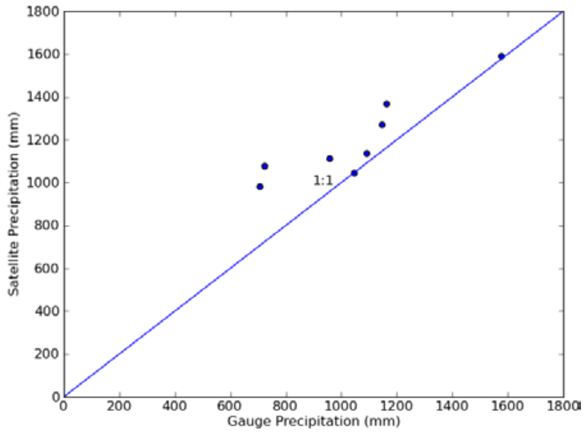

Figure 5-13: Scatter plot showing well correlated yearly precipitation by TRMM for station 1123

Most of the gauge stations have MRAD value between 0 and 0.5. This means that there is less relative difference between the two data sets.

Table 5-9: MRAD comparison for yearly precipitation

MRAD	No. of Station
0 - 0.5	152
0.5 - 1	19
1 - 2	1
2 - 3	2
3 - 5	0
5 - 10	1
	175

The statistical analysis for linear association of yearly TRMM data set with gauge data set is also not so good. The coefficient of correlation ranges from -0.86 to +0.8. The negative value means that there is an opposite relation between the data sets

5.1.4 Monthly Average precipitation

Monthly Average precipitation data sets are prepared by taking an average of monthly data for each month. This means there are 12 data in each station that represents average precipitation for each month. Data from 264 stations are used for the comparison.

Nash Sutcliffe Efficiency is calculated for all the stations and the result are plotted with elevation in Figure 5-15 and are arranged as shown in Table 5-10.

Table 5-10: R^2 comparison for monthly average precipitation

R2	No. of stations
1 - 0.5	226
0.5 - 0	19
-1 - 0	4
-3 - 1	5
-30 - 3	8
-40 - 30	2
	264

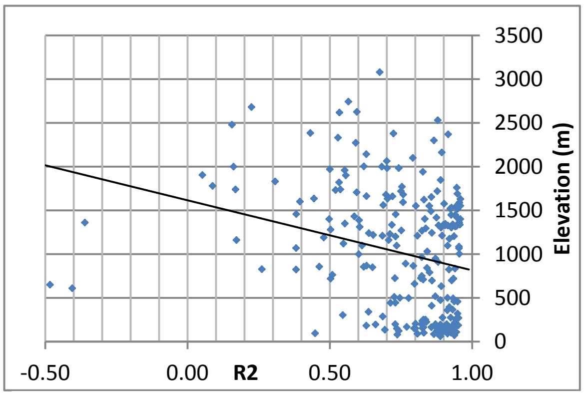

Figure 5-14: R^2 plotted with elevation for monthly average data sets

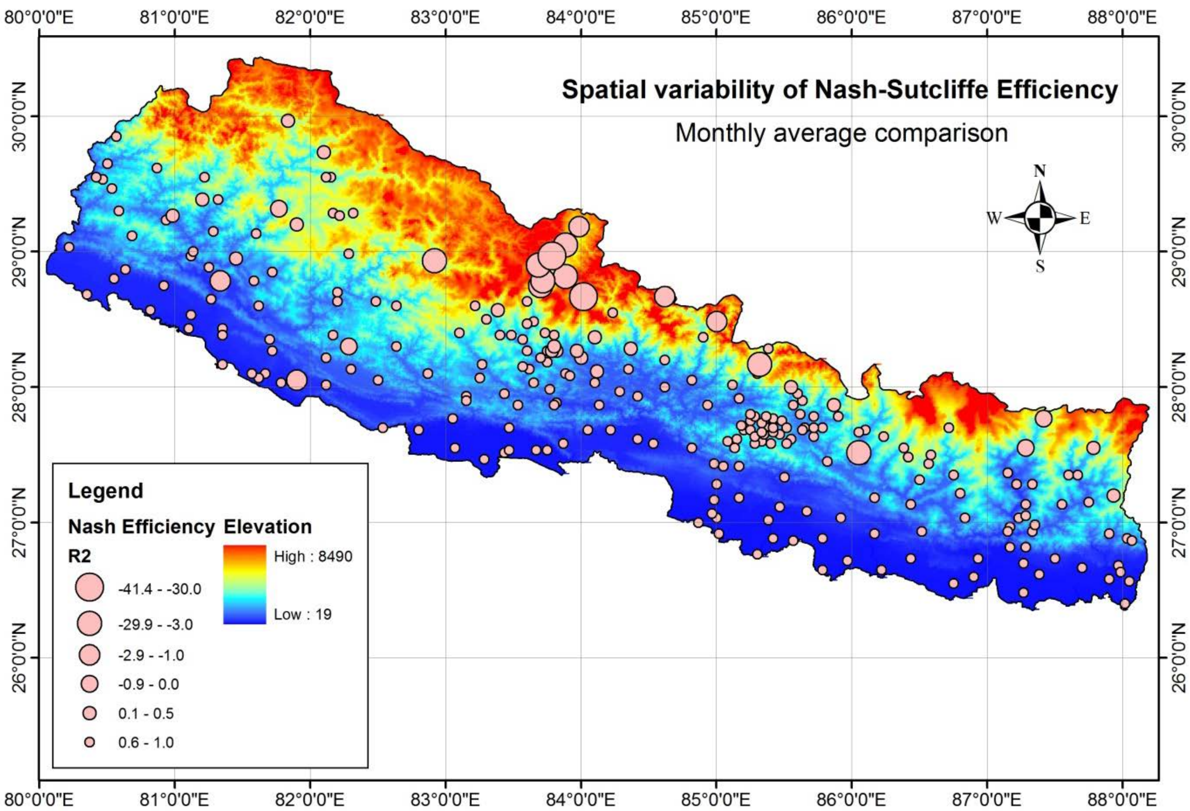

Figure 5-15: Spatial distribution of Nash Sutcliffe efficiency for monthly average precipitation

Figure 5-15 shows the distribution of Nash Sutcliffe Efficiency for the comparison of monthly average over the country. It elucidates that most of the unreliable comparison occurred in the higher elevation of the country. Three of the stations that lie above 3500 m elevation are taken to study the cause of this unreliability. The monthly average value as computed from daily precipitation data sets of both satellite and gauge station are presented in Table 5-11. The average value is prepared from 8 year's precipitation data.

Table 5-11: Comparison of Average monthly precipitation for three of gauge stations

Month	624		625		820	
	Gauge	Radar	Gauge	Radar	Gauge	Radar
Jan	9.30	12.19	12.24	14.90	29.82	18.10
Feb	3.43	17.57	17.01	16.87	27.54	27.29
Mar	13.97	14.75	28.58	13.07	24.78	21.36
Apr	5.23	14.32	16.47	14.37	30.07	26.63
May	2.07	26.85	12.17	38.96	23.72	66.59
Jun	10.17	83.21	20.00	98.45	33.43	197.23
Jul	30.58	187.88	40.96	219.45	55.02	350.58
Aug	32.22	147.74	46.46	176.71	67.92	316.02
Sep	13.95	75.10	28.53	91.64	79.44	139.58
Oct	9.44	40.40	14.56	43.90	33.36	74.92
Nov	3.30	2.80	1.93	2.00	6.51	5.37
Dec	2.53	3.21	2.00	2.86	3.19	5.24

As we can see from the Table 5-11 (with red text) that precipitation recorded by the gauge station during the monsoon season is very low. A scatter plot is also plotted with these data sets for station

624 (Figure 5-16). The average yearly precipitation for stations 624, 625 and 820 are respectively 136mm, 240 mm and 414 mm respectively. Though these stations lie in a rain shadow zone, this seems to be a bit unrealistic values. These stations lie in a very remote area of the country. There is a very simple rain gauge at the station and a unskilled local person is employed for the measurement. So, there could also be an error due to false reading. Hence, data from these remote stations should not be directly taken into consideration for hydrological studies and other purposes.

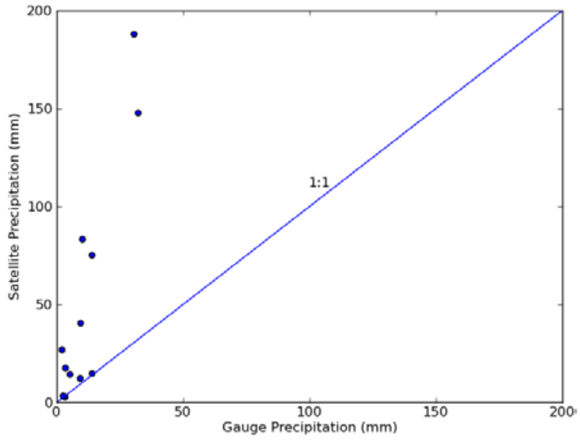

Figure 5-16: Overestimated scatter plot for monthly average precipitation [Station 624]

A scatter plot in Figure 5-17 shows a well estimated TRMM mean monthly data. The data is taken from Station Pattharkot, Sarlahi (Station ID 1109). R^2 value for this station is computed as 0.98. This states that TRMM precipitation data can be confidently used for determining monthly average precipitation with higher accuracy. The results of statistical comparison are presented in Appendix 4.

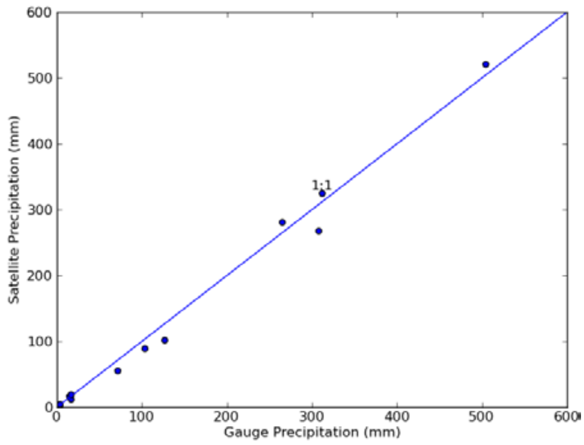

Figure 5-17: Scatter plot with good estimation of monthly average precipitation [Station 1109]

5.2 Spatial Variability within a Single Pixel

The precision of satellite precipitation map depends on pixel size (resolution) of the map. The pixel size of TRMM 3B42 maps is 0.25° x 0.25°. When these rainfall estimates are compared with gauge data in point to pixel comparison, any two or more gauging stations that fall within the same pixel will share the same pixel value. There are many pixels within the country that have more than one gauging stations. For the evaluation of spatial variability within the same pixel, the pixel of 85°15'E to 85°30'E and 27°30'N to 27°45'N is considered. Figure 5-18 shows this sample pixel that contains 11 gauge stations in the same pixel and Table 5-12 lists the gauge stations located in the this pixel.

Table 5-12: Gauge Stations lying in the same Pixel

Station ID	Station name	District	Type of Station	Easting (DD)	Northing (DD)	Elevation (m)
1022	Godavari	Lalitpur	Climatology	27.58	85.4	1400
1029	Khumaltar	Lalitpur	Agrometeorology	27.67	85.33	1350
1030	Kathmandu Airport	Kathmandu	Aeronautical	27.7	85.37	1337
1039	Panipokhari	Kathmandu	Climatology	27.73	85.33	1335
1052	Bhaktapur	Bhaktapur	Precipitation	27.67	85.42	1330
1059	Changu Narayan	Bhaktapur	Precipitation	27.7	85.42	1543
1060	Chapa Gaun	Lalitpur	Precipitation	27.6	85.33	1448
1073	Khokana	Lalitpur	Climatology	27.63	85.28	1212
1075	Lele	Lalitpur	Precipitation	27.58	85.28	1590
1080	Tikathali	Lalitpur	Precipitation	27.65	85.35	1341
1082	Nangkhel	Bhaktapur	Precipitation	27.65	85.47	1428

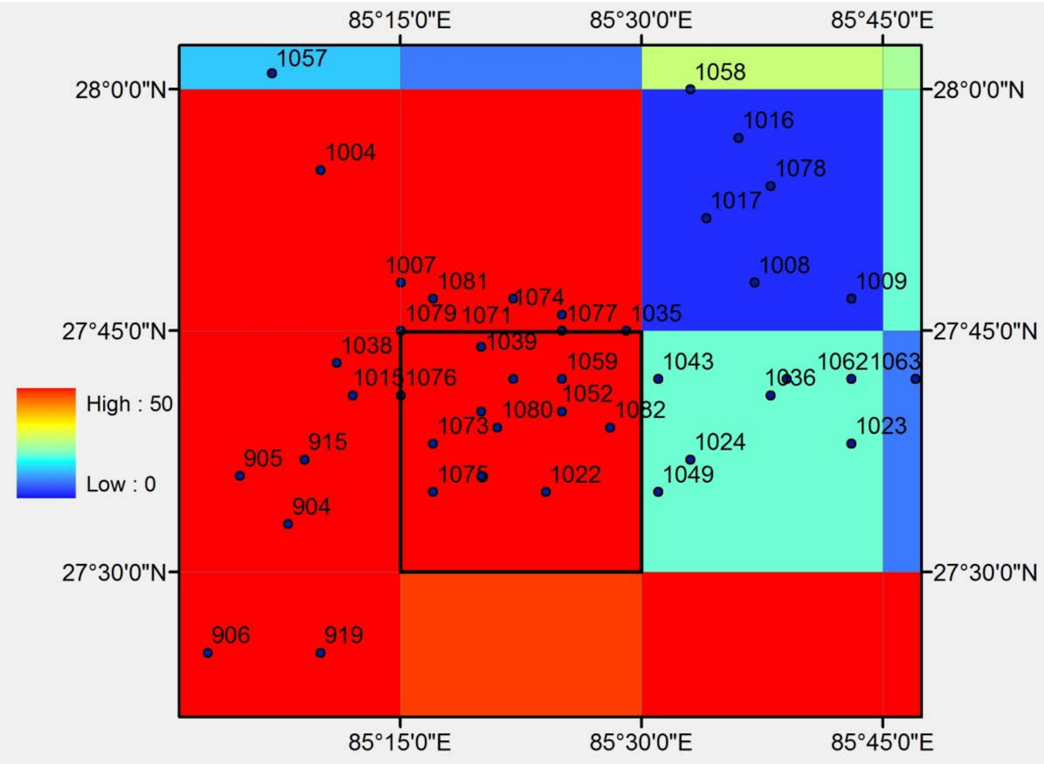

Figure 5-18: TRMM map showing a 0.25° x 0.25° pixel with gauge stations

Scatter plots are plotted among the gauge stations that lie within this pixel for the time period from 2001 to 2008 for evaluating the spatial variability of ground measurement. Table 5-12 shows variation of correlation coefficient, R^2 for different pairs of gauge stations within the same pixel with reference to the elevation difference between them.

Table 5-13: Correlation coefficient of different stations within same pixel

S.No	Station Pair	Elevation difference	R^2
4	1030 vs. 1039	2	0.27
6	1052 vs. 1080	11	0.23
2	1029 vs. 1030	13	0.26
3	1029 vs. 1039	15	0.19
1	1022 vs. 1029	50	0.38
7	1052 vs. 1082	98	0.44
10	1060 vs. 1075	142	0.18
11	1073 vs. 1082	216	0.35
9	1060 vs. 1073	236	0.22
5	1039 vs. 1075	255	0.04
8	1059 vs. 1073	331	0.18
12	1073 vs. 1075	378	0.19

From Table 5-13, it can be clearly seen that there is a high spatial variability within the small area also. The correlation between the rainfall stations is very low, the value ranged from 0.04 to 0.44. Additionally, the elevation difference between the stations has no relation with this variability. Stations 1030 and 1039 are nearly on the same elevation above sea level although they have high spatial variability.

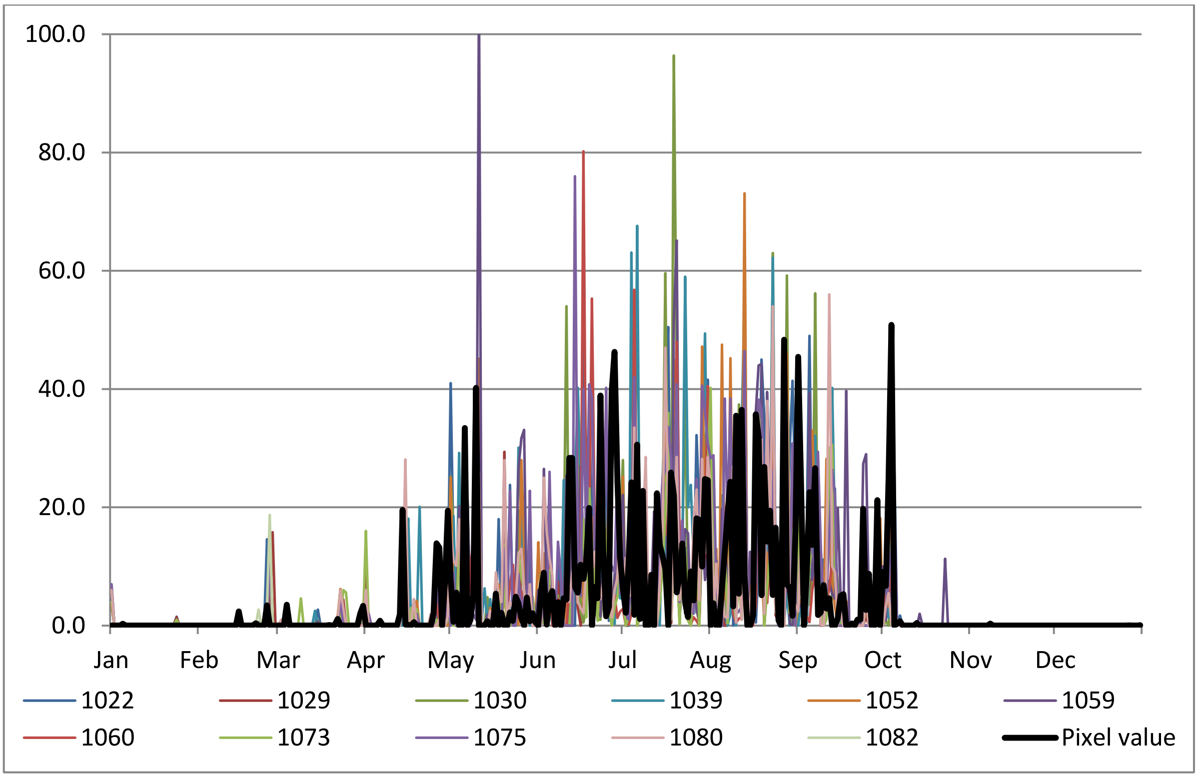

Figure 5-19: Comparison of daily rainfall within a same pixel for a year 2001

Figure 5-19: Comparison of daily rainfall within a same pixel for a year 2001 shows the daily precipitation data for all the stations lying in the pixel and TRMM value for that pixel plotted over the year 2001. This shows that TRMM satellite is estimating an average value for the pixel. This fact is more illustrative in Figure 5-20 where monthly accumulated precipitation is plotted against 8 years period.

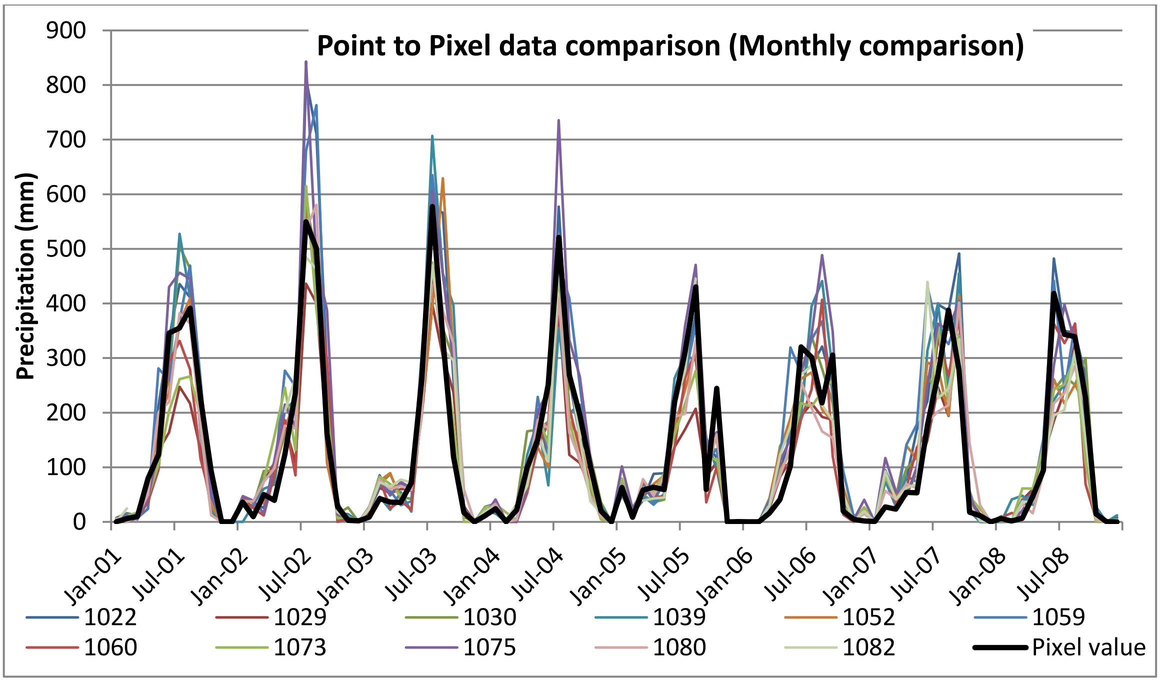

Figure 5-20: Monthly precipitation data sets within the same pixel

From the figure above, it can be seen that the TRMM data provides an average of the rainfall accounted by the gauge stations in that pixel. It is obvious that there could be a spatial variability in the small region also. But, since the spatial resolution of TRMM satellite data is not very small, this can't account this small variability within the same pixel. The pixel value for TRMM and rain gauge stations within that pixel are accumulated for each year and they are also plotted against time to see yearly variation as shown in Figure 5-21. This also explains the same fact.

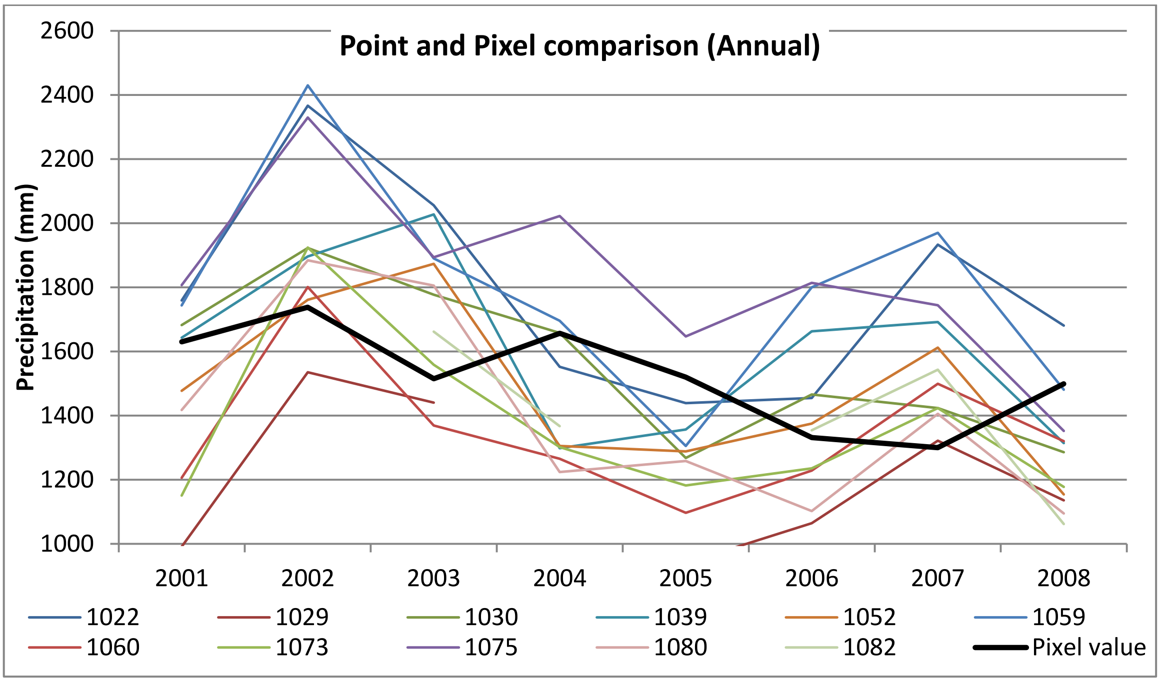

Figure 5-21: Yearly precipitation data sets within the same pixel

The comparison of monthly average rainfall as obtained for the TRMM map pixel and gauge stations within the same pixel is done as shown in Figure 5-22. This also shows the same trend except in dry season where it shows an underestimation of precipitation on all the station.

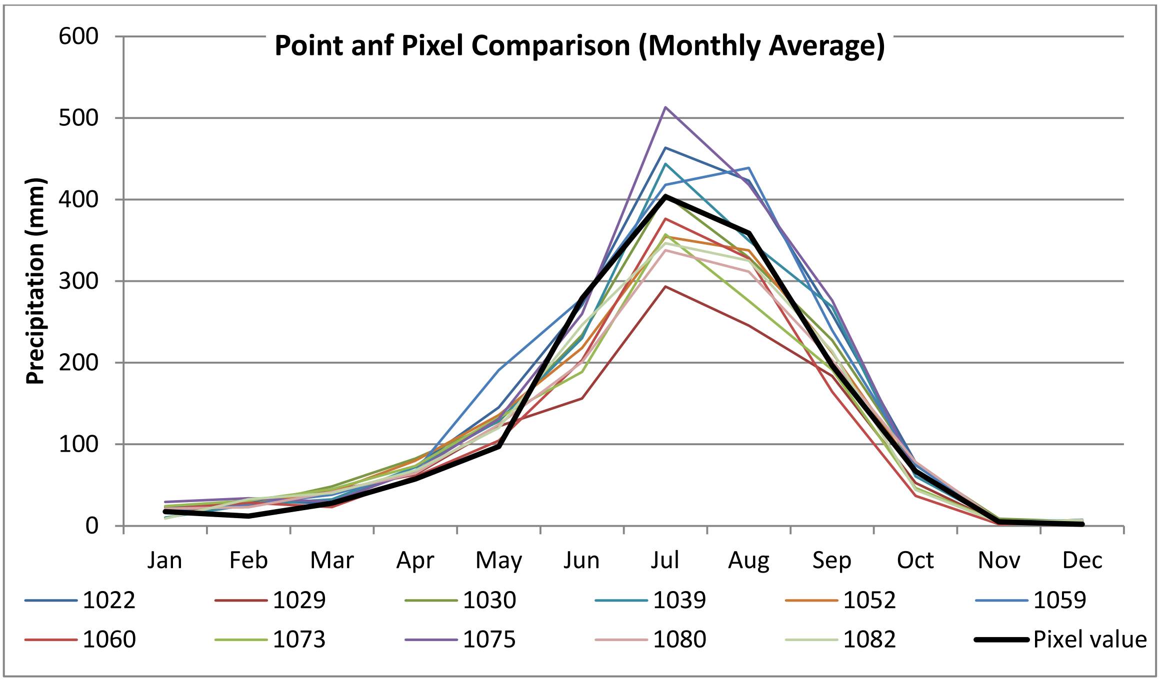

Figure 5-22: Monthly average precipitation data sets within the same pixel

The graph is plotted for studying the pattern of variation of rainfall over a pixel. The average rainfall for the month of July for stations lying within the same pixel is plotted against their elevation as shown in Figure 5-23. It can be observed that rainfall within a same pixel increases with increasing elevation. The TRMM satellite is estimating an average value of precipitation for this pixel. Thus, it is evident that the accuracy of the precipitation estimate also depends on spatial resolution of the satellite product.

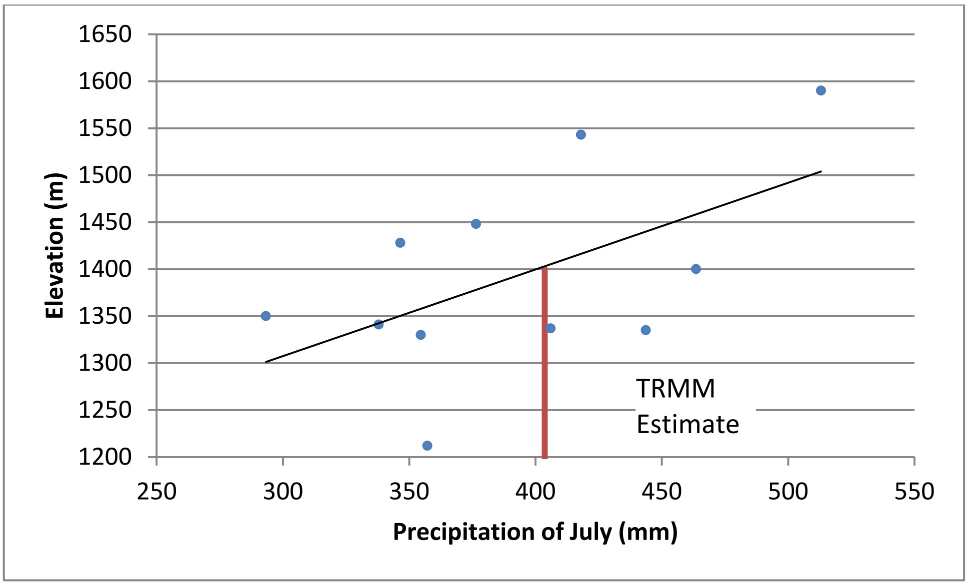

Figure 5-23: Precipitation plotted against elevation within a single Pixel

CHAPTER VI

APPLICATION WITH HYDROLOGICAL MODELLING

One of the applications of Satellite precipitation is the use as input on Rainfall runoff modeling. This model is used for the prediction of surface runoff from the catchment and is entirely dependent on rainfall received by the catchment and evaporation computed from the temperature. Satellite precipitation estimates have high spatial as well as temporal resolution. In this study, TRMM Satellite data that is compared with gauge precipitation data sets in the precious section is evaluated for their applications in a hydrological model to simulate runoffs. The model used for the study is a monthly water balance model initially developed by 'Thornthwaite' (1948).

6.1 Monthly Water Balance Model

A better concept of forecasting stream flow in the future can be valuable for water supply management. Water balance models are constructed to predict those forecasts. Water balance models have been developed at various time scales (e.g. hourly, daily, monthly and yearly) [41]. Monthly water balance model has been widely employed for long-term forecasting of the water resources distribution under different conditions [42]. Generally monthly water balance is applied for the study of hydrology of the catchment; assessment of climatic change impacts [43]; estimation of soil-moisture storage [44] [45], runoff [44] [46] and irrigation demand [47]; and evaluation of the hydrologic effects of climate change [46] [48].

Till date, different types of monthly water balance models have been presented by many researchers. Thornthwaite and Mather (1955) developed a set of deterministic monthly water balance models in 1940s that used two parameters soil moisture capacity and surplus water remaining [42]. Palmer (1965) suggested a model which divides the soil moisture storage into two layers. Thomas (1981) proposed a four-parameter for a water balance model. In 1987, Gleick developed a monthly water balance model specifically for climate impact assessment. Later on, more monthly water balance models were developed for studying the impact of climate change on the hydrological balance and for general water resources planning and management [49] [42]. After nearly 50 years of development, the monthly water balance models have been much more complicated. However, the simple monthly water balance model can still be efficient and useful in terms of runoff simulation. This study investigates on a three-parameter monthly water balance model, developed by Thornthwaite and then applied to four river basins and one sub-basin of Nepal. The script for this water balance model is prepared in 'Cran R' and script prepared by Emmanuel Jjunju (NTNU) to handle distributed (spatial) simulation.

6.2 Model Structure and Parameters

This model is initially proposed by Thornthwaite and Mather's (1955) as T model. This model consists of two storage parameters: soil moisture capacity (STC) and storage constant (ST). It was then revised by Alley's (1984) as Tα model. This model has some modifications with an assumption that a fraction precipitation is immediately transformed into direct runoff [41]. Temperature is used as a driving force to estimate potential evapotranspiration

Inputs to the model are mean monthly temperature (T, in degrees Celsius), monthly total precipitation (P, in millimeters), and shape file (in decimal degrees) of the catchment and mean discharge data for comparison. The latitude of the location is used for the computation of day length, which is needed for the computation of potential evapotranspiration (PET) [50]. The model is referred to as the Thornthwaite model. The framework of the model structure is as shown in Figure 6-1.

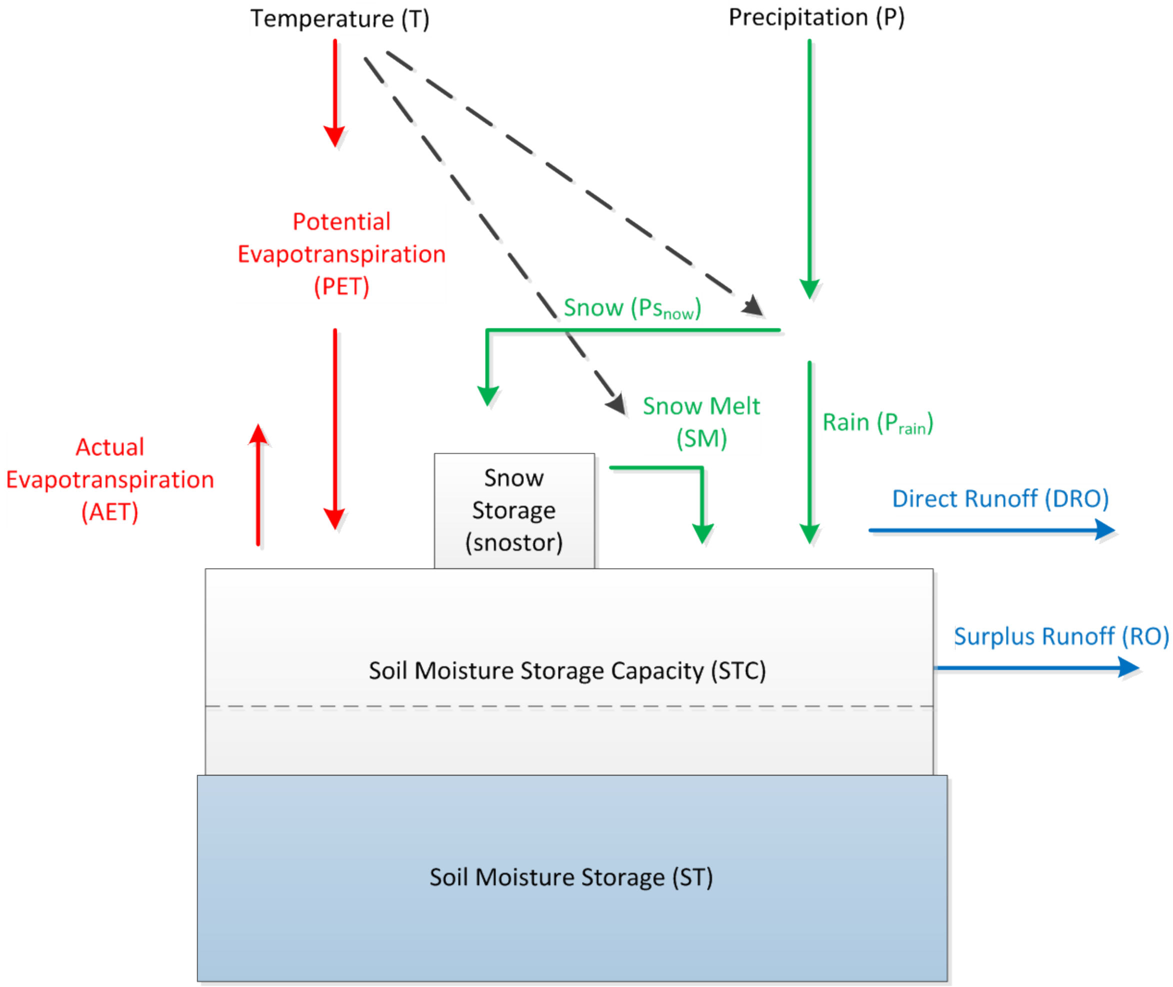

Figure 6-1: The water Balance model

6.2.1 Snow Accumulation

Snowfall and snowmelt play a significant role in the hydrologic regime of the catchment [41]. Snow accumulation is computed relating the mean temperature for the month with the threshold for snow or rain. When mean monthly temperature (T) is below a threshold temperature for snow (T_{snow}), all precipitation will be snow. If the temperature is greater than threshold for rain (T_{rain}), then all precipitation is considered to be rain. If the temperature with in between T_{snow} and T_{rain}, amount of accumulated snow or rain depends linearly with temperature.

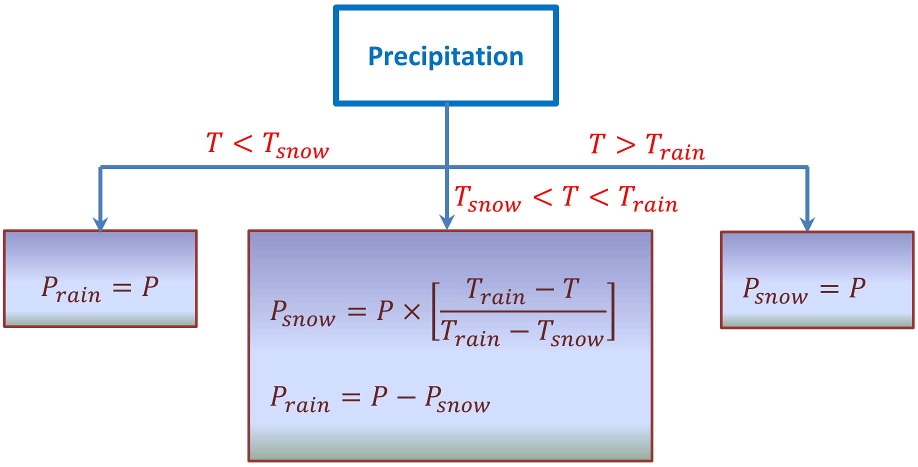

Figure 6-2: Snow accumulation computation

From the analysis of water balance model for a number of catchments, an approximate value for T_{rain} is found as 3.3°C [46]. It is also observed that value for T_{snow} varies with elevation. For computation of WB model below 1000m elevations, T_{snow} can be taken as -10°C and for those above 1000m elevations, -1°C is more appropriate [46].

The computed P_{snow} are accumulated as snow storage over the catchment while P_{rain} flows either as direct runoff or infiltrate in the soil as Soil Moisture Storage.

6.2.2 Direct Runoff

The concept of adding direct runoff to the model is devised by Alley (1984). It is the runoff resulting from impervious surface and excess overflow. This is the factor that provides fast runoff from the catchment. The expression for the calculation of Direct Runoff (DRO) is:

$$DRO = P_{rain} \times drofrac$$

The factor 'drofrac' is called Direct Runoff Factor that governs the immediate runoffs from the catchment. This factor depends on the type, vegetation and slopes of the catchment. It is recommended to assume the value to be 5% [46] but this parameter can be optimized for the catchment. The remaining precipitation after direct runoff is infiltrated in the soil.

$$P_{remain} = P_{rain} - DRO$$

6.2.3 Snow melt

Runoff from snowmelt is a major component of the global movement of water. The importance of snowmelt greatly varies with topography. It is directly dependent on the temperature of the catchment. A factor called Snow Melt Factor (SMF) is introduced to compute this snow melt (SM) from snow stored in the catchment. SMF can be computed from mean monthly temperature and a maximum melt rate (meltmax). It is recommended to set the initial value for meltmax to be 0.5 [46]. Then, SMF can be calculated as:

$$SMF = \frac{T - T_{snow}}{T_{rain} - T_{snow}} \times meltmax$$

If computed SMF is greater than meltmax, then SMF is set to meltmax. The amount of snow that is melted in a month (SM) in mm of snow water equivalent, is computed as,

$$SM = snostor \times SMF$$

SM is added to $\mathrm{P_{remain}}$ to compute total liquid water input $\mathrm{P_{total}}$ to the soil.

6.2.4 Evapotranspiration and soil moisture storage

Evapotranspiration is the combined transfer of water into the air by evaporation and transpiration. Precipitation and evapotranspiration are equally important climatic factors [43]. So, accurate spatial and temporal predictions of ET are required for water balance models [41].

For this model, monthly Potential Evapotranspiration (PET) is estimated from mean monthly temperature. It is assumed that the catchment never lacks water and water loss takes place from this large, homogeneous, vegetation-covered area [50]. 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 [51]. It is one of the simplest estimates of potential evapotranspiration and generally used to estimate seasonal (monthly) or annual values. Hamon's estimate of potential evaporation is:

$$PET_{Hamon} = 13.97 \times d \times D^2 \times W_t \qquad \text{in mm/month}$$

Where, d = number of days in a month
D = mean monthly hours of daylight in units of 12 hours
Wt. = Saturated water vapor density (gm./m^3) and is calculated as:

$$W_t = \frac{4.95 \times e^{0.062 \times T}}{100}$$

Actual evapotranspiration (AET) is then derived from this PET, $\mathrm{P_{total}}$, soil-moisture storage (ST) and soil moisture storage withdrawal (STW). When $\mathrm{P_{total}}$ for a month is less than PET, then AET is equal to $\mathrm{P_{total}}$ plus the amount of soil moisture that can be withdrawn from the storage in the soil. If P_{total} exceeds PET, then AET is equal to PET and the excess water replenishes soil moisture storage (ST).

$$AET = \begin{cases} PET & if\ P_{total} \geq PET \\ P_{total} + STW & if\ P_{total} < PET \end{cases}$$

And,

$$ST = \begin{cases} 0 & if\ AET < PET \\ P_{total} - PET & if\ AET = PET \end{cases}$$

When ST is greater than STC, the excess water becomes surplus (S) this Surplus is available for Surplus runoff (RO).

$$Water\ available\ for\ runoff = \begin{cases} 0 & if\ ST \leq STC \\ ST - STC & if\ ST > STC \end{cases}$$

Soil moisture storage withdrawal (STW) decreases linearly with decreasing soil moisture storage (ST) and can be computed as follows:

$$STW = ST_{i-1} - \left[|P_{total} - PET| \times \left(\frac{ST_{i-1}}{STC} \right) \right]$$

Where, ST_{i-1} is the soil moisture storage for the previous month

STC is the soil moisture storage capacity. STC can be initially assumed to be 150mm as this works from most of the locations [46].

As the soil becomes drier, it becomes more difficult to remove water from the soil, thus less water will be available for AET.

6.2.5 Runoff Generation

The surplus water in the soil moisture storage is left to the environment as Surplus Runoff (RO) at a specified rate called ‘rfactor’. The parameter ‘rfactor’ determines the fraction of surplus that becomes runoff in a month.

$$RO = rfactor \times S$$

The value for ‘rfactor’ is commonly taken to be 0.5 [46] but this can be adjusted as per the catchment conditions. The remaining surplus is carried over to the following month to compute total surplus for that month.

Now, total monthly runoff (RO_{total}) is computed by summing direct runoff (DRO) and surplus runoff (RO).

$$RO_{total} = RO + DRO$$

The calculation of runoff in this model is done in millimeters. So, obtained runoff should be multiplied with the catchment area and divided by the month days to get the discharge in cu.meters.

$$RO_{total} \left(in \ {}^{m^3}/_{s} \right) = RO_{total} \ (in \ mm) \times \frac{Catchment \ area \ (km^2) \times 10^3}{no. of \ \ days \ in \ a \ month \times 24 \times 3600}$$

CHAPTER VII

INPUT DATA PREPARATION FOR WB MODEL

7.1 Study Area

The model is tested on four different basins and one sub-basin of Nepal to see whether the satellite precipitation can be used to estimate the discharge from the catchment. The basins are Karnali, Narayani, Bagmati and Saptakoshi and sub-basin is Sunkoshi.

7.1.1 Karnali Basin

Karnali basin is located in the western part of the country and also includes some area of Tibet. The catchment area at the Gauge station at river is 45,876 km². Geographically, the catchment is extended from 80°34' to 83°42' E and 28°20' to 30°41' N. The elevation ranges from 7000 masl in the North to about 150 m in the south. Permanent snow occurs above 5,000 m elevation and represents the famous Himalayas of Nepal. A Tibetan autonomous region called Bhot valley that lies north of these mountain range represents a typical rain shadow areas of the Basin, with a wide expanse of high altitude range lands. Drainage from these valleys occur taking either an easterly or westerly turn in front of high mountains before emerging in the through deep gorges of Siwaliks at the south [52]. The location map and elevation model of the basin is shown in Figure 7-1.

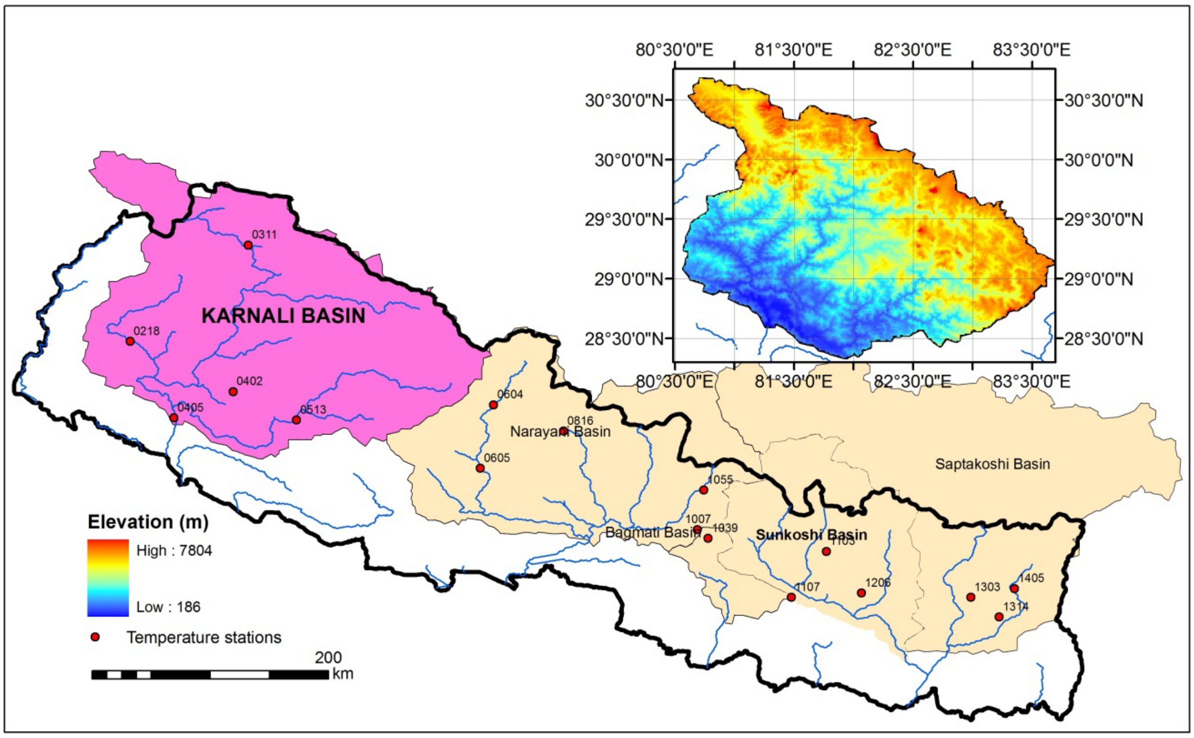

Figure 7-1: Karnali Basin and its DEM

Elevation and exposure play an important role in the spatial variations of air temperature in the Karnali Basin [52]. Lower temperatures occur mostly during December and January while maximum temperatures generally occur after monsoon in May and June. Maximum temperatures range from more than 40°C in southern part of the basin.

The Basin hydrological cycle is maintained by rain, snow, ice and groundwater. Peak river discharges occur during the monsoon season. Snow, ice and groundwater act as a natural reservoir, supplying rivers throughout the dry season. Since there are only a few lakes, natural surface storage does not play a major role in the hydrological cycle of the Basin.

7.1.2 Narayani Basin

Narayani basin is located in the central part of the country and also covers some part of Tibet, China. The catchment area at the Gauge station at river is 32203 km² with an elevation ranging from 6993 m to 400 masl. Geographically, the catchment is extended from 82°52' to 85°48' E and 27°20' to 33°20' N. Figure 7-2 shows the location and elevation map of the basin.

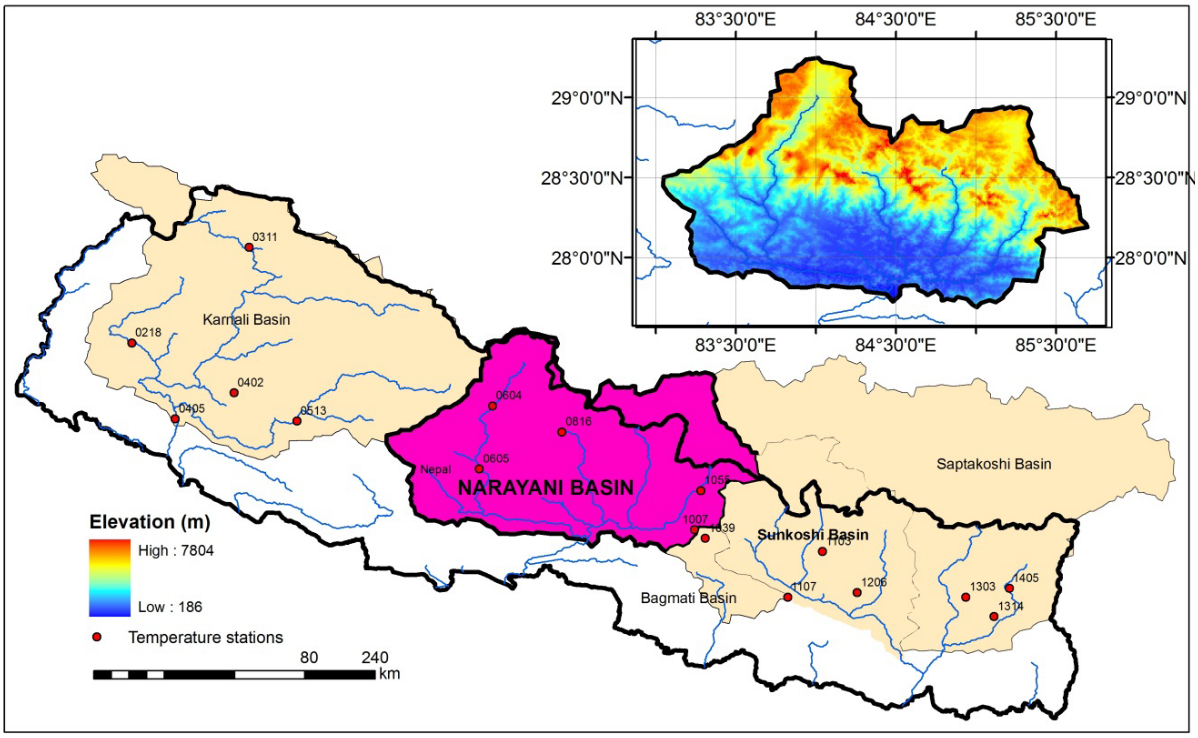

Figure 7-2: Narayani Basin and DEM

There is a wide variation of temperature in the basin, both due to elevation and seasonal effect. The temperature reaches to below -10°C during winter in the upper part of the catchment and lower part of the basin have a maximum temperature up to 30°C during summer.

The annual average discharge of the river in gauge station is 1599 m³/sec. The flow in river varies with season with high flows during monsoon. Snow, ice and groundwater act as a natural reservoir and supply water to the river in the dry season.

7.1.3 Saptakoshi Basin

Saptakoshi is the largest river basin of Nepal and lies between latitudes 27°06'23" to 28°09'23"N and longitude 88°22'36" to 88°23'37"E. It comprises an area of about 59, 000 sq.km and drains eastern part of the country. Out of a total catchment area, 27, 816 sq. km. (45.6%) lies in Nepal and the remaining 33, 184 sq.km. lies in Tibet. The highest elevation in this basin is 8848 masl (Mt. Everest) to 140 masl.

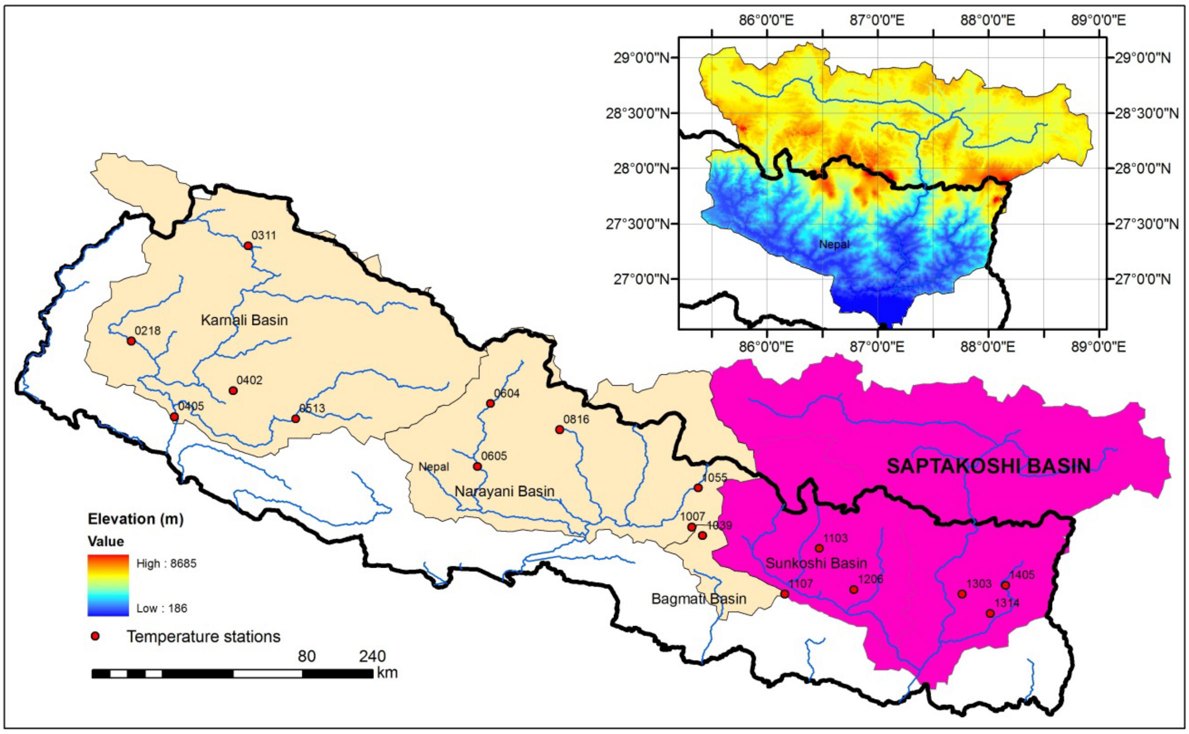

Figure 7-3: Saptakoshi Basin and its DEM

The average annual precipitation in this basin is 1600 mm. Wet season is likely to be wetter and dry seasons are apt to be drier. The extremes will accentuate differences between high and low water flow regimes. Life-threatening flash floods and inundation in the rainy season is more prone in this basin [26].

7.1.4 Sunkoshi Basin

Sunkoshi basin is a leaf shaped trans-boundary river basin originating from a glacier in the southern part of the Himalayan range in the Tibetan plateau. It is extended from 26°47' to 28°31' N latitude and 85°24' to 86°59' E longitude. It is a sub catchment of Saptakoshi basin that drains water from western part of Saptakosi basin. It contributes major part of water source to the Saptakoshi basin. The altitude ranges from 200 to 8012 masl. The basin covers an area of approximately 17,450 km². Many glacier lakes feed water to this basin. Figure 7-4 shows the location map of Sunkoshi basin. The average gradient of this river is about 1:34 in the upper reach and 1:194 in the lower reach.

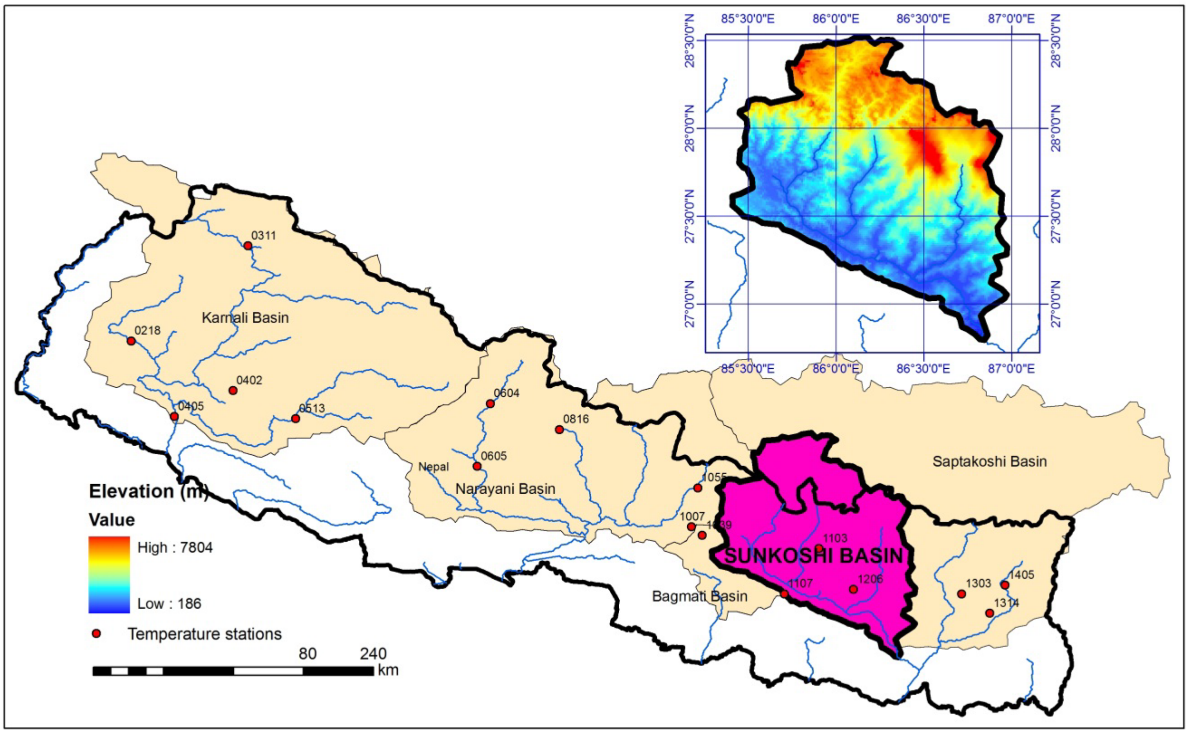

Figure 7-4: Sunkoshi sub-basin and its DEM

The average annual precipitation in this basin is about 1500 mm. Though the river is fed with much glacial sources, huge seasonal variation occurs in this river too. There is an average annual discharge of 700 m^3/s at the gauging station at Kampuaghat and this reaches up to 3000 m^3/s in monsoon season.

The purpose of study of this sub-basin is to verify whether the parameter of the model used for the main basin is applicable for its sub-basin.

7.1.5 Bagmati Basin

Bagmati is a small basin that originates in the Mahabharat range of middle mountains Nepal at an elevation of around 2700 m and joins the Ganges River [53]. The area extends from 85°01' to 85°58' East and 27°04' to 27°50' North covering an area of about 2934 km^2. This basin also covers whole Kathmandu valley. The location and elevation model of Bagmati basin is presented in Figure 7-5. The basin comprises of 75% of mountainous area, and the remaining part consists of flat land with an altitude of less than 100 meters above masl.

The climatic condition of the Bagmati basin is also variable as in other basins of Nepal due to an intricate topography [54]. Temperature is low in winter and reaches about 0°C in upper part of the catchment.

The basin is primarily fed up by springs and monsoon rainfall and there are no glacial sources. Hence, river becomes very low during the hot season (April to early June), then peaking during the monsoon season (Mid June-Mid August). The tributaries originate at Mahabharat and Chure range. Rainfall is also high along the Chure range due to the orographic effect.

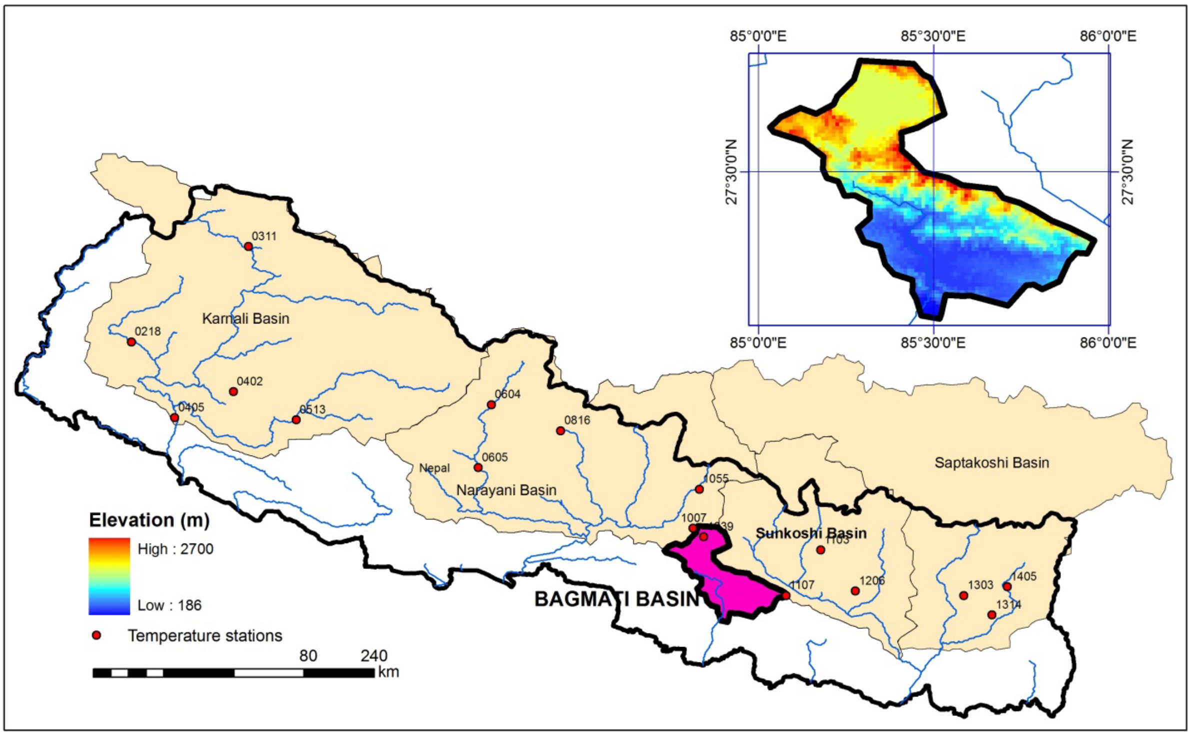

Figure 7-5: Bagmati basin and its DEM

7.2 Monthly Precipitation data

TRMM satellite maps are used to feed monthly precipitation data for the model. Monthly accumulated TRMM Satellite data of the basin is prepared using the python script. Raw TRMM data is used without adjustment of biasness. The precipitation data has a spatial resolution of 0.25°x0.25°. The comparison is done for the period from 2001 to 2006.

7.3 Temperature

Temperature data are collected from GoN, DHM. The obtained temperature data are in the form of daily maximum and minimum values. These data are converted to mean monthly temperature for each month. These data are used to prepare the temperature maps for each month. A lapse rate of -0.005 is used for the preparation of the temperature map. The list of stations used for the preparation of temperature map for each basin is presented in the Table 7-1:

Table 7-1: Temperature Stations used for the model

Basin	Station ID	Station Name	District	Northing	Easting	Elevation (m)
Karnali	218	Dipayal (Doti)	Doti	29.23	80.93	720
	311	Simikot	Humla	29.97	81.83	2800
	402	Dailekh	Dailekh	28.85	81.72	1402
	405	Chisapani (Karnali)	Bardiya	28.65	81.27	225
	513	Chaur jhari tar	Rukum	28.63	82.20	910
Narayani	604	Thakmarpha	Mustang	28.75	83.70	2566
	816	Chame	Manang	28.55	84.23	2680
	1007	Kakani	Nuwakot	27.80	85.25	2064
	1055	Dhunche	Rasuwa	28.10	85.30	1982
Sapta Koshi	1303	Chainpur (East)	Sankhuvwasabha	27.28	87.33	1329
	1314	Terhathum	Terhathum	27.13	87.55	1633
	1405	Taplejung	Taplejung	27.35	87.67	1732

Basin	Station ID	Station Name	District	Northing	Easting	Elevation (m)
	1103	Jiri	Dolkha	27.63	86.23	2003
	1107	Sindhuli gadhi	Sindhuli	27.28	85.97	1463
	1206	Okhaldhunga	Okhaldhunga	27.37	86.50	1720
	1103	Jiri	Dolkha	27.63	86.23	2003
Sunkoshi	1107	Sindhuli gadhi	Sindhuli	27.28	85.97	1463
	1206	Okhaldhunga	Okhaldhunga	27.37	86.50	1720
Bagmati	1039	Panipokhari	Kathmandu	27.73	85.33	1335

Source: Department of Hydrology and Metereology (DHM)/ GoN

Since, the program cannot run with the missing data, these missing values are estimated using the temperature for that day in the previous year and previous day.

7.4 Hydrological data

River discharge data is used for the calibration of parameters for the model and comparison. The data are collected from GoN, DHM. The data is recorded as a daily mean discharge in each station. Mean of these daily discharges is used to find the monthly discharge passing from each basin. The river stations used for the basin are listed in Table 7-2.

Table 7-2: River Gauge stations of Basins

Basin	Location	Longitude (E)	Latitude (N)	Elevation (m)	Drainage Area (Km²)
Karnali	Chisapani	**81.29**	**28.64**	191	42890
Narayani	Devghat	**84.43**	**27.71**	180	31100
Sunkosi	Kampughat	**86.82**	**26.87**	200	17600
Saptakosi	Chatara	**87.16**	**26.87**	140	54100
Bagmati	Karmaiya	**85.49**	**27.14**	177	2720

Source: Department of Hydrology and Metereology (DHM)/ GoN

From the discharge data, it can be seen that the rivers in Nepal are characterized by wide, seasonal fluctuation of flow. Peak river discharges occur during the monsoon season. The monthly flows generally reach their maximum in July-August and decline to their minimum in February-March. About 80% of the total flow occurs during five months (June-October) and the rest during the remaining months [55].

7.5 Methodology

The clipped catchment is divided into a number of cells. A cell of dimension 0.25 x 0.25 is chosen such that the dimension is same as that of the TRMM satellite map resolution.

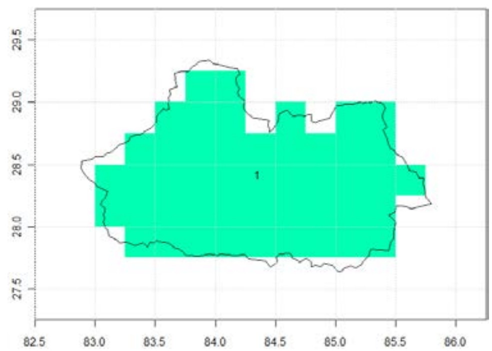

Figure 7-6: Grid size of Narayani Basin

The monthly mean temperature for each gauge station is calculated using available daily maximum and minimum temperature for each gauge station within the basin. These mean monthly temperature data is used to compute the lapse rate of the basin. Then, a monthly temperature map is prepared taking reference of station at lowest level and using this lapse rate. These monthly temperature data of each grid cell is stacked in a 3 x 3 matrix with Latitude, longitude and time series of monthly mean temperature along X, Y and Z axis respectively as shown in Figure 7-7.

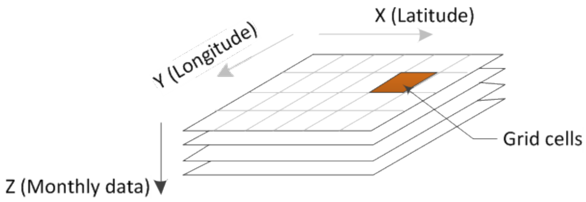

Figure 7-7: 3 x 3 matrix of Temperature and Precipitation data

A 3x3 matrix is prepared also for precipitation data with Latitude and longitude as row and column and time series of monthly precipitation values for each grid along Z axis. The monthly precipitation value is extracted from TRMM Monthly precipitation map.

Water balance equation is applied to each of the grid cells and water available for runoff is accumulated from each grid to determine the discharge at the exit point.

There are some parameters to be assumed for the model. [46] suggested to some constants for these values according to their study in different catchments in the United States. The values of these parameters can be adjusted as per the catchment characteristics. The parameters are,

i. Direct Runoff Factor, *drofrac* = 0.05
ii. Runoff Factor, rfactor *= 0.5*
iii. Soil Moisture Storage Capacity, *STC* = 150
iv. Initial Snow storage, *sn1* = 150
v. Initial Soil storage, *st1* = 150
vi. Initial surplus storage, *s1* = 150

CHAPTER VIII

SIMULATION AND RESULTS

8.1 Model calibration

Calibration is the process of determining the set of free parameters in the model that gives the best possible correspondence between observed and simulated runoff from the catchment (Killingveit, lecture notes). During calibration, those values are estimated which cannot be determined directly from field data.

There are different methods for calibrating a model. They could be:

- Trial and error, manual parameter adjustment.
- Automatic, numerical parameter optimization
- Combination of these two processes

For this model, parameters are adjusted by trial and error method.

8.2 Parameters adjustment

The model is run assuming different parameters for each basin and following parameters seemed best suited for each basin.

Table 8-1: Parameters for the Basins

Parameters	Karnali	Narayani	Bagmati	Saptakoshi	Sunkoshi
drofrac	0.93	0.90	0.70	0.85	0.85
rfactor	0.05	0.10	0.10	0.15	0.15
STC	300	300	300	300	300
sn1	350	400	160	350	350
st1	150	350	50	150	150
S1	50	50	50	50	50

The parameters for Sunkoshi Sub-basin are set same as that for the main basin to observe the discharge pattern produced by this sub-basin. The results are discussed latter in this chapter.

From the calibration it can be seen that all the basins of Nepal have high Direct Runoff factor (drofrac). That means most of the precipitation falling on the basin is immediately drained from the basin. Thus, this does not affect much on assumption of initial conditions of the basin. Also, calibration of parameters shows a decreasing order of direct runoff factor (drofrac) towards eastward. ‘drofrac’ is dependent on the type of soil and slope of the catchment.

8.3 Result

The model used the mean monthly temperature maps to find the amount of precipitation as snow or rain. A threshold temperature of -3.3°C is used for rain and threshold temperature of -1°C or -10°C is used for snow on elevations below or above 1000m elevation respectively [48].

Similarly, evapotranspiration (AET and PET) are calculated based on water available from total precipitation available after melting and soil moisture storage capacity of the basin. The simulated discharge is then calculated and compared with observed discharge for that basin.

8.3.1 Karnali Basin

Figure 8-1 shows the amount of precipitation falling on Karnali basin as snow or rain according to TRMM precipitation map. According to the figure, very little amount of snow is falling in the basin compared to that of rain. This is because snow precipitation usually occurs at higher elevations only. The graph is prepared taking an average value for the whole basin. It can also be seen that snow contributes in increasing the total precipitation from February of each year.

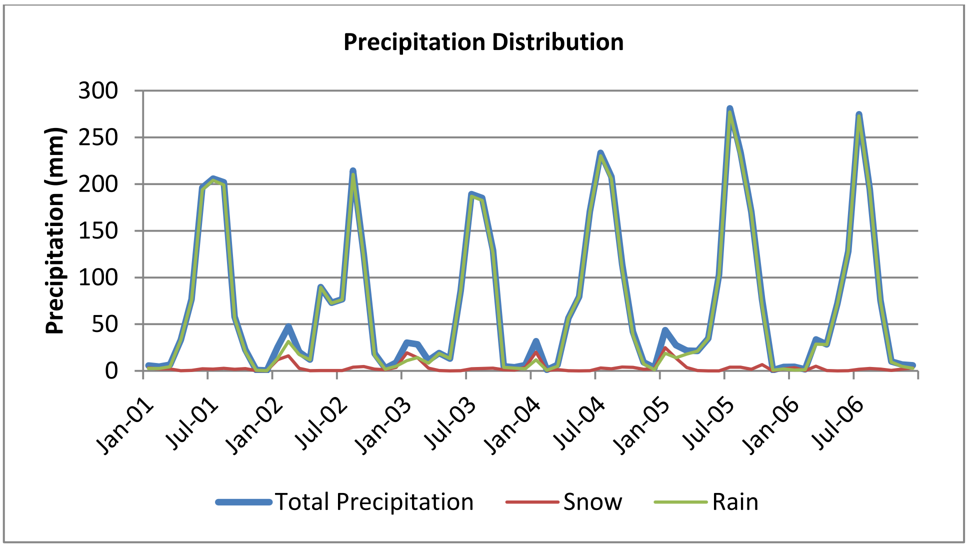

Figure 8-1: Precipitation distribution at Karnali Basin

Since there is a snow precipitation in the basin, snow refreezing and melting process occurs. Figure 8-2 shows the amount of snow melt and accumulation occurring in the basin. This shows that snow precipitation starts to occur from January till March and melting of these snow starts from February. There is always a snow accumulation of 5 mm in the basin.

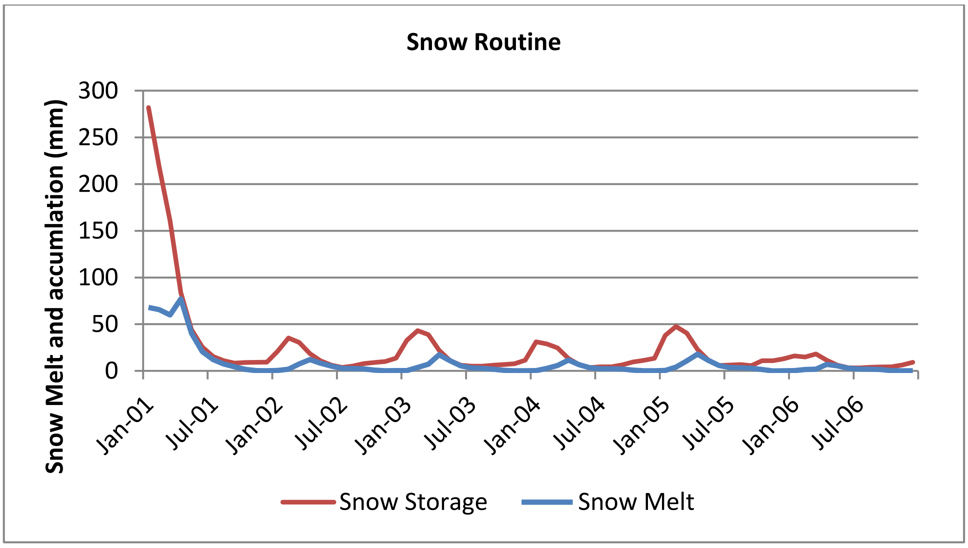

Figure 8-2: Snow storage and melting in Karnali Basin

Figure 8-2 and Figure 8-3 shows unrealistic patterns due to the initial conditions of model simulation. It may be due to the assumption of initial conditions of the basin. This period can be termed as 'warm up period' as the model needs some time for being stable.

The calculation of Potential Evapotranspiration (PET) is done with the help of Hamon's equation. Maximum ET occurs during July and minimum during cold season. The graph of AET and PET is shown in Figure 8-3.

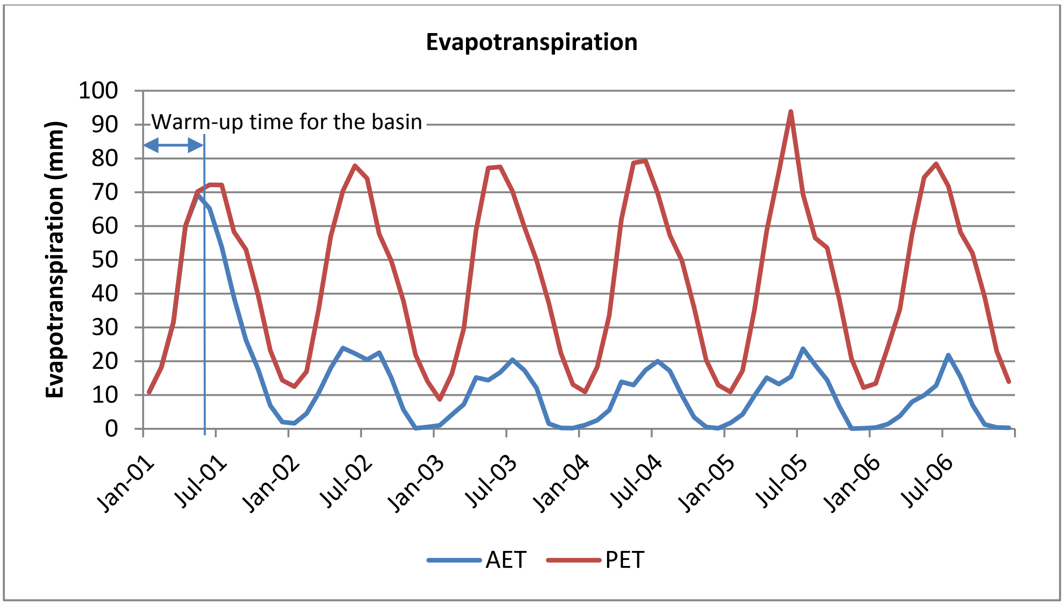

Figure 8-3: Evapotranspiration in Karnali Basin

The graph is plotted between observed and simulated discharges at the gauging station as shown in Figure 8-4. This shows that discharges are in good agreement with each other except in 2003 where there is lesser discharges simulated. This probably has caused due to low precipitation as shown by TRMM satellite data.

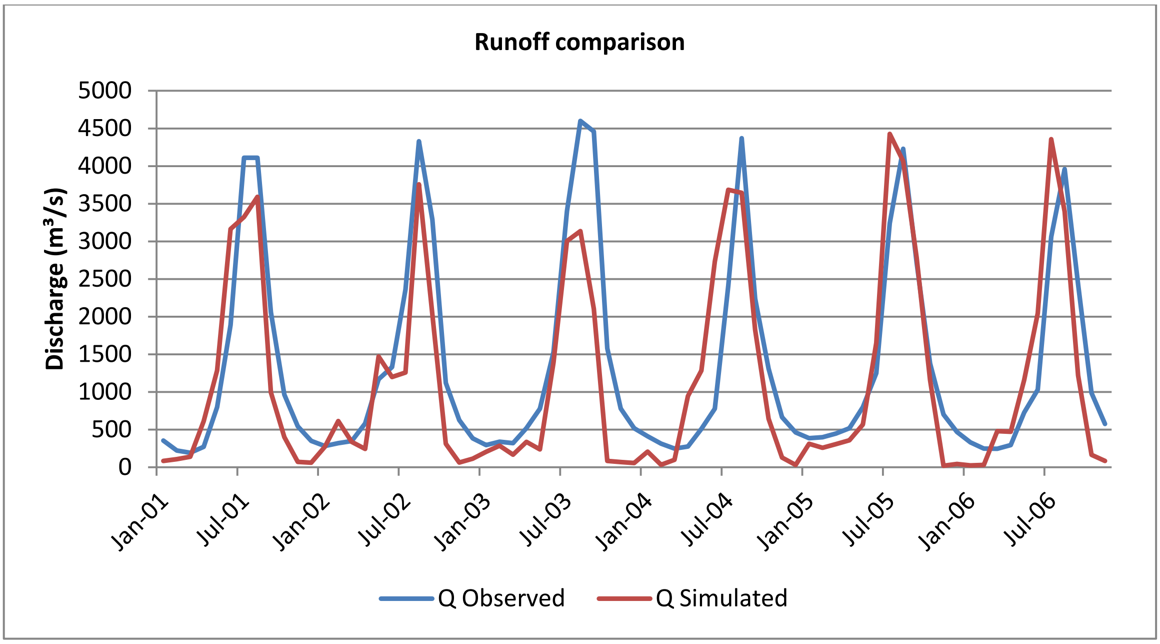

Figure 8-4: Comparison of observed and simulated discharge over Karnali Basin

The average observed and simulated discharges for each month are also compared as shown in Figure 8-5. It can be seen that the model has a good estimation of rising limb, but the recession limb is not yet estimated perfectly. This could probably due to lower precipitation values recorded by TRMM precipitation data.

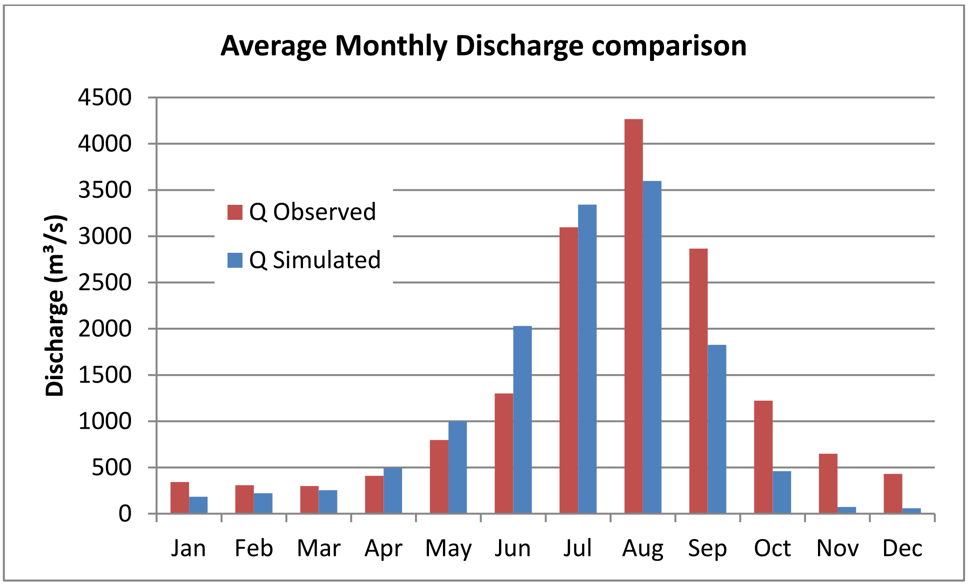

Figure 8-5: Comparison of Average monthly discharge for Karnali Basin

A scatter plot is prepared between observed and simulated discharge data. It can be seen that most of the data have a good correlation. The coefficient of correlation for this plot is 0.743. The lower value is probably because the model is unable to figure out some of high flows.

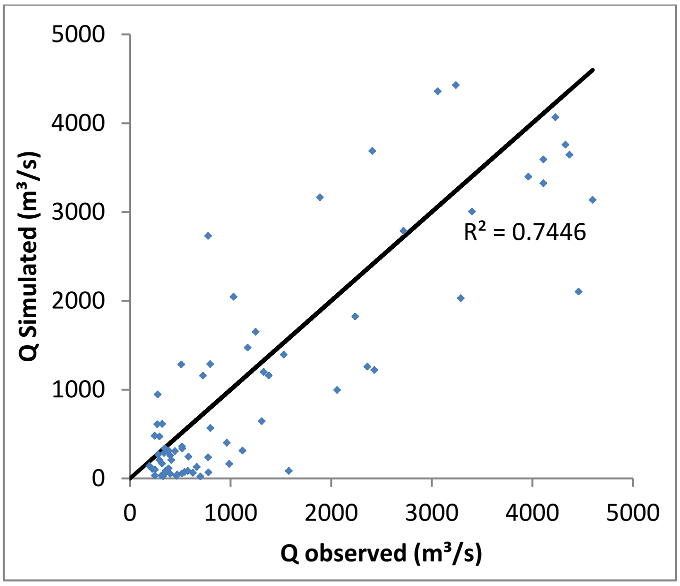

Figure 8-6: Scatter plot for Karnali Basin

8.3.2 Narayani Basin

The total precipitation occurring in the basin is divided as precipitation as rain and snow and plotted in the graph as shown in Figure 8-7. This shows that very less amount of total precipitation is contributed by snow. Snow precipitation only occurs in the Himalayas with elevations above 3000 masl. There is only about 10% of area greater than 3000 m elevation in the basin and this graph shows the average contribution of snow and rain.

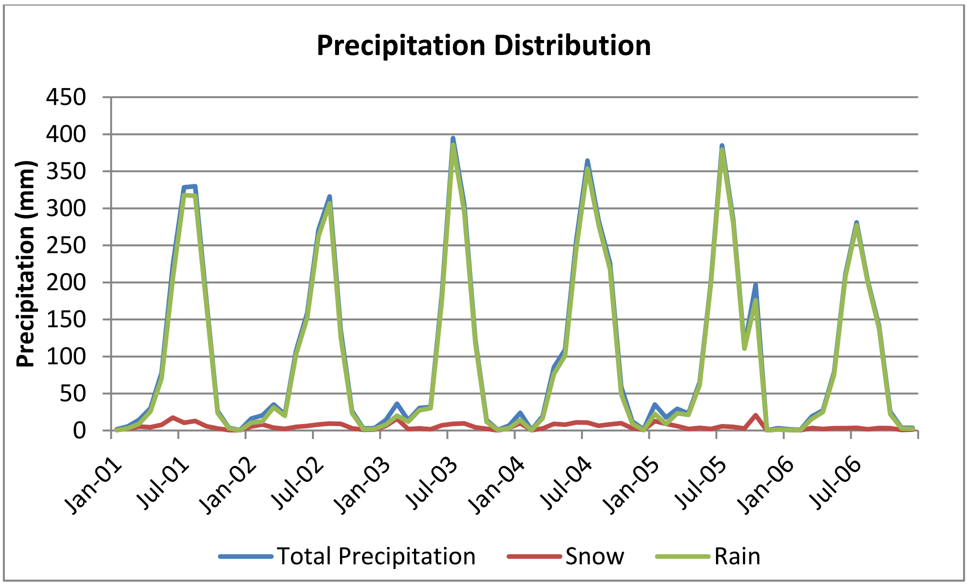

Figure 8-7: Precipitation for Narayani Basin

Potential and Actual Evapotranspiration for each month are computed from the precipitation and soil moisture data for each month as shown in Figure 8-8. This shows that there is almost zero Actual Evapotranspiration during winter and maximum in July of each year.

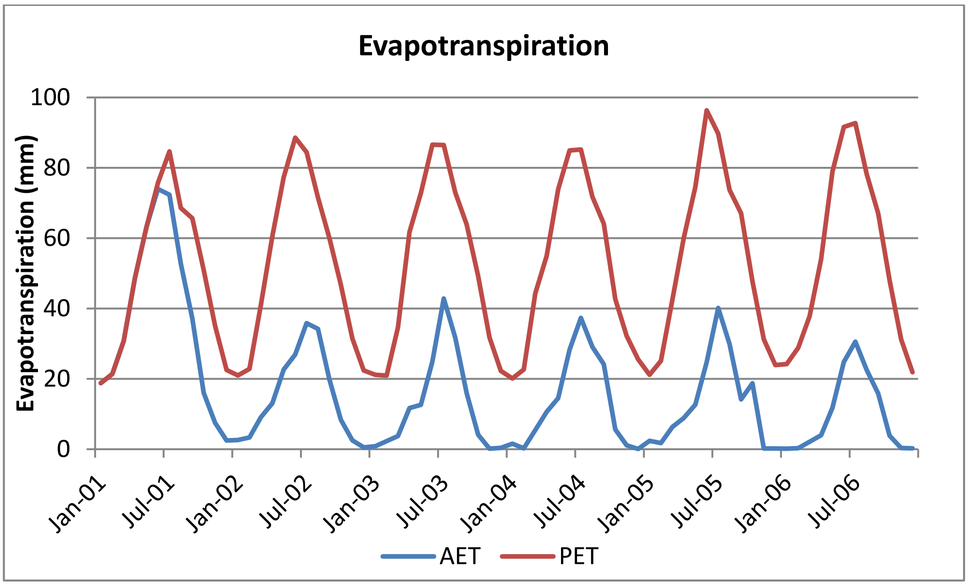

Figure 8-8: Evapotranspiration for Narayani Basin

The discharge from the basin is dominated by direct runoff of rain falling on the surface. Very less amount of precipitation is infiltrated as soil moisture. This could be because most of the soils have low infiltration capacity. Figure 8-9 shows comparative direct and surplus runoffs.

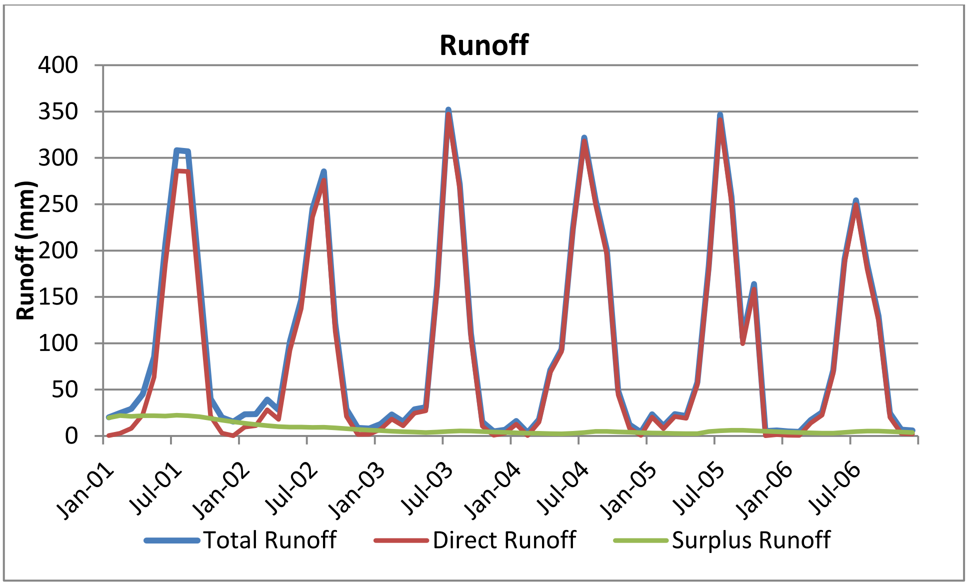

Figure 8-9: Simulated Runoff in Narayani Basin

Figure 8-10 shows the graph between observed and simulated river discharge from the basin. The model is unable to estimate flood discharges during the first three years but can predict nicely in the latter years.

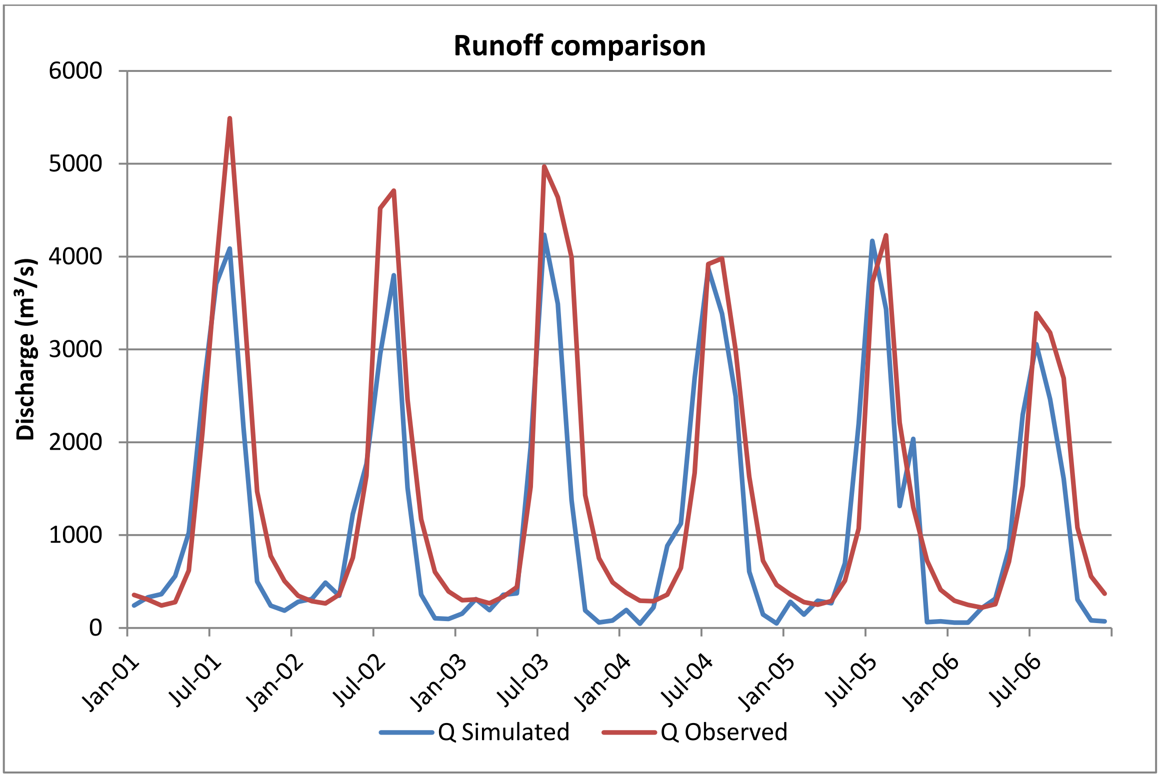

Figure 8-10: Comparison of Observed and simulated runoff in Narayani Basin

Average monthly simulated and observed runoffs are plotted as shown in Figure 8-11. It can be observed that the model is not able to estimate peak discharges from the catchment. This could probably be due to low precipitation amount recorded by TRMM. A curve is plotted between average TRMM precipitation and observed discharge data as shown in Figure 8-12. From the curve it can be observed that the peak discharges in first three years is greater than precipitation data for the same month. The discharge out from the catchment should always be less than input water to the basin i.e. precipitation. Since input water to the basin is less than observed discharge, the model is not able to estimate the discharge as observed. Thus, this shows that TRMM monthly precipitation data is estimating lesser precipitation in the first two year in this catchment.

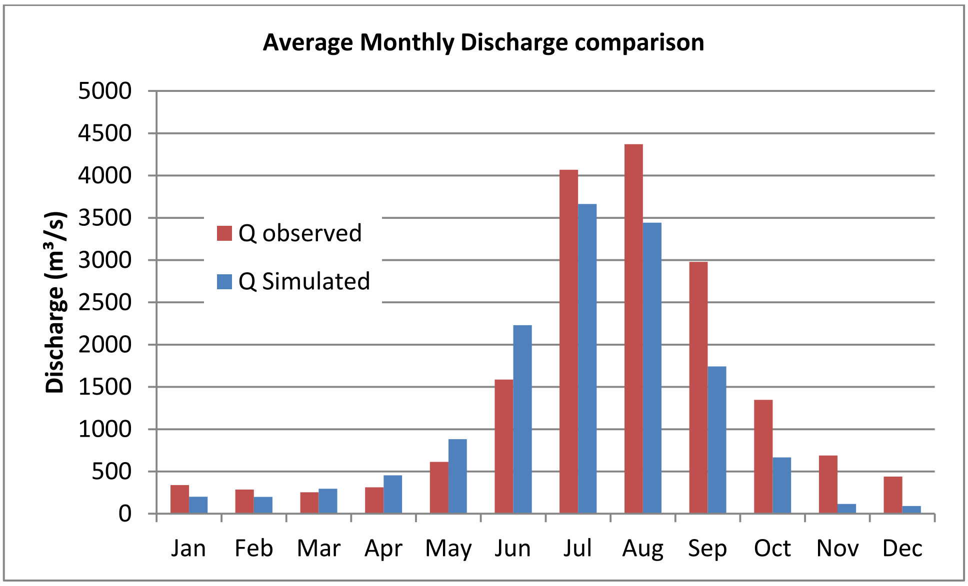

Figure 8-11: Comparison of Mean monthly discharge for Narayani Basin

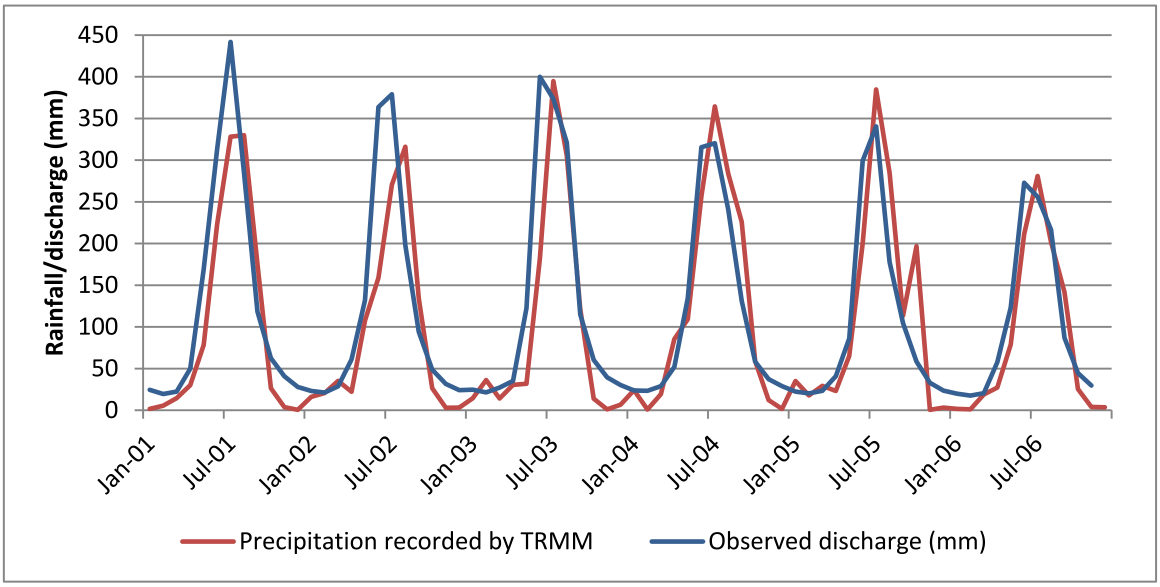

Figure 8-12: Relation between precipitation and discharge

Figure 8-12 also depicts that precipitation is close to the discharge from the basin. This is an indicator of high direct runoff (DRO) coefficient. Since direct runoff coefficient is high for the basin, the other parameters have fewer roles in governing the runoff from the basin.

A scattered plot is drawn between the observed and simulated discharge values. It can be seen from Figure 8-13 that correlation coefficient is 0.823. This means TRMM monthly precipitation data works well for estimation of discharges from the catchment.

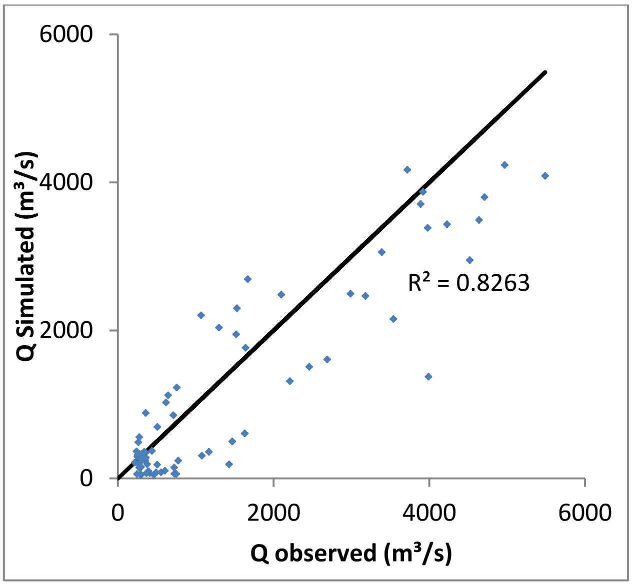

Figure 8-13: Scatter plot of observed and simulated discharge of Narayani Basin

8.3.3 Bagmati Basin

It can be seen from Figure 8-14 that all the precipitation falling on the basin is in the form of rain as it is obvious that maximum elevation on the catchment is below 3000 masl. Hence, the basin acquires snow precipitation very rarely. The maximum precipitation generally occurs in July of each year.

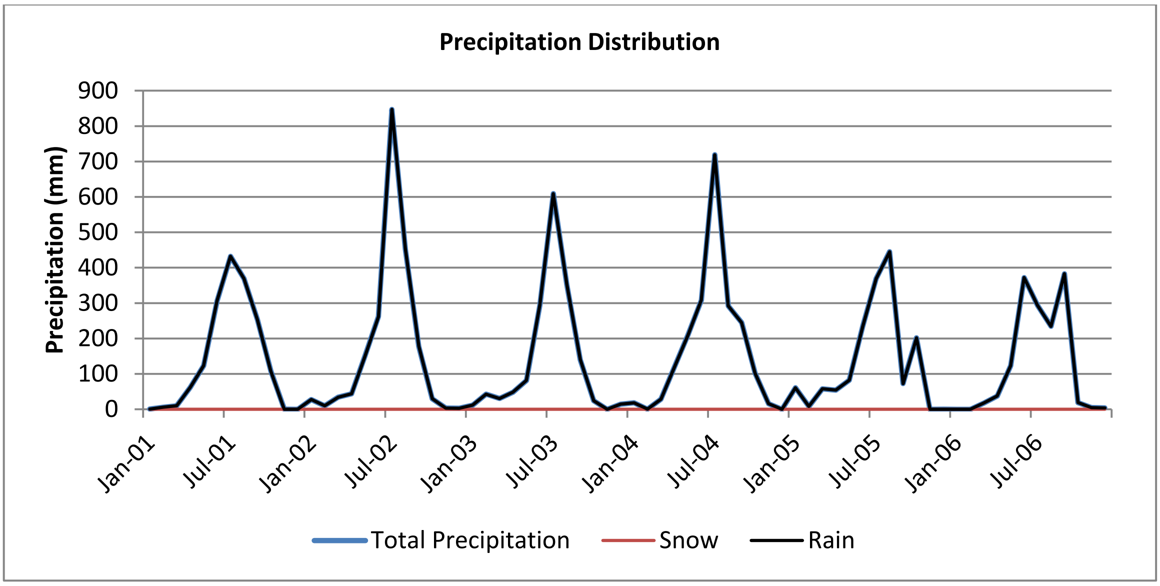

Figure 8-14: Precipitation distribution on Bagmati Basin

Runoff values, for each month from 2001 to 2006, is simulated using the parameters obtained by trial and error method to fit the curve with the observed discharge. It can be seen from Figure 8-15 that there is a sharp peak discharge on each year during July. Since much of rainfall also occurs on July, it can be understood that much of the rainfall is immediately discharged from the basin.

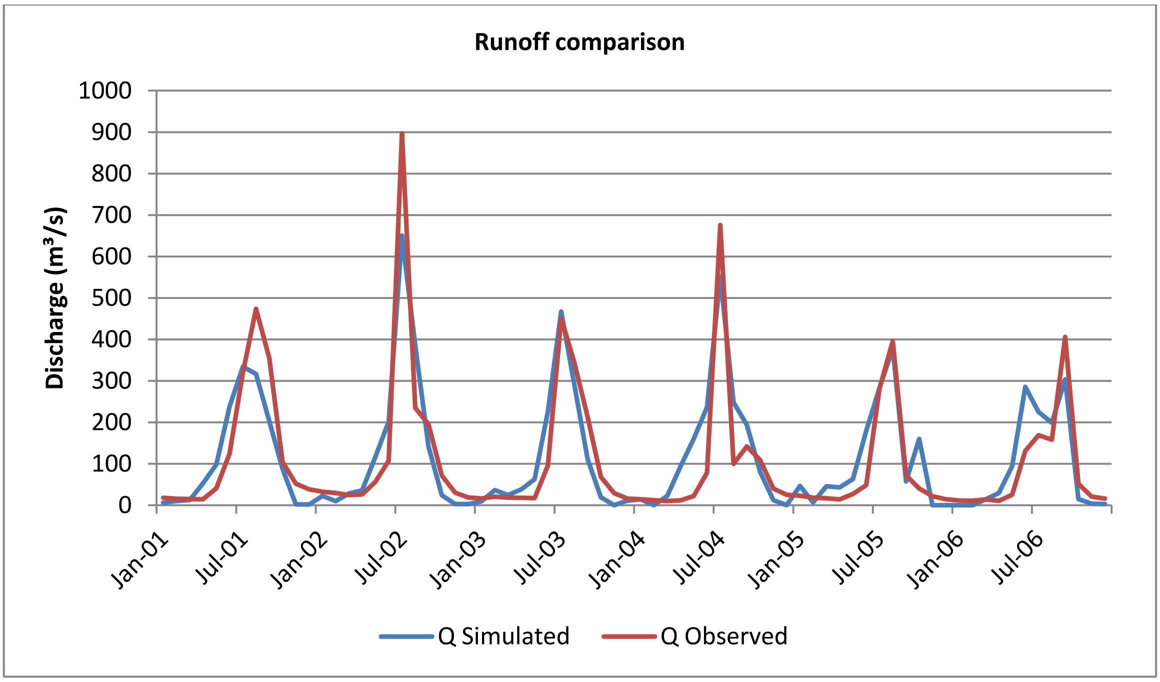

Figure 8-15: Comparison of observed and simulated Discharges of Bagmati Basin

Mean monthly observed and simulated discharges are plotted as shown in Figure 8-16. Maximum mean discharge can reach up to 450 m^3/s during July, but the model is not able to estimate this amount of mean discharge in that month due to low precipitation input from TRMM.

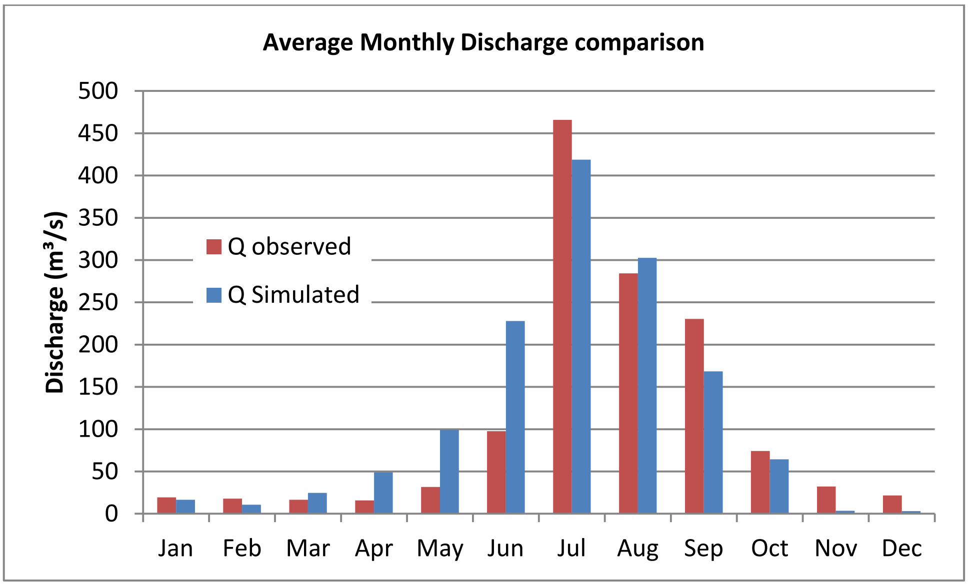

Figure 8-16: Mean monthly runoff comparison of Bagmati Basin

The scatter plot between observed and simulated discharges of Bagmati basin shows that the coefficient of correlation is in an acceptable range (value equal to 0.8)

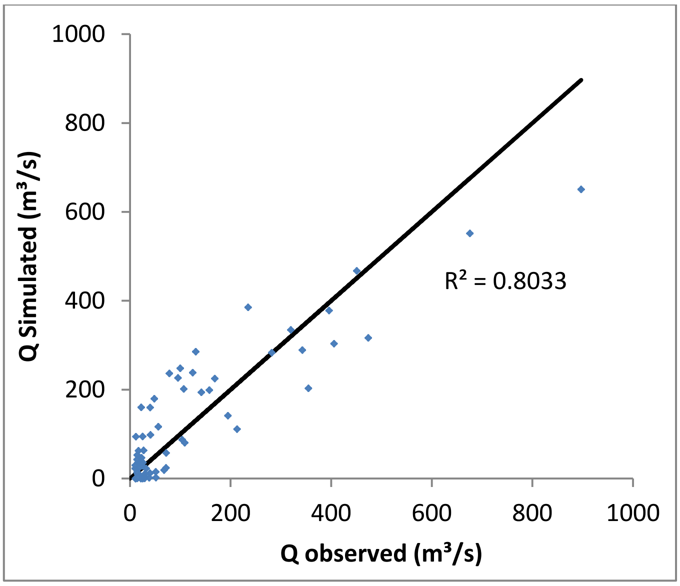

Figure 8-17: Scatter Plot observed and simulated discharges for Bagmati basin

8.3.4 Saptakoshi Basin

Saptakoshi is the biggest river basin in Nepal that has its catchment extended to the Tibet. This catchment also has many of the high mountains and thus possesses snow precipitation. This can also be observed from Figure 8-18 as well. The maximum average snow precipitation of 30 mm in a month can occur over the basin.

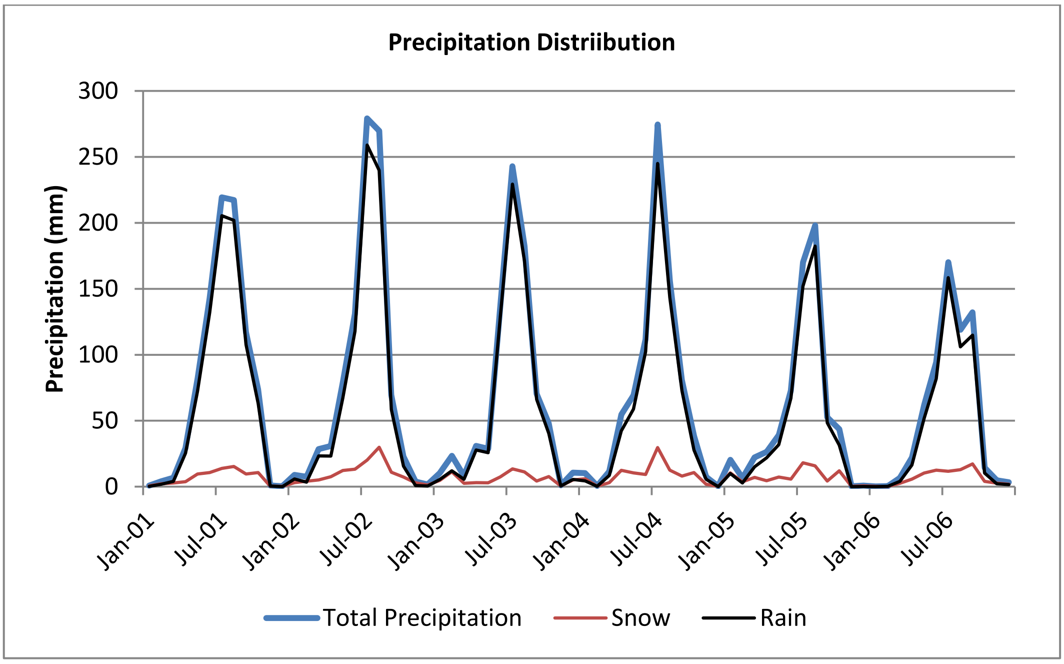

Figure 8-18: Precipitation distribution in Saptakoshi Basin

Figure 8-19 shows that there is a very little contribution of surplus runoff in total discharge from the catchment.

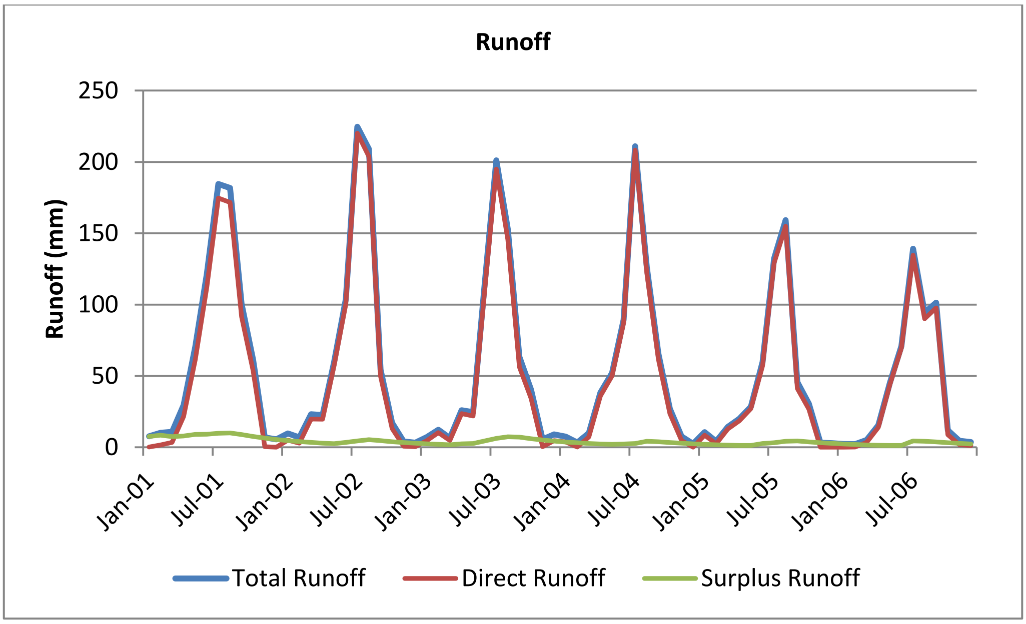

Figure 8-19: Direct and Surplus runoff in Saptakoshi Basin

The runoff data obtained from simulation is plotted with the observed values to make the comparison. Comparison graph illustrates that the model is not able to predict the flood discharges in the first three years. This could probably be due to low precipitation catch by the TRMM satellite data.

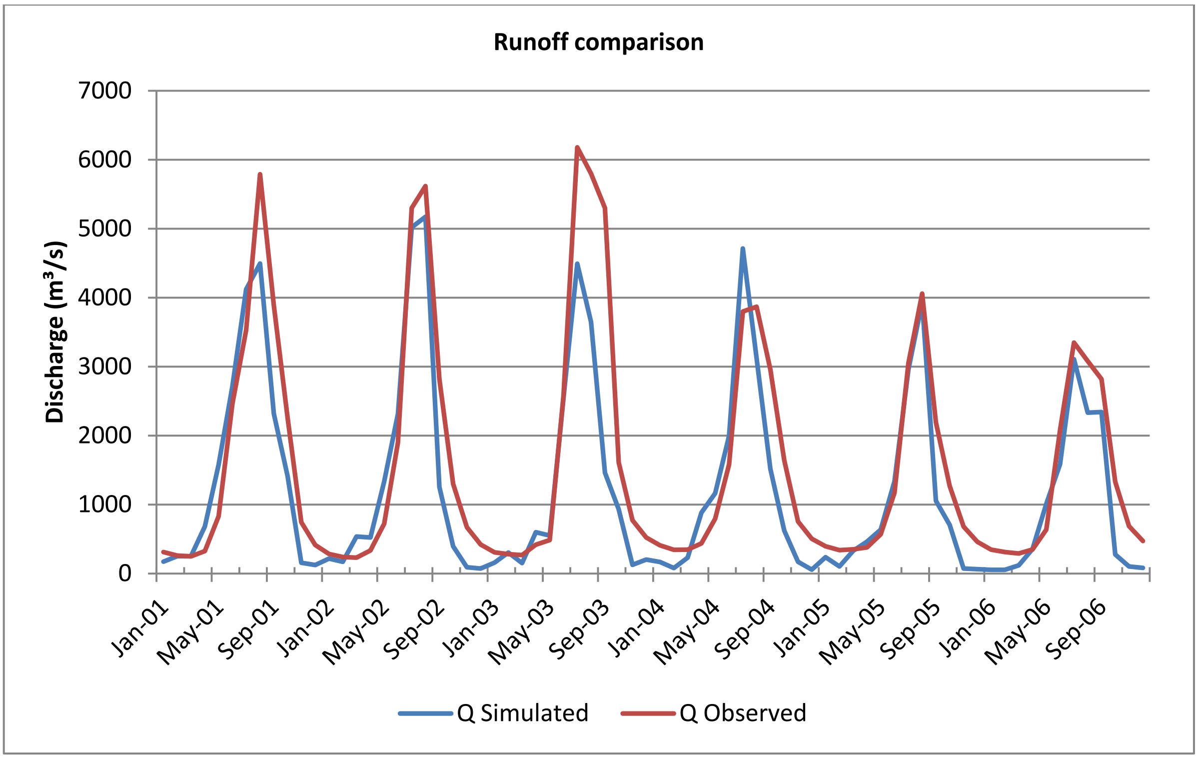

Figure 8-20: Comparison of observed and simulated discharges of Saptakoshi basin

Average monthly discharge from simulation and gauge observation is plotted for comparison as in Figure 8-21. This graph also shows the same characteristics as that for previous basins.

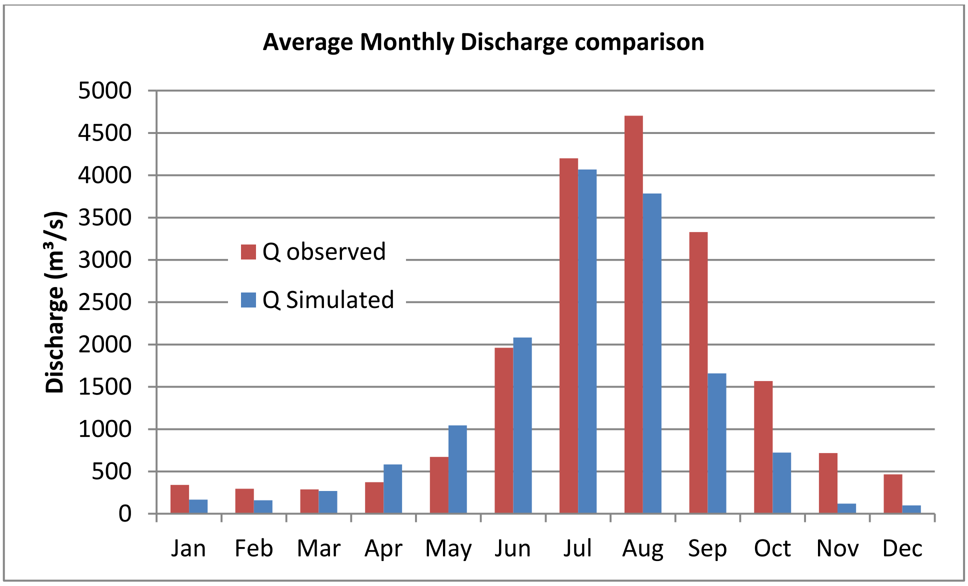

Figure 8-21: Mean monthly discharge of Saptakoshi Basin

A scatter plot is prepared to make a statistical comparison of observed and simulated discharge values. The coefficient of correlation is obtained to be 0.8156 which can be satisfactory for estimation of discharge for the big basin like Saptakoshi basin.

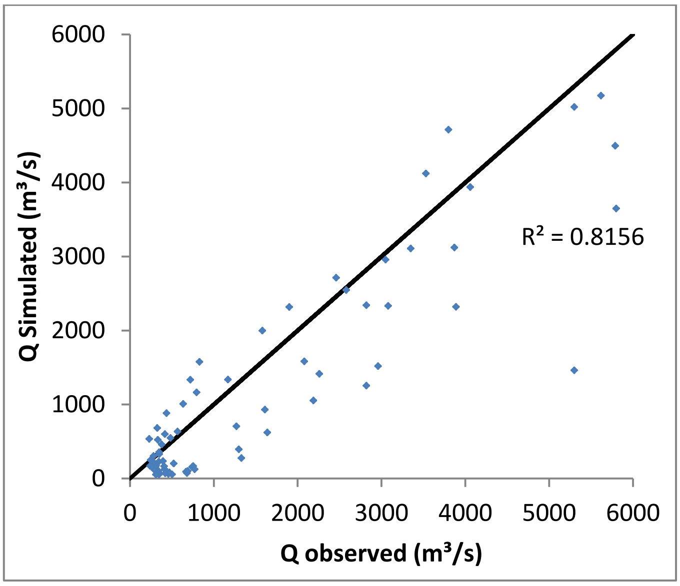

Figure 8-22: Scatter plot of observed and simulated discharges of Saptakoshi Basin

8.3.5 Sunkoshi Sub-basin

Sunkoshi is a sub-basin of Saptakoshi basin and study of discharge of this sub-basin is done to find the relation of this sub-basin with main basin. The runoff comparison between observed and simulated values shows quiet a good estimation of discharge values for this sub-basin. The comparison graph is shown in Figure 8-23.

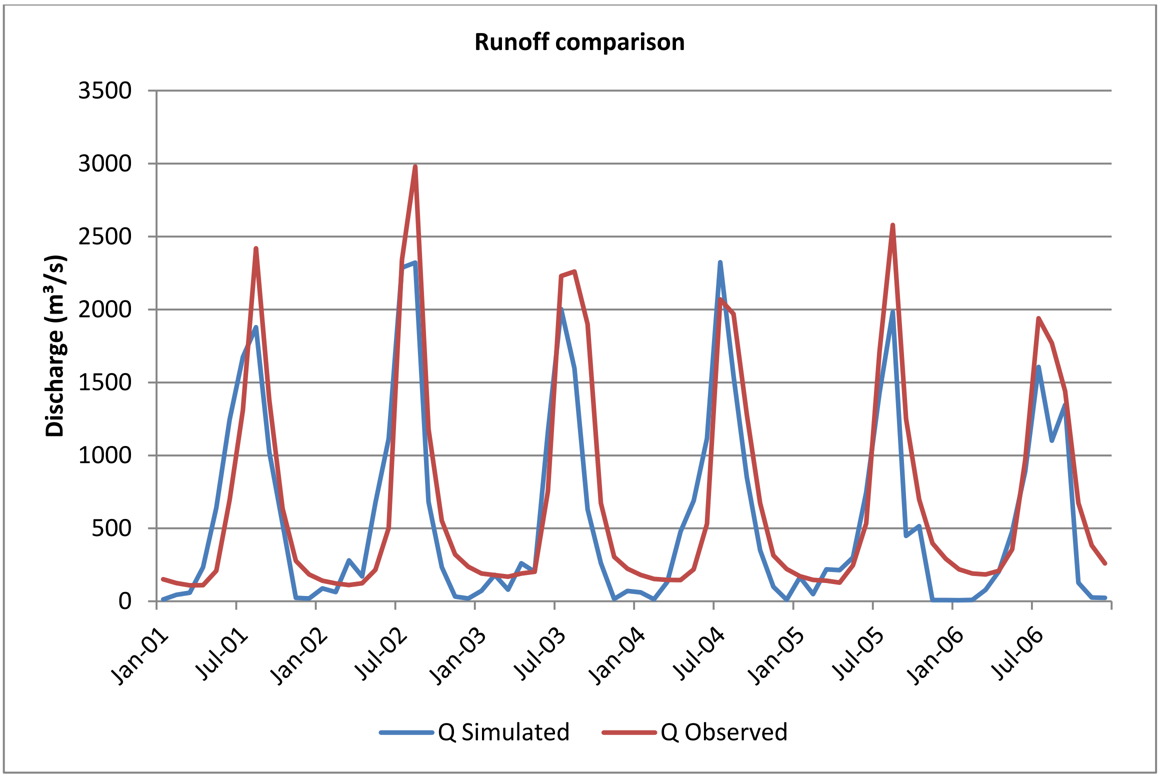

Figure 8-23: Runoff comparison for Sunkoshi Sub-basin

A scatter plot is prepared to study the statistical relation between simulated and observed discharge as shown in Figure 8-24. The correlation coefficient is obtained to be 0.8116 for these data. This value is quiet comparable with that of the main basin whose R^2 value is 0.8156.

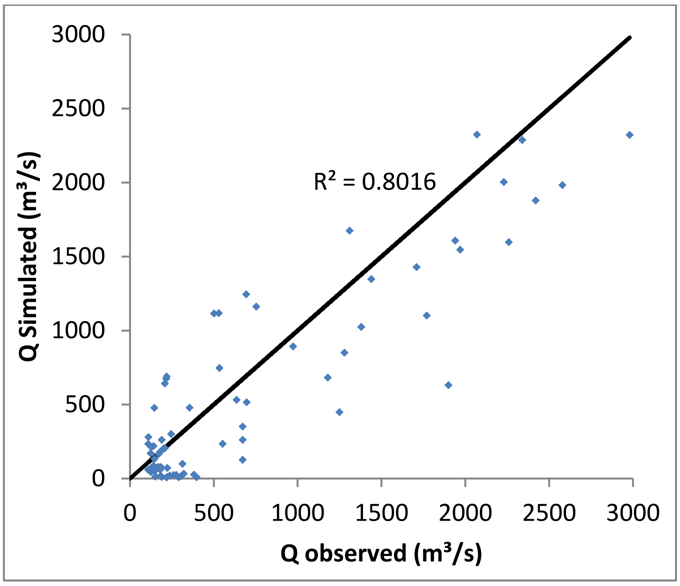

Figure 8-24: Scatter plot of observed and simulated discharges of Sunkoshi sub-basin

The comparison of simulated discharges between Saptakoshi basin and Sunkoshi sub-basin shows a similar pattern of discharge variation. Same parameters are used for both the basins.

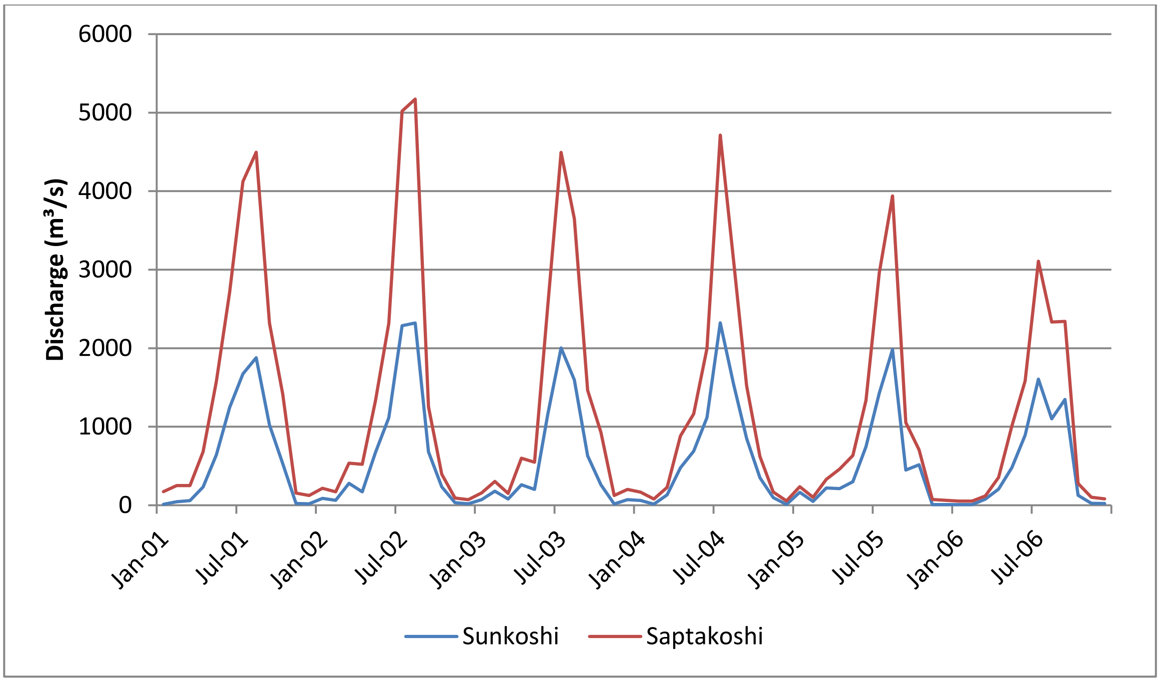

Figure 8-25: Comparison of simulated discharges main basin and sub-basin

8.4 Runoff map

An average runoff map is created using the monthly discharge computed by the model for each cell as shown in Figure 8-26. The model output provides discharge values for each pixel and each month. These data are accumulated as a (3x3) matrix for each basin. An excel VBA script and python script is written to compute average runoff for each of the catchment and produce and ASCII file that represents the runoff map of each basin.

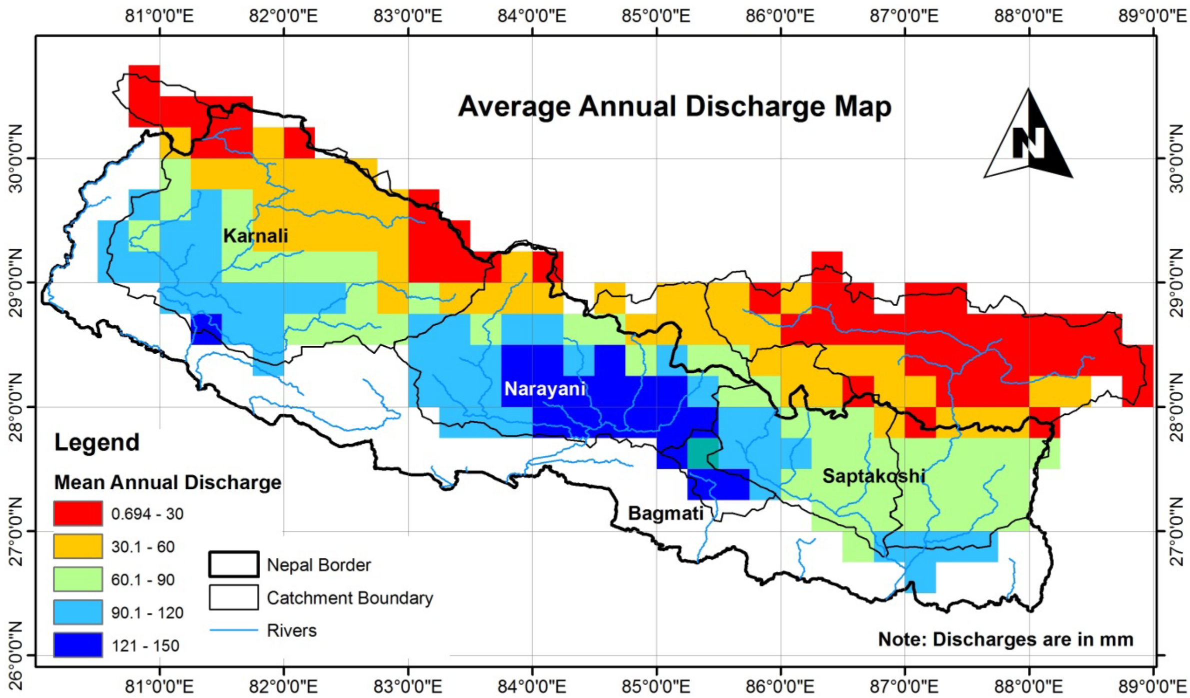

Figure 8-26: Average runoff map of Nepal

CHAPTER IX

CONCLUSION AND DISCUSSIONS

9.1 Conclusion

TRMM satellite precipitation product is assessed against the observed gauge rainfall data for the period from 2001 to 2008 on daily, monthly, yearly and mean monthly time scale over the basins of Nepal. Monthly TRMM satellite precipitation data is also tested for it applicability in runoff modeling over 4 major basins of Nepal.

Among the various satellite precipitation products, the basis for selecting TRMM product is their accumulation time, spatial resolution, data availability and conclusions from the previous studies about the use of satellite based precipitation product in the country.

Point to pixel comparison method is adopted for the evaluation of satellite products. In this approach, a point measurement of rainfall at the gauge station is compared with concurrent pixel values of satellite derived rainfall at the gauge location. The gauge value represents a rainfall at a point while satellite precipitation represents precipitation over the pixel.

The reliability of using Point to pixel comparison method and spatial variability of precipitation over the country is also checked. The TRMM precipitation data has a spatial resolution of 0.25° x 0.25°. This means it assigns a fix value for an area of about 27.5 km x 27.5 km. One of the pixels is selected and daily, monthly and yearly precipitation is compared with the gauge stations lying in the same pixel to observe the spatial variability within the pixel. It can be observed from the comparison that precipitation is not uniform in the gauge stations even within one pixel. The trend shows increasing precipitation on higher elevation. Comparing precipitation data of these gauge station with TRMM product shows that TRMM data estimates and assigns an average precipitation value falling over the pixel. The accuracy of the precipitation estimate also depends on spatial resolution of the satellite product.

The comparison of TRMM rainfall product with gauge observed data for daily precipitation showed that TRMM is underestimating rainfall for most of the regions. This is verified by most of the statistical comparison methods. Nash Sutcliffe Efficiency (R^2) for most of the stations is negative. It has also been identified from the study that the efficiency of estimation decreases with increasing elevation. The reason behind this decrement in performance of satellite product may be due to rain shadow effect on high hills. Moreover, an average of negative estimation bias (EB) and negative Normalized Accumulated Difference (NAD) states an underestimation of TRMM product. The overall average of Satellite Conditional Probability of Difference (CPOD_S) equal to 0.70 reflects accurate detection of precipitation by TRMM product.

On the other hand, when the daily precipitation data are accumulated and used for the comparison of monthly precipitation, the Nash Sutcliffe Efficiency increases. Most of the gauge stations show R^2 value above 0.5. An average Estimation Bias (EB) of -11.3% and Normalized Accumulated Difference (NAD) of -12% is achieved that reflects the suitability for use of monthly accumulated TRMM precipitation data for hydrological analysis. There are also some extreme events with some unreliable estimations. These estimations are generally on high elevation. The reason behind this is already explained.

Similarly, the yearly accumulated data are also used for comparison with yearly precipitation recordings on the gauge stations from the period of 2001 to 2008. But, this comparison did not show a good result. The yearly TRMM precipitation data sets seems to be deviated from those observed at stations. Most of the Statistical parameters showed an underestimation of precipitation values. This might have probably caused due to accumulation of errors from daily to monthly and then monthly to yearly as it can be seen from daily and monthly comparison of data sets that TRMM data sets are underestimating precipitation at the gauge stations. But they are still acceptable as the difference is small. Now, when it comes to comparison for annual precipitation, the difference accumulated and become high.

Moreover, the comparisons of monthly average precipitations also provide a good result. The Nash Sutcliffe Efficiency is found to be at the range of 0.5 to 1 for most of the stations. The maximum value of R^2 equal to 0.98 for some of the station shows a high reliability of TRMM precipitation data. An average Estimation Bias (EB) of -8% is achieved, which seems to be quiet acceptable.

Further, the satellite precipitation is analyzed for estimation of runoff for various river basins of Nepal. It is suggested to analyze the monthly discharges through the basin as the monthly satellite estimates appeared to be more reliable than daily and yearly.

The simple Monthly water balance model developed by Thornthwaite (1948) is used to check the applicability of TRMM Monthly data for discharge estimation; the model being run for 6 years period from 2001 to 2006. TRMM data without any bias correction is used to feed the precipitation data to the model. Discharge data estimated by the model is then compared with the actual observed data from the gauge station. The simulation of the model showed quiet acceptable result although it is unable to catch up the peak in some years. The parameters adjusted for the basins of Nepal showed that 90% of the rainfall is immediately drained by rivers resulting in flash floods.

9.2 Discussion

The overall conclusion of the study is that monthly accumulated TRMM data could be used independently without any bias correction factor for runoff simulation. But, since TRMM is underestimating the precipitation, appropriate correction factor can be developed for higher accuracy. TRMM satellite data can be used in the catchment areas with insufficient rain gauge networks for runoff simulation in early investigations.

Water balance model developed by Thornthwaite is a simple model for initial investigation of runoffs from the catchment. This model can also be easily used with TRMM monthly satellite data for prediction of monthly discharge in those catchments where data are not available.

The conclusions derived in this thesis work seem to be in good agreement with the last year's thesis analyzed by Mr. Sunil Ghaju [24]. Thus, it could be the correct analysis for precipitation evaluation for basins of Nepal.

9.3 Further Improvements

Considering the limitations of the study and results of the analysis, following recommendations are drawn:

- From the literatures, it can be seen that TRMM is well estimating precipitation data to derive hydrographs for large size catchments. But, in this case, TRMM satellite product is underestimating precipitation in most of the regions over Nepal. An appropriate correction factor should be developed that could take an account of change in elevation. It is wise to study the reason behind the underestimation of TRMM satellite data. The error in estimation could be due to two possible reasons.
  - Effect of localized precipitation that TRMM is unable to address
  - Error in recording at the gauge station. This could also be the cause as local, unskilled person is employed for daily observation of rainfall. There can also be the case that the observer is assuming the data without taking the record. So, regular evaluation of the gauge data should be done to accurate measurement of data. It can also be possible to use an automatic rain gauge station that directly sends the precipitation records to the central data collection station.
- This study focused on comparison of TRMM with Gauge data only by Point to Pixel approach. Further studies can be done with pixel to pixel comparison.
- The monthly water balance model seems working well for the estimation of discharges through the catchment. This model assumes a single value of soil Moisture for the whole area. Further improvements to the model can be done by dividing the area according to the soil type and land use.
- In this study, due to time limitation, only TRMM satellite product is evaluated. Further analyses of other satellite products are also recommended. The next alternative could be CMORPH which produces precipitation analysis at a very high spatial and temporal resolution.

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APPENDIX 1

HYDRO-METEREOLOGICAL STATIONS OF NEPAL

S.no	Station name	Index no.	Type of station	District	Latitude DD	Latitude MM	Longitude DD	Longitude MM	Elevation (m)
1	Kakerpakha	0101	Precipitation	Baitadi	29	39	80	30	842
2	Baitadi	0102	Precipitation	Baltadi	29	33	80	25	1635
3	Patan (west)	0103	Climatology	Baitadi	29	28	80	32	1266
4	Dadeldhura	0104	Synoptic	Dadeldhura	29	18	80	35	1848
5	Mahendra nagar	0105	Agrometeorology	Kanchanpur	29	2	80	13	176
6	Belauri santipur	0106	Precipitation	Kanchanpur	28	41	80	21	159
7	Darchula	0107	Climatology	Darchula	29	51	80	34	1097
8	Satbanjh	0108	Precipitation	Baltadi	29	32	80	28	2370
9	Pipalkot	0201	Precipitation	Bajhang	29	37	80	52	1456
10	Chainpur(west)	0202	Climatology	Bajhang	29	33	81	13	1304
11	Silgadhi doti	0203	Climatology	Doti	29	16	80	59	1360
12	Bajura	0204	Precipitation	Bajura	29	23	81	19	1400
13	Katai	0205	Precipitation	Doti	29	0	81	8	1388
14	Asara ghat	0206	Precipitation	Achham	28	57	81	27	650
15	Tikapur	0207	Climatology	Kailali	28	32	81	7	140
16	Sandepani	0208	Precipitation	Kailali	28	45	80	55	195
17	Dhangadhi(atariya)	0209	Synoptic	Kaliali	28	48	80	33	187
18	Bangga camp	0210	Precipitation	Achham	28	58	81	7	340
19	Khaptad	0211	Precipitation	Doti	29	23	81	12	3430
20	Sitapur	0212	Precipitation	Kailali	28	34	80	49	152
21	Kola gaun	0214	Precipitation	Doti	29	7	80	41	1304
22	Godavari(west)	0215	Climatology	Kailali	28	52	80	38	288
23	Mangalsen	0217	Precipitation	Achham	29	9	81	17	1345
24	Dipayal (doti)	0218	Synoptic	Doti	29	14	80	56	720
25	Oli gaun	0220	Climatology	Achham	29	10	81	17	820
26	Thirpu	0302	Precipitation	Kalikot	29	19	81	46	1006
27	Jumla	0303	Synoptic	Jumla	29	17	82	10	2300
28	Guthi chaur	0304	Precipitation	Jumla	29	17	82	19	3080
29	Sheri ghat	0305	Precipitation	Kalikot	29	8	81	36	1210
30	Gam shree nagar	0306	Precipitation	Mugu	29	33	82	9	2133
31	Rara	0307	Climatology	Mugu	29	33	82	7	3048
32	Nagma	0308	Precipitation	Kalikot	29	12	81	54	1905
33	Bijayapur (raskot)	0309	Precipitation	Kalikot	29	14	81	38	1814
34	Dipal gaun	0310	Climatology	Jumla	29	16	82	13	2310
35	Simikot	0311	Climatology	Humla	29	58	81	50	2800
36	Dunai	0312	Climatology	Dolpa	28	56	82	55	2058
37	Darma	0313	Precipitation	Humla	29	44	82	6	1950
38	Pusma camp	0401	Climatology	Surkhet	28	53	81	15	950
39	Dailekh	0402	Climatology	Dailekh	28	51	81	43	1402
40	Jamu (tikuwa kuna)	0403	Precipitation	Surkhet	28	47	81	20	260
41	Jajarkot	0404	Precipitation	Jajarkot	28	42	82	12	1231
42	Chisapani(karnali)	0405	Climatology	Bardiya	28	39	81	16	225
43	Surkhet(birendra nagar)	0406	Synoptic	Surkhet	28	36	81	37	720
44	Kusum	0407	Precipitation	Banke	28	1	82	7	235
45	Gulariya	0408	Precipitation	Bardiya	28	10	81	21	215
46	Khajura (nepalganj)	0409	Agrometeorology	Banke	28	6	81	34	190
47	Bale budha	0410	Precipitation	Dailekh	28	47	81	35	610
48	Rajapur	0411	Precipitation	Bardiya	28	26	81	6	129
49	Naubasta	0412	Precipitation	Banke	28	16	81	43	135
50	Shyano shree(chepang)	0413	Precipitation	Bardiya	28	21	81	42	510
51	Baijapur	0414	Precipitation	Banke	28	3	81	54	226
52	Bargadaha	0415	Precipitation	Bardiya	28	26	81	21	200

APPENDIX 1: Hydrometeorological Stations of Nepal

S.no	Station name	Index no.	Type of station	District	Latitude DD	Latitude MM	Longitude DD	Longitude MM	Elevation (m)
53	Nepalgunj(reg.off.)	0416	Climatology	Banke	28	4	81	37	144
54	Rani jaruwa nursery	0417	Climatology	Bardiya	28	23	81	21	200
55	Maina gaun (d.bas)	0418	Precipitation	Jajarkot	28	59	82	17	2000
56	Sikta	0419	Agrometeorology	Banke	28	2	81	47	195
57	Nepalgunj airport	0420	Aeronatical	Banke	28	6	81	40	165
58	Rukumkot	0501	Precipitation	Rukum	28	36	82	38	1560
59	Libang gaun	0504	Precipitation	Rolpa	28	18	82	38	1270
60	Bijuwar tar	0505	Precipitation	Pyuthan	28	6	82	52	823
61	Nayabasti (dang)	0507	Precipitation	Dang	28	13	82	7	698
62	Tulsipur	0508	Climatology	Dang	28	8	82	18	725
63	Ghorahi (masina)	0509	Precipitation	Dang	28	3	82	30	725
64	Koilabas	0510	Precipitation	Dang	27	42	82	32	320
65	Salyan bazar	0511	Climatology	Salyan	28	23	82	10	1457
66	Luwamjula bazar	0512	Precipitation	Salyan	28	18	82	17	885
67	Chaur jhari tar	0513	Climatology	Rukum	28	38	82	12	910
68	Musikot(rukumkot)	0514	Climatology	Rukum	28	38	82	29	2100
69	Ghorai (dang)	0515	Synoptic	Dang	28	3	82	30	634
70	Jomsom	0601	Climatology	Mustang	28	47	83	43	2744
71	Thakmarpha	0604	Agrometeorology	Mustang	28	45	83	42	2566
72	Baglung	0605	Climatology	Baglung	28	16	83	36	984
73	Tatopani	0606	Precipitation	Myagdi	28	29	83	39	1243
74	Lete	0607	Climatology	Mustang	28	38	83	36	2384
75	Ranipauwa (m.nath)	0608	Precipitation	Mustang	28	49	83	53	3609
76	Beni bazar	0609	Climatology	Myagdi	28	21	83	34	835
77	Ghami (mustang)	0610	Precipitation	Mustang	29	3	83	53	3465
78	Mustang(lomangthang)	0612	Climatology	Mustang	29	11	83	58	3705
79	Karki neta	0613	Precipitation	Parbat	28	11	83	45	1720
80	Kushma	0614	Climatology	Parbat	28	13	83	42	891
81	Bobang	0615	Precipitation	Baglung	28	24	83	6	2273
82	Gurja khani	0616	Climatology	Myagdi	28	36	83	13	2530
83	Ghorepani	0619	Precipitation	Myagdi	28	24	83	44	2742
84	Tribeni	0620	Precipitation	Parbat	28	2	83	39	700
85	Darbang	0621	Precipitation	Myagdi	28	23	83	24	1160
86	Rangkhani	0622	Precipitation	Baglung	28	9	83	34	1740
87	Samar gaun	0624	Precipitation	Mustang	28	58	83	47	3570
88	Sanda	0625	Precipitation	Mustang	28	54	83	41	3570
89	Bega	0626	Precipitation	Myagdi	28	28	83	36	1770
90	Kuhun	0627	Precipitation	Myagdi	28	23	83	29	1550
91	Muna	0628	Precipitation	Myagdi	28	30	83	18	1970
92	Baghara	0629	Precipitation	Myagdi	28	34	83	23	2330
93	Sirkon	0630	Precipitation	Parbat	28	8	83	37	790
94	Chhoser	0633	Climatology	Mustang	29	11	83	59	3870
95	Ridi bazar	0701	Precipitation	Gulmi	27	57	83	26	442
96	Tansen	0702	Climatology	Palpa	27	52	83	32	1067
97	Butwal	0703	Climatology	Rupandehi	27	42	83	28	205
98	Beluwa (girwari)	0704	Precipitation	Nawalparasi	27	41	84	3	150
99	Bhairahawa airport	0705	Aeronatical	Rupandehi	27	31	83	26	109
100	Dumkauli	0706	Agrometeorology	Nawalparasi	27	41	84	13	154
101	Bhairahawa (agric)	0707	Agrometeorology	Rupandehi	27	32	83	28	120
102	Parasi	0708	Precipitation	Nawalparasi	27	32	83	40	125
103	Dumkibas	0710	Precipitation	Nawalparasi	27	35	83	52	164
104	Khanchikot	0715	Climatology	Arghakhanchi	27	56	83	9	1760

S.no	Station name	Index no.	Type of station	District	Latitude DD	MM	Longitude DD	MM	Elevation (m)
105	Taulihawa	0716	Climatology	Kapilbastu	27	33	83	4	94
106	Pattharkot (west)	0721	Precipitation	Kapilbastu	27	46	83	3	200
107	Musikot	0722	Precipitation	Gulmi	28	10	83	16	1280
108	Bhagwanpur	0723	Precipitation	Kapilbastu	27	41	82	48	80
109	Tamghas	0725	Climatology	Gulmi	28	4	83	15	1530
110	Garakot	0726	Precipitation	Palpa	27	52	83	48	500
111	Lumbini mandir	0727	Climatology	Rupandehi	27	28	83	17	95
112	Simari	0728	Climatology	Nawalparasi	27	32	83	45	154
113	Sitapur(nepaney)	0730	Precipitation	Arghakhanchi	27	54	83	9	1201
114	Jagat (setibas)	0801	Precipitation	Gorkha	28	22	84	54	1334
115	Khudi bazar	0802	Climatology	Lamjung	28	17	84	22	823
116	Pokhara airport	0804	Aeronatical	Kaski	28	13	84	0	827
117	Syangja	0805	Climatology	Syangia	28	6	83	53	868
118	Larke samdo	0806	Precipitation	Gorkha	28	40	84	37	3650
119	Kunchha	0807	Precipitation	Lamiung	28	8	84	21	855
120	Bandipur	0808	Precipitation	Tanahun	27	56	84	25	965
121	Gorkha	0809	Agrometeorology	Gorkha	28	0	84	37	1097
122	Chapkot	0810	Climatology	Syangja	27	53	83	49	460
123	Malepatan (pokhara)	0811	Agrometeorology	Kaski	28	7	84	7	856
124	Bhadaure deurali	0813	Precipitation	Kaski	28	16	83	49	1600
125	Lumle	0814	Agrometeorology	Kaski	28	18	83	48	1740
126	Khairini tar	0815	Agrometeorology	Tanahun	28	2	84	6	500
127	Chame	0816	Climatology	Manang	28	33	84	14	2680
128	Damauli	0817	Climatology	Tanahun	27	58	84	17	358
129	Lamachaur	0818	Precipitation	Kaski	28	16	83	58	1070
130	Manang bhot	0820	Precipitation	Manang	28	40	84	1	3420
131	Ghandruk	0821	Precipitation	Kaski	28	23	83	48	1960
132	Gharedhunga	0823	Precipitation	Lamjung	28	12	84	37	1120
133	Siklesh	0824	Precipitation	Kaski	28	22	84	6	1820
134	Walling	0826	Precipitation	Syangja	27	59	83	46	750
135	Rumjakot	0827	Precipitation	Tanahun	27	52	84	8	660
136	Sallyan	0829	Precipitation	Kaski	28	16	83	45	1000
137	Pamdur	0830	Precipitation	Kaski	28	16	83	47	1160
138	Dandaswanra	0832	Precipitation	Syangja	28	5	83	55	1432
139	Chhekampar	0833	Precipitation	Gorkha	28	29	85	0	3300
140	Rampur	0902	Agrometeorology	Chitawan	27	37	84	25	256
141	Jhawani	0903	Precipitation	Chitawan	27	35	84	32	270
142	Chisapani gadhi	0904	Precipitation	Makwanpur	27	33	85	8	1706
143	Daman	0905	Climatology	Makwanpur	27	36	85	5	2314
144	Hetaunda n.f.i.	0906	Climatology	Makwanpur	27	25	85	3	474
145	Amlekhganj	0907	Precipitation	Bara	27	17	85	0	396
146	Simara airport	0909	Aeronatical	Bara	27	10	84	59	130
147	Nijgadh	0910	Precipitation	Bara	27	11	85	10	244
148	Parwanipur	0911	Agrometeorology	Bara	27	4	84	58	115
149	Ramoli bairiya	0912	Precipitation	Routahat	27	1	85	23	152
150	Markhu gaun	0915	Precipitation	Makwanpur	27	37	85	9	1530
151	Birganj	0918	Precipitation	Parsa	27	0	84	52	91
152	Makwanpur gadhi	0919	Precipitation	Makwanpur	27	25	85	10	1030
153	Beluwa(manahari)	0920	Precipitation	Makwanpur	27	33	84	49	274
154	Kalaiya	0921	Precipitation	Bara	27	2	85	0	140
155	Gaur	0922	Climatology	Routahat	26	46	85	18	90
156	Kolbhi	0923	Precipitation	Bara	26	55	85	1	109

APPENDIX 1: Hydrometeorological Stations of Nepal

S.no	Station name	Index no.	Type of station	District	Latitude DD	MM	Longitude DD	MM	Elevation (m)
157	Rajaiya	0925	Precipitation	Makwanpur	27	26	84	59	332
158	Bharatpur	0927	Climatology	Chitawan	27	40	84	26	205
159	Timure	1001	Climatology	Rasuwa	28	17	85	23	1900
160	Aru ghat d.bazar	1002	Precipitation	Dhading	28	3	84	49	518
161	Nuwakot	1004	Climatology	Nuwakot	27	55	85	10	1003
162	Dhading	1005	Precipitation	Dhading	27	52	84	56	1420
163	Gumthang	1006	Precipitation	Sindhupalchok	27	52	85	52	2000
164	Kakani	1007	Agrometeorology	Nuwakot	27	48	85	15	2064
165	Nawalpur	1008	Precipitation	Sindhupalchok	27	48	85	37	1592
166	Chautara	1009	Precipitation	Sindhupalchok	27	47	85	43	1660
167	Thankot	1015	Precipitation	Kathmandu	27	41	85	12	1630
168	Sarmathang	1016	Precipitation	Sindhupalchok	27	57	85	36	2625
169	Dubachaur	1017	Precipitation	Sindhupalchok	27	52	85	34	1550
170	Mandan	1020	Precipitation	Kabhre	27	42	85	39	1365
171	Godavari	1022	Climatology	Lalitpur	27	35	85	24	1400
172	Dolal ghat	1023	Precipitation	Kabhre	27	38	85	43	710
173	Dhulikhel	1024	Climatology	Kabhre	27	37	85	33	1552
174	Bahrabise	1027	Precipitation	Sindhupalchok	27	47	85	54	1220
175	Pachuwar ghat	1028	Precipitation	Kabhre	27	34	85	45	633
176	Khumaltar	1029	Agrometeorology	Lalitpur	27	40	85	20	1350
177	Kathmandu airport	1030	Aeronatical	Kathmandu	27	42	85	22	1337
178	Sankhu	1035	Precipitation	Kathmandu	27	45	85	29	1449
179	Panchkhal	1036	Climatology	Kabhre	27	41	85	38	865
180	Dhunibesi	1038	Climatology	Dhading	27	43	85	11	1085
181	Panipokhari(kathmandu)	1039	Climatology	Kathmandu	27	44	85	20	1335
182	Nagarkot	1043	Climatology	Bhaktapur	27	42	85	31	2163
183	Khopasi(panauti)	1049	Precipitation	Kabhre	27	35	85	31	1517
184	Bhaktapur	1052	Precipitation	Bhaktapur	27	40	85	25	1330
185	Thamachit	1054	Precipitation	Rasuwa	28	10	85	19	1847
186	Dhunche	1055	Climatology	Rasuwa	28	6	85	18	1982
187	Pansayakhola	1057	Precipitation	Nuwakot	28	1	85	7	1240
188	Tarke ghyang	1058	Precipitation	Sindhupalchok	28	0	85	33	2480
189	Changu harayan	1059	Precipitation	Bhaktapur	27	42	85	25	1543
190	Chapa gaun	1060	Precipitation	Lalitpur	27	36	85	20	1448
191	Sangachok	1062	Precipitation	Sindhupalchok	27	42	85	43	1327
192	Thokarpa	1063	Precipitation	Sindhupalchok	27	42	85	47	1750
193	Buddhanilakantha	1071	Climatology	Kathmandu	27	47	85	22	1350
194	Khokana	1073	Climatology	Lalitpur	27	38	85	17	1212
195	Sundarijal	1074	Precipitation	Kathmandu	27	46	85	25	1490
196	Lele	1075	Precipitation	Lalitpur	27	35	85	17	1590
197	Naikap	1076	Precipitation	Kathmandu	27	41	85	15	1520
198	Sundarijal	1077	Precipitation	Kathmandu	27	45	85	25	1360
199	Dhap	1078	Precipitation	Sindhupalchok	27	54	85	38	1310
200	Nagarjun	1079	Precipitation	Kathmandu	27	45	85	15	1690
201	Tikathali	1080	Precipitation	Lalitpur	27	39	85	21	1341
202	Jetpurphedhi	1081	Precipitation	Kathmandu	27	47	85	17	1320
203	Nangkhel	1082	Precipitation	Bhaktapur	27	39	85	28	1428
204	Tarebhir	1083	Climatology	Kathmandu	27	47	85	24	1848
205	Nagdaha	1101	Precipitation	Dolkha	27	41	86	6	850
206	Charikot	1102	Precipitation	Dolkha	27	40	86	3	1940
207	Jiri	1103	Agrometeorology	Dolkha	27	38	86	14	2003
208	Melung	1104	Precipitation	Dolkha	27	31	86	3	1536

S.no	Station name	Index no.	Type of station	District	Latitude DD	Latitude MM	Longitude DD	Longitude MM	Elevation (m)
209	Sindhuli gadhi	1107	Climatology	Sindhuli	27	17	85	58	1463
210	Bahun tilpung	1108	Precipitation	Sindhuli	27	11	86	10	1417
211	Pattharkot(east)	1109	Precipitation	Sarlahi	27	5	85	40	275
212	Tulsi	1110	Precipitation	Dhanusa	27	2	85	55	457
213	Janakpur airport	1111	Climatology	Dhanusa	26	43	85	58	90
214	Chisapani bazar	1112	Precipitation	Dhanusa	26	55	86	10	165
215	Nepalthok	1115	Precipitation	Sindhuli	27	27	85	49	1098
216	Hariharpur gadhi valley	1117	Precipitation	Sindhuli	27	20	85	30	250
217	Manusmara	1118	Climatology	Sarlahi	26	53	85	25	100
218	Gausala	1119	Precipitation	Mahottari	26	53	85	47	200
219	Malangwa	1120	Precipitation	Sarlahi	26	52	85	34	150
220	Karmaiya	1121	Climatology	Sarlahi	27	7	85	28	131
221	Jalesore	1122	Climatology	Mahottari	26	39	85	47	172
222	Manthali	1123	Precipitation	Ramechhap	27	28	86	5	495
223	Chaurikhark	1202	Precipitation	Solukhumbu	27	42	86	43	2619
224	Pakarnas	1203	Precipitation	Solukhumbu	27	26	86	34	1982
225	Aisealukhark	1204	Precipitation	Khotang	27	21	86	45	2143
226	Okhaldhunga	1206	Synoptic	Okhaldhunga	27	19	86	30	1720
227	Mane bhanjyang	1207	Precipitation	Okhaldhunga	27	29	86	25	1576
228	Kurule ghat	1210	Precipitation	Khotang	27	8	86	26	497
229	Khotang bazar	1211	Precipitation	Khotang	27	2	86	50	1295
230	Phatepur	1212	Climatology	Saptari	26	44	86	56	100
231	Udayapur gadhi	1213	Climatology	Udayapur	26	56	86	31	1175
232	Lahan	1215	Agrometeorology	Siraha	26	44	86	26	138
233	Siraha	1216	Precipitation	Siraha	26	39	86	13	102
234	Salleri	1219	Precipitation	Solukhumbu	27	30	86	35	2378
235	Diktel	1222	Precipitation	Khotang	27	13	86	48	1623
236	Rajbiraj	1223	Climatology	Saptari	26	33	86	45	91
237	Sirwa	1224	Precipitation	Solukhumbu	27	33	86	23	1662
238	Barmajhiya	1226	Precipitation	Saptari	26	36	86	54	85
239	Gaighat	1227	Precipitation	Udayapur	26	47	86	43	152
240	Num	1301	Precipitation	Sankhuvwasabha	27	33	87	17	1497
241	Chainpur (east)	1303	Climatology	Sankhuvwasabha	27	17	87	20	1329
242	Pakhribas	1304	Agrometeorology	Dhankuta	27	3	87	17	1680
243	Leguwa ghat	1305	Precipitation	Dhankuta	27	8	87	17	410
244	Munga	1306	Precipitation	Dhankuta	27	2	87	14	1317
245	Dhankuta	1307	Synoptic	Dhankuta	26	59	87	21	1210
246	Mul ghat	1308	Precipitation	Dhankuta	26	56	87	20	365
247	Tribeni	1309	Precipitation	Dhankuta	26	56	87	9	143
248	Dharan bazar	1311	Climatology	Sunsari	26	49	87	17	444
249	Haraincha	1312	Precipitation	Morang	26	37	87	23	152
250	Terhathum	1314	Climatology	Terhathum	27	8	87	33	1633
251	Chatara	1316	Precipitation	Sunsari	26	49	87	10	183
252	Chepuwa	1317	Precipitation	Sankhuvwasabha	27	46	87	25	2590
253	Biratnagar airpoart	1319	Aeronatical	Morang	26	29	87	16	72
254	Tarahara	1320	Agrometeorology	Sunsari	26	42	87	16	200
255	Tumlingtar	1321	Precipitation	Sankhuvwasabha	27	17	87	13	303
256	Machuwaghat	1322	Precipitation	Dhankuta	26	58	87	10	158
257	Dingla	1325	Precipitation	Bhojpur	27	22	87	9	1190
258	Letang	1326	Precipitation	Morang	26	44	87	30	250
259	Lungthung	1403	Precipitation	Taplejung	27	33	87	47	1780
260	Taplejung	1405	Synoptic	Taplejung	27	21	87	40	1732

APPENDIX 2

PYHTON SCRIPTS

APPENDIX 1: Hydrometeorological Stations of Nepal

S.no	Station name	Index no.	Type of station	District	Latitude DD	MM	Longitude DD	MM	Elevation (m)
261	Memeng jagat	1406	Precipitation	Panchther	27	12	87	56	1830
262	Ilam tea estate	1407	Agrometeorology	Ilam	26	55	87	54	1300
263	Damak	1408	Precipitation	Jhapa	26	40	87	42	163
264	Anarmani birta	1409	Precipitation	Jhapa	26	38	87	59	122
265	Himali gaun	1410	Precipitation	Ilam	26	53	88	2	1654
266	Chandra gadhi	1412	Precipitation	Jhapa	26	34	88	3	120
267	Sanischare	1415	Precipitation	Jhapa	26	41	87	58	168
268	Kanyam tea estate	1416	Climatology	Ilam	26	52	88	4	1678
269	Phidim (panchther)	1419	Climatology	Panchther	27	9	87	45	1205
270	Dovan	1420	Precipitation	Taplejung	27	21	87	36	763
271	Gaida (kankai)	1421	Agrometeorology	Jhapa	26	35	87	54	143
272	Kechana	1422	Climatology	Jhapa	26	24	88	1	60

The Gauge stations marked with red color are excluded in the beginning due to less precipitation data on those stations. The missing data on those stations are more than 1000 days (i.e. more than 3 years of data is missing out of 8 years).

Running the scripts

Map data

1. Put all the hdf files in one folder. E.g. C:\Mapdata\hdf_folder.

2. Create a directory to put ASCII file. E.g. C:\Mapdata\ASCII_folder.
   Run the script ***hdf_to_folder .py*** with syntax as following. Note: This command should be run in FWTools Shell.

C:\python25> *python␣<pythonscript>␣<Input Argument>␣<Output Argument>␣<GDAL location>*

C:\python25> *python ␣C:\mapdata\pythonscripts\hdf_to_ascii.py ␣ C:\mapdata\hdf_folder ␣ C:\mapdata\ascii_folder ␣ C:\FWTools1.2.2\bin*

3. Now, create a directory to save rotated, clipped ASCII files. E.g. C:\Mapdata\Rotate_ASCII. Note to modify the coordinates of the clip before running the script. The clip coordinates are taken to be 82°00' to 89°00' Easting to 26°00' to 31°00' Northing.
   Now, run the script ***rotate_clip.py*** with syntax as following. Note: This command should be run in FWTools Shell.

C:\python25> *python␣<pythonscript>␣<Input Argument>␣<Output Argument>*

C:\python25> *python ␣ C:\mapdata\pythonscripts\rotate_clip.py ␣ C:\mapdata\ascii_folder ␣ C:\mapdata\rotate_ascii*

4. Create a directory for summing up the ASCII file for one day. E.g. C:\Mapdata\sum_ASCII.
   Run the script ***sum_ascii.py*** with syntax as following. Note: This command should be run in FWTools Shell.

C:\python25> *python␣<pythonscript>␣<Input Argument>␣<Output Argument>*

C:\python25> *python ␣ C:\mapdata\pythonscripts\sum_ascii.py ␣ C:\mapdata\rotate_ascii ␣ C:\mapdata\sum_ascii*

5. Create a directory to save ascii files summed for one month. E.g. C:\Mapdata\sum_month.
   Run the script ***sum_month.py*** with syntax as following. Note: This command should be run in FWTools Shell.

C:\python25> *python␣<pythonscript>␣<Input Argument>␣<Output Argument>*

C:\python25> *python ␣ C:\mapdata\pythonscripts\sum_month.py ␣ C:\mapdata\sum_ascii ␣ C:\mapdata\sum_month*

6. Create a directory to save ascii files summed for one year. E.g. C:\Mapdata\sum_year.
   Run the script ***sum_year.py*** with syntax as following. Note: This command should be run in FWTools Shell.

C:\python25> *python␣<pythonscript>␣<Input Argument>␣<Output Argument>*

C:\python25> *python ⎵ C:\mapdata\pythonscripts\sum_year.py ⎵ C:\mapdata\sum_month ⎵ C:\mapdata\sum_year*

7. Now, the pixel value at the coordinate of each gauge station is extracted. The script name extract_pixel.py is prepared for this purpose. The script needs list of station with its coordinate and ASCII file as inputs. The path for input and output files are to be edited in the script itself. The script is run in FWTools shell.

C:\python25> *python⎵<pythonscript>*

C:\python25> *python ⎵ C:\mapdata\pythonscripts\extract_pixel.py*

8. Similar script ***'Extract_month.py'*** and ***'Extract-year.py'*** is prepared for extracting pixel values from monthly and yearly ASCII maps.

Gauge data

Sorting of Gauge data includes finding the missing value and arranging all data in a single file. All calculations for Gauge data are done in folder, C:\Gaugedata\Gauge_cal\.

9. Create a file named "*stncords.csv*" that contains station code along with its coordinates in decimal degrees.
10. Run the scripts '***nearstn.py'***. This script determines the three nearest gauge stations to each station. This script is run in command prompt.

C:\python25> *python⎵<pythonscript>⎵<Input Argument>⎵<Output Argument>*

C:\python25> *python ⎵ C:\mapdata\pythonscripts\neartstn.py ⎵ C:\Gaugedata\Gauge_cal\ nearstn.csv ⎵ C:\Gaugedata\Gauge_cal*

The script creates a file named *nearstn.csv*. Remove the blank lines between data.

11. Arrange the precipitation data in a folder C:\Gaugedata\Gauge\. Each station should contain 8 files each representing a year. If data of any year is missing, then create a file with days and data as "DNA".
    Run the script '***formatprecip.py'***. This script arranges all data of all stations in a single file. This script is run from command prompt.

C:\python25> *python⎵<pythonscript>⎵<Input Argument>⎵<Output Argument>*

C:\python25> *python ⎵ C:\mapdata\pythonscripts\formatprecip.py ⎵ C:\Gaugedata\Gauge C:\Gaugedata\Gauge_cal*

This script creates a file named "*formatprecip.txt*". Remove a blank line between station name and data. Missing data are represented as "999" and unavailable data as "-99".

12. Script 'f***indmissing.py'*** calculates the missing data on any day of the station from 3 nearest stations. This script takes 2 input files. The script is run in command prompt.

C:\python25> *python⎵<pythonscript>⎵<Input Argument1>⎵<Input Argument2>⎵<Output Argument>*

C:\python25> *python ␣ C:\mapdata\pythonscripts\findmissing.py ␣ C:\Gaugedata\Gauge_cal\formatprecip.txt ␣ C:\Gaugedata\Gauge_cal\nearstns.csv ␣ C:\Gaugedata\Gauge_cal*

This script creates a file "*combprecip.txt*". Unavailable data is represented as "-99".

13. A script ***'gauge_sum.py'*** is prepared for accumulating a monthly and yearly data from the daily gauge precipitation data. The path of input and output files should be edited in the script. The script is run in command prompt.

C:\python25> *python␣<pythonscript>*

C:\python25> *python ␣ C:\mapdata\pythonscripts\Gauge_sum.py*

14. Now, the data sets for the comparison are ready. The formulae for comparison of all statistical parameters are programmed in the script '***stat.py'***. The script needs multiple input files: path of output files, Gauge data sets, Radar data sets, number of data in each data sets, shape file of containing coordinates of the gauge stations and a projection file. The script is run in command prompt.

C:\python25> *python␣<pythonscript>␣<output_path> ␣<gauge_data_file>␣<radar_data_file> ␣<no._of data> ␣<shape_file> ␣<projection_file>*

C:\python25> *python C:\Pythonscripts\STAT.py C:\Stat C:\Stat\Gauge.txt C:\Stat\Radar.txt 2922 C:\stat\point_stat\Point_Stat.shp C:\stat\WGS_1984.prj*

The script outputs scatter plots in jpg format and other statistical parameters in a text file.

The scripts are listed in below:

Hdf_to_ascii.py

```
#####################################################################
# DESCRIPTION: Convert HDF file format to ASCII file format
# USAGE: run from the command prompt
# C:\Python24> python script_name.py input_folder output_folder
# e.g
# C:\Python25>python C:\Mapdata\pythonscripts\hdf_to_ascii.py
# c:\Mapdata\hdf_folder C:\Mapdata\ASCII_folder c:\FWTools1.2.2\bin
#####################################################################

# Import system modules
import sys
import os
import string
import subprocess
import linecache

#####################################################################
# Inputs
#####################################################################

# HDF grids location (folder)
hdf_folder = sys.argv[1]
# ASCII grids location (folder)
ascii_folder = sys.argv[2]
# Location of gdal_translate (bin folder for FWTools)
gdal_path = sys.argv[3]
gdal_path = (gdal_path.replace("\\", "/")) + "/gdal_translate.exe"
print gdal_path

#####################################################################
Setting number of Cells and cell size

Xcoord = "-180"
Ycoord = "-50"
cell_size = "0.25"

count = 0
dirList = os.listdir(hdf_folder)
for hdf_file in dirList:
    if hdf_file.endswith(".HDF"):
        count = count + 1
        print "Processing file No. " + str(count)
        hdf_file_ = hdf_file.replace(".", "")
        filename1 = hdf_file_[10:-4]
        if filename1 == "0":
            filename2 = hdf_file_[4:-5]+ "0" + hdf_file_[10:-4]
            print filename2
        elif filename1 == "3":
            filename2 = hdf_file_[4:-5]+ "0" + hdf_file_[10:-4]
            print filename2
        elif filename1 == "6":
            filename2 = hdf_file_[4:-5]+ "0" + hdf_file_[10:-4]
```

```
            print filename2
        elif filename1 == "9":
            filename2 = hdf_file_[4:-5]+ "0" + hdf_file_[10:-4]
            print filename2
        else:
            filename2 = hdf_file_[4:-4]
            print hdf_file_[4:-4]

        hdf_grid = hdf_folder + "\\" + hdf_file
        hdf_grid_ = "HDF4_SDS:" + hdf_folder + "\\" + hdf_file +
"://DATA_GRANULE/PlanetaryGrid/precipitation/" #the right
subdataset must be selected from the HDF5 file
        asciifile = ascii_folder + "\h" + filename2 + ".asc"
        print
        print "Converting HDF to ascii..."
        retcode = subprocess.call([gdal_path, "-of", "AAIGrid",
hdf_grid_, asciifile])
        print retcode
        print "Setting xll and yll..."
        fileInput = open(asciifile)
        text = fileInput.read()
        retrieved_line3 = linecache.getline(asciifile, 3)
        linearray3 = retrieved_line3.split("    ")
        xllcorner = linearray3[1].rstrip("\n")
        retrieved_line4 = linecache.getline(asciifile, 4)
        linearray4 = retrieved_line4.split("    ")
        yllcorner = linearray4[1].rstrip("\n")
        print "Setting cell_size..."
        retrieved_line5 = linecache.getline(asciifile, 5)
        linearray5 = retrieved_line5.split("    ")
        cellsize = linearray5[1].rstrip("\n")
        fileInput.close()
        fileOutput = open(asciifile, "w")
        fileOutput.write(text.replace(xllcorner, " " +
Xcoord).replace(yllcorner, " " + Ycoord).replace(cellsize, " " +
cell_size))
        fileOutput.close()
        linecache.clearcache()
```

Rotate_clip.py

```
#####################################################################
# DESCRIPTION: Read the ASCII matrix, rotate it 90 degree anti-
# clockwise, re-write the matrix and then clip to required region
# USAGE: From the FWtools shell
# C:\Python24> python script_name.py input_folder output_folder
# e.g
# C:\FWTools1.2.2> python c:\Mapdata\Pythonscripts\Rotate_clip.py
# C:\Mapdata\ASCII_folder C:\Mapdata\Rotated_ASCII
#####################################################################

# Import system modules
import os, sys, os.path
import gdal
from gdalconst import *

#####################################################################
# Inputs and Outputs
#####################################################################

# ASCII grids location (folder)
ascii_folder = sys.argv[1]
# Rotated ASCII grids location (folder)
ascii_rotate = sys.argv[2]

#####################################################################
# A simple matrix
# This matrix is a list of lists
# Column and row numbers start with 1
class RemoveString(str):
    def __init__(self, s=None):
        str.__init__(self, s)
    def remove(self, chars):
        s = self
        for c in chars:
            s = s.replace(c, ’’)
            return(s)

class Matrix(object):
    def __init__(self, cols, rows):
        self.cols = cols
        self.rows = rows
        # initialize matrix and fill with zeroes
        self.matrix = []
        for i in range(rows):
            ea_row = []
            for j in range(cols):
                ea_row.append(0)
            self.matrix.append(ea_row)

    def setitem(self, col, row, v):
        self.matrix[col-1][row-1] = v
        return self.matrix[col-1][row-1]
```

```
    def getitem(self, col, row):
        return self.matrix[col-1][row-1]

    def __repr__(self):
        outStr = ""
        for i in range(self.rows):
            outStr += ' %s  %s\n ' % ("", self.matrix[i])
        #################################################
        # Remove '[' and ']' from output
        #################################################
            a_outStr = outStr
            r_Remove = RemoveString(a_outStr)
            e_R = r_Remove.remove('[')
            f_Remove = RemoveString(e_R)
            g_R = f_Remove.remove(']')
        #################################################
        return g_R
###################################################################
Main program
###################################################################


driver = gdal.GetDriverByName('asc')
gdal.AllRegister()

count = 0
files = os.listdir(ascii_folder)
for name in files:
   if name.endswith(".asc"):
       filename=ascii_folder + "\\" + name
       count = count + 1
       print "Processing file No.", count
       ds = gdal.Open(filename, GA_ReadOnly)
       if ds is None:
           print 'Could not open image'
           sys.exit(1)
       rows = ds.RasterYSize
       cols = ds.RasterXSize
       bands = ds.RasterCount
       band = ds.GetRasterBand(1)
       data = band.ReadAsArray(0, 0, cols, rows)

       clip = ascii_rotate + '\\'+ name.replace("h","RC")
       f = open(clip,'w')
       print "Writing file ......."
       print >> f, 'ncols 40'
       print >> f, 'nrows 20'
       print >> f, 'xllcorner 80'
       print >> f, 'yllcorner 26'
       print >> f, 'cellsize 0.25'
       #It will Clip from 80E to 90E
       # and 26N to 31N
       print "Rotating and Writing Matrix......"
       a = Matrix(40,20) #Matrix(col,row)
```

```
        i = 1
        while i < 41:
            j = 1
            while j < 21:
                # Note the data in orginal file start from A(0,0),
while chainging grid value, change also the col and row nos.
                b = data[i+1039, j+303]
                #The data in rotated matrix start from A(1,1)
                a.setitem(21-j,i,b)
                j=j+1
            i=i+1
        print >> f, a
        f.close()
        print ″...........Ending process for file no.″, count
print ″Porcess is finished″
print ″Total No. of file processed is″, count
```

Sum_ascii.py

```
##################################################################
# DESCRIPTION: Sum 8 ASCII grids and multiply it by 3
# USAGE: From the FWtools shell
# C:\Python24> python script_name.py input_folder output_folder
# e.g
# C:\FWTools1.2.2> python c:\Mapdata\Pythonscripts\sum_ascii.py
# C:\Mapdata\Rotated_ASCII C:\Mapdata\sum_ASCII
##################################################################
#     It is IMPORTANT that the first file should be 03 UTC
##################################################################

# A simple matrix
# This matrix is a list of lists
# Column and row numbers start with 1
class RemoveString(str):
    def __init__(self, s=None):
        str.__init__(self, s)
    def remove(self, chars):
        s = self
        for c in chars:
            s = s.replace(c, '')
            return(s)

class Matrix(object):
     def __init__(self, cols, rows):
         self.cols = cols
         self.rows = rows
         # initialize matrix and fill with zeroes
         self.matrix = []
         for i in range(rows):
             ea_row = []
             for j in range(cols):
                 ea_row.append(0)
             self.matrix.append(ea_row)

     def setitem(self, col, row, v):
         self.matrix[col-1][row-1] = v
         return self.matrix[col-1][row-1]

     def getitem(self, col, row):
         return self.matrix[col-1][row-1]

     def __repr__(self):
         outStr = ""
         for i in range(self.rows):
             outStr += ' %s  %s\n ' % ("", self.matrix[i])
          ################################################
          # Remove '[' and ']' from output
          ################################################
             a_outStr = outStr
             r_Remove = RemoveString(a_outStr)
             e_R = r_Remove.remove('[')
```

```
            f_Remove = RemoveString(e_R)
            g_R = f_Remove.remove(']')
         #################################################
        return g_R

####################################################################
##Main program

import os, sys, os.path
import gdal
from gdalconst import *

k = 0
count=0
cowrite=0
l = 8
driver = gdal.GetDriverByName('asc')
gdal.AllRegister()

####################################################################
# Inputs

# HDF grids location (folder)
ascii_rotate = sys.argv[1]
# ASCII grids location (folder)
sum_ascii = sys.argv[2]

error = sum_ascii + "\\errorlog.txt"
fe = open(error,'w')
print >>fe, "Day","03","06","09","12","15","18","21","00"

files = os.listdir(ascii_rotate)
for name in files:
       filename = ascii_rotate + "\\" + name
       if filename.endswith(".asc"):
           count = count + 1
           filename_ = os.path.join(name)
           filename1 = filename_[8:-4]
           print "Processing file No.", count, filename_

###############################################################
     #give starting hour of accumation in series
     #It is very important that the initial file shoud be of 03 UTC

###############################################################
           if filename1 == "03":
               filename2 = filename_[2:-6]
               ds03 = gdal.Open(filename, GA_ReadOnly)
               if ds03 is None:
                   print 'Could not open image'
                   sys.exit(1)
               rows03 = ds03.RasterYSize
               cols03 = ds03.RasterXSize
               bands03 = ds03.RasterCount
               band03 = ds03.GetRasterBand(1)
```

```
        data03 = band03.ReadAsArray(0, 0, cols03, rows03)
    if filename1 == "06":
        ds06 = gdal.Open(filename, GA_ReadOnly)
        if ds06 is None:
            print 'Could not open image'
            sys.exit(1)
        rows06 = ds06.RasterYSize
        cols06 = ds06.RasterXSize
        bands06 = ds06.RasterCount
        band06 = ds06.GetRasterBand(1)
        data06 = band06.ReadAsArray(0, 0, cols06, rows06)
    if filename1 == "09":
        ds09 = gdal.Open(filename, GA_ReadOnly)
        if ds09 is None:
            print 'Could not open image'
            sys.exit(1)
        rows09 = ds09.RasterYSize
        cols09 = ds09.RasterXSize
        bands09 = ds09.RasterCount
        band09 = ds09.GetRasterBand(1)
        data09 = band09.ReadAsArray(0, 0, cols09, rows09)
    if filename1 == "12":
        ds12 = gdal.Open(filename, GA_ReadOnly)
        if ds12 is None:
            print 'Could not open image'
            sys.exit(1)
        rows12 = ds12.RasterYSize
        cols12 = ds12.RasterXSize
        bands12 = ds12.RasterCount
        band12 = ds12.GetRasterBand(1)
        data12 = band12.ReadAsArray(0, 0, cols12, rows12)
    if filename1 == "15":
        ds15 = gdal.Open(filename, GA_ReadOnly)
        if ds15 is None:
            print 'Could not open image'
            sys.exit(1)
        rows15 = ds15.RasterYSize
        cols15 = ds15.RasterXSize
        bands15 = ds15.RasterCount
        band15 = ds15.GetRasterBand(1)
        data15 = band15.ReadAsArray(0, 0, cols15, rows15)
    if filename1 == "18":
        ds18 = gdal.Open(filename, GA_ReadOnly)
        if ds18 is None:
            print 'Could not open image'
            sys.exit(1)
        rows18 = ds18.RasterYSize
        cols18 = ds18.RasterXSize
        bands18= ds18.RasterCount
        band18 = ds18.GetRasterBand(1)
        data18 = band18.ReadAsArray(0, 0, cols18, rows18)
    if filename1 == "21":
        ds21 = gdal.Open(filename, GA_ReadOnly)
        if ds21 is None:
            print 'Could not open image'
```

```
            sys.exit(1)
        rows21 = ds21.RasterYSize
        cols21 = ds21.RasterXSize
        bands21 = ds21.RasterCount
        band21 = ds21.GetRasterBand(1)
        data21 = band21.ReadAsArray(0, 0, cols21, rows21)
    if filename1 == "00":
        ds00 = gdal.Open(filename, GA_ReadOnly)
        if ds00 is None:
            print 'Could not open image'
            sys.exit(1)
        rows00 = ds00.RasterYSize
        cols00 = ds00.RasterXSize
        bands00 = ds00.RasterCount
        band00 = ds00.GetRasterBand(1)
        data00 = band00.ReadAsArray(0, 0, cols00, rows00)
    ########################################################
    #Ending hour in daily accumulation
    ########################################################
    k = count - 1
    if k == 0:
        summ = sum_ascii + "\\" + filename2 + ".asc"

        f = open(summ,'w')

        print "Writing file ...",filename2,".asc"
        print >> f, 'ncols 40'
        print >> f, 'nrows 20'
        print >> f, 'xllcorner 80'
        print >> f, 'yllcorner 26'
        print >> f, 'cellsize 0.25'

        a = Matrix(40,20) #Matrix(col,row)
        i = 1
        c03,c06,c09,c12,c15,c18,c21,c00 = 0,0,0,0,0,0,0,0
        while i < 21:
            j = 1
            while j < 41:
                b = 0
                if data03[i-1, j-1] >=0:
                    b = data03[i-1, j-1]
                else:
                    c03=c03+1

                if data06[i-1, j-1] >=0:
                    b = b + data06[i-1, j-1]
                else:
                    c06=c06+1

                if data09[i-1, j-1] >=0:
                    b = b + data09[i-1, j-1]
                else:
                    c09=c09+1

                if data12[i-1, j-1] >=0:
```

```
                    b = b + data12[i-1, j-1]
                else:
                    c12=c12+1
                if data15[i-1, j-1] >=0:
                    b = b + data15[i-1, j-1]
                else:
                    c15=c15+1
                if data18[i-1, j-1] >=0:
                    b = b + data18[i-1, j-1]
                else:
                    c18=c18+1
                if data21[i-1, j-1] >=0:
                    b = b + data21[i-1, j-1]
                else:
                    c21=c21+1
                if data00[i-1, j-1] >=0:
                    b = b + data00[i-1, j-1]
                else:
                    c00=c00+1
                b = 3*b
                a.setitem(i,j,b)
                j=j+1
            i=i+1
        print >> f, a
        f.close()
        print >> fe,
filename2,c03,c06,c09,c12,c15,c18,c21,c00

        print ″....Ending process for file″,
filename2,″.asc″
        print
        cowrite = cowrite + 1
        l = l + 8
print ″Process is finished″
print ″Total No. of file processed is″, count
print ″Total no. of files written″,cowrite
```

Sum_month.py

```
####################################################################
# DESCRIPTION: Sum up ASCII grids for each month
# USAGE: From the FWtools shell
# C:\Python24> python script_name.py input_folder output_folder
# e.g
# C:\FWTools1.2.2> python c:\Mapdata\Pythonscripts\sum_month.py
C:\Mapdata\sum_ASCII C:\Mapdata\sum_month
####################################################################

# A simple matrix
# This matrix is a list of lists
# Column and row numbers start with 1

class RemoveString(str):
    def __init__(self, s=None):
        str.__init__(self, s)
    def remove(self, chars):
        s = self
        for c in chars:
            s = s.replace(c, '')
            return(s)

class Matrix(object):
     def __init__(self, cols, rows):
         self.cols = cols
         self.rows = rows
         # initialize matrix and fill with zeroes
         self.matrix = []
         for i in range(rows):
             ea_row = []
             for j in range(cols):
                 ea_row.append(0)
             self.matrix.append(ea_row)

     def setitem(self, col, row, v):
         self.matrix[col-1][row-1] = v
         return self.matrix[col-1][row-1]

     def getitem(self, col, row):
         return self.matrix[col-1][row-1]

     def __repr__(self):
         outStr = ""
         for i in range(self.rows):
             outStr += ' %s  %s\n ' % ("", self.matrix[i])
          #################################################
          # Remove '[' and ']' from output
          #################################################
             a_outStr = outStr
             r_Remove = RemoveString(a_outStr)
             e_R = r_Remove.remove('[')
             f_Remove = RemoveString(e_R)
```

```
                g_R = f_Remove.remove(']')
            ###############################################
            return g_R

####################################################################
##Main program

import os, sys, os.path
import gdal
import calendar
from gdalconst import *

count=0
totout = 0
d = 1

driver = gdal.GetDriverByName('asc')
gdal.AllRegister()

####################################################################
# Inputs

# HDF grids location (folder)
ascii_sum = sys.argv[1]
# ASCII grids location (folder)
sum_month = sys.argv[2]


files = os.listdir(ascii_sum)
for name in files:
        filename = ascii_sum + "\\" + name
        if filename.endswith(".asc"):
            count = count + 1
            filename_ = os.path.join(name)
            year = int(filename_[0:-8])
            month = int(filename_[2:-6])
            days = calendar.monthrange(year,month)
            if d <= days[1]:
                print "Processing file No.", count, filename_
                fileout = filename_[0:-6]
                ds = gdal.Open(filename, GA_ReadOnly)
                if ds is None:
                    print 'Could not open image'
                    sys.exit(1)
                rows = ds.RasterYSize
                cols = ds.RasterXSize
                bands = ds.RasterCount
                band = ds.GetRasterBand(1)
                data = band.ReadAsArray(0, 0, cols, rows)

            if d == 1:
                 summ = sum_month + "\\" + fileout + ".asc"
                 f = open(summ,'w')
                 print >> f, 'ncols 40'
                 print >> f, 'nrows 20'
```

```
                print >> f, 'xllcorner 80'
                print >> f, 'yllcorner 26'
                print >> f, 'cellsize 0.25'
                a = Matrix(40,20) #Matrix(col,row)

            if d <= days:

                i = 1
                while i <= 20:
                   j = 1
                   while j <= 40:
                       c = a.getitem(i,j)
                       b = data[i-1, j-1] + c
                       a.setitem(i,j,b)
                       j=j+1
                   i=i+1
                d = d + 1

            if d > days[1]:
                print >> f, a
                f.close()
                totout = totout + 1
                d = 1
                print "....Ending process for file", fileout,".asc"
                print

print "Process is finished"
print "Total No. of file processed is", count
print "Total no. of files written",totout
```

Sum_year.py

```
####################################################################
# DESCRIPTION: Sum up ASCII grids for each year
# USAGE: From the FWtools shell
# C:\Python24> python script_name.py input_folder output_folder
# e.g
# C:\FWTools1.2.2> python c:\Mapdata\Pythonscripts\sum_year.py
# C:\Mapdata\sum_month C:\Mapdata\sum_year
####################################################################


# A simple matrix
# This matrix is a list of lists
# Column and row numbers start with 1

class RemoveString(str):
    def __init__(self, s=None):
        str.__init__(self, s)
    def remove(self, chars):
        s = self
        for c in chars:
            s = s.replace(c, '')
            return(s)

class Matrix(object):
     def __init__(self, cols, rows):
         self.cols = cols
         self.rows = rows
         # initialize matrix and fill with zeroes
         self.matrix = []
         for i in range(rows):
             ea_row = []
             for j in range(cols):
                 ea_row.append(0)
             self.matrix.append(ea_row)

     def setitem(self, col, row, v):
         self.matrix[col-1][row-1] = v
         return self.matrix[col-1][row-1]

     def getitem(self, col, row):
         return self.matrix[col-1][row-1]

     def __repr__(self):
         outStr = ""
         for i in range(self.rows):
             outStr += ' %s  %s\n ' % ("", self.matrix[i])
          ################################################
          # Remove '[' and ']' from output
          ################################################
             a_outStr = outStr
             r_Remove = RemoveString(a_outStr)
             e_R = r_Remove.remove('[')
```

```
            f_Remove = RemoveString(e_R)
            g_R = f_Remove.remove(']')
         ################################################
        return g_R

###################################################################
##Main program

import os, sys, os.path
import gdal
import calendar
from gdalconst import *

count=0
totout = 0

driver = gdal.GetDriverByName('asc')
gdal.AllRegister()

###################################################################
# Inputs

# HDF grids location (folder)
sum_month = sys.argv[1]
# ASCII grids location (folder)
sum_year = sys.argv[2]


files = os.listdir(sum_month)
for name in files:
       filename = sum_month + "\\" + name
       if filename.endswith(".asc"):
           count = count + 1
           filename_ = os.path.join(name)
           month = int(filename_[2:-4])
           if month <= 12:
               print "Processing file No.", count, filename_
               fileout = filename_[0:-6]
               ds = gdal.Open(filename, GA_ReadOnly)
               if ds is None:
                   print 'Could not open image'
                   sys.exit(1)
               rows = ds.RasterYSize
               cols = ds.RasterXSize
               bands = ds.RasterCount
               band = ds.GetRasterBand(1)
               data = band.ReadAsArray(0, 0, cols, rows)

           if month == 1:
                summ = sum_year + "\\" + fileout + ".asc"
                f = open(summ,'w')
                print "Writing file ...",fileout,".asc"
                print >> f, 'ncols 36'
                print >> f, 'nrows 20'
                print >> f, 'xllcorner 80'
```

```
                print >> f, 'yllcorner 26'
                print >> f, 'cellsize 0.25'
                a = Matrix(36,20) #Matrix(col,row)

            if month <= 12:

                i = 1
                while i <= 20:
                    j = 1
                    while j <= 36:
                        c = a.getitem(i,j)
                        b = data[i-1, j-1] + c
                        a.setitem(i,j,b)
                        j=j+1
                    i=i+1
                month = month + 1

            if month > 12:
                print >> f, a
                f.close()
                totout = totout + 1
                month = 1
                print "....Ending process for file", fileout,".asc"
                print

print "Process is finished"
print "Total No. of file processed is", count
print "Total no. of files written",totout
```

Extract_point.py

```
####################################################################
# DESCRIPTION: Read coordinate of gauge location and extract the
# pixel value for each day
# USAGE: From the FWtools shell
# C:\Python24> python script_name.py
# e.g
# C:\FWTools1.2.2> python c:\Mapdata\Pythonscripts\extract_point.py
# Before running the program set the location of input and output
# file location
####################################################################

# A simple matrix
# This matrix is a list of lists
# Column and row numbers start with 1
class RemoveString(str):
    def __init__(self, s=None):
        str.__init__(self, s)
    def remove(self, chars):
        s = self
        for c in chars:
            s = s.replace(c, '')
            return(s)
class Matrix(object):
     def __init__(self, cols, rows):
         self.cols = cols
         self.rows = rows
         # initialize matrix and fill with zeroes
         self.matrix = []
         for i in range(rows):
             ea_row = []
             for j in range(cols):
                 ea_row.append(0)
             self.matrix.append(ea_row)

     def setitem(self, col, row, v):
         self.matrix[col-1][row-1] = v
         return self.matrix[col-1][row-1]

     def getitem(self, col, row):
         return self.matrix[col-1][row-1]

     def __repr__(self):
         outStr = ""
         for i in range(self.rows):
             outStr += ' %s  %s\n ' % ("", self.matrix[i])
          ################################
          # Remove '[' and ']' from output
          ################################
             a_outStr = outStr
             r_Remove = RemoveString(a_outStr)
             e_R = r_Remove.remove('[')
             f_Remove = RemoveString(e_R)
```

```
              g_R = f_Remove.remove(']')
           ################################
          return g_R
###################################################################

import os, sys, os.path
import gdal
from gdalconst import *
driver = gdal.GetDriverByName('asc')
gdal.AllRegister()

    ################################
    ##Set output file location below
    ################################

f = open('i:\\Mapdata\\extract_point.txt','w')
a = Matrix(264,2923)

###################################################################
##Read cordinates of stations from set in ascii format. Gauge
station coordinate
##start from 6th line
###################################################################
istn = 0
#####################################################
###Set the input file location for station list below
#####################################################
os.chdir(r'i:\\Mapdata\\')
dstn = gdal.Open('station_list.asc', GA_ReadOnly)
if dstn is None:
    print 'Could not open image'
    sys.exit(1)
rowstn = dstn.RasterYSize
colstn = dstn.RasterXSize
bandstn = dstn.RasterCount
bandtn = dstn.GetRasterBand(1)
datastn = bandtn.ReadAsArray(0, 0, colstn, rowstn)
while istn < rowstn:
    stn = int(datastn[istn, 0])
    Ystn = datastn[istn,1]
    Xstn = datastn[istn,2]
    print 'Extracting data for station no.', stn
    a.setitem(1,istn+1,stn)
    ###############################################
    #Fix rows and cols number for given co-ordinate
    ###############################################
    i = 1
    j = 1
    colno = 0
    rowno = 0
    Xll = Xstn
    Yll = Ystn
    l = 0
    m = 0
    while i < 100:
```

```
        l = ((Xll - 80.0 - 0.25 * i))
        if l < 0:
            colno = i
            i = 100
        i = i + 1

    while j < 100:
        m = ((Yll - 26.0 - 0.25 * j))
        if m < 0:
            rowno = 20 - (j - 1)
            j = 100
        j = j + 1

####################################################################
##Extrat Pixel value for given coordinates (station)
####################################################################
    count = 1

    ################################
    ##Set input file location below
    ################################
    for root, dirs, files in os.walk('i:\\Mapdata\\sum_ascii\\'):
       for name in files:
           filename = os.path.join(root, name) #to list filename
with path: filename = os.path.join (root, name)
           if filename.endswith(".asc"):
               count = count + 1
               #print "Processing file No.", count
               ds = gdal.Open(filename, GA_ReadOnly)
               if ds is None:
                   print 'Could not open image'
                   sys.exit(1)
               rows = ds.RasterYSize
               cols = ds.RasterXSize
               bands = ds.RasterCount
               band = ds.GetRasterBand(1)
               data = band.ReadAsArray(0, 0, cols, rows)
               b = data[rowno-1,colno-1] #Gauge Grid
               a.setitem(count,istn+1,b)
    istn = istn + 1
print >> f, a
f.close()
print 'The data is extracted for ', istn ,'no. of gauging stations'
```

Extract_month.py

```
####################################################################
# DESCRIPTION: Read coordinate of gauge location and extract the
# pixel value for every month
# USAGE: From the FWtools shell
# C:\Python24> python script_name.py
# e.g
# C:\FWTools1.2.2> python c:\Mapdata\Pythonscripts\extract_point.py
# Before running the program set the location of input and output
# file location
####################################################################

# A simple matrix
# This matrix is a list of lists
# Column and row numbers start with 1
class RemoveString(str):
    def __init__(self, s=None):
        str.__init__(self, s)
    def remove(self, chars):
        s = self
        for c in chars:
            s = s.replace(c, '')
            return(s)
class Matrix(object):
     def __init__(self, cols, rows):
         self.cols = cols
         self.rows = rows
         # initialize matrix and fill with zeroes
         self.matrix = []
         for i in range(rows):
             ea_row = []
             for j in range(cols):
                 ea_row.append(0)
             self.matrix.append(ea_row)

     def setitem(self, col, row, v):
         self.matrix[col-1][row-1] = v
         return self.matrix[col-1][row-1]

     def getitem(self, col, row):
         return self.matrix[col-1][row-1]

     def __repr__(self):
         outStr = ""
         for i in range(self.rows):
             outStr += ' %s  %s\n ' % ("", self.matrix[i])
          ################################
          # Remove '[' and ']' from output
          ################################
             a_outStr = outStr
             r_Remove = RemoveString(a_outStr)
             e_R = r_Remove.remove('[')
             f_Remove = RemoveString(e_R)
```

```
            g_R = f_Remove.remove(']')
          ################################
        return g_R

###################################################################
import os, sys, os.path
import gdal
from gdalconst import *
driver = gdal.GetDriverByName('asc')
gdal.AllRegister()

    ################################
    ##Set output file location below
    ################################

f = open('i:\\Mapdata\\extract_month.txt','w')
a = Matrix(264,97)

###################################################################
##Read cordinates of stations from set in ascii format. Gauge
station coordinate
##start from 6th line
###################################################################
istn = 0
#####################################################
###Set the input file location for station list below
#####################################################
os.chdir(r'i:\\Mapdata\\')
dstn = gdal.Open('station_list.asc', GA_ReadOnly)
if dstn is None:
    print 'Could not open image'
    sys.exit(1)
rowstn = dstn.RasterYSize
colstn = dstn.RasterXSize
bandstn = dstn.RasterCount
bandtn = dstn.GetRasterBand(1)
datastn = bandtn.ReadAsArray(0, 0, colstn, rowstn)
while istn < rowstn:
    stn = int(datastn[istn, 0])
    Ystn = datastn[istn,1]
    Xstn = datastn[istn,2]
    print 'Extracting data for station no.', stn
    a.setitem(1,istn+1,stn)
    ###############################################
    #Fix rows and cols number for given co-ordinate
    ###############################################
    i = 1
    j = 1
    colno = 0
    rowno = 0
    Xll = Xstn
    Yll = Ystn
    l = 0
    m = 0
    while i < 100:
```

```
        l = ((Xll - 80.0 - 0.25 * i))
        if l < 0:
            colno = i
            i = 100
        i = i + 1
    #print colno


    while j < 100:
        m = ((Yll - 26.0 - 0.25 * j))
        if m < 0:
            rowno = 20 - (j - 1)
            j = 100
        j = j + 1
####################################################################
##Extract Pixel value for given coordinates (station)
####################################################################
    count = 1

    ################################
    ##Set input file location below
    ################################
    for root, dirs, files in os.walk('i:\\Mapdata\\Sum_month\\'):
       for name in files:
           filename = os.path.join(root, name) #to list filename
with path: filename = os.path.join (root, name)
           if filename.endswith(".asc"):
               count = count + 1
               #print "Processing file No.", count
               ds = gdal.Open(filename, GA_ReadOnly)
               if ds is None:
                   print 'Could not open image'
                   sys.exit(1)
               rows = ds.RasterYSize
               cols = ds.RasterXSize
               bands = ds.RasterCount
               band = ds.GetRasterBand(1)
               data = band.ReadAsArray(0, 0, cols, rows)
               b = data[rowno-1,colno-1] #Gauge Grid
               a.setitem(count,istn+1,b)
    istn = istn + 1
print >> f, a
f.close()
print 'The data is extracted for ', istn ,'no. of gauging stations'
```

Extract_year.py

```
####################################################################
# DESCRIPTION: Read coordinate of gauge location and extract the
# pixel value for a year
# USAGE: From the FWtools shell
# C:\Python24> python script_name.py
# e.g
# C:\FWTools1.2.2> python c:\Mapdata\Pythonscripts\extract_point.py
# Before running the program set the location of input and output
# file location
####################################################################

# A simple matrix
# This matrix is a list of lists
# Column and row numbers start with 1
class RemoveString(str):
    def __init__(self, s=None):
        str.__init__(self, s)
    def remove(self, chars):
        s = self
        for c in chars:
            s = s.replace(c, '')
            return(s)
class Matrix(object):
     def __init__(self, cols, rows):
         self.cols = cols
         self.rows = rows
         # initialize matrix and fill with zeroes
         self.matrix = []
         for i in range(rows):
             ea_row = []
             for j in range(cols):
                 ea_row.append(0)
             self.matrix.append(ea_row)

     def setitem(self, col, row, v):
         self.matrix[col-1][row-1] = v
         return self.matrix[col-1][row-1]

     def getitem(self, col, row):
         return self.matrix[col-1][row-1]

     def __repr__(self):
         outStr = ""
         for i in range(self.rows):
             outStr += ' %s  %s\n ' % ("", self.matrix[i])
          ################################
          # Remove '[' and ']' from output
          ################################
             a_outStr = outStr
             r_Remove = RemoveString(a_outStr)
             e_R = r_Remove.remove('[')
             f_Remove = RemoveString(e_R)
```

```
             g_R = f_Remove.remove(']')
          ################################
         return g_R

###################################################################
import os, sys, os.path
import gdal
from gdalconst import *
driver = gdal.GetDriverByName('asc')
gdal.AllRegister()

    ################################
    ##Set output file location below
    ################################

f = open('i:\\Mapdata\\extract_year.txt','w')
a = Matrix(264,9)

###################################################################
##Read cordinates of stations from set in ascii format. Gauge
station coordinate
##start from 6th line
###################################################################
istn = 0
#####################################################
###Set the input file location for station list below
#####################################################
os.chdir(r'i:\\Mapdata\\')
dstn = gdal.Open('station_list.asc', GA_ReadOnly)
if dstn is None:
    print 'Could not open image'
    sys.exit(1)
rowstn = dstn.RasterYSize
colstn = dstn.RasterXSize
bandstn = dstn.RasterCount
bandtn = dstn.GetRasterBand(1)
datastn = bandtn.ReadAsArray(0, 0, colstn, rowstn)
while istn < rowstn:
    stn = int(datastn[istn, 0])
    Ystn = datastn[istn,1]
    Xstn = datastn[istn,2]
    print 'Extracting data for station no.', stn
    a.setitem(1,istn+1,stn)
    ###############################################
    #Fix rows and cols number for given co-ordinate
    ###############################################
    i = 1
    j = 1
    colno = 0
    rowno = 0
    Xll = Xstn
    Yll = Ystn
    l = 0
    m = 0
    while i < 100:
```

```
        l = ((Xll - 80.0 - 0.25 * i))
        if l < 0:
            colno = i
            i = 100
        i = i + 1
    #print colno


    while j < 100:
        m = ((Yll - 26.0 - 0.25 * j))
        if m < 0:
            rowno = 20 - (j - 1)
            j = 100
        j = j + 1
####################################################################
##Extract Pixel value for given coordinates (station)
####################################################################
    count = 1

    ################################
    ##Set input file location below
    ################################
    for root, dirs, files in os.walk('i:\\Mapdata\\Sum_year\\'):
       for name in files:
           filename = os.path.join(root, name) #to list filename
with path: filename = os.path.join (root, name)
           if filename.endswith(".asc"):
               count = count + 1
               #print "Processing file No.", count
               ds = gdal.Open(filename, GA_ReadOnly)
               if ds is None:
                   print 'Could not open image'
                   sys.exit(1)
               rows = ds.RasterYSize
               cols = ds.RasterXSize
               bands = ds.RasterCount
               band = ds.GetRasterBand(1)
               data = band.ReadAsArray(0, 0, cols, rows)
               b = data[rowno-1,colno-1] #Gauge Grid
               a.setitem(count,istn+1,b)
    istn = istn + 1
print >> f, a
f.close()
print 'The data is extracted for ', istn ,'no. of gauging stations'
```

Extract_pixel.py

```
###################################################################
# DESCRIPTION: Extract pixel value for given pixel from ASCII map
# USAGE: From the FWtools shell
# C:\Python24> python script_name.py input_folder input_folder
# e.g
# C:\FWTools1.2.2> python
c:\Mapdata\Pythonscripts\eExtract_pixel.py
# Before running the program set the location of input and output
# file location
###################################################################

import os, sys, os.path
import gdal
import calendar
from gdalconst import *

count=0
totout = 0
d = 1

driver = gdal.GetDriverByName('asc')
gdal.AllRegister()

###################################################################
# Inputs
###################################################################

ascii = "i:\\Mapdata\\sum_ascii"

rr=open("i:\\Ptp\\rr.txt",'w')

#       31/80           85.25 85.5
#
#       27.75            |------|
#       27.50            |------|

col=int((85.5-80)/0.25)
row=int((31-27.5)/0.25)
print row,col

files = os.listdir(ascii)
for name in files:
        filename = ascii + "\\" + name
        if filename.endswith(".asc"):
            count = count + 1
            filename_ = os.path.join(name)

            print "Processing file No.", count, filename_
            ds = gdal.Open(filename, GA_ReadOnly)
            if ds is None:
                    print 'Could not open image'
                    sys.exit(1)
```

```
            rows = ds.RasterYSize
            cols = ds.RasterXSize
            bands = ds.RasterCount
            band = ds.GetRasterBand(1)
            data = band.ReadAsArray(0, 0, cols, rows)

            a = data[row-1,col-1]

            print >>rr, filename_[0:-4],a

print ″Process is finished″
print ″Total No. of file processed is″, count
```

Nearstn.py

```
###################################################################
# DESCRIPTION: Find nearest three Gauging stations using cordinates
# USAGE: From command prompt
# C:\Python24> python script_name.py input_file output_location
# e.g
# C:\FWTools1.2.2> python c:\Mapdata\Pythonscripts\nearstn.py
# C:\Mapdata\Gauge_data\Gauge_cal\stncords.csv
# C:\Mapdata\Gaugedata\Gauge_cal\
###################################################################

#Note Remember to delete the last line of the input CSV file

import os, sys
import csv
import math

# Input File
inputcsv = sys.argv[1]
# Output file Location (folder)
outputcsv = sys.argv[2]

read = csv.reader(open(inputcsv,"rb"))
write = csv.writer(open(outputcsv + "\\nearstns.csv",'w'))
co=0

for X in read:
	stnx = X[0]
	Ex = float(X[1])
	Nx = float(X[2])
	print "Calculating distance for stn",stnx
	co=co+1
	a=100; ax = 0  #Reset the values of comparators
	b=100; bx = 0
	c=100; cx = 0
	read1 = csv.reader(open(inputcsv,"rb"))
	for Y in read1:
		stny = Y[0]
		Ey = float(Y[1])
		Ny = float(Y[2])
		dist = math.sqrt((Ex-Ey)**2+(Nx-Ny)**2)
		if dist <> 0:
			if dist < c:
				if dist <b:
					if dist<a:
						c = b; b = a; a = dist
						cx = bx; bx = ax; ax = stny
					else:
						c = b; b = dist
						cx = bx; bx = stny
				else:
					c = dist
					cx = stny
```

```
      write.writerow([stnx,ax,bx,cx])
      print stnx, ax,bx,cx
print ”Total no. of Stations”,co
```

Formatprecip.py

```
#####################################################################
# DESCRIPTION: Sum up precipitation data of all stations to one
# text file
# USAGE: From command prompt
# C:\Python24> python script_name.py input_file output_folder
# e.g
# C:\FWTools1.2.2> python c:\Pythonscripts\formatprecip.py
C:\Gaugedata\Gauge C:\Gaugedata\Gauge_cal
#####################################################################

# A simple matrix
# This matrix is a list of lists
# Column and row numbers start with 1

import os, sys
import array
from decimal import * #to convert float to decimal with precision 1
getcontext().prec = 2

class RemoveString(str):
    def __init__(self, s=None):
        str.__init__(self, s)
    def remove(self, chars):
        s = self
        for c in chars:
            s = s.replace(c, '')
            return(s)

class Matrix(object):
     def __init__(self, cols, rows):
         self.cols = cols
         self.rows = rows
         # initialize matrix and fill with '999' values
         self.matrix = []
         for i in range(rows):
             ea_row = []
             for j in range(cols):
                 ea_row.append(999)
             self.matrix.append(ea_row)

     def setitem(self, col, row, v):
         self.matrix[col-1][row-1] = v
         return self.matrix[col-1][row-1]

     def getitem(self, col, row):
         return self.matrix[col-1][row-1]

     def __repr__(self):
         outStr = ""
         for i in range(self.rows):
             outStr += ' %s  %s\n ' % ("", self.matrix[i])
          #################################################
```

```
            # Remove ’[’ and ’]’ from output
            ################################################
               a_outStr = outStr
               r_Remove = RemoveString(a_outStr)
               e_R = r_Remove.remove(’[’)
               f_Remove = RemoveString(e_R)
               g_R = f_Remove.remove(’]’)
            ################################################
          return g_R

d=1

b = Matrix (265,1)
a = Matrix(265,2922)  #Matrix(no. of stations + 1 (for day number),
total no. of data)

while d <= 2922:
    a.setitem(d,1,d)
    d=d+1

# Gauging station location (folder)
rain = sys.argv[1]
# Output Location (folder)
finaldata = sys.argv[2]

fileout = finaldata + ”\\” + ”formatprecip.txt”
f = open(fileout,’w’)

c=2
n=1
rainstn = os. listdir(rain)
for stn in rainstn:
    print ”Switching to the Station ”,stn
    b.setitem(1,c,int(stn))
    os.chdir(rain + ”//” + stn)
    raindata = os.listdir(rain + ”//” + stn)
    for data in raindata:
        print ” Reading data file”, data
        fileloc = rain + ”//” + stn + ”//” + data
        r = open (fileloc)
        for i in r.readlines():
            ic = i[8:-1]
            ic=ic.lstrip()
            ic=ic.rstrip()
            if ic == ”T”:  #Assigned Missing data
                ic = 999
            if ic == ”DNA”:  #Assigned Data not Available
                ic = -99
            else:
                ic = float(ic)   # convert string value to decimal
            a.setitem(n,c,ic)
            n=n+1
    n=1
    c=c+1
    print
```

```
print ”Total station”,c-2
print ”Writing output file”, fileout

print >> f, b
print >> f, a
f.close()
```

Findmissing.py

```
###################################################################
# DESCRIPTION: Find Missing data for a gauge stationusing data from
# three nearest stations.
# USAGE: From command prompt
# C:\Python24> python script_name.py input_file input_file
# output_folder
# e.g
# C:\FWTools1.2.2> python c:\Pythonscripts\findmissing.py
# C:\Gaugedata\Gauge_cal\formatprecip.txt
# C:\Gaugedata\Gauge_cal\nearstn.csv C:\Gaugedata\gauge_cal\
###################################################################

#Remember to delete one empty second row

import os, sys
import csv

class RemoveString(str):
    def __init__(self, s=None):
        str.__init__(self, s)
    def remove(self, chars):
        s = self
        for c in chars:
            s = s.replace(c, '')
            return(s)

class Matrix(object):
     def __init__(self, cols, rows):
         self.cols = cols
         self.rows = rows
         self.matrix = []
         for i in range(rows):
             ea_row = []
             for j in range(cols):
                 ea_row.append(0)
             self.matrix.append(ea_row)

     def setitem(self, col, row, v):
         self.matrix[col-1][row-1] = v
         return self.matrix[col-1][row-1]

     def getitem(self, col, row):
         return self.matrix[col-1][row-1]

     def __repr__(self):
         outStr = ""
         for i in range(self.rows):
             outStr += ' %s  %s\n ' % ("", self.matrix[i])
          ################################################
          # Remove '[' and ']' from output
          ################################################
             a_outStr = outStr
```

```
            r_Remove = RemoveString(a_outStr)
            e_R = r_Remove.remove('[')
            f_Remove = RemoveString(e_R)
            g_R = f_Remove.remove(']')
        ################################################
        return g_R


# Gauge data file location (folder)
indata = sys.argv[1]
# Nearest Gauging station location (folder)
instn = sys.argv[2]
# Output Location (folder)
output = sys.argv[3]

read = csv.reader(open(indata,"rb"))
read2 = csv.reader(open(instn,"rb"))
fileout = open(output+"//"+"finalprecip.txt","w")

a = Matrix(264,2924)    # Create a Matrix(no. of stations, 2722+1+1)
one for station name and one for average
b = Matrix(4,264)       # Only 264 Stations are selected for
computation

print "Reading Input file....."
j = 1
for X in read:
    i = 1
    while i <= 264:
            data = float(X[i])
            a.setitem(j,i,data)  #setitem(row,col, data)
            i = i + 1
    j = j + 1

print "Reading Near Stations ........"
j = 1
for X in read2:
    i = 0
    while i < 4:
            data = float(X[i])
            b.setitem(j,i+1,data)  #setitem(row,col, data)
            i = i + 1
    j = j + 1

print "Finding average precipitation for each station...."
i,j = 1,2
while i <= 264:
    co = 1
    av = 0
    j = 2
    while j < 2923:
        d = a.getitem(j,i)
        if d <> 999 and d <> -99:
            av = av + d
            co = co + 1
```

```
        j = j + 1
    av = av/co
    a.setitem(j+1,i,av)
    i = i + 1

print "Finding Missing values...."
i = 1
count = 0
while i <= 264:
    mstn = a.getitem(1,i)
    mav = a.getitem(2924,i)
    print "Estimating for station ", int(mstn)

    # Finding Near stations
    k = 1
    while k <= 264:
        mstn1 = b.getitem(k,1)
        if mstn == mstn1:
            n1 = b.getitem(k,2)
            n2 = b.getitem(k,3)
            n3 = b.getitem(k,4)
            k = 271 + 1          # To exit the loop
        else:
            k = k + 1

    j = 2
    while j <= 2923:
        data = a.getitem(j,i)
        if data == 999:
            data = 0             # Reseting the value
            count = count + 1

            #Find location of missing in Main Matrix
            k = 1
            nx = 0
            while k <= 264:
                n = a.getitem(1,k)

                if n == n1 or n == n2 or n == n3:
                    d = a.getitem(j,k)
                    if d <> 999 and d<>-99:
                        nx = nx + 1
                        dav = a.getitem(2924,k)
                        data = data + d/dav

                k = k + 1
            if nx == 0:    # Check if all data are missing
                data = d
            else:
                data = mav*data/nx
        a.setitem(j,i,data)
        j = j + 1
    i = i + 1

print "Total Missing data filled", count
```

```
print ”Writing output file....”
print >> fileout,a
fileout.close()
```

Gauge_sum.py

```
####################################################################
# DESCRIPTION: Sum up precipitation data of all stations for each
# month and year to one text file
# USAGE: From command prompt
# C:\Python24> python script_name.py
# e.g
# C:\FWTools1.2.2> python c:\Pythonscripts\Gauge_sum.py
# Before running the program set the location of input and output
# file location
####################################################################

import sys, os
import calendar
import csv

class RemoveString(str):
    def __init__(self, s=None):
        str.__init__(self, s)
    def remove(self, chars):
        s = self
        for c in chars:
            s = s.replace(c, '')
            return(s)

class Matrix(object):
     def __init__(self, cols, rows):
         self.cols = cols
         self.rows = rows
         # initialize matrix and fill with '999' values
         self.matrix = []
         for i in range(rows):
             ea_row = []
             for j in range(cols):
                 ea_row.append(0)
             self.matrix.append(ea_row)

     def setitem(self, col, row, v):
         self.matrix[col-1][row-1] = v
         return self.matrix[col-1][row-1]

     def getitem(self, col, row):
         return self.matrix[col-1][row-1]

     def __repr__(self):
         outStr = ""
         for i in range(self.rows):
             outStr += ' %s  %s\n ' % ("", self.matrix[i])
          ################################################
          # Remove '[' and ']' from output
          ################################################
             a_outStr = outStr
             r_Remove = RemoveString(a_outStr)
```

```
            e_R = r_Remove.remove('[')
            f_Remove = RemoveString(e_R)
            g_R = f_Remove.remove(']')
          #################################################
        return g_R


read =
csv.reader(open("j:/Gaugedata/gauge_cal/finalprecip.txt","rb"))
fileout = open("j:/Gaugedata/gauge_cal/monthly.txt","w")
fileout2 = open("j:/Gaugedata/gauge_cal/yearly.txt","w")

a = Matrix(264,2924)   # Create a Matrix(no. of stations, 2722+1+1)
one for station name and one for average
b = Matrix(264,97)
c = Matrix(264,9)

print "Reading Input file....."
i,j = 1,1
for X in read:
    #print X
    while i <= 264:
            data = float(X[i-1])
            a.setitem(j,i,data)  #setitem(row,col, data)
            i = i + 1
    i = 1
    j = j + 1

print "Calculating Monthly sums"
i = 1
while i <= 264:
    stn = a.getitem(1,i)
    b.setitem(1,i,stn)
    # print "Calculating monthy sum for stn", stn
    j = 1
    count = 1
    year,month,days = 2001,01,31
    sum_m = 0
    while j <= 2922:           # The last data is at 2923th column
        data = a.getitem(j+1,i)
        if data <> -99:
            sum_m = sum_m + data
        else:
            sum_m = -99
            j = days


        if j == days:
            count = count + 1
            b.setitem(count,i,sum_m)
            sum_m = 0
            if month < 12:
                month = month + 1
            else:
                year = year + 1
```

```
                month = 1
            days = days + calendar.monthrange(year,month)[1]
        j = j + 1
    i = i + 1
print "Writing output file...."
print >> fileout,b
fileout.close()

print "Calculating Yearly sums"
i=1
while i <= 264:
    stn = b.getitem(1,i)
    c.setitem(1,i,stn)
    # print "Calculating yearly sum for stn", stn
    j = 1
    yr = 1
    sum_y = 0
    while j <= 96:           # The last data is at 97th column
        data = b.getitem(j+1,i)
        if data <> -99:
            sum_y = sum_y + data
        else:
            sum_y = -99
            j = 12 * yr


        if j == 12 * yr:
            yr = yr + 1
            c.setitem(yr,i,sum_y)
            sum_y = 0

        j = j + 1
    i = i + 1


#print c
print "Writing output file...."
print >> fileout2,c
fileout2.close()
```

Stat.py

```
###################################################################
# DESCRIPTION: this scripts performs the following
# - Computes the statistical measures listed below for comparing
#   gauge precipitation with corresponding satellite pixel
precipitation
#     - R2: Nash Sutcliffe Efficiency Coefficient
#     - NAD: Normalised Accumulated Difference
#     - RMSD: Root Mean Squared Difference
# - Generates scatter plots for each station (gauge location)
# - Linear regression between R2 and distance from radar
# - Generates the plot for the regression
# USAGE: run from the command prompt
# C:\Python24> python script_name.py input_argument_1
input_argument_2 ...
# e.g.
# python C:\Pythonscripts\STAT.py C:\Stat C:\Stat\Gauge.txt
C:\Stat\Radar.txt
# 2922 C:\stat\point_stat\Point_Stat.shp C:\stat\WGS_1984.prj
###################################################################

# Import system modules
import arcgisscripting
import sys
import os, csv
import string

print "Loading..."
from numpy import *
from pylab import *

# Create the Geoprocessor object
gp = arcgisscripting.create()

###################################################################
# Inputs

# Define the workspace
gp.workspace = sys.argv[1]

# Text file with gauge data
fileG = open(sys.argv[2], "r")

# Text file with extracted radar data
fileR = open(sys.argv[3], "r")

# Length of date series (in days, hours, etc...)
SeriesLength = int(sys.argv[4]) + 4

# Name of shape file with computed statistics
fcname = sys.argv[5]

# Projection file for georeferencing gauge locations
```

```
cs = sys.argv[6]

# Radar Location
#coords = sys.argv[7]
#coords = coords.split(";")
#RadarX = float(coords[0])#559440.3 for Rissa radar
#RadarY = float(coords[1])#7063029.7 for Rissa radar

####################################################################

# Create a shape file with gauge locations as point features and
# add Station Name, Elevation, R2, NAD and RMSD as fields
#gp.CreateFeatureclass_management(gp.workspace, fcname, "POINT",
"","DISABLED", "DISABLED",cs, "", "0", "0", "0")
#gp.AddField(fcname, "StationID", "text")
#gp.AddField(fcname, "Elevation", "double")
#gp.AddField(fcname, "STN_ID", "text")
gp.AddField(fcname, "R2", "double")
gp.AddField(fcname, "NAD", "double")
gp.AddField(fcname, "RMSD", "double")
gp.AddField(fcname, "MAD", "double")
gp.AddField(fcname, "MRAD", "double")
gp.AddField(fcname, "PrecDays", "double")
gp.AddField(fcname, "PrecDays_R", "double")
gp.AddField(fcname, "PrecDays_G", "double")
gp.AddField(fcname, "Higher_R", "double")
gp.AddField(fcname, "Higher_G", "double")
gp.AddField(fcname, "POD_R", "double")
gp.AddField(fcname, "POD_G", "double")
gp.AddField(fcname, "CPOD_R", "double")
gp.AddField(fcname, "CPOD_G", "double")
gp.AddField(fcname, "Mean_R", "double")
gp.AddField(fcname, "Mean_G", "double")
gp.AddField(fcname, "CMean_R", "double")
gp.AddField(fcname, "CMean_G", "double")
gp.AddField(fcname, "EB", "double")
gp.AddField(fcname, "RR", "double")
gp.AddField(fcname, "a", "double")
gp.AddField(fcname, "b", "double")

pnt = gp.CreateObject("Point")

write = csv.writer(open(sys.argv[1] + "\\Statresult.csv",'w'))
write.writerow(["Station","SumG","Gauge Precip Days","SumR","Radar
Precip
Days","R2","NAD","RMSD","MAD","MRAD","EB","CPOD_S","CPOD_G"])
HeaderLineG = fileG.readline()# skip the header line
HeaderLineR = fileR.readline()# skip the header line

fileListG = fileG.readlines()

StationCount = 0

PointDataG = [] # List for stationID(name), coordinates and
GaugePrecipitation values
```

```
PointDataR = [] # List for stationID(name), coordinates and
RadarPrecipitation values

Nash_R2 = [] # List for R2 values of the gauges
STN_ID = [] # Station ID
PrecG = [] # List for GaugePrecipitation values
PrecR = [] # List for RaugePrecipitation values
PrecG_ = [] # List for GaugePrecipitation values without missing
values
PrecR_ = [] # List for RaugePrecipitation values without missing
values
Days = 4 # The first four columns in input txt file are not
precipitation values
Diff = 0 # Sum of (RadarPrecipitation - GaugePrecipitation)
AbsDiff = 0 # Sum of Abs(RadarPrecipitation - GaugePrecipitation)
RelAbsDiff = 0 # Sum of (Abs(RadarPrecipitation -
GaugePrecipitation))/GaugePrecipitation
DiffSqr = 0 # Sum of ((RadarPrecipitation - GaugePrecipitation)^2)
G_GavgSqr = 0 # Sum of ((GaugePrecipitation -
AverageGaugePrecipitation)^2)
PrecDays = 0 # No of days when neither Gauge nor Radar data is
missing
SumPrecG = 0 # Sum of GaugePrecipitation when (PrecG and PrecR) > 0
SumPrecR = 0 # Sum of RadarPrecipitation when (PrecG and PrecR) > 0
SumG = 0 # Sum of GaugePrecipitation
SumR = 0 # Sum of RadarPrecipitation
r2 = 0 # Nash Sutcliffe Efficiency Index
nad = 0 # Normalised Accumulated Difference
rmsd = 0 # Root Mean Squared Difference
mad = 0 # Mean Absolute Difference
mrad = 0 # Mean Relative Absolute Difference
CmeanR = 0 # Radar Conditional Mean
CmeanG = 0 # Gauge Conditional Mean
MeanR = 0 # Radar Mean
MeanG = 0 # Gauge Mean
EB = 0 # Estimation Bias
GaugePrecDays = 0
RadarPrecDays = 0
RadarDays = 0 # Days for which radar data is available
GaugeRadarDays = 0 # Days for which both gauge and radar data is
available
HigherRadarDays = 0 # Days for which both gauge and radar data is
available and PrecR > PrecG
HigherGaugeDays = 0 # Days for which both gauge and radar data is
available and PrecG > PrecR
CondPrecDaysR = 0
CondPrecDaysG = 0
CondPrecDaysGR = 0
CondPrecDaysRG = 0

#Returns coefficients and R^2 to the regression line ”y=ax+b” from
x[] and y[].

def linreg(X, Y):
    from math import sqrt
```

```
    if len(X) != len(Y):  raise ValueError, 'unequal length'

    N = len(X)
    Sx = Sy = Sxx = Syy = Sxy = 0.0
    for x, y in map(None, X, Y):
        Sx = Sx + x
        Sy = Sy + y
        Sxx = Sxx + x*x
        Syy = Syy + y*y
        Sxy = Sxy + x*y
    det = Sxx * N - Sx * Sx
    if det <>0:
        a, b = (Sxy * N - Sy * Sx)/det, (Sxx * Sy - Sx * Sxy)/det
    else:
        a,b = 0,0

    meanerror = residual = 0.0
    for x, y in map(None, X, Y):
        meanerror = meanerror + (y - Sy/N)**2
        residual = residual + (y - a * x - b)**2
    if meanerror <>0:
        RR = 1 - residual/meanerror
    else:
        RR=0
    if N<>2:
        ss = residual / (N-2)
    else:
        ss=0
    if det <>0:
        Var_a, Var_b = ss * N / det, ss * Sxx / det
    else:
        Var_a, Var_b = 0,0

    return a, b, RR

for fileLine in fileListG:
    StationCount = StationCount + 1
    print
    print "For station ",StationCount
    LineR = fileR.readline()
    PointDataR = LineR.split("\t")              # Makes the data as
comma seperated
    PointDataG = fileLine.split("\t")
    while (Days < SeriesLength):
        PrecG.append(float(PointDataG[Days]))   # take one data on
that col
        PrecR.append(float(PointDataR[Days]))
        if (PrecR[Days - 4] >= 0 ):             # Checking the
station name
            RadarDays = RadarDays + 1
        if (PrecR[Days - 4] >= 0 and PrecG[Days - 4] >= 0):
            if (PrecR[Days - 4] > 0.0 and PrecG[Days - 4] > 0.0):
                Diff = Diff + (PrecR[Days - 4] - PrecG[Days - 4])
                AbsDiff = AbsDiff + abs(PrecR[Days - 4] -
PrecG[Days - 4])
```

```
                RelAbsDiff = RelAbsDiff + ((abs(PrecR[Days - 4] -
PrecG[Days - 4]))/PrecG[Days - 4])
                DiffSqr = DiffSqr + (PrecR[Days - 4] - PrecG[Days -
4])**2
                SumPrecG = SumPrecG + PrecG[Days - 4]
                SumPrecR = SumPrecR + PrecR[Days - 4]
                PrecDays = PrecDays + 1
                PrecG_.append(PrecG[Days - 4])
                PrecR_.append(PrecR[Days - 4])
                if (PrecR[Days - 4] > PrecG[Days - 4]):
                    HigherRadarDays = HigherRadarDays + 1
                if (PrecG[Days - 4] > PrecR[Days - 4]):
                    HigherGaugeDays = HigherGaugeDays + 1
            if (PrecG[Days - 4] > 0.0):
                GaugePrecDays = GaugePrecDays + 1
            if (PrecR[Days - 4] > 0.0):
                RadarPrecDays = RadarPrecDays + 1

            if (PrecR[Days - 4] > 0.1):
                CondPrecDaysR = CondPrecDaysR + 1
            if (PrecR[Days - 4] > 0.1 and PrecG[Days - 4] > 0):
                CondPrecDaysGR = CondPrecDaysGR + 1

            if (PrecG[Days - 4] > 0.1):
                CondPrecDaysG = CondPrecDaysG + 1
            if (PrecR[Days - 4] > 0 and PrecG[Days - 4] > 0.1):
                CondPrecDaysRG = CondPrecDaysRG + 1

            SumG = SumG + PrecG[Days - 4]
            SumR = SumR + PrecR[Days - 4]
            GaugeRadarDays = GaugeRadarDays + 1

        Days = Days + 1
    Days = 4

    AnalysisDays = float(GaugeRadarDays) / float(RadarDays)
    if (PrecDays > 0):
     HigherR = float(HigherRadarDays) / float(PrecDays)
     HigherG = float(HigherGaugeDays) / float(PrecDays)

    if (PrecDays <= 0 or SumPrecG <= 0 or SumG <= 0 or AnalysisDays
< 0.8 or PrecDays <= 2):
        print "No data for station " + PointDataG[0]
        Diff = 0
        AbsDiff = 0
        RelAbsDiff = 0
        DiffSqr = 0
        SumPrecG = 0
        SumPrecR = 0
        SumG = 0
        SumR = 0
        G_GavgSqr = 0
        PrecDays = 0
        GaugePrecDays = 0
        RadarPrecDays = 0
```

```
        RadarDays = 0
        GaugeRadarDays = 0
        HigherRadarDays = 0
        HigherGaugeDays = 0
        CondPrecDaysR = 0
    CondPrecDaysG = 0
    CondPrecDaysGR = 0
    CondPrecDaysRG = 0
        Days = 4
        PrecG[:] = []
        PrecR[:] = []
        PrecG_[:] = []
        PrecR_[:] = []
        continue

    AvgPrecG = SumPrecG / PrecDays

    while (Days < SeriesLength):
        if (PrecR[Days - 4] > 0.0 and PrecG[Days - 4] > 0.0):
            G_GavgSqr = G_GavgSqr + (PrecG[Days - 4] - AvgPrecG)**2
        Days = Days + 1


    print "Gauge Precipitation Days", GaugePrecDays
    print "Radar Precipitation Days", RadarPrecDays
    print
    print "Comparison statistics for " + PointDataG[0]
    POD_R = float(PrecDays) / float(GaugePrecDays)
    POD_G = float(PrecDays) / float(RadarPrecDays)
    CPOD_R = float(CondPrecDaysRG) / float(CondPrecDaysG)
    CPOD_G = float(CondPrecDaysGR) / float(CondPrecDaysR)

    (a, b, RR) = linreg(PrecG_, PrecR_)

    r2 = 1 - (DiffSqr / G_GavgSqr)
    Nash_R2.append(r2)
    float(PointDataG[2]))**2))**0.5) / 1000
    print "R2 = " + str(r2)
    nad = (Diff / SumPrecG) * 100
    print "NAD = " + str(nad)
    rmsd = (DiffSqr / PrecDays)**0.5
    print "RMSD = " + str(rmsd)
    mad = AbsDiff / PrecDays
    print "MAD = " + str(mad)
    mrad = RelAbsDiff / PrecDays
    print "MRAD = " + str(mrad)
    CmeanR = SumPrecR / PrecDays
    CmeanG = SumPrecG / PrecDays
    MeanR = SumR / RadarPrecDays
    MeanG = SumG / GaugePrecDays
    EB = ((SumR - SumG) /SumG) * 100
    cur = gp.InsertCursor(fcname)
    feat = cur.NewRow()
    feat.shape = pnt
    feat.R2 = r2
```

```
    feat.NAD = nad
    feat.RMSD = rmsd
    feat.MAD = mad
    feat.MRAD = mrad
    feat.PrecDays = PrecDays
    feat.PrecDays_R = RadarPrecDays
    feat.PrecDays_G = GaugePrecDays
    feat.Higher_R = HigherR
    feat.Higher_G = HigherG
    feat.POD_R = POD_R
    feat.POD_G = POD_G
    feat.CPOD_R = CPOD_R
    feat.CPOD_G = CPOD_G
    feat.Mean_R = CmeanR
    feat.Mean_G = CmeanG
    feat.CMean_R = MeanR
    feat.CMean_G = MeanG
    feat.EB = EB
    feat.RR = RR
    feat.a = a
    feat.b = b
    cur.InsertRow(feat)
    del cur

write.writerow([PointDataG[0],SumG,GaugePrecDays,SumR,RadarPrecDays
,r2,nad,rmsd,mad,mrad,EB,CPOD_R,CPOD_G])
    Diff = 0
    AbsDiff = 0
    RelAbsDiff = 0
    DiffSqr = 0
    SumPrecG = 0
    SumPrecR = 0
    SumG = 0
    SumR = 0
    G_GavgSqr = 0
    PrecDays = 0
    GaugePrecDays = 0
    RadarPrecDays = 0
    RadarDays = 0
    GaugeRadarDays = 0
    HigherRadarDays = 0
    HigherGaugeDays = 0
    CondPrecDaysR = 0
    CondPrecDaysG = 0
    CondPrecDaysGR = 0
    CondPrecDaysRG = 0
    Days = 4


    print "Generating scatter plot for ",PointDataG[0]
    figure(StationCount)
    scatter (PrecG_, PrecR_)
    xlim(xmin=0) # adjust the min leaving max unchanged
    ylim(ymin=0) # adjust the min leaving max unchanged
    Gmin, Gmax = xlim()
```

```
    Rmin, Rmax = ylim()
    G = arange(Gmin, Gmax, 0.1)
    R = arange(Rmin, Rmax, 0.1)
    Xhalf = (Gmax/2)
    Yhalf = (Rmax/2)
    if Gmax >= Rmax:
        plot(G, G)
        text (Xhalf, Xhalf * 1.1, '1:1', fontsize=12)
    else:
        plot(R, R)
        text (Yhalf, Yhalf * 1.1, '1:1', fontsize=12)
    xlim(xmin=0)
    ylim(ymin=0)
    xlabel('Gauge Precipitation (mm)')
    ylabel('Satellite Precipitation (mm)')
    savefig(gp.workspace + "\\" + PointDataG[0])# saved in png
format
    close(StationCount)
    PrecG[:] = []
    PrecR[:] = []
    PrecG_[:] = []
    PrecR_[:] = []
#print PrecG
#print PrecR
fileG.close()
fileR.close()
```

APPENDIX 3

EXCLUDED STATIONS FROM COMPARISON

Stations exluded from prior to comparison

Station ID	Station Name	District	Easting	Northing	Elevation (m)	Years of data available	Missing day data
220	Oli Gaun	Achham	81.28	29.17	820	1	
309	Bijayapur (Raskot)	Kalikot	81.63	29.23	1814	6	1229
612	Mustang (Lomangthang)	Mustang	83.97	29.18	3705	5	2328
927	Bharatpur	Chitawan	84.43	27.67	205	8	921
1028	Pachuwar Ghat	Kabhre	85.75	27.57	633	8	1030
1083	Tarebhir	Kathmandu	85.40	27.78	1848	6	1026
1107	Sindhuli Gadhi	Sindhuli	85.97	27.28	1463	7	907
1227	Gaighat	Udayapur	86.72	26.78	152	6	886

Note: The number of years available is taken from data provided by DHM/GoN.

Stations exluded from daily rainfall data comparison

S.No.	Station ID	Station Name	District	Easting	Northing	Elevation	Gauge Radar Days	Radar Days	Precipitation Days	Analysis Days
1	105	Mahendra Nagar	Kanchanpur	29.03	80.22	176	2236	2922	321	0.77
2	211	Khaptad	Doti	29.38	81.20	3430	2132	2922	526	0.73
3	306	Gam Shree Nagar	Mugu	29.55	82.15	2133	2221	2922	346	0.76
4	307	Rara	Mugu	29.55	82.12	3048	2130	2922	421	0.73
5	310	Dipal Gaun	Jumla	29.27	82.22	2310	2313	2922	375	0.79
6	311	Simikot	Humla	29.97	81.83	2800	2224	2922	395	0.76
7	313	Darma	Humla	29.73	82.10	1950	1567	2922	267	0.54
8	605	Baglung	Baglung	28.27	83.60	984	2263	2922	486	0.77
9	608	Ranipauwa	Mustang	28.82	83.88	3609	2120	2922	232	0.73
10	633	Chhoser	Mustang	29.18	83.98	3870	1296	2922	107	0.44
11	905	Daman	Makwanpur	27.60	85.08	2314	2052	2922	578	0.70
12	925	Rajaiya	Makwanpur	27.43	84.98	332	2221	2922	579	0.76
13	1063	Thokarpa	Sindhupalchok	27.70	85.78	1750	2325	2922	516	0.80
14	1122	Jalesore	Mahottari	26.65	85.78	172	2267	2922	149	0.78
15	1215	Lahan	Siraha	26.73	86.43	138	2329	2922	269	0.80
16	1407	Ilam Tea Estate	Ilam	26.92	87.90	1300	2291	2922	347	0.78

Stations exluded from monthly rainfall data comparison

S.No.	StationID	Station Name	District	Easting	Northing	Elevation	Gauge Radar Days	Radar Days	Precipitation Days	Analysis Days
1	105	Mahendra Nagar	Kanchanpur	29.03	80.22	176	73	96	59	0.76
2	211	Khaptad	Doti	29.38	81.20	3430	70	96	60	0.73
3	306	Gam Shree Nagar	Mugu	29.55	82.15	2133	73	96	60	0.76
4	307	Rara	Mugu	29.55	82.12	3048	70	96	62	0.73
5	310	Dipal Gaun	Jumla	29.27	82.22	2310	76	96	56	0.79
6	311	Simikot	Humla	29.97	81.83	2800	73	96	69	0.76
7	313	Darma	Humla	29.73	82.10	1950	51	96	47	0.53
8	605	Baglung	Baglung	28.27	83.60	984	73	96	64	0.76
9	608	Ranipauwa	Mustang	28.82	83.88	3609	68	96	56	0.71
10	624	Samar Gaun	Mustang	28.97	83.78	3570	75	96	59	0.78
11	633	Chhoser	Mustang	29.18	83.98	3870	42	96	30	0.44
12	905	Daman	Makwanpur	27.60	85.08	2314	67	96	56	0.70
13	910	Nijgadh	Bara	27.18	85.17	244	76	96	66	0.79
14	921	Kalaiya	Bara	27.03	85.00	140	76	96	61	0.79
15	922	Gaur	Routahat	26.77	85.30	90	76	96	51	0.79
16	925	Rajaiya	Makwanpur	27.43	84.98	332	71	96	62	0.74
17	1020	Mandan	Kabhre	27.70	85.65	1365	74	96	60	0.77
18	1063	Thokarpa	Sindhupalchok	27.70	85.78	1750	76	96	63	0.79
19	1082	Nangkhel	Bhaktapur	27.65	85.47	1428	76	96	66	0.79
20	1122	Jalesore	Mahottari	26.65	85.78	172	71	96	39	0.74
21	1215	Lahan	Siraha	26.73	86.43	138	76	96	59	0.79
22	1407	Ilam Tea Estate	Ilam	26.92	87.90	1300	74	96	58	0.77

APPENDIX 3: Excluded stations from comparison

Stations exluded from yearly rainfall data comparison

S.No.	StationID	Station Name	District	Easting	Northing	Elevation	Gauge Radar Days	Radar Days	Precipitation Days	Analysis Days
1	101	Kakerpakha	Baitadi	29.65	80.50	842	6	8	6	0.75
2	102	Baitadi	Baltadi	29.55	80.42	1635	6	8	6	0.75
3	105	Mahendra Nagar	Kanchanpur	29.03	80.22	176	4	8	4	0.50
4	203	Silgadhi Doti	Doti	29.27	80.98	1360	6	8	6	0.75
5	205	Katai	Doti	29.00	81.13	1388	6	8	6	0.75
6	211	Khaptad	Doti	29.38	81.20	3430	5	8	5	0.63
7	215	Godavari(West)	Kailali	28.87	80.63	288	6	8	6	0.75
8	302	Thirpu	Kalikot	29.32	81.77	1006	3	8	3	0.38
9	304	Guthi Chaur	Jumla	29.28	82.32	3080	6	8	6	0.75
10	305	Sheri Ghat	Kalikot	29.13	81.60	1210	4	8	4	0.50
11	306	Gam Shree Nagar	Mugu	29.55	82.15	2133	4	8	4	0.50
12	307	Rara	Mugu	29.55	82.12	3048	5	8	5	0.63
13	310	Dipal Gaun	Jumla	29.27	82.22	2310	4	8	4	0.50
14	311	Simikot	Humla	29.97	81.83	2800	4	8	4	0.50
15	313	Darma	Humla	29.73	82.10	1950	2	8	2	0.25
16	401	Pusma Camp	Surkhet	28.88	81.25	950	6	8	6	0.75
17	407	Kusum	Banke	28.02	82.12	235	6	8	6	0.75
18	408	Gulariya	Bardiya	28.17	81.35	215	6	8	6	0.75
19	414	Baijapur	Banke	28.05	81.90	226	5	8	5	0.63
20	418	Maina Gaun (D.Bas)	Jajarkot	28.98	82.28	2000	6	8	6	0.75
21	507	Nayabasti (Dang)	Dang	28.22	82.12	698	6	8	6	0.75
22	605	Baglung	Baglung	28.27	83.60	984	5	8	5	0.63
23	608	Ranipauwa	Mustang	28.82	83.88	3609	4	8	4	0.50
24	609	Beni Bazar	Myagdi	28.35	83.57	835	4	8	4	0.50

S.No.	StationID	Station Name	District	Easting	Northing	Elevation	Gauge Radar Days	Radar Days	Precipitation Days	Analysis Days
25	610	Ghami (Mustang)	Mustang	29.05	83.88	3465	6	8	6	0.75
26	616	Gurja Khani	Myagdi	28.60	83.22	2530	6	8	6	0.75
27	620	Tribeni	Parbat	28.03	83.65	700	5	8	5	0.63
28	624	Samar Gaun	Mustang	28.97	83.78	3570	4	8	4	0.50
29	625	Sanda	Mustang	28.90	83.68	3570	6	8	6	0.75
30	630	Sirkon	Parbat	28.13	83.62	790	6	8	6	0.75
31	633	Chhoser	Mustang	29.18	83.98	3870	3	8	3	0.38
32	702	Tansen	Palpa	27.87	83.53	1067	6	8	6	0.75
33	703	Butwal	Rupandehi	27.70	83.47	205	5	8	5	0.63
34	715	Khanchikot	Arghakhanchi	27.93	83.15	1760	6	8	6	0.75
35	716	Taulihawa	Kapilbastu	27.55	83.07	94	5	8	5	0.63
36	730	Sitapur(Nepaney)	Arghakhanchi	27.90	83.15	1201	6	8	6	0.75
37	806	Larke Samdo	Gorkha	28.67	84.62	3650	6	8	6	0.75
38	818	Lamachaur	Kaski	28.27	83.97	1070	6	8	6	0.75
39	821	Ghandruk	Kaski	28.38	83.80	1960	6	8	6	0.75
40	832	Dandaswanra	Syangja	28.08	83.92	1432	6	8	6	0.75
41	833	Chhekampar	Gorkha	28.48	85.00	3300	5	8	5	0.63
42	905	Daman	Makwanpur	27.60	85.08	2314	3	8	3	0.38
43	910	Nijgadh	Bara	27.18	85.17	244	4	8	4	0.50
44	912	Ramoli Bairiya	Routahat	27.02	85.38	152	6	8	6	0.75
45	919	Makwanpur Gadhi	Makwanpur	27.42	85.17	1030	5	8	5	0.63
46	921	Kalaiya	Bara	27.03	85.00	140	5	8	5	0.63
47	922	Gaur	Routahat	26.77	85.30	90	6	8	6	0.75
48	925	Rajaiya	Makwanpur	27.43	84.98	332	5	8	5	0.63
49	1002	Aru Ghat D.Bazar	Dhading	28.05	84.82	518	6	8	6	0.75
50	1008	Nawalpur	Sindhupalchok	27.80	85.62	1592	6	8	6	0.75
51	1016	Sarmathang	Sindhupalchok	27.95	85.60	2625	6	8	6	0.75

APPENDIX 3: Excluded stations from comparison

S.No.	StationID	Station Name	District	Easting	Northing	Elevation	Gauge Radar Days	Radar Days	Precipitation Days	Analysis Days
52	1017	Dubachaur	Sindhupalchok	27.87	85.57	1550	6	8	6	0.75
53	1020	Mandan	Kabhre	27.70	85.65	1365	5	8	5	0.63
54	1023	Dolal Ghat	Kabhre	27.63	85.72	710	6	8	6	0.75
55	1036	Panchkhal	Kabhre	27.68	85.63	865	5	8	5	0.63
56	1058	Tarke Ghyang	Sindhupalchok	28.00	85.55	2480	6	8	6	0.75
57	1062	Sangachok	Sindhupalchok	27.70	85.72	1327	3	8	3	0.38
58	1063	Thokarpa	Sindhupalchok	27.70	85.78	1750	6	8	6	0.75
59	1071	Buddhanilakantha	Kathmandu	27.78	85.37	1350	3	8	3	0.38
60	1077	Sundarijal	Kathmandu	27.75	85.42	1360	6	8	6	0.75
61	1078	Dhap	Sindhupalchok	27.90	85.63	1310	4	8	4	0.50
62	1082	Nangkhel	Bhaktapur	27.65	85.47	1428	5	8	5	0.63
63	1101	Nagdaha	Dolkha	27.68	86.10	850	2	8	2	0.25
64	1103	Jiri	Dolkha	27.63	86.23	2003	5	8	5	0.63
65	1104	Melung	Dolkha	27.52	86.05	1536	4	8	4	0.50
66	1108	Bahun Tilpung	Sindhuli	27.18	86.17	1417	6	8	6	0.75
67	1109	Pattharkot(East)	Sarlahi	27.08	85.67	275	4	8	4	0.50
68	1119	Gausala	Mahottari	26.88	85.78	200	5	8	5	0.63
69	1120	Malangwa	Sarlahi	26.87	85.57	150	6	8	6	0.75
70	1121	Karmaiya	Sarlahi	27.12	85.47	131	6	8	6	0.75
71	1122	Jalesore	Mahottari	26.65	85.78	172	3	8	3	0.38
72	1203	Pakarnas	Solukhumbu	27.43	86.57	1982	6	8	6	0.75
73	1207	Mane Bhanjyang	Okhaldhunga	27.48	86.42	1576	5	8	5	0.63
74	1210	Kurule Ghat	Khotang	27.13	86.43	497	6	8	6	0.75
75	1211	Khotang Bazar	Khotang	27.03	86.83	1295	5	8	5	0.63
76	1215	Lahan	Siraha	26.73	86.43	138	5	8	5	0.63
77	1219	Salleri	Solukhumbu	27.50	86.58	2378	6	8	6	0.75
78	1223	Rajbiraj	Saptari	26.55	86.75	91	5	8	5	0.63

S.No.	StationID	Station Name	District	Easting	Northing	Elevation	Gauge Radar Days	Radar Days	Precipitation Days	Analysis Days
79	1224	Sirwa	Solukhumbu	27.55	86.38	1662	6	8	6	0.75
80	1301	Num	Sankhuvwasabha	27.55	87.28	1497	4	8	4	0.50
81	1308	Mul Ghat	Dhankuta	26.93	87.33	365	5	8	5	0.63
82	1312	Haraincha	Morang	26.62	87.38	152	5	8	5	0.63
83	1316	Chatara	Sunsari	26.82	87.17	183	5	8	5	0.63
84	1317	Chepuwa	Sankhuvwasabha	27.77	87.42	2590	5	8	5	0.63
85	1322	Machuwaghat	Dhankuta	26.97	87.17	158	6	8	6	0.75
86	1325	Dingla	Bhojpur	27.37	87.15	1190	6	8	6	0.75
87	1406	Memeng Jagat	Panchther	27.20	87.93	1830	6	8	6	0.75
88	1407	Ilam Tea Estate	Ilam	26.92	87.90	1300	4	8	4	0.50
89	1420	Dovan	Taplejung	27.35	87.60	763	5	8	5	0.63

APPENDIX 4

RESULTS OF COMPARISON

Comparison of daily precipitation data sets

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
101	29.65	80.50	842.00	-0.46	-30.87	23.80	14.97	3.08	-23.68	0.74	0.63
102	29.55	80.42	1635.00	-0.87	-15.17	22.08	13.72	1.97	0.84	0.72	0.50
103	29.47	80.53	1266.00	-1.14	-6.37	25.13	14.76	10.12	-7.96	0.66	0.61
104	29.30	80.58	1848.00	-1.34	3.71	23.46	13.30	8.49	-3.46	0.67	0.65
106	28.68	80.35	159.00	-0.24	-16.80	36.74	23.90	5.16	-18.27	0.63	0.60
107	29.85	80.57	1097.00	-0.67	-47.22	27.23	17.94	1.55	-44.01	0.76	0.65
108	29.53	80.47	2370.00	-0.50	-26.43	23.05	14.28	3.65	-21.44	0.68	0.63
201	29.62	80.87	1456.00	-0.61	-38.61	24.46	15.03	3.96	-39.58	0.76	0.67
202	29.55	81.22	1304.00	-0.72	-29.40	19.33	12.49	3.65	-27.11	0.75	0.62
203	29.27	80.98	1360.00	-0.13	-35.32	53.96	17.36	1.71	-32.73	0.66	0.44
204	29.38	81.32	1400.00	-0.56	-44.31	19.34	13.32	1.56	-15.85	0.71	0.42
205	29.00	81.13	1388.00	-0.17	-34.64	28.12	17.44	1.78	-31.02	0.74	0.61
206	28.95	81.45	650.00	-0.86	-26.64	23.53	16.70	2.03	29.90	0.73	0.38
207	28.53	81.12	140.00	-0.52	-14.57	42.72	25.76	4.25	3.74	0.67	0.53
208	28.75	80.92	195.00	-0.23	-32.27	42.00	25.92	2.18	-17.50	0.69	0.48
209	28.80	80.55	187.00	-0.29	-21.37	38.99	23.21	10.36	-18.56	0.68	0.63
210	28.97	81.12	340.00	-1.17	-19.95	31.28	18.41	4.78	1.84	0.66	0.48
212	28.57	80.82	152.00	-0.28	-21.55	36.73	23.20	3.00	-1.44	0.68	0.44
214	29.12	80.68	1304.00	-0.69	-18.51	27.80	16.90	5.44	-21.26	0.67	0.64
215	28.87	80.63	288.00	-0.49	-46.22	42.16	27.57	2.38	-25.65	0.68	0.48
217	29.15	81.28	1345.00	-0.46	-18.40	23.58	15.26	3.93	-13.49	0.71	0.51
218	29.23	80.93	720.00	-0.73	8.91	20.57	12.65	5.79	21.42	0.69	0.57
302	29.32	81.77	1006.00	-0.73	5.68	17.70	10.19	3.49	43.08	0.62	0.35
303	29.28	82.17	2300.00	-1.21	2.34	12.63	8.01	4.96	-5.38	0.64	0.63
304	29.28	82.32	3080.00	-0.67	-36.10	10.10	6.94	2.80	-30.31	0.70	0.54
305	29.13	81.60	1210.00	-0.51	-36.79	23.94	15.31	5.53	-13.85	0.66	0.41

APPENDIX 4: Results of comparison

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
308	29.20	81.90	1905.00	-1.41	-2.25	14.87	9.18	3.28	24.38	0.77	0.40
312	28.93	82.92	2058.00	-27.69	175.86	10.08	5.82	4.50	308.44	0.72	0.30
401	28.88	81.25	950.00	-0.96	-21.46	28.22	18.68	2.39	-0.20	0.71	0.50
402	28.85	81.72	1402.00	-0.81	-27.88	24.54	16.06	1.47	-24.79	0.73	0.67
403	28.78	81.33	260.00	-0.65	-18.50	20.88	14.11	1.88	115.53	0.69	0.28
404	28.70	82.20	1231.00	-0.64	-40.65	28.83	18.59	2.03	-30.52	0.70	0.55
405	28.65	81.27	225.00	-0.37	-30.41	42.18	24.76	7.28	-28.26	0.70	0.69
406	28.60	81.62	720.00	-0.88	-12.55	27.19	17.46	5.07	-10.40	0.71	0.67
407	28.02	82.12	235.00	-0.11	-24.20	33.06	19.99	4.05	-8.78	0.68	0.50
408	28.17	81.35	215.00	-0.79	-18.16	44.53	25.81	3.69	6.10	0.64	0.44
409	28.10	81.57	190.00	-0.45	-18.60	38.99	23.34	3.64	8.06	0.62	0.47
410	28.78	81.58	610.00	-1.07	-13.61	25.94	16.46	2.25	25.12	0.74	0.43
411	28.43	81.10	129.00	0.12	-4.16	31.83	19.84	1.43	10.57	0.82	0.55
412	28.27	81.72	135.00	-0.49	-26.35	41.02	23.87	2.43	24.29	0.71	0.39
413	28.35	81.70	510.00	-0.60	-30.65	36.56	23.91	2.42	-5.64	0.68	0.47
414	28.05	81.90	226.00	-4.96	5.71	27.60	17.62	3.67	122.78	0.61	0.24
415	28.43	81.35	200.00	-0.56	-15.41	37.49	21.85	2.90	-11.94	0.68	0.61
416	28.07	81.62	144.00	-0.49	-13.26	38.15	23.29	4.08	8.29	0.63	0.48
417	28.38	81.35	200.00	-0.42	-7.25	34.41	22.26	2.40	32.54	0.69	0.41
418	28.98	82.28	2000.00	-1.66	-41.89	18.55	13.35	0.92	-23.94	0.82	0.43
419	28.03	81.78	195.00	-1.01	-14.14	30.34	19.45	6.26	13.25	0.68	0.47
420	28.10	81.67	165.00	-0.47	-9.73	40.31	22.47	6.40	-6.94	0.60	0.59
501	28.60	82.63	1560.00	-0.53	-39.33	20.37	13.00	1.73	-33.15	0.77	0.61
504	28.30	82.63	1270.00	-0.72	-40.84	25.09	16.14	2.12	-27.40	0.72	0.54
505	28.10	82.87	823.00	-0.68	-23.55	24.54	15.30	3.98	4.13	0.67	0.50
507	28.22	82.12	698.00	-0.38	-33.42	30.72	19.83	2.15	-16.46	0.65	0.52
508	28.13	82.30	725.00	-0.66	-34.41	30.17	19.02	3.73	-30.34	0.66	0.61
509	28.05	82.50	725.00	-0.74	-27.46	26.34	17.18	2.36	-37.32	0.64	0.71

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
510	27.70	82.53	320.00	-0.44	-26.96	37.51	24.78	3.09	-13.71	0.63	0.48
511	28.38	82.17	1457.00	-1.49	4.01	23.01	14.05	2.83	25.45	0.69	0.53
512	28.30	82.28	885.00	-0.64	8.95	22.25	13.33	2.76	73.29	0.65	0.36
513	28.63	82.20	910.00	-1.45	-14.13	23.27	14.87	4.61	2.17	0.72	0.56
514	28.63	82.48	2100.00	-0.81	-41.19	24.61	16.70	2.24	-38.61	0.72	0.63
515	28.05	82.50	634.00	-0.59	-20.07	25.57	16.26	7.89	-25.15	0.62	0.71
601	28.78	83.72	2744.00	-1.46	17.32	11.21	6.44	2.56	151.22	0.73	0.23
604	28.75	83.70	2566.00	-1.19	33.07	9.31	5.22	5.88	78.93	0.68	0.41
606	28.48	83.65	1243.00	-1.13	-9.45	17.62	11.43	5.68	-18.05	0.71	0.77
607	28.63	83.60	2384.00	-0.75	-24.59	12.61	8.06	2.33	-25.00	0.80	0.66
609	28.35	83.57	835.00	-0.92	-14.80	18.44	12.32	4.30	-7.86	0.74	0.65
610	29.05	83.88	3465.00	-1.24	-19.55	11.05	6.82	1.25	192.89	0.58	0.14
613	28.18	83.75	1720.00	-0.79	-28.78	28.75	17.81	1.69	-22.68	0.73	0.64
614	28.22	83.70	891.00	-0.52	-41.37	29.08	19.50	1.70	-38.55	0.68	0.65
615	28.40	83.10	2273.00	-0.79	-49.86	25.20	17.95	1.07	-45.08	0.69	0.59
616	28.60	83.22	2530.00	-0.42	-39.88	15.97	10.79	2.28	-35.83	0.84	0.68
619	28.40	83.73	2742.00	-0.63	-44.52	22.84	15.67	1.56	-48.11	0.71	0.78
620	28.03	83.65	700.00	-0.44	-51.76	31.23	21.28	1.22	-16.70	0.73	0.41
621	28.38	83.40	1160.00	-1.09	-42.17	21.00	15.07	1.30	-40.80	0.71	0.67
622	28.15	83.57	1740.00	-0.06	-49.96	31.10	18.92	2.50	-50.95	0.76	0.80
624	28.97	83.78	3570.00	-1.16	20.08	9.20	4.85	1.90	332.03	0.61	0.16
625	28.90	83.68	3570.00	-5.42	44.98	12.12	6.85	3.34	209.54	0.68	0.20
626	28.47	83.60	1770.00	-0.37	-29.48	19.50	12.13	1.36	-31.66	0.78	0.76
627	28.38	83.48	1550.00	-1.02	-20.36	20.38	13.00	2.88	-18.30	0.73	0.64
628	28.50	83.30	1970.00	-0.57	-56.54	22.80	15.78	1.32	-51.25	0.89	0.59
629	28.57	83.38	2330.00	-0.52	-59.70	23.88	16.16	1.14	-54.77	0.85	0.60
630	28.13	83.62	790.00	-0.29	-46.79	32.26	19.76	2.22	-33.93	0.72	0.58
701	27.95	83.43	442.00	-0.62	-9.98	28.42	17.59	4.09	14.42	0.69	0.49

APPENDIX 4: Results of comparison

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
702	27.87	83.53	1067.00	-0.28	-29.93	27.64	17.85	1.83	4.84	0.70	0.47
703	27.70	83.47	205.00	-0.32	-40.63	39.28	26.60	2.71	-29.19	0.63	0.52
704	27.68	84.05	150.00	-0.29	-50.90	48.12	29.72	1.95	-37.75	0.72	0.53
705	27.52	83.43	109.00	-0.37	-24.63	39.81	23.64	7.06	-6.60	0.62	0.53
706	27.68	84.22	154.00	-0.23	-45.03	39.86	24.77	2.20	-33.67	0.69	0.55
707	27.53	83.47	120.00	-0.22	-36.35	42.14	25.70	7.36	-19.56	0.60	0.50
708	27.53	83.67	125.00	-0.31	-23.50	40.91	23.87	11.61	-14.21	0.66	0.63
710	27.58	83.87	164.00	-0.33	-54.36	56.54	32.83	1.27	-32.16	0.71	0.45
715	27.93	83.15	1760.00	-0.33	-17.64	28.88	17.03	6.49	-18.59	0.64	0.69
716	27.55	83.07	94.00	-0.80	-19.19	35.09	22.84	2.60	30.82	0.63	0.38
721	27.77	83.05	200.00	-0.31	-41.13	33.97	21.38	2.43	-38.27	0.69	0.61
722	28.17	83.27	1280.00	-0.79	-55.01	32.43	22.84	1.02	-43.58	0.70	0.49
723	27.68	82.80	80.00	-0.51	-37.16	42.88	26.82	2.46	-18.32	0.59	0.42
725	28.07	83.25	1530.00	-0.53	-36.31	28.05	18.18	3.66	-23.98	0.67	0.60
726	27.87	83.80	500.00	-0.19	-40.33	33.73	19.96	4.03	-20.93	0.71	0.55
727	27.47	83.28	95.00	-0.38	-30.15	39.64	26.85	1.39	1.43	0.64	0.38
728	27.53	83.75	154.00	-0.27	-41.78	44.37	27.44	1.80	-13.20	0.68	0.42
730	27.90	83.15	1201.00	-0.52	-41.67	31.24	18.26	1.44	-35.04	0.58	0.52
801	28.37	84.90	1334.00	-0.97	-44.49	15.02	10.49	1.05	-41.31	0.79	0.56
802	28.28	84.37	823.00	-0.44	-59.12	28.32	18.81	1.83	-57.82	0.79	0.69
804	28.22	84.00	827.00	-0.26	-52.57	39.52	23.44	5.93	-57.04	0.67	0.79
805	28.10	83.88	868.00	-0.38	-47.00	35.60	23.31	2.24	-41.05	0.73	0.66
806	28.67	84.62	3650.00	-1.44	38.64	8.05	5.31	4.43	79.24	0.82	0.55
807	28.13	84.35	855.00	-0.54	-61.73	35.62	24.68	1.32	-40.96	0.76	0.50
808	27.93	84.42	965.00	-0.14	-29.63	23.99	15.21	2.16	-9.01	0.75	0.61
809	28.00	84.62	1097.00	-0.74	-12.96	19.94	13.50	3.28	-4.73	0.77	0.66
810	27.88	83.82	460.00	-0.30	-32.77	29.14	18.25	2.67	-9.76	0.69	0.53
811	28.12	84.12	856.00	-0.33	-52.18	38.26	23.64	3.32	-54.91	0.70	0.75

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
813	28.27	83.82	1600.00	-0.62	-67.74	40.65	28.72	1.04	-56.23	0.83	0.51
814	28.30	83.80	1740.00	-0.33	-69.28	44.41	28.20	1.68	-68.28	0.81	0.75
815	28.03	84.10	500.00	-0.51	-36.77	29.29	18.87	6.84	-27.43	0.70	0.61
816	28.55	84.23	2680.00	-2.36	-18.27	10.84	7.54	1.09	17.97	0.80	0.45
817	27.97	84.28	358.00	-0.52	-19.95	27.27	16.46	5.25	-9.74	0.71	0.66
818	28.27	83.97	1070.00	-0.33	-61.31	38.13	23.49	1.39	-59.45	0.81	0.72
820	28.67	84.02	3420.00	-2.23	53.23	12.18	7.37	3.48	207.42	0.80	0.31
821	28.38	83.80	1960.00	-0.33	-52.81	27.80	18.56	1.44	-50.02	0.83	0.70
823	28.20	84.62	1120.00	-0.57	-53.35	30.07	21.45	2.01	-50.89	0.78	0.70
824	28.37	84.10	1820.00	-0.28	-52.82	26.07	17.23	1.99	-52.38	0.81	0.74
826	27.98	83.77	750.00	-0.35	-52.44	41.47	26.66	1.44	-9.48	0.71	0.32
827	27.87	84.13	660.00	-0.41	-26.74	30.48	18.24	2.92	-4.26	0.71	0.53
829	28.27	83.75	1000.00	-0.27	-53.33	30.29	19.33	2.54	-53.32	0.81	0.76
830	28.27	83.78	1160.00	-0.47	-67.18	42.51	28.27	1.52	-64.43	0.84	0.68
832	28.08	83.92	1432.00	-0.33	-47.31	36.10	23.57	3.74	-49.56	0.69	0.72
833	28.48	85.00	3300.00	-2.45	43.71	9.40	6.49	3.24	103.88	0.86	0.48
902	27.62	84.42	256.00	-0.39	-19.33	32.92	19.50	9.90	-20.58	0.69	0.70
903	27.58	84.53	270.00	-0.41	-33.02	36.24	21.55	2.62	-22.02	0.73	0.57
904	27.55	85.13	1706.00	-0.10	-40.59	49.79	20.05	8.68	-38.20	0.75	0.67
906	27.42	85.05	474.00	-0.03	-33.89	37.01	20.18	5.23	-30.88	0.62	0.67
907	27.28	85.00	396.00	-0.29	-55.92	50.51	32.02	1.05	-16.97	0.72	0.32
909	27.17	84.98	130.00	-0.13	-34.21	38.32	24.13	6.15	-29.20	0.61	0.58
910	27.18	85.17	244.00	0.11	-27.84	38.49	22.91	5.15	-30.68	0.58	0.64
911	27.07	84.97	115.00	-0.31	-31.50	37.31	24.44	3.24	-18.12	0.64	0.49
912	27.02	85.38	152.00	-0.22	-34.01	39.91	24.07	1.79	-17.67	0.68	0.48
915	27.62	85.15	1530.00	-0.35	-1.22	25.05	14.68	10.01	17.15	0.76	0.56
918	27.00	84.87	91.00	-0.30	-27.62	34.15	21.62	3.19	-15.52	0.64	0.53
919	27.42	85.17	1030.00	0.00	-37.66	34.35	20.20	2.16	-35.41	0.71	0.68

APPENDIX 4: Results of comparison

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
920	27.55	84.82	274.00	-0.29	-25.97	30.29	17.23	6.17	-24.42	0.76	0.70
921	27.03	85.00	140.00	-0.41	-15.88	34.77	21.52	1.64	-0.92	0.74	0.51
922	26.77	85.30	90.00	-0.27	-39.01	33.33	22.61	0.95	-7.30	0.50	0.31
923	26.92	85.02	109.00	-0.31	-18.00	34.70	22.27	2.07	-10.08	0.58	0.50
1001	28.28	85.38	1900.00	-0.92	-45.21	11.63	8.03	1.47	-31.49	0.72	0.49
1002	28.05	84.82	518.00	-0.54	-36.28	24.37	16.49	1.95	-31.09	0.79	0.65
1004	27.92	85.17	1003.00	-0.60	-47.67	26.20	18.14	1.01	-12.30	0.79	0.45
1005	27.87	84.93	1420.00	-0.26	-27.35	20.52	13.92	1.77	-21.46	0.80	0.70
1006	27.87	85.87	2000.00	-2.21	-62.90	22.95	18.98	0.74	-65.80	0.74	0.77
1007	27.80	85.25	2064.00	-0.46	-42.63	25.33	16.44	3.33	-46.30	0.76	0.79
1008	27.80	85.62	1592.00	-0.44	-46.12	25.64	17.59	4.48	-42.80	0.78	0.69
1009	27.78	85.72	1660.00	-0.45	-47.49	26.33	17.59	1.76	-38.73	0.81	0.63
1015	27.68	85.20	1630.00	-0.53	-3.59	21.57	12.78	2.80	0.16	0.76	0.65
1016	27.95	85.60	2625.00	-0.64	-53.71	25.00	18.26	1.96	-52.04	0.75	0.74
1017	27.87	85.57	1550.00	-0.45	-45.83	24.35	16.48	2.11	-40.13	0.76	0.66
1020	27.70	85.65	1365.00	-0.78	5.05	15.94	10.27	2.42	20.92	0.79	0.60
1022	27.58	85.40	1400.00	-0.48	-30.04	24.40	15.61	2.64	-14.41	0.76	0.57
1023	27.63	85.72	710.00	-0.89	-3.11	18.75	11.60	2.72	13.28	0.74	0.60
1024	27.62	85.55	1552.00	-0.43	-23.81	21.36	13.22	3.81	-13.97	0.69	0.62
1027	27.78	85.90	1220.00	-0.53	-48.90	22.32	15.42	1.60	-49.26	0.77	0.76
1029	27.67	85.33	1350.00	-1.08	14.72	18.46	11.62	5.65	27.71	0.74	0.62
1030	27.70	85.37	1337.00	-0.68	-2.52	20.25	12.79	5.97	-2.35	0.73	0.73
1035	27.75	85.48	1449.00	-0.60	-25.96	21.80	14.60	2.05	-17.98	0.82	0.63
1036	27.68	85.63	865.00	-0.65	-18.32	19.38	12.25	2.01	21.68	0.72	0.48
1038	27.72	85.18	1085.00	-0.75	-14.93	22.10	14.11	2.28	0.60	0.73	0.57
1039	27.73	85.33	1335.00	-0.86	-20.71	22.14	15.03	3.33	-5.44	0.76	0.56
1043	27.70	85.52	2163.00	-0.44	-31.45	21.46	13.96	3.66	-28.43	0.72	0.69
1049	27.58	85.52	1517.00	-0.50	-4.76	19.33	11.68	6.93	-7.58	0.69	0.72

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
1052	27.67	85.42	1330.00	-0.73	-5.15	21.35	13.73	5.99	2.90	0.72	0.61
1054	28.17	85.32	1847.00	-31.97	239.30	12.15	7.11	8.68	279.93	0.82	0.52
1055	28.10	85.30	1982.00	-0.69	-46.41	17.91	12.83	1.39	-35.85	0.83	0.51
1057	28.02	85.12	1240.00	-1.04	-63.28	29.94	22.79	0.84	-46.45	0.83	0.48
1058	28.00	85.55	2480.00	-0.56	-67.61	26.14	18.00	1.51	-67.12	0.82	0.75
1059	27.70	85.42	1543.00	-0.72	-17.82	21.69	13.96	4.00	-14.85	0.72	0.67
1060	27.60	85.33	1448.00	-0.56	5.20	20.12	12.73	6.04	13.00	0.76	0.66
1062	27.70	85.72	1327.00	-0.66	-22.00	20.39	12.96	2.15	-22.25	0.74	0.70
1071	27.78	85.37	1350.00	-0.56	-27.62	21.67	14.22	1.88	-23.49	0.79	0.66
1073	27.63	85.28	1212.00	-0.67	5.13	20.88	12.46	5.00	11.27	0.73	0.63
1074	27.77	85.42	1490.00	-0.62	-18.81	20.07	13.09	5.28	-6.30	0.78	0.64
1075	27.58	85.28	1590.00	-0.39	-25.80	23.44	14.48	2.00	-16.56	0.75	0.61
1076	27.68	85.25	1520.00	-0.41	-29.64	22.17	14.62	2.44	5.49	0.75	0.47
1077	27.75	85.42	1360.00	-0.51	-23.86	20.75	13.89	2.64	-11.77	0.80	0.60
1078	27.90	85.63	1310.00	-0.44	-50.52	25.56	17.09	2.66	-52.32	0.78	0.79
1079	27.75	85.25	1690.00	-0.65	-18.14	20.74	14.02	4.72	-2.04	0.79	0.59
1080	27.65	85.35	1341.00	-0.78	2.05	19.99	12.55	4.59	8.91	0.76	0.64
1081	27.78	85.28	1320.00	-0.56	-21.08	20.41	13.71	3.90	-18.92	0.77	0.70
1082	27.65	85.47	1428.00	-0.71	-10.13	21.04	12.89	3.99	3.51	0.75	0.62
1101	27.68	86.10	850.00	-0.64	-32.30	20.04	13.24	3.48	-13.14	0.77	0.52
1102	27.67	86.05	1940.00	-0.42	-33.42	19.17	12.31	5.95	-40.01	0.71	0.78
1103	27.63	86.23	2003.00	-0.43	-44.83	20.67	13.82	3.33	-51.03	0.70	0.83
1104	27.52	86.05	1536.00	-34.66	166.39	11.57	7.10	3.71	247.85	0.68	0.51
1108	27.18	86.17	1417.00	-0.28	-29.29	24.84	15.85	1.57	-33.30	0.63	0.67
1109	27.08	85.67	275.00	-0.85	-26.95	30.30	19.92	2.08	-8.30	0.68	0.48
1110	27.03	85.92	457.00	-0.12	-40.82	30.77	20.28	1.54	-15.84	0.69	0.44
1111	26.72	85.97	90.00	-0.17	-34.17	40.82	25.07	3.95	-26.54	0.55	0.46
1112	26.92	86.17	165.00	-0.37	-51.00	38.24	27.02	0.89	-19.81	0.63	0.31

APPENDIX 4: Results of comparison

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
1115	27.45	85.82	1098.00	-0.63	5.30	23.39	15.04	3.04	49.17	0.75	0.40
1117	27.33	85.50	250.00	0.10	-45.27	33.31	20.18	1.63	-38.73	0.82	0.66
1118	26.88	85.42	100.00	-0.32	-27.07	38.88	24.20	1.97	-17.53	0.58	0.46
1119	26.88	85.78	200.00	-0.47	-9.73	28.65	17.62	2.98	-8.23	0.59	0.58
1120	26.87	85.57	150.00	-0.15	-30.82	32.74	21.93	2.05	-17.68	0.56	0.45
1121	27.12	85.47	131.00	0.09	-35.30	42.52	26.13	1.83	-23.10	0.67	0.51
1123	27.47	86.08	495.00	-0.46	-20.84	21.46	13.18	2.02	13.75	0.66	0.39
1202	27.70	86.72	2619.00	-0.54	-56.14	18.54	12.21	1.12	-51.17	0.81	0.63
1203	27.43	86.57	1982.00	-0.34	-44.36	21.16	14.14	1.60	-41.80	0.69	0.60
1204	27.35	86.75	2143.00	-0.69	-49.06	21.19	14.44	1.08	-46.32	0.73	0.65
1206	27.32	86.50	1720.00	-0.24	-41.20	21.63	13.38	4.75	-41.99	0.66	0.68
1207	27.48	86.42	1576.00	-0.14	-34.45	20.54	12.74	1.50	-14.59	0.71	0.49
1210	27.13	86.43	497.00	0.12	-15.29	19.56	11.19	4.51	10.91	0.62	0.45
1211	27.03	86.83	1295.00	-0.25	-52.17	25.41	17.03	4.19	-22.87	0.69	0.38
1212	26.73	86.93	100.00	-0.20	-41.51	32.96	21.60	2.71	-35.45	0.59	0.56
1213	26.93	86.52	1175.00	-0.77	-31.31	20.56	15.01	2.46	-25.83	0.65	0.56
1216	26.65	86.22	102.00	0.16	-26.13	27.38	18.22	1.50	-23.22	0.72	0.62
1219	27.50	86.58	2378.00	-0.36	-44.41	14.85	9.77	2.35	-43.81	0.78	0.70
1222	27.22	86.80	1623.00	-0.94	-21.11	16.61	11.40	1.84	-18.44	0.64	0.56
1223	26.55	86.75	91.00	-0.05	-29.86	29.78	18.86	3.26	-21.16	0.58	0.52
1224	27.55	86.38	1662.00	-0.57	-46.56	16.48	11.73	1.58	-47.86	0.70	0.69
1226	26.60	86.90	85.00	-0.23	-39.62	31.28	21.34	2.09	-30.38	0.59	0.47
1301	27.55	87.28	1497.00	-0.57	-75.95	35.71	23.02	1.14	-77.69	0.71	0.76
1303	27.28	87.33	1329.00	-0.46	-34.86	16.37	10.95	2.45	-25.38	0.74	0.62
1304	27.05	87.28	1680.00	0.18	-33.49	15.71	9.70	2.49	-35.69	0.75	0.76
1305	27.13	87.28	410.00	-0.78	-5.36	14.07	8.74	2.74	2.03	0.69	0.59
1306	27.03	87.23	1317.00	-0.66	-35.29	19.03	12.77	1.21	-8.14	0.65	0.40
1307	26.98	87.35	1210.00	-0.11	10.99	16.85	10.61	5.29	23.88	0.62	0.57

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
1308	26.93	87.33	365.00	-0.03	-14.87	22.19	13.63	3.60	1.69	0.64	0.51
1309	26.93	87.15	143.00	-0.14	-37.23	26.01	17.07	2.64	-28.37	0.62	0.56
1311	26.82	87.28	444.00	-0.15	-41.09	26.83	17.10	6.08	-43.61	0.61	0.64
1312	26.62	87.38	152.00	-0.22	-34.37	32.09	20.85	3.90	-32.15	0.58	0.59
1314	27.13	87.55	1633.00	-0.69	-38.27	14.40	9.96	1.78	-17.53	0.64	0.49
1316	26.82	87.17	183.00	-0.24	-49.80	35.48	22.22	1.82	-42.56	0.64	0.52
1317	27.77	87.42	2590.00	-0.94	-66.30	14.36	10.76	1.26	-78.44	0.47	0.71
1319	26.48	87.27	72.00	-0.40	-19.01	32.63	20.70	8.17	-22.88	0.56	0.63
1320	26.70	87.27	200.00	-0.27	-29.24	30.55	19.30	4.65	-27.61	0.59	0.64
1321	27.28	87.22	303.00	-0.49	-33.17	17.76	11.67	2.31	-26.49	0.75	0.60
1322	26.97	87.17	158.00	-0.44	-30.22	21.57	14.98	2.31	-3.66	0.67	0.46
1325	27.37	87.15	1190.00	-0.54	-49.28	21.94	15.11	1.82	-44.01	0.74	0.60
1326	26.73	87.50	250.00	-0.28	-38.80	33.92	21.98	3.55	-37.44	0.60	0.62
1403	27.55	87.78	1780.00	-0.57	-61.82	15.91	11.20	1.37	-66.49	0.67	0.76
1405	27.35	87.67	1732.00	-0.35	-41.98	17.19	11.18	4.19	-49.10	0.68	0.79
1406	27.20	87.93	1830.00	-0.42	-38.98	17.45	10.92	2.79	-52.47	0.61	0.89
1408	26.67	87.70	163.00	-0.33	-38.67	32.68	21.64	3.14	-28.40	0.63	0.51
1409	26.63	87.98	122.00	-0.20	-43.17	35.15	22.75	2.27	-41.23	0.64	0.62
1410	26.88	88.03	1654.00	-0.26	-38.51	27.23	17.63	2.11	-34.69	0.71	0.65
1412	26.57	88.05	120.00	-0.19	-40.53	34.62	22.24	1.91	-24.42	0.68	0.52
1415	26.68	87.97	168.00	-0.14	-44.11	34.93	22.70	2.29	-39.73	0.64	0.59
1416	26.87	88.07	1678.00	-0.27	-46.82	31.66	19.51	2.61	-44.90	0.67	0.64
1419	27.15	87.75	1205.00	-0.51	-26.66	16.00	10.09	3.82	-18.64	0.68	0.61
1420	27.35	87.60	763.00	-0.75	-49.05	15.18	11.21	0.96	-42.07	0.69	0.59
1421	26.58	87.90	143.00	-0.11	-37.55	32.63	20.96	3.12	-32.88	0.62	0.64
1422	26.40	88.02	60.00	-0.23	-27.39	32.91	21.57	6.34	-27.12	0.63	0.65
	Average			-0.96	-26.65	27.02	17.15	3.19	-9.95	0.70	0.57
	Maximum			**0.18**	**239.30**	**56.54**	**32.83**	**11.61**	**332.03**	**0.89**	**0.89**

Comparison of monthly precipitation data sets

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
101	29.65	80.50	842.00	0.65	-23.83	113.19	69.72	0.59	-23.68	0.99	0.90
102	29.55	80.42	1635.00	0.33	-0.35	97.76	67.77	0.78	0.84	1.00	0.88
103	29.47	80.53	1266.00	0.63	-7.97	80.15	51.25	0.65	-7.96	1.00	0.98
104	29.30	80.58	1848.00	0.70	-3.49	65.64	43.56	0.81	-3.46	1.00	0.94
106	28.68	80.35	159.00	0.74	-18.44	111.99	65.53	1.92	-18.28	0.99	0.93
107	29.85	80.57	1097.00	0.57	-44.10	172.48	105.94	0.55	-44.00	0.98	0.94
108	29.53	80.47	2370.00	0.73	-21.62	79.78	52.04	0.53	-21.45	1.00	0.93
201	29.62	80.87	1456.00	0.56	-39.63	142.99	86.87	0.60	-39.58	1.00	0.98
202	29.55	81.22	1304.00	0.71	-27.25	82.63	50.73	0.52	-27.11	1.00	0.95
203	29.27	80.98	1360.00	-0.05	-33.03	468.17	113.44	1.78	-32.72	0.99	0.90
204	29.38	81.32	1400.00	0.35	-19.86	133.85	91.99	1.31	-15.86	1.00	0.86
205	29.00	81.13	1388.00	0.46	-31.46	148.72	90.45	0.88	-31.02	0.99	0.85
206	28.95	81.45	650.00	-0.29	28.21	124.21	80.39	1.25	29.90	0.99	0.85
207	28.53	81.12	140.00	0.73	3.71	106.77	65.61	0.57	3.82	0.97	0.93
208	28.75	80.92	195.00	0.70	-17.60	131.07	72.41	1.10	-17.50	0.99	0.91
209	28.80	80.55	187.00	0.81	-18.61	103.12	60.75	7.60	-18.55	0.98	0.93
210	28.97	81.12	340.00	0.47	-0.05	123.99	82.76	1.26	1.84	1.00	0.85
212	28.57	80.82	152.00	0.60	-2.59	120.57	78.84	2.26	-1.44	0.95	0.81
214	29.12	80.68	1304.00	0.75	-21.58	86.32	54.47	0.44	-21.26	1.00	0.90
215	28.87	80.63	288.00	0.51	-26.24	206.23	120.24	1.57	-25.51	0.99	0.87
217	29.15	81.28	1345.00	0.73	-13.77	71.40	52.28	0.61	-13.47	1.00	0.90
218	29.23	80.93	720.00	0.37	21.28	80.35	49.03	1.94	21.45	0.99	0.91
302	29.32	81.77	1006.00	-0.41	44.15	72.10	50.60	1.43	46.13	0.99	0.86
303	29.28	82.17	2300.00	0.67	-6.84	42.90	29.94	0.66	-6.87	0.98	0.91
304	29.28	82.32	3080.00	0.51	-32.26	72.88	48.06	4.63	-32.04	1.00	0.88
305	29.13	81.60	1210.00	0.51	-14.11	116.15	79.72	4.48	-13.85	0.99	0.88

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
308	29.20	81.90	1905.00	0.00	23.39	73.94	47.94	1.39	24.41	0.99	0.89
312	28.93	82.92	2058.00	-13.25	233.90	97.41	77.07	12.12	308.56	1.00	0.49
401	28.88	81.25	950.00	0.68	-0.28	85.53	57.15	0.65	-0.20	1.00	0.92
402	28.85	81.72	1402.00	0.64	-25.06	124.26	77.93	1.57	-24.78	0.97	0.85
403	28.78	81.33	260.00	-0.98	72.79	138.22	88.95	1.69	115.53	0.98	0.67
404	28.70	82.20	1231.00	0.54	-35.16	134.06	86.72	0.65	-30.53	1.00	0.83
405	28.65	81.27	225.00	0.65	-28.60	180.99	106.19	1.07	-28.25	0.96	0.92
406	28.60	81.62	720.00	0.76	-10.73	89.40	57.74	0.49	-10.39	0.97	0.90
407	28.02	82.12	235.00	0.63	-10.52	121.42	65.93	0.78	-9.58	0.98	0.82
408	28.17	81.35	215.00	0.78	5.83	81.70	46.76	0.45	6.10	0.99	0.84
409	28.10	81.57	190.00	0.76	7.84	86.63	47.07	3.18	8.07	1.00	0.91
410	28.78	81.58	610.00	-0.16	27.38	115.84	74.17	1.00	29.05	1.00	0.83
411	28.43	81.10	129.00	0.69	9.62	107.62	71.13	0.47	10.57	0.97	0.85
412	28.27	81.72	135.00	0.52	23.36	143.28	91.82	1.65	24.29	1.00	0.84
413	28.35	81.70	510.00	0.55	-9.30	150.65	94.33	0.73	-5.63	0.99	0.80
414	28.05	81.90	226.00	-2.58	101.24	160.34	109.20	1.46	122.81	1.00	0.64
415	28.43	81.35	200.00	0.77	-12.01	115.43	60.03	0.63	-11.93	0.99	0.94
416	28.07	81.62	144.00	0.72	7.66	90.03	50.51	0.83	8.30	1.00	0.88
417	28.38	81.35	200.00	0.55	22.80	113.85	68.20	0.95	32.55	1.00	0.78
418	28.98	82.28	2000.00	0.51	-25.38	123.32	84.89	0.60	-23.93	1.00	0.82
419	28.03	81.78	195.00	0.50	11.67	107.55	70.81	0.88	13.26	1.00	0.77
420	28.10	81.67	165.00	0.79	-7.01	94.17	50.25	0.55	-6.93	1.00	0.96
501	28.60	82.63	1560.00	0.52	-34.29	125.28	84.39	1.06	-33.13	0.99	0.91
504	28.30	82.63	1270.00	0.59	-27.37	102.41	66.42	0.49	-27.40	0.98	0.95
505	28.10	82.87	823.00	0.73	2.63	61.03	41.93	0.68	4.14	0.99	0.89
507	28.22	82.12	698.00	0.67	-18.05	108.00	74.30	0.53	-16.46	0.99	0.87
508	28.13	82.30	725.00	0.62	-30.62	123.18	79.45	1.55	-30.34	0.99	0.89
509	28.05	82.50	725.00	0.55	-37.56	136.90	91.29	0.66	-37.32	0.99	0.90

APPENDIX 4: Results of comparison

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
510	27.70	82.53	320.00	0.80	-14.84	88.26	57.53	0.74	-13.71	1.00	0.90
511	28.38	82.17	1457.00	0.31	25.51	86.01	56.63	0.94	25.43	0.99	0.93
512	28.30	82.28	885.00	-0.65	64.56	122.53	81.43	3.28	73.30	1.00	0.80
513	28.63	82.20	910.00	0.69	2.01	67.47	41.52	0.57	2.16	1.00	0.94
514	28.63	82.48	2100.00	0.60	-40.64	142.00	89.39	0.76	-38.59	1.00	0.93
515	28.05	82.50	634.00	0.71	-25.28	90.67	61.15	0.50	-25.15	0.99	0.93
601	28.78	83.72	2744.00	-9.67	147.34	78.60	52.25	2.80	151.16	1.00	0.82
604	28.75	83.70	2566.00	-4.29	77.74	67.73	45.92	3.05	78.90	1.00	0.90
606	28.48	83.65	1243.00	0.66	-18.04	80.03	59.01	0.56	-18.04	0.99	0.93
607	28.63	83.60	2384.00	0.32	-25.22	78.51	58.38	0.56	-25.01	1.00	0.94
609	28.35	83.57	835.00	0.78	-7.72	63.78	42.72	0.48	-7.57	0.99	0.95
610	29.05	83.88	3465.00	-3.95	164.08	51.53	36.85	7.95	233.44	0.96	0.55
613	28.18	83.75	1720.00	0.69	-23.65	127.35	83.90	0.60	-22.66	0.99	0.92
614	28.22	83.70	891.00	0.60	-38.52	152.78	101.90	0.58	-38.54	0.99	0.98
615	28.40	83.10	2273.00	0.45	-45.48	187.65	124.70	0.53	-45.08	1.00	0.86
616	28.60	83.22	2530.00	0.69	-35.96	114.04	74.18	0.53	-35.82	1.00	0.92
619	28.40	83.73	2742.00	0.44	-48.14	187.35	133.66	0.61	-48.10	0.99	0.93
620	28.03	83.65	700.00	0.75	-16.84	94.68	61.31	0.48	-16.69	0.99	0.90
621	28.38	83.40	1160.00	0.53	-40.74	150.17	94.14	0.72	-40.79	0.98	0.98
622	28.15	83.57	1740.00	0.41	-50.96	249.22	148.83	0.66	-50.95	0.99	0.98
625	28.90	83.68	3570.00	-19.47	201.10	86.97	58.09	3.78	208.30	1.00	0.81
626	28.47	83.60	1770.00	0.59	-31.65	115.54	69.20	0.49	-31.65	1.00	0.98
627	28.38	83.48	1550.00	0.66	-18.84	89.36	61.28	0.47	-18.30	0.96	0.88
628	28.50	83.30	1970.00	0.37	-52.15	242.84	153.00	2.78	-51.24	1.00	0.80
629	28.57	83.38	2330.00	0.40	-54.91	225.82	145.32	0.56	-54.76	1.00	0.91
630	28.13	83.62	790.00	0.66	-34.03	141.44	88.99	0.61	-33.92	1.00	0.95
701	27.95	83.43	442.00	0.54	14.22	92.78	56.09	1.16	14.42	0.98	0.91
702	27.87	83.53	1067.00	0.82	4.63	68.94	48.15	0.55	4.88	1.00	0.91

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
703	27.70	83.47	205.00	0.61	-28.56	157.92	97.89	0.69	-29.20	0.96	0.91
704	27.68	84.05	150.00	0.57	-37.79	213.12	122.97	1.16	-37.74	1.00	0.96
705	27.52	83.43	109.00	0.79	-6.67	90.75	55.04	0.50	-6.62	0.96	0.94
706	27.68	84.22	154.00	0.63	-33.86	165.54	114.49	0.63	-33.67	0.99	0.94
707	27.53	83.47	120.00	0.73	-19.55	125.02	74.86	0.54	-19.57	0.91	0.94
708	27.53	83.67	125.00	0.73	-14.31	113.80	68.97	0.71	-14.20	0.99	0.95
710	27.58	83.87	164.00	0.64	-32.26	194.92	112.10	0.56	-32.15	0.99	0.93
715	27.93	83.15	1760.00	0.80	-19.28	83.85	52.78	0.38	-19.25	0.97	0.95
716	27.55	83.07	94.00	0.33	28.63	136.48	79.50	1.59	30.29	1.00	0.86
721	27.77	83.05	200.00	0.62	-38.30	155.74	94.76	0.62	-38.27	0.99	0.94
722	28.17	83.27	1280.00	0.39	-44.00	186.81	132.93	0.60	-43.58	0.99	0.80
723	27.68	82.80	80.00	0.58	-18.85	136.43	72.48	0.53	-18.32	0.99	0.89
725	28.07	83.25	1530.00	0.75	-24.27	87.73	60.82	0.69	-23.99	0.99	0.91
726	27.87	83.80	500.00	0.73	-20.97	105.02	70.50	0.75	-20.93	1.00	0.96
727	27.47	83.28	95.00	0.69	-4.04	110.02	68.83	0.72	1.66	0.96	0.83
728	27.53	83.75	154.00	0.70	-14.98	130.98	79.39	0.54	-13.19	0.97	0.87
730	27.90	83.15	1201.00	0.56	-35.64	136.48	87.35	0.70	-35.04	0.99	0.90
801	28.37	84.90	1334.00	0.55	-41.79	99.30	74.48	0.61	-41.54	1.00	0.92
802	28.28	84.37	823.00	0.31	-57.92	278.31	185.82	0.70	-57.81	1.00	0.92
804	28.22	84.00	827.00	0.28	-57.02	325.47	208.73	0.61	-57.03	0.98	0.97
805	28.10	83.88	868.00	0.47	-41.12	216.70	141.74	0.55	-41.04	1.00	0.89
806	28.67	84.62	3650.00	-1.46	78.12	84.46	57.57	2.19	79.27	1.00	0.89
807	28.13	84.35	855.00	0.46	-41.02	193.45	130.32	0.55	-40.94	1.00	0.93
808	27.93	84.42	965.00	0.63	-9.04	112.93	69.57	0.65	-9.00	1.00	0.95
809	28.00	84.62	1097.00	0.73	-4.79	82.58	56.61	0.97	-4.73	1.00	0.94
810	27.88	83.82	460.00	0.77	-9.79	85.40	63.03	0.53	-9.48	1.00	0.90
811	28.12	84.12	856.00	0.34	-54.93	301.45	191.61	0.59	-54.90	0.98	0.97
813	28.27	83.82	1600.00	0.32	-56.37	332.09	223.41	0.62	-56.22	1.00	0.86

APPENDIX 4: Results of comparison

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
814	28.30	83.80	1740.00	0.15	-68.28	519.41	346.67	0.69	-68.24	1.00	0.94
815	28.03	84.10	500.00	0.58	-27.40	132.84	86.65	0.48	-27.42	0.99	0.92
816	28.55	84.23	2680.00	0.24	16.30	90.39	65.27	1.05	18.00	1.00	0.83
817	27.97	84.28	358.00	0.73	-9.76	91.12	63.23	0.64	-9.74	0.98	0.95
818	28.27	83.97	1070.00	0.30	-59.52	347.12	235.25	0.78	-59.45	1.00	0.93
820	28.67	84.02	3420.00	-16.53	207.43	138.96	87.99	2.63	208.81	1.00	0.88
821	28.38	83.80	1960.00	0.42	-50.09	301.04	185.89	0.70	-50.02	1.00	0.90
823	28.20	84.62	1120.00	0.42	-51.35	251.02	172.66	0.59	-51.27	0.98	0.93
824	28.37	84.10	1820.00	0.41	-52.40	247.11	176.11	0.60	-52.37	1.00	0.97
826	27.98	83.77	750.00	0.63	-13.55	130.18	81.71	0.73	-9.48	1.00	0.80
827	27.87	84.13	660.00	0.61	-4.20	97.36	68.06	0.52	-4.22	0.97	0.93
829	28.27	83.75	1000.00	0.45	-53.37	282.67	185.00	0.58	-53.32	1.00	0.94
830	28.27	83.78	1160.00	0.19	-64.54	464.33	303.31	0.66	-64.43	1.00	0.90
832	28.08	83.92	1432.00	0.44	-49.48	238.42	164.35	0.59	-49.46	0.99	0.95
833	28.48	85.00	3300.00	-1.24	102.41	118.51	79.93	7.98	106.08	1.00	0.88
902	27.62	84.42	256.00	0.79	-20.63	104.30	68.23	0.66	-20.58	0.99	0.98
903	27.58	84.53	270.00	0.81	-22.17	111.40	69.16	0.82	-22.03	0.99	0.94
904	27.55	85.13	1706.00	0.45	-38.18	228.40	112.06	1.15	-38.19	0.98	0.98
906	27.42	85.05	474.00	0.70	-38.20	166.51	112.17	0.56	-30.87	0.99	0.90
907	27.28	85.00	396.00	0.74	-18.49	127.87	81.47	0.61	-17.00	1.00	0.82
909	27.17	84.98	130.00	0.74	-29.26	121.33	73.67	0.63	-29.20	0.99	0.95
911	27.07	84.97	115.00	0.72	-18.28	114.66	60.56	0.73	-18.11	1.00	0.92
912	27.02	85.38	152.00	0.72	-15.82	141.37	73.80	0.86	-15.70	0.99	0.93
915	27.62	85.15	1530.00	0.81	16.01	66.97	47.66	0.71	17.16	1.00	0.88
918	27.00	84.87	91.00	0.73	-15.75	108.29	60.48	1.21	-15.58	0.99	0.93
919	27.42	85.17	1030.00	0.65	-35.61	210.63	128.29	0.66	-35.45	0.99	0.91
920	27.55	84.82	274.00	0.74	-24.65	127.71	88.47	0.77	-24.43	1.00	0.89
923	26.92	85.02	109.00	0.75	-10.73	102.32	67.42	1.68	-10.08	0.98	0.92

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
1001	28.28	85.38	1900.00	0.43	-31.95	76.23	51.04	1.08	-31.52	1.00	0.85
1002	28.05	84.82	518.00	0.68	-30.20	128.59	78.89	0.56	-30.14	0.99	0.87
1004	27.92	85.17	1003.00	0.82	-12.58	79.60	49.77	0.41	-12.30	1.00	0.89
1005	27.87	84.93	1420.00	0.80	-22.05	91.75	60.32	1.90	-21.67	1.00	0.90
1006	27.87	85.87	2000.00	0.09	-65.85	363.07	259.76	0.72	-65.80	1.00	0.91
1007	27.80	85.25	2064.00	0.52	-46.31	194.98	131.75	0.52	-46.30	0.99	0.93
1008	27.80	85.62	1592.00	0.59	-42.71	168.70	107.03	0.55	-42.71	0.99	0.94
1009	27.78	85.72	1660.00	0.55	-39.18	170.55	109.90	0.73	-38.73	1.00	0.88
1015	27.68	85.20	1630.00	0.88	-0.10	55.54	38.73	0.53	-0.41	0.96	0.96
1016	27.95	85.60	2625.00	0.45	-52.08	237.83	154.43	0.57	-52.09	0.97	0.96
1017	27.87	85.57	1550.00	0.61	-40.89	150.88	99.18	0.61	-40.90	0.97	0.93
1022	27.58	85.40	1400.00	0.85	-14.46	69.38	43.79	0.46	-14.40	0.99	0.91
1023	27.63	85.72	710.00	0.63	15.97	66.31	44.09	0.83	15.71	0.97	0.96
1024	27.62	85.55	1552.00	0.85	-13.67	59.10	42.26	0.48	-13.98	0.96	0.96
1027	27.78	85.90	1220.00	0.50	-49.35	194.88	128.20	0.61	-49.26	1.00	0.95
1029	27.67	85.33	1350.00	0.43	27.51	81.52	56.19	0.58	27.63	1.00	0.90
1030	27.70	85.37	1337.00	0.83	-2.34	59.01	41.65	0.44	-2.34	0.98	0.91
1035	27.75	85.48	1449.00	0.75	-18.59	102.58	70.26	0.54	-17.98	0.99	0.84
1036	27.68	85.63	865.00	0.60	21.15	66.89	45.24	1.42	21.44	0.99	0.92
1038	27.72	85.18	1085.00	0.82	0.67	65.43	43.17	0.48	0.61	0.98	0.95
1039	27.73	85.33	1335.00	0.72	-6.26	85.10	58.57	0.49	-5.43	0.99	0.82
1043	27.70	85.52	2163.00	0.71	-28.35	97.31	65.44	0.49	-28.43	0.98	0.94
1049	27.58	85.52	1517.00	0.80	-7.44	61.40	41.69	0.49	-7.58	0.95	0.95
1052	27.67	85.42	1330.00	0.73	2.84	73.99	48.63	0.51	2.90	0.99	0.89
1054	28.17	85.32	1847.00	-14.30	276.76	124.74	87.47	7.26	279.91	1.00	0.89
1055	28.10	85.30	1982.00	0.58	-36.70	127.13	78.71	0.55	-35.85	1.00	0.87
1057	28.02	85.12	1240.00	0.48	-46.53	218.46	145.17	0.58	-46.44	1.00	0.85
1058	28.00	85.55	2480.00	0.09	-67.32	365.37	231.86	0.93	-67.25	1.00	0.92

APPENDIX 4: Results of comparison

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
1059	27.70	85.42	1543.00	0.79	-14.92	80.09	54.75	0.43	-14.85	0.98	0.89
1060	27.60	85.33	1448.00	0.79	12.94	64.46	44.69	4.89	13.02	1.00	0.91
1062	27.70	85.72	1327.00	0.73	-21.21	79.79	57.32	0.74	-21.20	0.97	0.93
1071	27.78	85.37	1350.00	0.81	-23.14	93.34	60.73	0.47	-22.77	1.00	0.87
1073	27.63	85.28	1212.00	0.72	10.95	66.24	48.90	0.57	11.28	1.00	0.90
1074	27.77	85.42	1490.00	0.66	-6.43	101.53	72.98	0.80	-6.30	0.98	0.91
1075	27.58	85.28	1590.00	0.83	-16.73	75.30	48.13	0.47	-16.56	1.00	0.91
1076	27.68	85.25	1520.00	0.74	4.21	72.23	50.05	0.53	5.87	1.00	0.81
1077	27.75	85.42	1360.00	0.82	-11.25	78.94	53.58	4.02	-10.81	0.99	0.89
1078	27.90	85.63	1310.00	0.46	-51.87	226.55	153.50	0.55	-51.84	0.99	0.92
1079	27.75	85.25	1690.00	0.80	-1.54	71.52	49.17	0.43	-0.81	0.99	0.84
1080	27.65	85.35	1341.00	0.76	8.87	65.94	46.98	2.07	8.92	1.00	0.90
1081	27.78	85.28	1320.00	0.79	-19.09	83.90	57.77	0.76	-18.92	0.99	0.92
1101	27.68	86.10	850.00	0.49	-12.54	116.64	75.86	2.81	-11.99	1.00	0.90
1102	27.67	86.05	1940.00	0.63	-40.01	125.66	82.11	0.70	-40.01	0.99	0.95
1103	27.63	86.23	2003.00	0.47	-51.27	176.62	113.99	0.56	-51.30	0.99	0.99
1104	27.52	86.05	1536.00	-18.63	246.83	140.37	92.74	4.15	247.13	0.99	0.89
1108	27.18	86.17	1417.00	0.68	-33.28	107.14	73.17	0.49	-33.28	0.99	0.95
1109	27.08	85.67	275.00	0.72	-7.06	90.82	57.49	0.87	-6.90	0.97	0.96
1110	27.03	85.92	457.00	0.80	-16.06	95.98	61.29	0.44	-15.85	0.99	0.88
1111	26.72	85.97	90.00	0.62	-27.99	149.06	79.56	0.83	-26.53	1.00	0.84
1112	26.92	86.17	165.00	0.66	-21.01	130.09	82.57	0.93	-19.81	1.00	0.79
1115	27.45	85.82	1098.00	0.46	43.41	91.81	65.13	1.15	48.15	1.00	0.79
1117	27.33	85.50	250.00	0.64	-38.82	203.48	122.66	0.92	-38.73	1.00	0.91
1118	26.88	85.42	100.00	0.75	-18.08	109.20	66.12	0.66	-17.54	1.00	0.89
1119	26.88	85.78	200.00	0.68	-8.27	96.85	58.30	0.81	-8.24	0.96	0.93
1120	26.87	85.57	150.00	0.73	-19.20	110.53	63.38	0.81	-19.02	1.00	0.91
1121	27.12	85.47	131.00	0.71	-24.11	165.81	86.69	0.93	-23.11	0.99	0.89

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
1123	27.47	86.08	495.00	0.76	13.16	58.38	42.54	0.61	13.75	0.99	0.88
1202	27.70	86.72	2619.00	0.41	-51.57	171.53	110.11	0.64	-51.15	1.00	0.87
1203	27.43	86.57	1982.00	0.53	-41.92	140.65	85.69	0.65	-41.80	0.99	0.89
1204	27.35	86.75	2143.00	0.47	-46.37	163.51	105.18	0.70	-46.32	1.00	0.93
1206	27.32	86.50	1720.00	0.59	-42.02	117.77	77.61	0.53	-41.99	0.98	0.98
1207	27.48	86.42	1576.00	0.73	-15.33	81.42	49.36	0.77	-14.59	1.00	0.88
1210	27.13	86.43	497.00	0.60	10.74	85.61	52.40	1.06	10.64	0.97	0.94
1211	27.03	86.83	1295.00	0.65	-22.87	80.50	55.93	0.85	-22.72	1.00	0.90
1212	26.73	86.93	100.00	0.64	-35.42	135.61	80.38	0.45	-35.45	0.96	0.98
1213	26.93	86.52	1175.00	0.74	-26.15	87.69	62.12	0.71	-25.83	0.97	0.93
1216	26.65	86.22	102.00	0.74	-23.32	99.33	61.97	0.82	-23.22	1.00	0.95
1219	27.50	86.58	2378.00	0.55	-43.84	123.13	75.64	0.60	-43.80	1.00	0.94
1222	27.22	86.80	1623.00	0.64	-19.35	76.41	49.49	0.58	-18.45	1.00	0.89
1223	26.55	86.75	91.00	0.71	-21.12	112.97	62.95	1.35	-21.17	0.99	0.94
1224	27.55	86.38	1662.00	0.47	-48.27	155.96	98.77	0.67	-48.30	0.99	0.94
1226	26.60	86.90	85.00	0.68	-31.08	122.27	72.90	0.57	-30.56	0.99	0.90
1301	27.55	87.28	1497.00	-0.56	-77.68	423.55	322.44	0.77	-77.66	1.00	0.99
1303	27.28	87.33	1329.00	0.70	-25.46	70.58	48.01	0.62	-25.37	1.00	0.92
1304	27.05	87.28	1680.00	0.59	-35.75	91.39	61.96	0.69	-35.70	1.00	0.92
1305	27.13	87.28	410.00	0.66	1.30	51.03	35.57	2.29	1.64	1.00	0.90
1306	27.03	87.23	1317.00	0.79	-8.58	49.16	32.60	0.46	-8.12	1.00	0.89
1307	26.98	87.35	1210.00	0.62	23.82	64.75	43.88	0.75	23.89	0.99	0.94
1308	26.93	87.33	365.00	0.75	-0.43	65.88	45.09	1.41	0.19	0.99	0.90
1309	26.93	87.15	143.00	0.74	-28.42	98.07	60.91	0.54	-28.37	0.99	0.95
1311	26.82	87.28	444.00	0.56	-43.62	141.24	96.38	2.12	-43.60	0.99	0.98
1312	26.62	87.38	152.00	0.61	-32.12	153.82	86.29	0.73	-32.15	0.96	0.99
1314	27.13	87.55	1633.00	0.53	-18.49	65.32	46.47	0.54	-18.22	0.99	0.88
1316	26.82	87.17	183.00	0.47	-42.25	163.51	105.47	0.70	-42.16	0.99	0.94

APPENDIX 4: Results of comparison

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
1317	27.77	87.42	2590.00	-0.54	-78.68	203.75	156.46	0.92	-78.65	1.00	0.97
1319	26.48	87.27	72.00	0.77	-22.86	101.68	61.41	0.57	-22.88	0.95	0.99
1320	26.70	87.27	200.00	0.73	-28.27	105.70	68.01	0.44	-27.61	0.96	0.95
1321	27.28	87.22	303.00	0.41	-27.96	104.47	76.29	0.56	-26.47	1.00	0.76
1322	26.97	87.17	158.00	0.69	-2.85	82.94	57.79	3.32	-2.67	0.99	0.91
1325	27.37	87.15	1190.00	0.35	-43.99	147.61	105.06	0.54	-43.84	1.00	0.88
1326	26.73	87.50	250.00	0.64	-37.42	147.03	96.74	0.71	-37.45	0.98	0.95
1403	27.55	87.78	1780.00	0.06	-66.49	199.98	140.58	0.69	-66.48	1.00	0.97
1405	27.35	87.67	1732.00	0.40	-49.12	129.71	91.53	0.54	-49.10	0.98	0.94
1406	27.20	87.93	1830.00	0.30	-52.44	151.50	112.33	0.79	-52.56	0.95	0.98
1408	26.67	87.70	163.00	0.73	-28.37	112.86	70.05	0.39	-28.41	0.99	0.94
1409	26.63	87.98	122.00	0.58	-41.42	189.04	115.87	0.57	-41.22	1.00	0.94
1410	26.88	88.03	1654.00	0.66	-34.70	139.61	89.97	0.86	-34.68	0.98	0.94
1412	26.57	88.05	120.00	0.78	-24.56	119.18	69.09	0.42	-24.42	1.00	0.93
1415	26.68	87.97	168.00	0.60	-39.97	181.07	113.93	0.46	-39.73	0.99	0.92
1416	26.87	88.07	1678.00	0.52	-44.95	190.55	121.92	0.51	-44.90	0.96	0.95
1419	27.15	87.75	1205.00	0.77	-18.54	57.08	41.20	0.53	-18.45	0.99	0.91
1420	27.35	87.60	763.00	0.40	-42.24	109.31	78.56	0.78	-42.07	1.00	0.92
1421	26.58	87.90	143.00	0.70	-32.90	141.39	82.36	0.77	-32.87	1.00	0.96
1422	26.40	88.02	60.00	0.70	-27.20	140.74	83.79	0.43	-27.12	0.99	0.93
	Maximum			-19.47	-78.68	42.90	29.94	0.38	-78.65	0.91	0.49
	Average			0.11	-12.75	132.35	85.00	1.09	-11.29	0.99	0.90
	Minimum			0.88	276.76	519.41	346.67	12.12	308.56	1.00	0.99

Comparison of yearly precipitation data sets

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
103	29.47	80.53	1266.00	-3.09	-4.91	273.96	226.79	0.16	-4.91	1.00	1.00
104	29.30	80.58	1848.00	-1.25	-3.46	316.83	295.02	0.23	-3.46	1.00	1.00
106	28.68	80.35	159.00	-2.35	-18.28	552.75	445.15	0.23	-18.28	1.00	1.00
107	29.85	80.57	1097.00	-10.53	-44.00	1172.09	1110.81	0.44	-44.00	1.00	1.00
108	29.53	80.47	2370.00	-4.72	-21.45	436.31	381.89	0.23	-21.45	1.00	1.00
201	29.62	80.87	1456.00	-25.39	-41.12	1046.71	922.38	0.40	-41.12	1.00	1.00
202	29.55	81.22	1304.00	-6.23	-27.11	562.91	450.32	0.26	-27.11	1.00	1.00
204	29.38	81.32	1400.00	-0.55	-15.36	781.80	670.11	0.56	-15.36	1.00	1.00
206	28.95	81.45	650.00	-13.04	29.90	542.93	433.70	0.39	29.90	1.00	1.00
207	28.53	81.12	140.00	-0.35	1.12	381.94	320.28	0.18	1.12	1.00	1.00
208	28.75	80.92	195.00	-0.74	-17.50	599.27	528.28	0.26	-17.50	1.00	1.00
209	28.80	80.55	187.00	-0.13	-18.55	522.83	375.10	0.18	-18.55	1.00	1.00
210	28.97	81.12	340.00	-2.81	1.84	594.22	458.19	0.30	1.84	1.00	1.00
212	28.57	80.82	152.00	-1.01	-1.44	532.43	504.98	0.35	-1.44	1.00	1.00
214	29.12	80.68	1304.00	-6.45	-18.67	422.87	368.66	0.22	-18.67	1.00	1.00
217	29.15	81.28	1345.00	-6.97	-13.21	430.57	374.97	0.24	-13.21	1.00	1.00
218	29.23	80.93	720.00	-19.31	21.45	437.71	336.97	0.31	21.45	1.00	1.00
303	29.28	82.17	2300.00	-3.83	-8.07	200.84	163.10	0.19	-8.07	1.00	1.00
308	29.20	81.90	1905.00	-3.00	24.41	320.77	264.77	0.32	24.41	1.00	1.00
312	28.93	82.92	2058.00	-43.90	308.56	600.19	574.31	8.07	308.56	1.00	1.00
402	28.85	81.72	1402.00	-3.70	-21.61	572.79	470.57	0.25	-21.61	1.00	1.00
403	28.78	81.33	260.00	-15.26	75.99	692.11	590.85	0.91	75.99	1.00	1.00
404	28.70	82.20	1231.00	-4.74	-32.38	598.69	563.82	0.33	-32.38	1.00	1.00
405	28.65	81.27	225.00	-3.73	-30.13	873.68	752.02	0.30	-30.13	1.00	1.00
406	28.60	81.62	720.00	-9.53	-10.39	505.35	425.45	0.25	-10.39	1.00	1.00
409	28.10	81.57	190.00	-0.25	8.07	394.28	326.63	0.23	8.07	1.00	1.00

APPENDIX 4: Results of comparison

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
410	28.78	81.58	610.00	-19.92	33.39	575.83	465.37	0.45	33.39	1.00	1.00
411	28.43	81.10	129.00	0.32	10.73	359.58	323.90	0.24	10.73	1.00	1.00
412	28.27	81.72	135.00	-0.77	36.88	737.43	610.57	0.61	36.88	1.00	1.00
413	28.35	81.70	510.00	-2.03	5.06	443.78	363.09	0.21	5.06	1.00	1.00
415	28.43	81.35	200.00	-0.05	-11.93	491.92	363.32	0.17	-11.93	1.00	1.00
416	28.07	81.62	144.00	-0.86	8.30	425.63	328.72	0.24	8.30	1.00	1.00
417	28.38	81.35	200.00	-2.92	32.55	578.85	469.17	0.44	32.55	1.00	1.00
419	28.03	81.78	195.00	-1.07	18.45	500.71	447.60	0.35	18.45	1.00	1.00
420	28.10	81.67	165.00	-0.24	-6.93	461.61	388.22	0.23	-6.93	1.00	1.00
501	28.60	82.63	1560.00	-8.02	-34.10	817.46	666.30	0.33	-34.10	1.00	1.00
504	28.30	82.63	1270.00	-3.55	-27.40	663.40	486.73	0.26	-27.40	1.00	1.00
505	28.10	82.87	823.00	-0.21	-1.70	213.66	175.77	0.15	-1.70	1.00	1.00
508	28.13	82.30	725.00	-3.76	-30.34	723.13	563.60	0.28	-30.34	1.00	1.00
509	28.05	82.50	725.00	-5.97	-38.33	921.37	814.05	0.39	-38.33	1.00	1.00
510	27.70	82.53	320.00	-1.59	-13.71	349.66	320.56	0.20	-13.71	1.00	1.00
511	28.38	82.17	1457.00	-6.45	25.43	418.69	352.88	0.35	25.43	1.00	1.00
512	28.30	82.28	885.00	-2.66	56.22	550.67	468.61	0.87	56.22	1.00	1.00
513	28.63	82.20	910.00	-6.31	2.16	354.16	300.20	0.24	2.16	1.00	1.00
514	28.63	82.48	2100.00	-7.44	-38.59	894.06	807.86	0.38	-38.59	1.00	1.00
515	28.05	82.50	634.00	-4.95	-25.15	501.61	421.52	0.26	-25.15	1.00	1.00
601	28.78	83.72	2744.00	-195.18	151.16	450.27	436.03	1.56	151.16	1.00	1.00
604	28.75	83.70	2566.00	-44.28	78.90	338.81	319.51	0.82	78.90	1.00	1.00
606	28.48	83.65	1243.00	-3.54	-18.04	437.64	380.43	0.22	-18.04	1.00	1.00
607	28.63	83.60	2384.00	-8.72	-25.01	434.24	391.10	0.26	-25.01	1.00	1.00
613	28.18	83.75	1720.00	-1.64	-22.66	770.21	664.49	0.28	-22.66	1.00	1.00
614	28.22	83.70	891.00	-6.67	-38.54	1108.58	1034.49	0.40	-38.54	1.00	1.00
615	28.40	83.10	2273.00	-11.79	-42.87	1070.69	988.29	0.42	-42.87	1.00	1.00
616	28.60	83.22	2530.00	-8.51	-48.10	1396.83	1281.94	0.46	-48.10	1.00	1.00

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
621	28.38	83.40	1160.00	-22.85	-40.79	994.68	905.44	0.40	-40.79	1.00	1.00
622	28.15	83.57	1740.00	-6.32	-50.18	1716.85	1548.46	0.48	-50.18	1.00	1.00
626	28.47	83.60	1770.00	-5.68	-34.72	796.89	721.41	0.34	-34.72	1.00	1.00
627	28.38	83.48	1550.00	-5.74	-24.20	520.84	496.41	0.30	-24.20	1.00	1.00
628	28.50	83.30	1970.00	-15.79	-51.24	1397.00	1360.58	0.51	-51.24	1.00	1.00
629	28.57	83.38	2330.00	-51.82	-54.76	1586.09	1567.43	0.55	-54.76	1.00	1.00
701	27.95	83.43	442.00	-1.47	14.42	360.44	308.33	0.27	14.42	1.00	1.00
704	27.68	84.05	150.00	-5.58	-37.74	1191.53	1076.04	0.36	-37.74	1.00	1.00
705	27.52	83.43	109.00	-0.18	-6.62	307.01	241.77	0.14	-6.62	1.00	1.00
706	27.68	84.22	154.00	-3.19	-33.67	1017.70	900.85	0.32	-33.67	1.00	1.00
707	27.53	83.47	120.00	-0.74	-23.30	582.28	510.60	0.25	-23.30	1.00	1.00
708	27.53	83.67	125.00	-1.25	-14.20	626.30	526.85	0.28	-14.20	1.00	1.00
710	27.58	83.87	164.00	-1.29	-32.15	1071.58	838.57	0.28	-32.15	1.00	1.00
721	27.77	83.05	200.00	-17.29	-37.42	886.92	862.78	0.38	-37.42	1.00	1.00
722	28.17	83.27	1280.00	-12.28	-43.58	1095.94	1058.18	0.43	-43.58	1.00	1.00
723	27.68	82.80	80.00	-0.89	-24.09	650.28	453.30	0.23	-24.09	1.00	1.00
725	28.07	83.25	1530.00	-1.60	-23.99	589.88	483.03	0.25	-23.99	1.00	1.00
726	27.87	83.80	500.00	-1.54	-19.14	463.75	371.80	0.19	-19.14	1.00	1.00
727	27.47	83.28	95.00	0.03	8.15	427.69	340.39	0.25	8.15	1.00	1.00
728	27.53	83.75	154.00	-1.19	-13.19	482.71	393.00	0.19	-13.19	1.00	1.00
801	28.37	84.90	1334.00	-17.18	-40.75	773.54	735.50	0.40	-40.75	1.00	1.00
802	28.28	84.37	823.00	-22.58	-57.81	2043.46	2014.63	0.58	-57.81	1.00	1.00
804	28.22	84.00	827.00	-12.96	-57.03	2334.20	2227.73	0.56	-57.03	1.00	1.00
805	28.10	83.88	868.00	-5.32	-41.04	1425.20	1241.66	0.38	-41.04	1.00	1.00
807	28.13	84.35	855.00	-5.87	-43.36	1295.52	1197.60	0.42	-43.36	1.00	1.00
808	27.93	84.42	965.00	-0.14	-9.00	477.37	366.16	0.22	-9.00	1.00	1.00
809	28.00	84.62	1097.00	-0.66	-7.72	332.58	304.97	0.17	-7.72	1.00	1.00
810	27.88	83.82	460.00	0.06	-5.26	371.46	320.03	0.19	-5.26	1.00	1.00

APPENDIX 4: Results of comparison

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
811	28.12	84.12	856.00	-14.86	-54.90	2114.09	2043.31	0.54	-54.90	1.00	1.00
813	28.27	83.82	1600.00	-10.09	-56.74	2401.15	2280.13	0.55	-56.74	1.00	1.00
814	28.30	83.80	1740.00	-28.09	-68.58	3914.97	3851.18	0.68	-68.58	1.00	1.00
815	28.03	84.10	500.00	-4.72	-27.42	779.69	634.09	0.26	-27.42	1.00	1.00
816	28.55	84.23	2680.00	-0.24	20.11	355.52	319.46	0.36	20.11	1.00	1.00
817	27.97	84.28	358.00	-0.94	-9.74	376.15	310.93	0.15	-9.74	1.00	1.00
820	28.67	84.02	3420.00	-225.57	222.37	882.01	864.72	2.25	222.37	1.00	1.00
823	28.20	84.62	1120.00	-31.77	-50.09	1683.10	1648.86	0.50	-50.09	1.00	1.00
824	28.37	84.10	1820.00	-27.72	-52.37	2094.81	2038.16	0.52	-52.37	1.00	1.00
826	27.98	83.77	750.00	-0.22	-9.48	579.47	507.81	0.30	-9.48	1.00	1.00
827	27.87	84.13	660.00	-1.58	-3.03	371.13	316.36	0.19	-3.03	1.00	1.00
829	28.27	83.75	1000.00	-18.19	-53.32	2101.74	2048.17	0.53	-53.32	1.00	1.00
830	28.27	83.78	1160.00	-13.75	-64.43	3365.65	3247.59	0.63	-64.43	1.00	1.00
902	27.62	84.42	256.00	-1.37	-20.58	597.25	489.96	0.20	-20.58	1.00	1.00
903	27.58	84.53	270.00	-1.50	-22.03	607.62	536.29	0.21	-22.03	1.00	1.00
904	27.55	85.13	1706.00	-1.43	-38.19	1377.10	1011.22	0.33	-38.19	1.00	1.00
906	27.42	85.05	474.00	-1.58	-30.87	942.34	891.74	0.34	-30.87	1.00	1.00
907	27.28	85.00	396.00	-1.14	-16.99	536.76	404.89	0.18	-16.99	1.00	1.00
909	27.17	84.98	130.00	-3.51	-29.20	725.17	622.38	0.28	-29.20	1.00	1.00
911	27.07	84.97	115.00	-0.88	-14.90	394.98	266.02	0.13	-14.90	1.00	1.00
915	27.62	85.15	1530.00	-0.43	17.16	313.60	258.31	0.20	17.16	1.00	1.00
918	27.00	84.87	91.00	-0.50	-13.69	434.05	270.11	0.13	-13.69	1.00	1.00
920	27.55	84.82	274.00	-1.43	-24.43	715.47	609.96	0.25	-24.43	1.00	1.00
923	26.92	85.02	109.00	-0.91	-10.08	356.18	307.33	0.18	-10.08	1.00	1.00
1001	28.28	85.38	1900.00	-2.19	-31.52	426.19	356.64	0.32	-31.52	1.00	1.00
1004	27.92	85.17	1003.00	-0.10	-12.30	369.50	275.84	0.14	-12.30	1.00	1.00
1005	27.87	84.93	1420.00	-4.99	-20.84	537.72	461.11	0.21	-20.84	1.00	1.00
1006	27.87	85.87	2000.00	-18.33	-65.80	2812.73	2748.90	0.65	-65.80	1.00	1.00

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
1007	27.80	85.25	2064.00	-25.27	-46.30	1376.46	1341.16	0.46	-46.30	1.00	1.00
1009	27.78	85.72	1660.00	-4.53	-38.73	1041.49	928.42	0.36	-38.73	1.00	1.00
1015	27.68	85.20	1630.00	0.41	-3.84	238.32	172.80	0.10	-3.84	1.00	1.00
1022	27.58	85.40	1400.00	-0.61	-14.40	382.54	302.75	0.16	-14.40	1.00	1.00
1024	27.62	85.55	1552.00	-0.07	-13.98	342.65	239.95	0.13	-13.98	1.00	1.00
1027	27.78	85.90	1220.00	-19.70	-48.48	1370.49	1340.53	0.48	-48.48	1.00	1.00
1029	27.67	85.33	1350.00	-2.12	24.97	376.98	306.90	0.29	24.97	1.00	1.00
1030	27.70	85.37	1337.00	0.37	-2.34	175.93	152.83	0.10	-2.34	1.00	1.00
1035	27.75	85.48	1449.00	-0.94	-17.98	549.72	407.77	0.20	-17.98	1.00	1.00
1038	27.72	85.18	1085.00	-0.25	0.61	274.08	208.25	0.13	0.61	1.00	1.00
1039	27.73	85.33	1335.00	-0.44	-5.43	304.15	264.05	0.16	-5.43	1.00	1.00
1043	27.70	85.52	2163.00	-4.58	-28.43	587.60	543.19	0.28	-28.43	1.00	1.00
1049	27.58	85.52	1517.00	0.14	-7.58	314.24	259.98	0.18	-7.58	1.00	1.00
1052	27.67	85.42	1330.00	-0.26	2.90	261.51	227.09	0.16	2.90	1.00	1.00
1054	28.17	85.32	1847.00	-221.31	279.91	943.47	920.01	2.96	279.91	1.00	1.00
1055	28.10	85.30	1982.00	-3.68	-33.79	767.67	638.80	0.31	-33.79	1.00	1.00
1057	28.02	85.12	1240.00	-8.19	-46.44	1437.26	1354.59	0.45	-46.44	1.00	1.00
1059	27.70	85.42	1543.00	-0.70	-14.85	410.50	323.83	0.17	-14.85	1.00	1.00
1060	27.60	85.33	1448.00	-0.86	13.02	278.27	241.05	0.19	13.02	1.00	1.00
1073	27.63	85.28	1212.00	-0.30	11.28	281.49	242.80	0.19	11.28	1.00	1.00
1074	27.77	85.42	1490.00	-0.67	-6.30	487.29	450.50	0.29	-6.30	1.00	1.00
1075	27.58	85.28	1590.00	-1.01	-16.56	375.08	339.06	0.18	-16.56	1.00	1.00
1076	27.68	85.25	1520.00	0.05	9.71	214.09	147.36	0.12	9.71	1.00	1.00
1079	27.75	85.25	1690.00	-2.91	-1.01	295.89	260.93	0.16	-1.01	1.00	1.00
1080	27.65	85.35	1341.00	0.00	8.92	281.44	260.32	0.20	8.92	1.00	1.00
1081	27.78	85.28	1320.00	-4.33	-18.92	451.58	384.21	0.19	-18.92	1.00	1.00
1102	27.67	86.05	1940.00	-5.94	-40.01	884.80	829.92	0.39	-40.01	1.00	1.00
1110	27.03	85.92	457.00	-0.66	-15.85	368.06	324.68	0.18	-15.85	1.00	1.00

APPENDIX 4: Results of comparison

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
1111	26.72	85.97	90.00	-0.68	-26.53	587.35	537.92	0.29	-26.53	1.00	1.00
1112	26.92	86.17	165.00	-0.13	-18.38	401.81	338.36	0.19	-18.38	1.00	1.00
1115	27.45	85.82	1098.00	-4.54	48.18	577.72	521.33	0.58	48.18	1.00	1.00
1117	27.33	85.50	250.00	-6.66	-38.73	1225.88	1142.68	0.38	-38.73	1.00	1.00
1118	26.88	85.42	100.00	-1.37	-17.54	486.85	435.83	0.25	-17.54	1.00	1.00
1123	27.47	86.08	495.00	0.48	13.75	187.27	145.29	0.17	13.75	1.00	1.00
1202	27.70	86.72	2619.00	-10.90	-52.01	1132.58	1096.85	0.51	-52.01	1.00	1.00
1204	27.35	86.75	2143.00	-10.11	-46.32	1033.34	997.11	0.46	-46.32	1.00	1.00
1206	27.32	86.50	1720.00	-8.14	-42.88	827.12	783.73	0.42	-42.88	1.00	1.00
1212	26.73	86.93	100.00	-2.16	-36.58	823.64	742.72	0.34	-36.58	1.00	1.00
1213	26.93	86.52	1175.00	-8.04	-25.83	475.64	459.60	0.26	-25.83	1.00	1.00
1216	26.65	86.22	102.00	-0.27	-22.75	466.44	432.91	0.26	-22.75	1.00	1.00
1222	27.22	86.80	1623.00	-0.32	-17.44	399.86	332.30	0.25	-17.44	1.00	1.00
1226	26.60	86.90	85.00	-5.18	-31.79	604.11	582.94	0.31	-31.79	1.00	1.00
1303	27.28	87.33	1329.00	-4.31	-25.37	416.48	393.11	0.25	-25.37	1.00	1.00
1304	27.05	87.28	1680.00	-13.32	-35.70	585.12	541.23	0.35	-35.70	1.00	1.00
1305	27.13	87.28	410.00	0.34	4.31	167.99	145.62	0.17	4.31	1.00	1.00
1306	27.03	87.23	1317.00	-1.97	-8.12	186.10	155.08	0.14	-8.12	1.00	1.00
1307	26.98	87.35	1210.00	-4.35	21.99	306.56	248.24	0.26	21.99	1.00	1.00
1309	26.93	87.15	143.00	-3.83	-31.25	616.07	580.98	0.31	-31.25	1.00	1.00
1311	26.82	87.28	444.00	-15.29	-43.60	983.87	972.83	0.44	-43.60	1.00	1.00
1314	27.13	87.55	1633.00	-1.50	-19.27	400.38	324.46	0.26	-19.27	1.00	1.00
1319	26.48	87.27	72.00	-1.88	-22.88	522.93	439.69	0.22	-22.88	1.00	1.00
1320	26.70	87.27	200.00	-3.43	-27.61	597.03	548.43	0.27	-27.61	1.00	1.00
1321	27.28	87.22	303.00	-5.15	-26.44	471.64	406.98	0.25	-26.44	1.00	1.00
1326	26.73	87.50	250.00	-13.32	-37.99	910.68	886.66	0.38	-37.99	1.00	1.00
1403	27.55	87.78	1780.00	-20.21	-67.48	1616.73	1590.78	0.67	-67.48	1.00	1.00
1405	27.35	87.67	1732.00	-16.77	-49.10	1015.61	997.03	0.49	-49.10	1.00	1.00

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
1408	26.67	87.70	163.00	-5.23	-29.43	663.55	603.51	0.29	-29.43	1.00	1.00
1409	26.63	87.98	122.00	-4.77	-40.30	1098.69	1056.42	0.40	-40.30	1.00	1.00
1410	26.88	88.03	1654.00	-10.61	-34.68	852.87	808.99	0.34	-34.68	1.00	1.00
1412	26.57	88.05	120.00	-0.92	-23.36	588.92	520.89	0.22	-23.36	1.00	1.00
1415	26.68	87.97	168.00	-5.89	-39.58	1063.10	1025.22	0.39	-39.58	1.00	1.00
1416	26.87	88.07	1678.00	-21.01	-44.79	1275.48	1228.74	0.44	-44.79	1.00	1.00
1419	27.15	87.75	1205.00	-3.09	-20.96	345.93	290.90	0.21	-20.96	1.00	1.00
1421	26.58	87.90	143.00	-3.54	-32.87	811.90	774.42	0.32	-32.87	1.00	1.00
1422	26.40	88.02	60.00	-2.08	-27.87	790.41	680.29	0.26	-27.87	1.00	1.00
Maximum				-225.57	-68.58	167.99	145.29	0.10	-68.58	1.00	1.00
Average				-9.83	-12.76	742.48	669.42	0.39	-12.76	1.00	1.00
Minimum				0.48	308.56	3914.97	3851.18	8.07	308.56	1.00	1.00

Comparison of mean monthly precipitation data sets

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
101	29.65	80.50	842.00	0.88	-22.51	58.93	35.98	0.34	-22.51	1.00	1.00
102	29.55	80.42	1635.00	0.81	2.67	41.24	31.03	0.34	2.67	1.00	1.00
103	29.47	80.53	1266.00	0.94	-5.81	27.87	23.76	0.38	-5.81	1.00	1.00
104	29.30	80.58	1848.00	0.95	-1.63	22.37	18.56	0.34	-1.63	1.00	1.00
105	29.03	80.22	176.00	0.98	2.26	19.11	13.76	0.55	2.26	1.00	1.00
106	28.68	80.35	159.00	0.94	-17.28	45.00	29.93	0.27	-17.28	1.00	1.00
107	29.85	80.57	1097.00	0.64	-43.12	147.47	91.26	0.47	-43.12	1.00	1.00
108	29.53	80.47	2370.00	0.89	-20.24	44.88	32.99	0.40	-20.24	1.00	1.00
201	29.62	80.87	1456.00	0.70	-38.65	110.26	71.66	0.40	-38.65	1.00	1.00
202	29.55	81.22	1304.00	0.86	-26.33	53.40	38.65	0.40	-26.33	1.00	1.00
203	29.27	80.98	1360.00	0.05	-29.76	149.92	61.14	0.38	-29.76	1.00	1.00
204	29.38	81.32	1400.00	0.92	-5.32	34.26	27.67	0.41	-5.32	1.00	1.00
205	29.00	81.13	1388.00	0.80	-30.83	72.32	48.31	0.43	-30.83	1.00	1.00
206	28.95	81.45	650.00	0.38	34.63	70.73	52.80	0.67	34.63	1.00	1.00
207	28.53	81.12	140.00	0.98	5.52	24.68	16.57	0.24	5.52	1.00	1.00
208	28.75	80.92	195.00	0.92	-16.58	55.48	32.16	0.29	-16.58	1.00	1.00
209	28.80	80.55	187.00	0.91	-17.78	58.66	33.40	0.23	-17.78	1.00	1.00
210	28.97	81.12	340.00	0.87	6.26	48.19	33.76	0.43	6.26	1.00	1.00
211	29.38	81.20	3430.00	0.16	-68.87	417.71	246.74	0.63	-68.87	1.00	1.00
212	28.57	80.82	152.00	0.93	12.45	41.56	25.84	1.66	12.45	1.00	1.00
214	29.12	80.68	1304.00	0.91	-19.67	46.74	32.48	0.32	-19.67	1.00	1.00
215	28.87	80.63	288.00	0.83	-23.94	90.08	53.24	0.68	-23.94	1.00	1.00
217	29.15	81.28	1345.00	0.93	-13.12	30.29	22.82	0.38	-13.12	1.00	1.00
218	29.23	80.93	720.00	0.73	22.68	44.57	29.73	0.34	22.68	1.00	1.00
302	29.32	81.77	1006.00	-0.36	43.04	45.18	33.78	0.64	43.04	1.00	1.00
303	29.28	82.17	2300.00	0.92	-4.98	17.17	12.24	0.33	-4.98	1.00	1.00

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
304	29.28	82.32	3080.00	0.80	-29.38	41.22	26.84	0.37	-29.38	1.00	1.00
305	29.13	81.60	1210.00	0.85	-13.71	47.94	37.16	1.39	-13.71	1.00	1.00
306	29.55	82.15	2133.00	0.96	-5.25	13.15	10.75	0.74	-5.25	1.00	1.00
307	29.55	82.12	3048.00	0.83	-9.39	23.99	20.66	0.48	-9.39	1.00	1.00
308	29.20	81.90	1905.00	0.22	25.44	48.46	35.87	0.46	25.44	1.00	1.00
310	29.27	82.22	2310.00	0.74	4.61	28.53	22.03	0.85	4.61	1.00	1.00
311	29.97	81.83	2800.00	0.50	-23.14	29.83	24.65	0.49	-23.14	1.00	1.00
312	28.93	82.92	2058.00	-12.35	301.79	66.32	52.37	5.02	305.19	1.00	0.92
313	29.73	82.10	1950.00	0.45	-48.64	83.25	57.91	0.53	-48.64	1.00	1.00
401	28.88	81.25	950.00	0.97	2.25	24.03	18.27	0.27	2.25	1.00	1.00
402	28.85	81.72	1402.00	0.89	-23.46	58.89	38.69	0.35	-23.46	1.00	1.00
403	28.78	81.33	260.00	-1.88	123.76	110.56	72.60	1.41	123.76	1.00	1.00
404	28.70	82.20	1231.00	0.82	-29.13	68.36	44.49	0.40	-29.13	1.00	1.00
405	28.65	81.27	225.00	0.83	-26.89	107.51	57.91	0.27	-26.89	1.00	1.00
406	28.60	81.62	720.00	0.96	-8.64	34.41	24.51	0.25	-8.64	1.00	1.00
407	28.02	82.12	235.00	0.90	0.23	51.70	30.01	0.50	0.23	1.00	1.00
408	28.17	81.35	215.00	0.95	7.72	32.35	19.96	0.25	7.72	1.00	1.00
409	28.10	81.57	190.00	0.95	10.89	32.78	21.45	0.53	10.89	1.00	1.00
410	28.78	81.58	610.00	0.68	29.03	54.71	37.20	0.41	29.03	1.00	1.00
411	28.43	81.10	129.00	0.96	12.02	27.45	19.43	0.28	12.02	1.00	1.00
412	28.27	81.72	135.00	0.89	26.00	50.52	32.62	0.94	26.07	1.00	0.92
413	28.35	81.70	510.00	0.93	-3.42	49.14	34.32	0.61	-3.42	1.00	1.00
414	28.05	81.90	226.00	-1.67	133.36	113.40	80.83	1.44	133.47	1.00	0.92
415	28.43	81.35	200.00	0.96	-9.78	37.01	25.04	0.35	-9.78	1.00	1.00
416	28.07	81.62	144.00	0.95	11.42	30.86	19.95	0.61	11.42	1.00	1.00
417	28.38	81.35	200.00	0.74	36.90	64.38	42.59	0.76	36.90	1.00	1.00
418	28.98	82.28	2000.00	0.86	-23.21	55.94	34.24	0.39	-23.21	1.00	1.00
419	28.03	81.78	195.00	0.94	16.10	32.93	23.06	0.41	16.16	1.00	0.92

APPENDIX 4: Results of comparison

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
420	28.10	81.67	165.00	0.96	-4.36	34.19	20.12	0.29	-4.36	1.00	1.00
501	28.60	82.63	1560.00	0.79	-31.76	73.00	52.68	0.49	-31.76	1.00	1.00
504	28.30	82.63	1270.00	0.88	-26.05	45.96	36.67	0.43	-26.05	1.00	1.00
505	28.10	82.87	823.00	0.97	3.75	18.42	12.07	0.27	3.75	1.00	1.00
507	28.22	82.12	698.00	0.96	-15.44	31.17	22.19	0.30	-15.44	1.00	1.00
508	28.13	82.30	725.00	0.85	-28.79	66.74	45.15	0.62	-28.79	1.00	1.00
509	28.05	82.50	725.00	0.74	-36.57	91.94	61.54	0.48	-36.57	1.00	1.00
510	27.70	82.53	320.00	0.94	-12.28	42.96	21.70	4.34	-12.28	1.00	1.00
511	28.38	82.17	1457.00	0.72	27.44	45.36	33.62	0.43	27.44	1.00	1.00
512	28.30	82.28	885.00	-0.40	78.48	72.56	49.74	0.89	78.48	1.00	1.00
513	28.63	82.20	910.00	0.96	4.73	21.34	16.91	0.33	4.73	1.00	1.00
514	28.63	82.48	2100.00	0.76	-37.48	96.22	66.39	0.48	-37.48	1.00	1.00
515	28.05	82.50	634.00	0.87	-23.43	55.01	34.31	0.25	-23.43	1.00	1.00
601	28.78	83.72	2744.00	-15.92	145.84	67.30	41.52	1.67	145.84	1.00	1.00
604	28.75	83.70	2566.00	-6.62	76.34	59.14	37.92	0.98	76.34	1.00	1.00
605	28.27	83.60	984.00	0.86	-31.07	66.02	52.45	0.49	-31.07	1.00	1.00
606	28.48	83.65	1243.00	0.88	-18.43	44.69	33.43	0.43	-18.43	1.00	1.00
607	28.63	83.60	2384.00	0.57	-25.57	55.42	40.45	0.44	-25.57	1.00	1.00
608	28.82	83.88	3609.00	-3.87	127.86	49.50	31.97	2.02	127.86	1.00	1.00
609	28.35	83.57	835.00	0.96	-8.93	25.45	18.13	0.35	-8.93	1.00	1.00
610	29.05	83.88	3465.00	-10.45	258.03	42.59	27.77	6.15	258.03	1.00	1.00
613	28.18	83.75	1720.00	0.90	-22.34	63.86	43.35	0.41	-22.34	1.00	1.00
614	28.22	83.70	891.00	0.76	-37.41	110.24	77.91	0.51	-37.41	1.00	1.00
615	28.40	83.10	2273.00	0.63	-44.72	135.21	89.00	0.54	-44.72	1.00	1.00
616	28.60	83.22	2530.00	0.75	-35.62	95.66	58.22	0.37	-35.62	1.00	1.00
619	28.40	83.73	2742.00	0.60	-48.13	144.93	107.95	0.59	-48.13	1.00	1.00
620	28.03	83.65	700.00	0.92	-15.83	46.93	29.88	0.29	-15.83	1.00	1.00
621	28.38	83.40	1160.00	0.71	-40.78	105.40	76.41	0.53	-40.78	1.00	1.00

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
622	28.15	83.57	1740.00	0.54	-50.50	196.26	132.96	0.59	-50.50	1.00	1.00
624	28.97	83.78	3570.00	-41.37	359.67	63.92	40.90	3.52	359.67	1.00	1.00
625	28.90	83.68	3570.00	-27.83	204.34	71.18	43.98	1.57	204.34	1.00	1.00
626	28.47	83.60	1770.00	0.80	-31.95	73.21	54.63	0.50	-31.95	1.00	1.00
627	28.38	83.48	1550.00	0.95	-18.18	29.76	24.65	0.35	-18.18	1.00	1.00
628	28.50	83.30	1970.00	0.52	-51.43	187.33	117.20	0.55	-51.43	1.00	1.00
629	28.57	83.38	2330.00	0.46	-54.85	197.69	132.23	0.55	-54.85	1.00	1.00
630	28.13	83.62	790.00	0.80	-32.57	98.37	66.69	0.46	-32.57	1.00	1.00
633	29.18	83.98	3870.00	-1.78	130.47	35.23	25.14	2.29	131.02	1.00	0.92
701	27.95	83.43	442.00	0.88	14.02	40.12	25.87	0.31	14.02	1.00	1.00
702	27.87	83.53	1067.00	0.96	4.85	25.47	17.33	0.32	4.85	1.00	1.00
703	27.70	83.47	205.00	0.83	-30.03	86.33	59.40	0.43	-30.03	1.00	1.00
704	27.68	84.05	150.00	0.74	-37.23	140.35	90.52	0.49	-37.23	1.00	1.00
705	27.52	83.43	109.00	0.98	-5.17	26.27	15.31	0.23	-5.17	1.00	1.00
706	27.68	84.22	154.00	0.81	-33.14	98.60	74.47	0.42	-33.14	1.00	1.00
707	27.53	83.47	120.00	0.90	-15.32	63.55	25.09	0.24	-15.32	1.00	1.00
708	27.53	83.67	125.00	0.97	-12.90	31.43	21.13	0.28	-12.90	1.00	1.00
710	27.58	83.87	164.00	0.82	-31.09	111.08	71.08	0.42	-31.09	1.00	1.00
715	27.93	83.15	1760.00	0.95	-17.80	35.37	28.26	0.37	-17.80	1.00	1.00
716	27.55	83.07	94.00	0.86	29.29	45.50	32.18	0.46	29.29	1.00	1.00
721	27.77	83.05	200.00	0.73	-37.83	115.86	73.88	0.35	-37.83	1.00	1.00
722	28.17	83.27	1280.00	0.61	-43.50	134.74	97.20	0.51	-43.37	1.00	0.92
723	27.68	82.80	80.00	0.95	-16.92	38.74	26.61	0.26	-16.92	1.00	1.00
725	28.07	83.25	1530.00	0.91	-23.99	47.48	37.51	0.39	-23.99	1.00	1.00
726	27.87	83.80	500.00	0.93	-20.41	45.53	35.74	0.39	-20.41	1.00	1.00
727	27.47	83.28	95.00	0.93	3.98	35.12	22.89	0.54	3.98	1.00	1.00
728	27.53	83.75	154.00	0.92	-11.01	59.30	38.73	0.34	-11.01	1.00	1.00
730	27.90	83.15	1201.00	0.89	-26.82	56.01	44.70	0.43	-26.82	1.00	1.00

APPENDIX 4: Results of comparison

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
801	28.37	84.90	1334.00	0.65	-41.97	81.84	65.33	0.46	-41.97	1.00	1.00
802	28.28	84.37	823.00	0.38	-57.72	242.17	168.66	0.58	-57.72	1.00	1.00
804	28.22	84.00	827.00	0.38	-56.81	258.29	186.05	0.63	-56.81	1.00	1.00
805	28.10	83.88	868.00	0.70	-40.92	139.82	104.40	0.52	-40.92	1.00	1.00
806	28.67	84.62	3650.00	-1.64	83.02	72.76	49.26	1.27	83.02	1.00	1.00
807	28.13	84.35	855.00	0.70	-40.89	122.93	93.38	0.50	-40.89	1.00	1.00
808	27.93	84.42	965.00	0.93	-8.84	40.88	27.97	0.35	-8.84	1.00	1.00
809	28.00	84.62	1097.00	0.94	-4.70	33.83	27.33	0.40	-4.70	1.00	1.00
810	27.88	83.82	460.00	0.97	-8.93	27.56	20.84	0.34	-8.93	1.00	1.00
811	28.12	84.12	856.00	0.43	-54.80	243.08	171.46	0.60	-54.80	1.00	1.00
813	28.27	83.82	1600.00	0.44	-56.10	280.30	192.24	0.59	-56.10	1.00	1.00
814	28.30	83.80	1740.00	0.17	-68.36	481.54	324.95	0.69	-68.36	1.00	1.00
815	28.03	84.10	500.00	0.82	-27.62	74.92	53.97	0.41	-27.62	1.00	1.00
816	28.55	84.23	2680.00	0.63	17.89	47.63	33.86	0.44	17.89	1.00	1.00
817	27.97	84.28	358.00	0.92	-9.74	42.18	32.53	0.37	-9.74	1.00	1.00
818	28.27	83.97	1070.00	0.31	-60.69	320.99	232.23	0.65	-60.69	1.00	1.00
820	28.67	84.02	3420.00	-31.55	201.09	123.52	72.84	1.60	201.09	1.00	1.00
821	28.38	83.80	1960.00	0.55	-50.85	223.82	155.59	0.55	-50.85	1.00	1.00
823	28.20	84.62	1120.00	0.50	-51.98	211.46	147.56	0.57	-51.98	1.00	1.00
824	28.37	84.10	1820.00	0.48	-52.32	214.95	170.99	0.63	-52.32	1.00	1.00
826	27.98	83.77	750.00	0.93	-8.51	45.63	34.04	0.69	-8.51	1.00	1.00
827	27.87	84.13	660.00	0.88	-3.44	45.13	31.26	0.35	-3.44	1.00	1.00
829	28.27	83.75	1000.00	0.50	-53.50	247.52	173.06	0.56	-53.50	1.00	1.00
830	28.27	83.78	1160.00	0.26	-64.65	408.86	275.14	0.64	-64.65	1.00	1.00
832	28.08	83.92	1432.00	0.60	-47.10	182.52	134.24	0.59	-47.10	1.00	1.00
833	28.48	85.00	3300.00	-1.19	103.06	85.64	60.68	1.25	103.06	1.00	1.00
902	27.62	84.42	256.00	0.93	-20.24	52.36	38.19	0.32	-20.24	1.00	1.00
903	27.58	84.53	270.00	0.91	-21.59	65.31	45.52	0.35	-21.59	1.00	1.00

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
904	27.55	85.13	1706.00	0.69	-37.69	135.94	84.21	0.42	-37.69	1.00	1.00
905	27.60	85.08	2314.00	0.89	-10.05	52.42	36.10	0.35	-10.05	1.00	1.00
906	27.42	85.05	474.00	0.84	-29.62	93.72	65.09	0.36	-29.62	1.00	1.00
907	27.28	85.00	396.00	0.95	-13.55	46.65	27.74	0.32	-13.55	1.00	1.00
909	27.17	84.98	130.00	0.86	-28.82	77.81	52.11	0.31	-28.82	1.00	1.00
910	27.18	85.17	244.00	0.80	-32.51	110.25	67.42	0.30	-32.51	1.00	1.00
911	27.07	84.97	115.00	0.93	-17.56	47.80	28.28	0.24	-17.56	1.00	1.00
912	27.02	85.38	152.00	0.94	-13.29	49.57	24.78	0.49	-13.29	1.00	1.00
915	27.62	85.15	1530.00	0.91	14.45	36.80	27.96	0.51	14.45	1.00	1.00
918	27.00	84.87	91.00	0.94	-15.14	42.21	24.28	0.21	-15.14	1.00	1.00
919	27.42	85.17	1030.00	0.75	-35.42	145.10	84.83	0.33	-35.42	1.00	1.00
920	27.55	84.82	274.00	0.88	-24.05	76.33	52.34	0.30	-23.90	1.00	0.92
921	27.03	85.00	140.00	0.94	1.56	41.18	29.97	0.79	1.56	1.00	1.00
922	26.77	85.30	90.00	0.79	-9.05	73.57	57.31	0.97	-8.72	1.00	0.83
923	26.92	85.02	109.00	0.94	-10.71	40.02	22.56	0.36	-10.71	1.00	1.00
925	27.43	84.98	332.00	0.87	-26.43	80.51	57.97	0.38	-26.43	1.00	1.00
1001	28.28	85.38	1900.00	0.69	-32.17	49.33	31.89	0.45	-32.17	1.00	1.00
1002	28.05	84.82	518.00	0.87	-27.56	71.35	51.72	0.37	-27.56	1.00	1.00
1004	27.92	85.17	1003.00	0.98	-12.44	25.88	18.76	0.24	-12.44	1.00	1.00
1005	27.87	84.93	1420.00	0.90	-23.25	60.18	42.82	0.34	-23.25	1.00	1.00
1006	27.87	85.87	2000.00	0.17	-66.03	323.84	233.77	0.72	-66.03	1.00	1.00
1007	27.80	85.25	2064.00	0.63	-46.28	160.85	113.01	0.53	-46.28	1.00	1.00
1008	27.80	85.62	1592.00	0.68	-43.06	138.93	93.78	0.47	-43.06	1.00	1.00
1009	27.78	85.72	1660.00	0.73	-38.98	113.80	79.19	0.46	-38.98	1.00	1.00
1015	27.68	85.20	1630.00	0.97	-0.36	21.79	17.62	0.35	-0.36	1.00	1.00
1016	27.95	85.60	2625.00	0.53	-51.85	204.39	133.50	0.54	-51.85	1.00	1.00
1017	27.87	85.57	1550.00	0.72	-39.56	118.12	81.79	0.45	-39.56	1.00	1.00
1020	27.70	85.65	1365.00	0.89	21.17	34.55	23.51	1.44	21.17	1.00	1.00

APPENDIX 4: Results of comparison

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
1022	27.58	85.40	1400.00	0.95	-14.53	35.03	24.88	0.31	-14.53	1.00	1.00
1023	27.63	85.72	710.00	0.89	16.00	32.29	21.52	0.35	16.00	1.00	1.00
1024	27.62	85.55	1552.00	0.96	-13.99	25.96	21.94	0.41	-13.99	1.00	1.00
1027	27.78	85.90	1220.00	0.56	-49.36	170.88	117.19	0.52	-49.36	1.00	1.00
1029	27.67	85.33	1350.00	0.60	27.34	59.40	37.93	0.38	27.34	1.00	1.00
1030	27.70	85.37	1337.00	0.97	-2.94	22.62	17.91	0.26	-2.94	1.00	1.00
1035	27.75	85.48	1449.00	0.92	-17.77	50.93	35.32	0.29	-17.77	1.00	1.00
1036	27.68	85.63	865.00	0.78	26.11	43.63	26.00	0.40	26.11	1.00	1.00
1038	27.72	85.18	1085.00	0.96	0.44	26.09	18.86	0.29	0.44	1.00	1.00
1039	27.73	85.33	1335.00	0.95	-5.63	30.69	22.61	0.30	-5.63	1.00	1.00
1043	27.70	85.52	2163.00	0.83	-28.14	67.30	47.09	0.34	-28.14	1.00	1.00
1049	27.58	85.52	1517.00	0.96	-6.68	24.92	20.13	0.32	-6.68	1.00	1.00
1052	27.67	85.42	1330.00	0.95	2.85	28.15	21.73	0.39	2.85	1.00	1.00
1054	28.17	85.32	1847.00	-14.16	279.44	111.54	77.43	3.77	279.44	1.00	1.00
1055	28.10	85.30	1982.00	0.72	-35.92	93.64	59.05	0.34	-35.92	1.00	1.00
1057	28.02	85.12	1240.00	0.61	-46.57	171.05	114.20	0.51	-46.57	1.00	1.00
1058	28.00	85.55	2480.00	0.16	-67.20	322.03	202.61	0.57	-67.20	1.00	1.00
1059	27.70	85.42	1543.00	0.94	-14.42	38.48	23.46	0.23	-14.42	1.00	1.00
1060	27.60	85.33	1448.00	0.94	14.00	30.53	21.23	0.42	14.00	1.00	1.00
1062	27.70	85.72	1327.00	0.88	-23.00	51.17	35.43	0.98	-23.00	1.00	1.00
1063	27.70	85.78	1750.00	0.93	-18.65	40.97	30.04	0.38	-18.65	1.00	1.00
1071	27.78	85.37	1350.00	0.89	-26.27	62.80	46.74	0.33	-26.27	1.00	1.00
1073	27.63	85.28	1212.00	0.86	11.94	41.77	30.21	0.35	11.94	1.00	1.00
1074	27.77	85.42	1490.00	0.95	-6.70	32.82	24.11	0.34	-6.70	1.00	1.00
1075	27.58	85.28	1590.00	0.93	-16.03	45.18	30.97	0.28	-16.03	1.00	1.00
1076	27.68	85.25	1520.00	0.91	7.79	37.46	25.05	0.28	8.14	1.00	0.92
1077	27.75	85.42	1360.00	0.97	-11.63	26.57	19.27	0.23	-11.63	1.00	1.00
1078	27.90	85.63	1310.00	0.55	-50.91	190.52	128.61	0.54	-50.91	1.00	1.00

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
1079	27.75	85.25	1690.00	0.98	-1.33	19.82	15.20	0.23	-1.20	1.00	0.92
1080	27.65	85.35	1341.00	0.91	8.90	33.95	22.44	0.24	8.90	1.00	1.00
1081	27.78	85.28	1320.00	0.93	-19.25	44.13	31.64	0.34	-19.25	1.00	1.00
1082	27.65	85.47	1428.00	0.95	5.80	27.00	21.90	0.38	5.80	1.00	1.00
1101	27.68	86.10	850.00	0.90	-13.35	38.55	26.95	0.34	-13.35	1.00	1.00
1102	27.67	86.05	1940.00	0.71	-40.17	101.59	70.23	0.44	-40.17	1.00	1.00
1103	27.63	86.23	2003.00	0.53	-50.89	152.79	108.43	0.52	-50.89	1.00	1.00
1104	27.52	86.05	1536.00	-22.99	254.08	122.77	75.07	1.83	254.08	1.00	1.00
1108	27.18	86.17	1417.00	0.77	-32.82	79.97	59.61	0.42	-32.82	1.00	1.00
1109	27.08	85.67	275.00	0.99	-3.15	16.98	12.64	0.15	-3.15	1.00	1.00
1110	27.03	85.92	457.00	0.94	-15.65	41.20	27.90	0.23	-15.65	1.00	1.00
1111	26.72	85.97	90.00	0.83	-25.53	73.40	41.83	2.98	-25.53	1.00	1.00
1112	26.92	86.17	165.00	0.84	-20.63	69.38	39.11	0.69	-20.63	1.00	1.00
1115	27.45	85.82	1098.00	0.53	50.50	64.48	44.61	2.14	50.50	1.00	1.00
1117	27.33	85.50	250.00	0.71	-38.21	157.23	94.61	0.35	-38.21	1.00	1.00
1118	26.88	85.42	100.00	0.91	-16.10	51.66	26.51	0.57	-16.10	1.00	1.00
1119	26.88	85.78	200.00	0.98	-6.78	20.35	14.77	0.26	-6.78	1.00	1.00
1120	26.87	85.57	150.00	0.89	-18.46	55.47	29.44	0.41	-18.46	1.00	1.00
1121	27.12	85.47	131.00	0.89	-22.28	73.57	42.87	0.34	-22.28	1.00	1.00
1122	26.65	85.78	172.00	0.74	19.74	47.29	31.18	0.51	21.64	1.00	0.83
1123	27.47	86.08	495.00	0.87	14.81	32.99	20.24	0.58	14.81	1.00	1.00
1202	27.70	86.72	2619.00	0.51	-50.92	142.13	87.05	0.38	-50.92	1.00	1.00
1203	27.43	86.57	1982.00	0.66	-41.48	102.28	64.83	0.74	-41.48	1.00	1.00
1204	27.35	86.75	2143.00	0.59	-46.57	130.02	84.67	0.51	-46.57	1.00	1.00
1206	27.32	86.50	1720.00	0.68	-41.93	91.98	65.49	0.44	-41.93	1.00	1.00
1207	27.48	86.42	1576.00	0.91	-16.32	39.58	23.01	0.42	-16.32	1.00	1.00
1210	27.13	86.43	497.00	0.87	14.83	37.65	25.61	0.38	14.83	1.00	1.00
1211	27.03	86.83	1295.00	0.90	-23.63	34.02	27.46	1.29	-23.63	1.00	1.00

APPENDIX 4: Results of comparison

Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
1212	26.73	86.93	100.00	0.77	-34.81	87.18	58.19	0.37	-34.81	1.00	1.00
1213	26.93	86.52	1175.00	0.88	-26.03	53.18	39.70	0.36	-26.03	1.00	1.00
1215	26.73	86.43	138.00	0.84	-18.34	52.18	30.07	0.22	-18.16	1.00	0.92
1216	26.65	86.22	102.00	0.90	-22.30	47.48	32.97	0.29	-22.26	1.00	0.92
1219	27.50	86.58	2378.00	0.63	-43.96	101.92	65.83	0.39	-43.96	1.00	1.00
1222	27.22	86.80	1623.00	0.93	-18.49	28.10	20.74	0.32	-18.49	1.00	1.00
1223	26.55	86.75	91.00	0.89	-20.86	49.69	29.90	0.23	-20.86	1.00	1.00
1224	27.55	86.38	1662.00	0.59	-48.09	124.80	88.25	0.51	-48.09	1.00	1.00
1226	26.60	86.90	85.00	0.84	-30.04	65.73	46.92	0.31	-30.04	1.00	1.00
1301	27.55	87.28	1497.00	-0.48	-77.94	377.58	294.46	0.79	-77.94	1.00	1.00
1303	27.28	87.33	1329.00	0.83	-25.04	47.32	32.29	0.36	-25.04	1.00	1.00
1304	27.05	87.28	1680.00	0.73	-35.92	66.21	46.04	0.72	-35.92	1.00	1.00
1305	27.13	87.28	410.00	0.94	3.13	17.69	13.04	1.63	3.13	1.00	1.00
1306	27.03	87.23	1317.00	0.97	-7.92	14.95	11.32	0.19	-7.92	1.00	1.00
1307	26.98	87.35	1210.00	0.73	24.38	42.13	29.54	0.31	24.38	1.00	1.00
1308	26.93	87.33	365.00	0.95	2.02	21.95	17.13	1.22	2.02	1.00	1.00
1309	26.93	87.15	143.00	0.83	-28.33	68.44	44.07	0.30	-28.33	1.00	1.00
1311	26.82	87.28	444.00	0.62	-43.81	114.94	82.35	0.44	-43.81	1.00	1.00
1312	26.62	87.38	152.00	0.73	-32.07	108.08	56.98	0.34	-32.07	1.00	1.00
1314	27.13	87.55	1633.00	0.90	-17.64	26.49	19.56	0.96	-17.64	1.00	1.00
1316	26.82	87.17	183.00	0.62	-42.33	114.62	81.28	0.49	-42.33	1.00	1.00
1317	27.77	87.42	2590.00	-0.64	-78.90	191.55	154.20	0.79	-78.90	1.00	1.00
1319	26.48	87.27	72.00	0.91	-23.17	51.92	37.53	0.26	-23.17	1.00	1.00
1320	26.70	87.27	200.00	0.82	-28.00	73.43	46.87	0.38	-28.00	1.00	1.00
1321	27.28	87.22	303.00	0.69	-26.94	66.93	45.90	0.39	-26.31	1.00	0.92
1322	26.97	87.17	158.00	0.97	-2.12	19.44	13.29	0.29	-2.12	1.00	1.00
1325	27.37	87.15	1190.00	0.55	-44.18	109.93	76.93	0.71	-44.18	1.00	1.00
1326	26.73	87.50	250.00	0.70	-37.91	116.27	76.07	0.40	-37.91	1.00	1.00

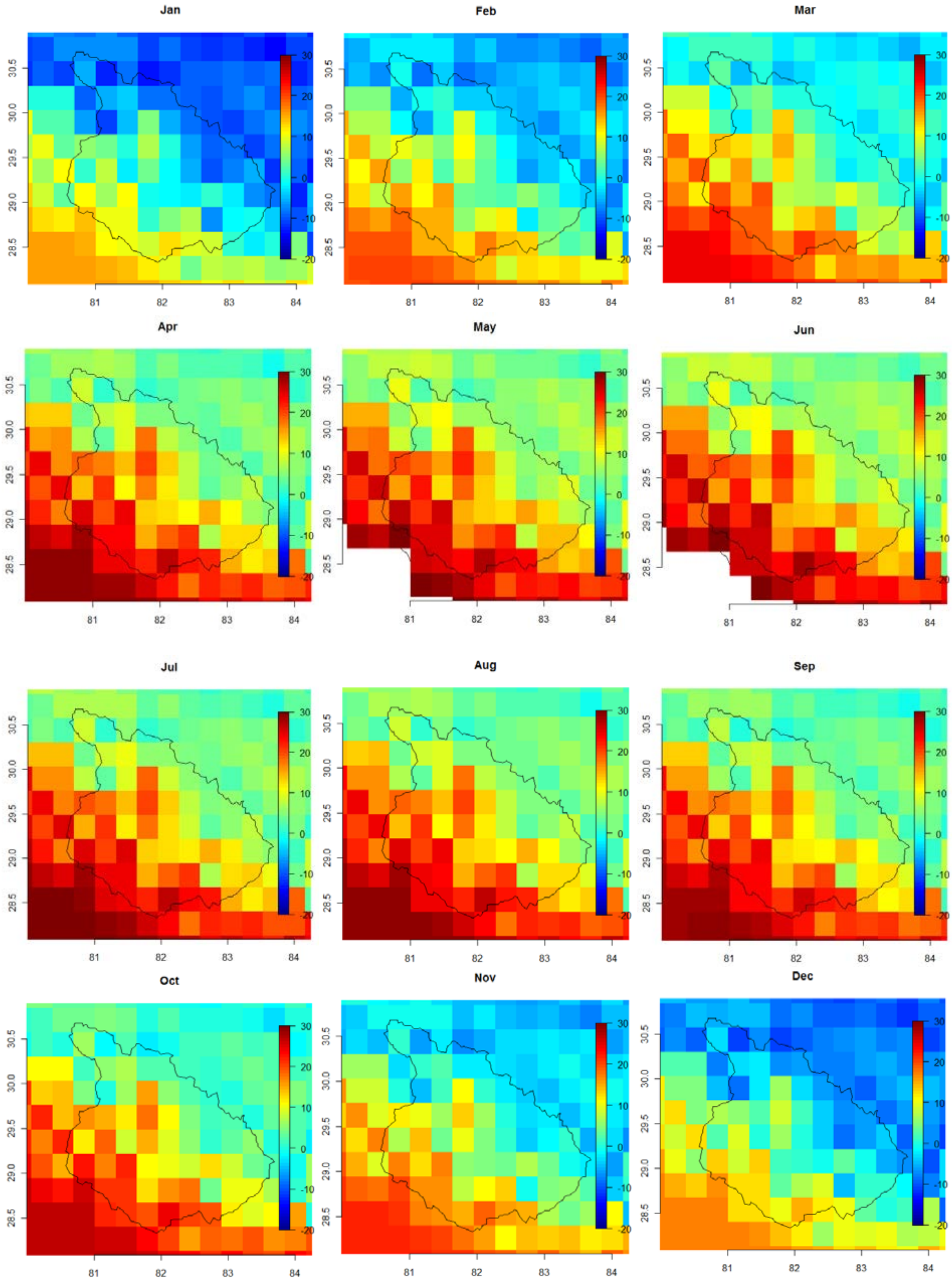
Station	Xcoord	Ycoord	Elevation	R2	NAD	RMSD	MAD	MRAD	EB	CPOD_S	CPOD_G
1403	27.55	87.78	1780.00	0.09	-66.80	188.05	134.24	0.67	-66.80	1.00	1.00
1405	27.35	87.67	1732.00	0.50	-49.23	107.21	83.65	0.55	-49.23	1.00	1.00
1406	27.20	87.93	1830.00	0.40	-52.95	125.69	100.93	0.61	-52.95	1.00	1.00
1407	26.92	87.90	1300.00	0.93	0.74	31.79	21.59	0.49	0.74	1.00	1.00
1408	26.67	87.70	163.00	0.82	-28.36	75.21	49.28	0.38	-28.36	1.00	1.00
1409	26.63	87.98	122.00	0.64	-41.09	153.02	92.47	0.39	-41.09	1.00	1.00
1410	26.88	88.03	1654.00	0.75	-34.52	106.93	67.18	0.32	-34.52	1.00	1.00
1412	26.57	88.05	120.00	0.84	-24.81	83.96	47.59	0.28	-24.81	1.00	1.00
1415	26.68	87.97	168.00	0.65	-39.60	147.60	86.89	0.35	-39.60	1.00	1.00
1416	26.87	88.07	1678.00	0.59	-44.60	161.08	102.78	0.45	-44.60	1.00	1.00
1419	27.15	87.75	1205.00	0.93	-17.96	27.00	21.59	0.55	-17.96	1.00	1.00
1420	27.35	87.60	763.00	0.55	-42.77	83.31	64.82	0.57	-42.77	1.00	1.00
1421	26.58	87.90	143.00	0.75	-32.84	109.47	64.80	0.33	-32.84	1.00	1.00
1422	26.40	88.02	60.00	0.83	-27.59	91.12	56.70	0.57	-27.59	1.00	1.00
	Maximum			-41.37	-78.90	13.15	10.75	0.15	-78.90	1.00	0.83
	Average			-0.02	-8.18	82.17	55.84	0.60	-8.15	1.00	0.99
	Minimum			0.99	359.67	481.54	324.95	6.15	359.67	1.00	1.00

APPENDIX 5

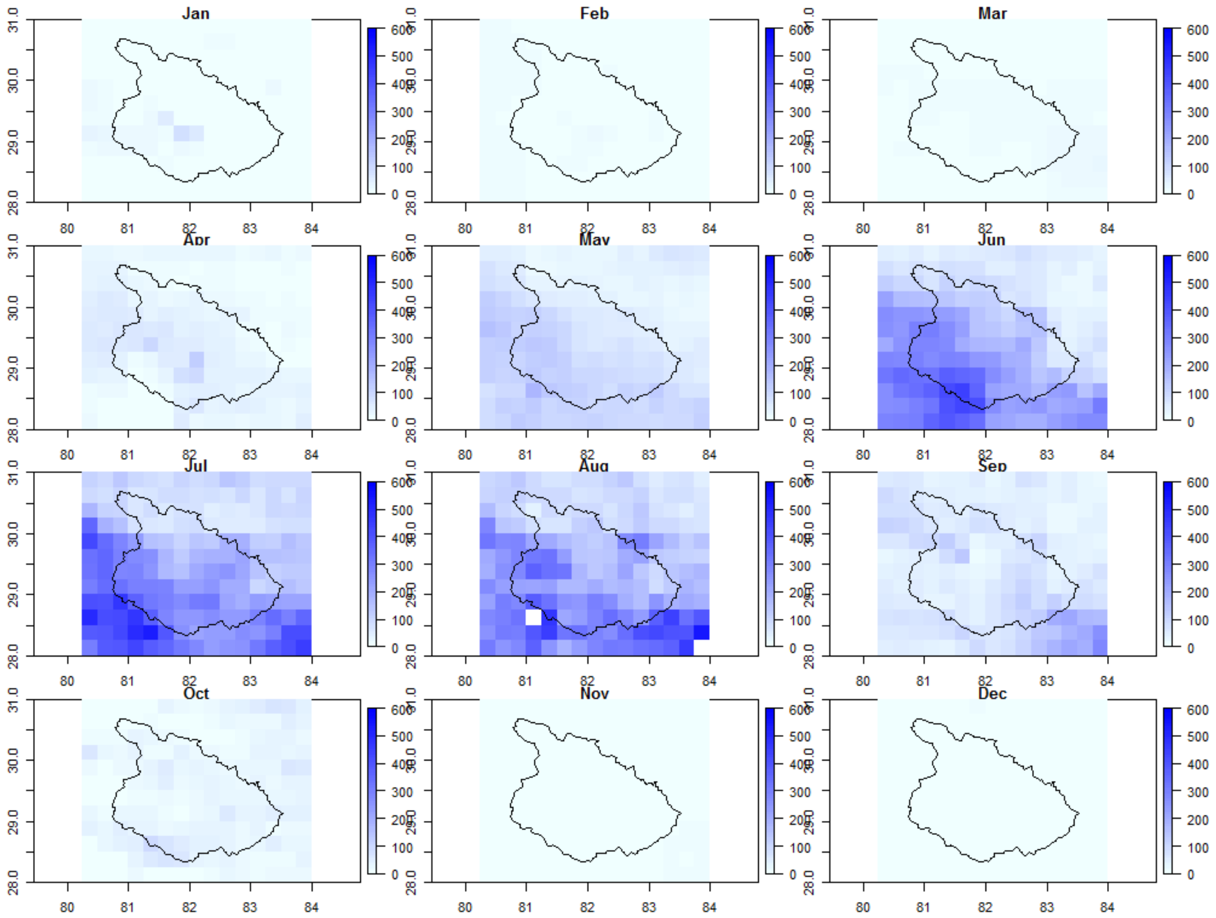
MODEL RESULTS

Karnali Basin

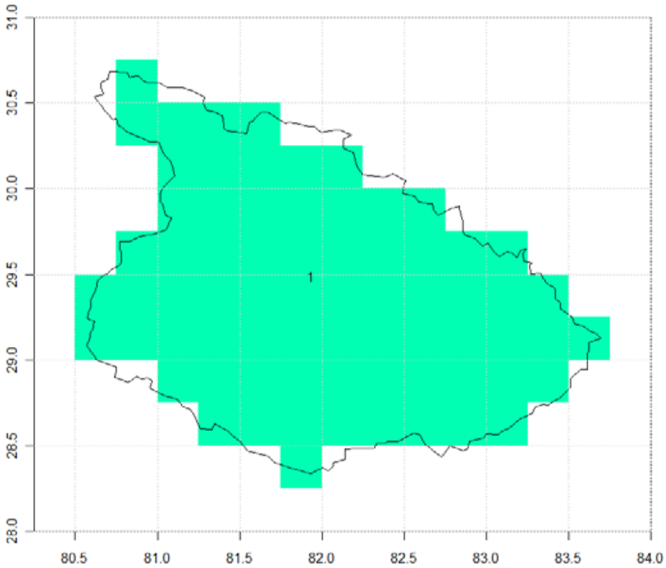
Average Temperature



Average Precipitaion



Pixel selection



Model output results

Date	Q sim (m^3/s)	Q obs (m^3/s)	Precipitation (mm)			Temp °C	Soil moisture storage	Surplus storage	Evapotranspiration		Runoff			Snow Accumulation	Snow Melt	Snow Melt Factor
			Total	Snow	Rain				Actual	Potential	Direct	Surplus	Total			
Jan-01	84	354	5.70	3.12	2.58	-0.95	206.86	47.92	10.90	10.90	2.40	2.52	4.92	281.98	68.02	0.19
Feb-01	109	223	4.56	2.01	2.56	3.74	235.34	63.65	18.19	18.19	2.38	3.35	5.73	218.41	65.58	0.28
Mar-01	139	193	6.54	2.06	4.48	7.35	253.51	70.50	31.57	31.57	4.16	3.71	7.87	160.49	59.98	0.36
Apr-01	611	272	33.19	0.25	32.94	13.34	265.75	73.74	60.00	60.00	30.64	3.88	34.52	83.67	77.06	0.49
May-01	1,287	799	76.65	0.59	76.06	13.50	228.01	83.27	69.30	70.19	70.73	4.38	75.12	44.12	40.14	0.49
Jun-01	3,164	1,890	196.18	2.25	193.93	13.02	193.08	82.96	65.20	72.18	180.36	4.37	184.72	25.62	20.75	0.49
Jul-01	3,323	4,110	205.95	1.87	204.08	13.40	163.88	80.54	53.78	72.13	189.79	4.24	194.03	15.37	12.12	0.49
Aug-01	3,592	4,110	201.95	2.72	199.23	13.16	144.60	78.01	38.89	58.29	185.28	4.11	189.39	10.86	7.23	0.49
Sep-01	995	2,060	57.98	1.75	56.23	12.79	125.93	74.73	26.30	53.04	52.29	3.93	56.23	8.27	4.35	0.48
Oct-01	402	964	22.80	2.41	20.39	10.75	111.19	71.13	17.64	39.54	18.96	3.74	22.70	9.06	1.62	0.45
Nov-01	71	544	1.01	0.36	0.65	6.06	104.54	67.57	6.92	23.23	0.60	3.56	4.16	9.20	0.23	0.33
Dec-01	62	350	0.51	0.27	0.24	1.81	102.59	64.19	2.03	14.37	0.22	3.38	3.60	9.41	0.07	0.25
Jan-02	270	282	25.51	11.98	13.53	0.32	102.31	60.98	1.65	12.50	12.58	3.21	15.79	20.96	0.42	0.21
Feb-02	614	321	47.60	16.09	31.52	3.03	101.82	57.94	4.55	16.96	29.31	3.05	32.36	35.20	1.85	0.27
Mar-02	338	347	20.14	2.69	17.45	8.22	99.91	55.04	10.59	35.30	16.22	2.90	19.12	30.43	7.46	0.39
Apr-02	245	582	12.12	0.26	11.86	12.49	93.97	53.16	18.02	57.00	11.03	2.80	13.83	18.51	12.18	0.48
May-02	1,472	1,170	89.81	0.34	89.47	13.55	83.26	51.67	23.92	70.41	83.21	2.72	85.93	10.67	8.18	0.49
Jun-02	1,199	1,330	72.87	0.40	72.47	14.28	70.22	49.87	22.32	77.84	67.40	2.62	70.02	6.05	5.03	0.50
Jul-02	1,258	2,360	76.69	0.43	76.26	13.85	57.66	47.55	20.43	74.09	70.92	2.50	73.43	3.76	2.71	0.49
Aug-02	3,757	4,330	214.49	4.05	210.44	12.97	51.95	45.62	22.54	57.62	195.71	2.40	198.11	5.24	2.56	0.49
Sep-02	2,028	3,290	125.43	4.69	120.74	11.82	47.21	43.52	15.15	49.72	112.29	2.29	114.58	7.78	2.15	0.47
Oct-02	313	1,120	18.65	1.99	16.66	10.25	43.52	41.34	5.68	37.84	15.49	2.18	17.67	8.95	0.82	0.44
Nov-02	63	626	2.92	1.22	1.70	5.43	43.53	39.27	0.17	21.87	1.58	2.07	3.65	10.10	0.07	0.32
Dec-02	113	385	8.82	3.83	4.99	1.64	43.63	37.31	0.57	14.01	4.64	1.96	6.60	13.60	0.32	0.24
Jan-03	206	294	30.33	19.41	10.92	-2.74	43.64	35.45	1.03	8.69	10.16	1.87	12.02	32.75	0.27	0.17
Feb-03	286	340	28.30	14.02	14.28	2.44	44.11	33.67	4.18	16.33	13.28	1.77	15.06	43.11	3.65	0.26
Mar-03	167	320	11.30	2.99	8.31	6.55	44.59	31.99	7.30	29.76	7.73	1.68	9.41	38.90	7.20	0.34
Apr-03	337	520	19.06	0.41	18.65	12.99	46.51	31.83	15.18	58.75	17.34	1.68	19.02	22.00	17.31	0.49
May-03	238	777	13.15	0.01	13.14	15.08	42.19	31.86	14.39	77.15	12.22	1.68	13.90	11.16	10.86	0.50
Jun-03	1,393	1,530	85.97	0.25	85.72	14.20	36.71	30.41	16.68	77.48	79.72	1.60	81.32	6.05	5.36	0.50

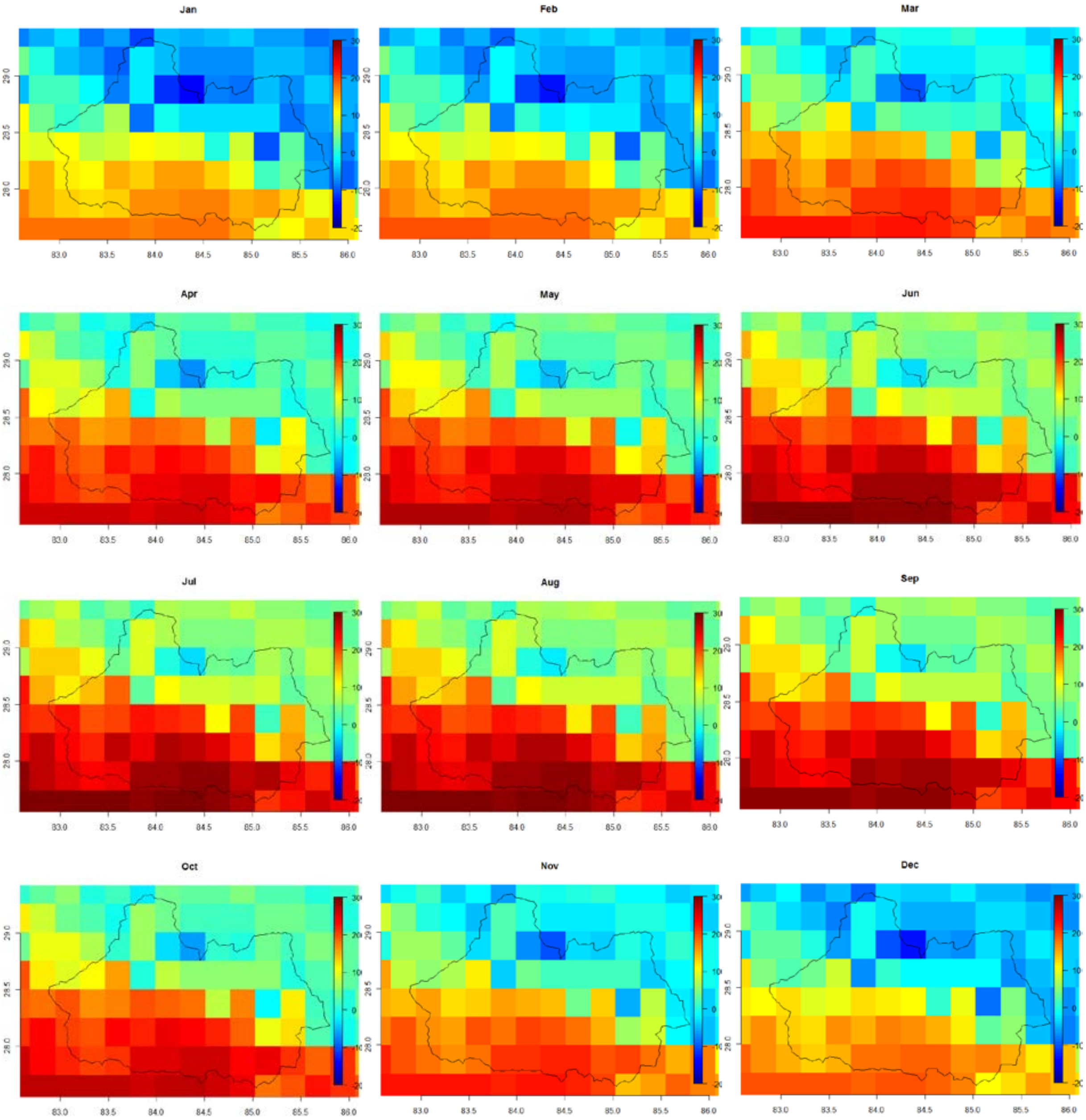
Date	Q sim (m³/s)	Q obs (m³/s)	Precipitation (mm)			Temp °C	Soil moisture storage	Surplus storage	Evapotranspiration		Runoff			Snow Accumu lation	Snow Melt	Snow Melt Factor
			Total	Snow	Rain				Actual	Potential	Direct	Surplus	Total			
Jul-03	3,005	3,400	189.21	2.21	187.01	12.99	32.50	28.91	20.45	70.36	173.92	1.52	175.44	5.09	3.17	0.49
Aug-03	3,136	4,600	185.22	2.63	182.58	12.95	30.47	27.63	17.27	59.61	169.80	1.45	171.26	5.08	2.64	0.49
Sep-03	2,103	4,460	129.21	2.93	126.28	11.86	28.95	26.40	12.05	49.84	117.44	1.39	118.83	6.18	1.84	0.47
Oct-03	85	1,580	4.87	1.15	3.71	10.14	28.20	25.17	1.53	37.34	3.45	1.32	4.78	6.72	0.61	0.43
Nov-03	69	780	3.93	0.95	2.98	5.68	28.22	23.91	0.26	22.46	2.77	1.26	4.03	7.60	0.08	0.32
Dec-03	56	519	6.09	3.87	2.22	1.11	28.24	22.72	0.23	13.12	2.06	1.20	3.26	11.37	0.10	0.23
Jan-04	207	412	31.86	20.09	11.77	-0.88	28.26	21.58	1.13	10.95	10.94	1.14	12.08	31.13	0.33	0.20
Feb-04	32	314	1.19	0.45	0.74	3.43	28.39	20.50	2.55	18.25	0.69	1.08	1.77	28.95	2.64	0.28
Mar-04	100	249	6.38	1.43	4.95	7.95	28.96	19.48	5.51	33.50	4.60	1.03	5.62	24.66	5.72	0.38
Apr-04	945	276	56.51	0.21	56.29	13.79	28.81	20.16	13.91	61.90	52.35	1.06	53.41	13.31	11.56	0.49
May-04	1,284	510	79.47	0.01	79.46	15.36	27.36	19.79	12.95	78.67	73.90	1.04	74.94	6.70	6.62	0.50
Jun-04	2,732	778	170.59	0.17	170.42	14.58	25.21	18.81	17.36	79.30	158.49	0.99	159.48	3.58	3.29	0.50
Jul-04	3,686	2,410	233.51	3.10	230.40	12.85	23.68	17.86	20.02	69.62	214.27	0.94	215.21	4.33	2.36	0.49
Aug-04	3,644	4,370	207.88	2.22	205.66	12.94	23.02	17.08	17.15	57.26	191.27	0.90	192.17	4.34	2.21	0.49
Sep-04	1,824	2,240	114.05	4.15	109.90	11.92	22.65	16.32	9.93	49.79	102.21	0.86	103.07	6.51	1.97	0.47
Oct-04	644	1,310	42.13	3.88	38.25	9.75	22.59	15.61	3.42	36.01	35.58	0.82	36.40	9.59	0.80	0.42
Nov-04	130	665	9.12	1.81	7.31	4.87	22.64	14.83	0.54	20.37	6.80	0.78	7.58	11.33	0.08	0.31
Dec-04	31	462	3.41	2.26	1.15	0.91	22.64	14.09	0.17	12.94	1.07	0.74	1.82	13.49	0.10	0.23
Jan-05	311	386	43.71	24.91	18.79	-0.88	22.69	13.39	1.74	10.95	17.48	0.70	18.18	37.93	0.47	0.20
Feb-05	260	400	27.59	13.59	14.00	3.22	23.42	12.72	4.24	17.17	13.02	0.67	13.69	47.53	3.99	0.28
Mar-05	307	448	21.65	3.69	17.96	8.21	25.66	12.08	9.83	35.27	16.70	0.64	17.34	40.41	10.81	0.39
Apr-05	359	519	21.41	0.35	21.06	12.93	27.91	13.36	15.12	58.53	19.59	0.70	20.29	22.87	17.88	0.49
May-05	566	800	34.78	0.04	34.74	14.83	26.56	14.39	13.24	75.98	32.31	0.76	33.06	11.67	11.24	0.50
Jun-05	1,651	1,250	102.88	-	102.88	17.45	23.97	13.88	15.41	93.91	95.68	0.73	96.41	5.84	5.84	0.50
Jul-05	4,428	3,240	281.16	3.94	277.22	12.76	23.03	13.35	23.73	69.40	257.82	0.70	258.52	6.21	3.56	0.48
Aug-05	4,066	4,230	233.70	3.89	229.82	12.64	22.84	13.36	18.90	56.47	213.73	0.70	214.43	6.76	3.34	0.48
Sep-05	2,786	2,720	170.28	1.77	168.51	12.95	22.55	13.18	14.45	53.56	156.72	0.69	157.41	5.66	2.88	0.49
Oct-05	1,159	1,380	76.37	6.66	69.71	10.35	22.24	12.52	6.67	38.32	64.83	0.66	65.49	10.84	1.47	0.44
Nov-05	21	701	0.74	0.10	0.64	4.91	22.24	11.89	0.06	20.73	0.60	0.63	1.22	10.92	0.02	0.31
Dec-05	44	470	4.20	2.09	2.11	0.49	22.28	11.30	0.20	12.19	1.96	0.59	2.56	12.91	0.09	0.22
Jan-06	24	331	4.31	3.40	0.91	0.88	22.26	10.73	0.36	13.41	0.85	0.56	1.41	16.04	0.27	0.23
Feb-06	32	248	1.60	0.36	1.25	6.58	22.49	10.20	1.42	24.19	1.16	0.54	1.69	14.84	1.56	0.34

APPENDIX 5: Model Results

Date	Q sim (m^3/s)	Q obs (m^3/s)	Precipitation (mm)			Temp °C	Soil moisture storage	Surplus storage	Evapotranspiration		Runoff			Snow Accumu lation	Snow Melt	Snow Melt Factor
			Total	Snow	Rain				Actual	Potential	Direct	Surplus	Total			
Mar-06	480	247	33.69	5.06	28.63	8.24	22.49	9.69	3.79	35.34	26.62	0.51	27.13	18.12	1.79	0.39
Apr-06	472	294	28.45	0.35	28.10	12.65	22.96	9.65	8.00	57.54	26.13	0.51	26.64	11.50	6.97	0.48
May-06	1,158	726	72.21	0.09	72.12	14.47	22.80	9.86	9.94	74.40	67.07	0.52	67.59	6.12	5.47	0.50
Jun-06	2,045	1,030	128.10	0.23	127.87	14.39	21.72	9.49	12.83	78.38	118.92	0.50	119.42	3.41	2.93	0.50
Jul-06	4,358	3,060	274.80	1.75	273.06	13.33	20.87	9.07	21.82	71.81	253.94	0.48	254.42	3.25	1.91	0.49
Aug-06	3,397	3,960	194.64	2.53	192.11	13.13	20.57	8.87	15.39	58.18	178.67	0.47	179.13	3.87	1.90	0.49
Sep-06	1,221	2,430	75.51	1.84	73.67	12.44	20.05	8.48	7.09	51.95	68.51	0.45	68.96	4.25	1.47	0.48
Oct-06	164	987	10.08	0.56	9.52	10.63	19.75	8.06	1.31	39.00	8.85	0.42	9.28	4.45	0.36	0.45
Nov-06	85	575	6.83	1.93	4.90	5.85	19.79	7.66	0.42	22.92	4.56	0.40	4.96	6.26	0.12	0.33
Dec-06	51	401	5.90	3.10	2.81	1.56	19.83	7.28	0.33	13.94	2.61	0.38	2.99	9.19	0.17	0.24

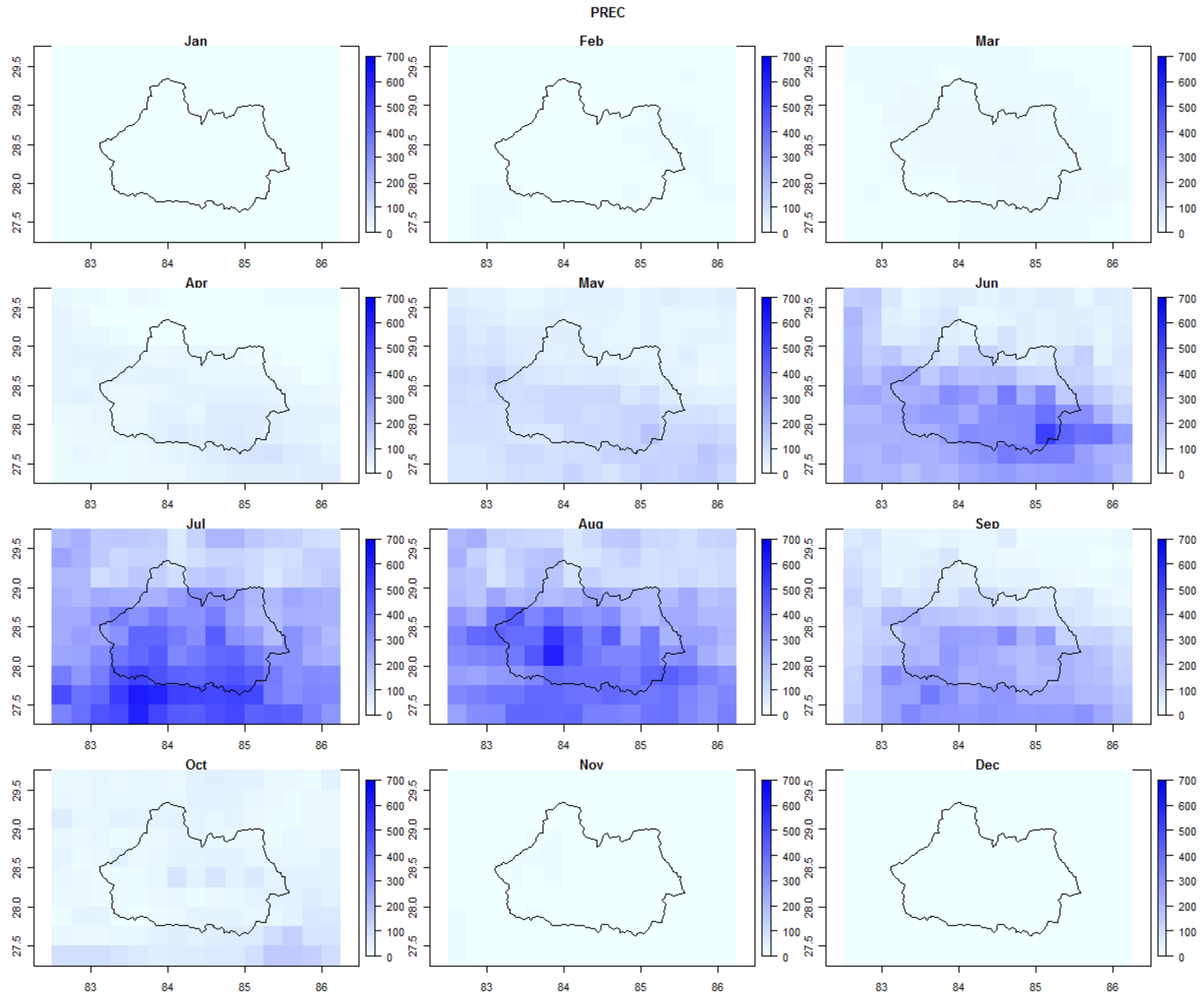
Narayani Basin

Average Temperature

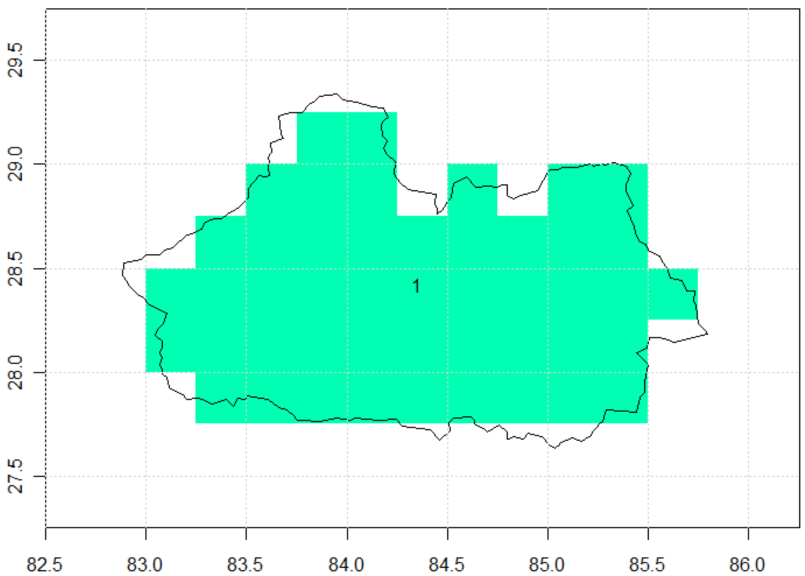


APPENDIX 5: Model Results

Average Precipitaion



Pixel selection



Model output results

Date	Q sim (m³/s)	Q obs (m³/s)	Precipitation (mm)			Temp °C	Soil moisture storage	Surplus storage	Evapotranspiration		Runoff			Snow Accumulation	Snow Melt	Snow Melt Factor
			Total	Snow	Rain				Actual	Potential	Direct	Surplus	Total			
Jan-01	241	355	1.67	1.14	0.53	3.34	300.00	176.39	18.79	18.79	0.47	19.60	20.07	285.26	114.74	0.29
Feb-01	329	305	5.55	2.44	3.10	4.84	300.00	197.62	21.38	21.38	2.79	21.96	24.75	223.46	64.25	0.30
Mar-01	364	242	14.53	5.40	9.13	6.96	297.67	189.82	30.78	30.78	8.22	21.09	29.31	188.04	40.82	0.32
Apr-01	558	277	30.13	4.51	25.61	10.59	273.10	196.59	48.84	48.84	23.05	21.84	44.90	142.21	50.34	0.40
May-01	1025	619	78.24	7.67	70.56	12.21	233.12	195.88	63.27	63.27	63.51	21.76	85.27	112.60	37.28	0.42
Jun-01	2483	2100	223.09	17.56	205.52	13.74	193.18	193.73	73.97	75.72	184.97	21.53	206.49	97.31	32.85	0.45
Jul-01	3706	3890	328.25	10.49	317.76	15.90	160.78	200.53	72.37	84.65	285.99	22.28	308.27	70.53	37.27	0.48
Aug-01	4087	5490	329.93	13.01	316.92	15.63	144.21	196.14	52.76	68.56	285.23	21.79	307.02	61.64	21.90	0.48
Sep-01	2155	3540	175.46	5.91	169.55	16.02	128.62	187.45	37.16	65.65	152.60	20.83	173.42	50.80	16.75	0.48
Oct-01	499	1470	26.41	2.72	23.69	14.30	118.22	169.90	16.04	50.95	21.32	18.88	40.20	48.92	4.60	0.46
Nov-01	240	776	3.85	0.56	3.29	10.64	111.48	152.91	7.54	35.14	2.96	16.99	19.95	49.01	0.47	0.40
Dec-01	186	506	0.54	0.33	0.22	6.04	109.08	137.62	2.50	22.54	0.20	15.29	15.49	49.25	0.08	0.31
Jan-02	281	347	16.14	5.46	10.68	4.81	107.70	123.86	2.61	20.98	9.61	13.76	23.38	54.56	0.15	0.30
Feb-02	313	288	20.57	8.21	12.36	5.42	105.95	111.47	3.33	22.85	11.13	12.39	23.51	62.42	0.35	0.31
Mar-02	489	264	35.18	3.87	31.31	10.06	103.23	100.32	9.07	40.96	28.18	11.15	39.33	63.08	3.21	0.39
Apr-02	347	358	22.12	2.29	19.83	13.45	97.23	90.88	13.09	60.57	17.85	10.10	27.94	59.60	5.77	0.44
May-02	1227	757	107.71	4.86	102.84	15.03	89.61	85.49	22.66	77.34	92.56	9.50	102.05	55.61	8.86	0.47
Jun-02	1766	1640	158.82	6.30	152.52	16.28	81.15	86.23	26.94	88.56	137.27	9.58	146.85	48.35	13.55	0.48
Jul-02	2949	4520	270.55	8.30	262.25	15.86	73.65	83.46	35.85	84.45	236.02	9.27	245.30	48.02	8.63	0.48
Aug-02	3799	4710	316.10	9.40	306.70	16.37	70.61	84.51	34.23	71.59	276.03	9.39	285.42	46.48	10.95	0.49
Sep-02	1508	2460	134.33	9.00	125.33	14.60	64.70	77.52	19.77	59.95	112.80	8.61	121.41	52.53	2.95	0.46
Oct-02	359	1170	26.44	3.01	23.43	13.13	59.25	70.00	8.39	46.75	21.09	7.78	28.87	54.68	0.87	0.44
Nov-02	104	604	2.96	1.09	1.87	9.19	57.02	63.00	2.53	31.50	1.68	7.00	8.68	55.66	0.11	0.37
Dec-02	96	393	3.25	1.37	1.88	5.92	56.70	56.70	0.54	22.38	1.69	6.30	7.99	57.00	0.03	0.31
Jan-03	154	299	14.25	6.34	7.91	4.94	56.76	51.03	0.85	21.15	7.12	5.67	12.79	63.22	0.12	0.30
Feb-03	310	307	36.26	16.07	20.19	4.51	56.82	45.93	2.30	20.93	18.17	5.10	23.27	78.96	0.34	0.30
Mar-03	192	266	14.06	1.95	12.11	8.07	56.98	41.34	3.76	34.67	10.90	4.59	15.49	78.20	2.71	0.35
Apr-03	357	337	30.36	3.02	27.34	13.64	56.85	37.39	11.72	61.76	24.61	4.15	28.76	72.15	9.07	0.45
May-03	372	439	31.86	1.66	30.20	14.01	53.10	33.87	12.63	72.83	27.18	3.76	30.94	67.73	6.08	0.45
Jun-03	1947	1520	182.43	7.18	175.26	15.89	50.33	38.02	24.93	86.60	157.73	4.22	161.95	61.89	13.02	0.48

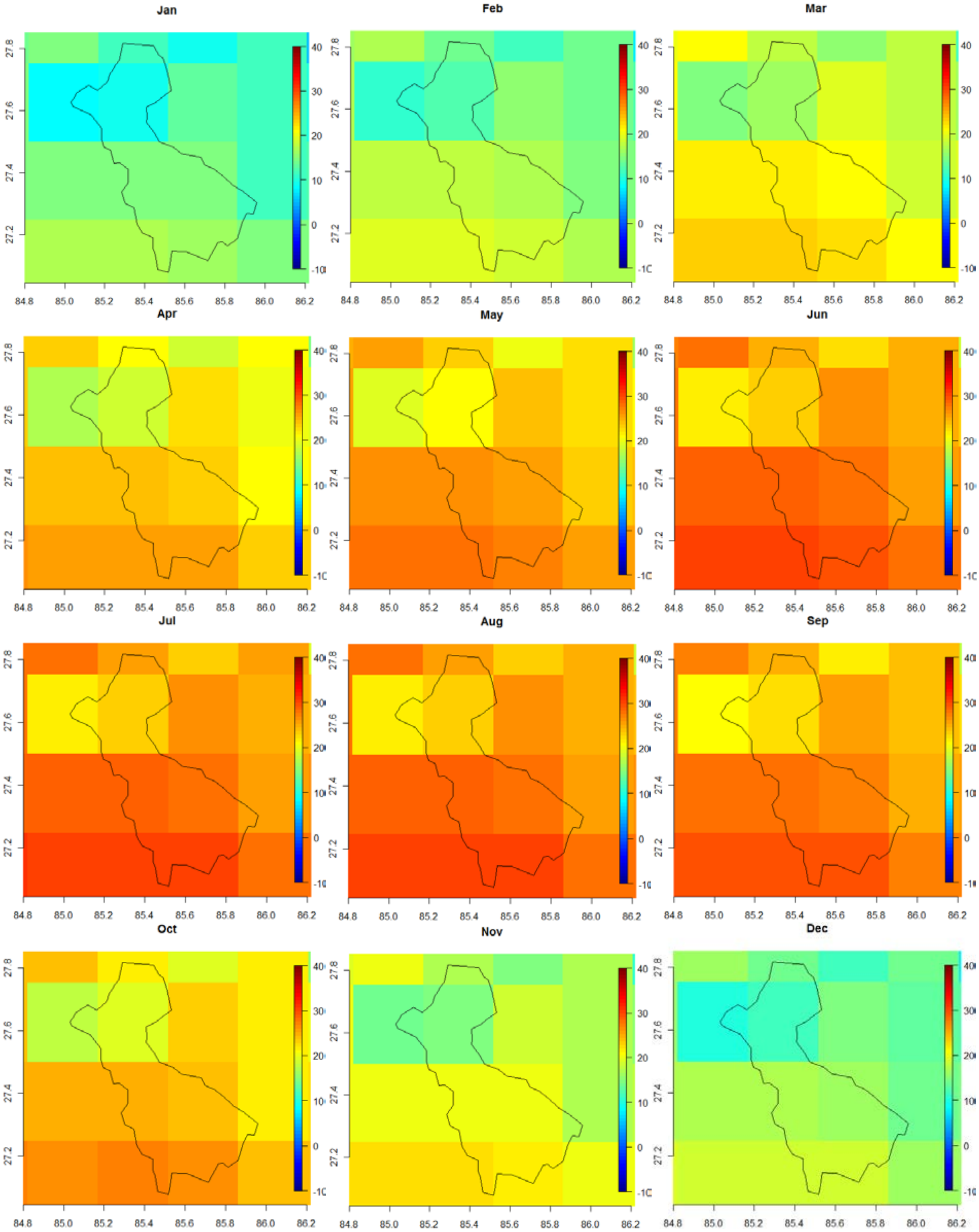
APPENDIX 5: Model Results

Date	Q sim (m^3/s)	Q obs (m^3/s)	Precipitation (mm)			Temp °C	Soil moisture storage	Surplus storage	Evapotranspiration		Runoff			Snow Accumulation	Snow Melt	Snow Melt Factor
			Total	Snow	Rain				Actual	Potential	Direct	Surplus	Total			
Jul-03	4235	4970	394.84	8.97	385.87	16.26	48.23	44.28	42.83	86.47	347.28	4.92	352.20	57.54	13.32	0.48
Aug-03	3490	4640	305.51	9.77	295.74	16.10	47.18	48.31	31.73	73.00	266.17	5.37	271.54	56.81	10.50	0.48
Sep-03	1374	3990	121.48	4.37	117.11	15.57	44.38	46.78	15.99	63.94	105.40	5.20	110.60	56.04	5.15	0.48
Oct-03	189	1430	13.99	2.29	11.70	13.71	42.21	42.10	4.12	49.20	10.53	4.68	15.20	57.54	0.78	0.45
Nov-03	60	751	1.10	0.26	0.84	9.34	42.17	37.89	0.17	31.77	0.76	4.21	4.97	57.76	0.04	0.37
Dec-03	80	491	6.65	3.42	3.23	5.83	42.17	34.10	0.40	22.26	2.90	3.79	6.69	61.11	0.08	0.31
Jan-04	193	377	24.04	10.02	14.02	4.15	42.17	30.69	1.59	20.13	12.62	3.41	16.03	70.95	0.18	0.29
Feb-04	45	294	0.85	0.39	0.46	5.21	42.34	27.62	0.24	22.64	0.41	3.07	3.48	70.97	0.37	0.31
Mar-04	220	289	19.35	2.71	16.64	11.27	42.30	24.86	5.42	44.29	14.98	2.76	17.74	69.96	3.72	0.41
Apr-04	884	359	85.38	9.08	76.30	12.17	42.22	22.38	10.62	54.93	68.67	2.49	71.16	76.13	2.91	0.42
May-04	1123	646	109.21	8.03	101.19	14.21	43.01	20.86	14.52	73.91	91.07	2.32	93.39	78.15	6.00	0.45
Jun-04	2692	1670	256.65	11.01	245.65	15.56	43.41	25.43	28.26	84.93	221.08	2.83	223.91	77.67	11.48	0.48
Jul-04	3871	3920	364.43	10.86	353.57	16.05	43.69	33.54	37.33	85.20	318.22	3.73	321.94	74.45	14.08	0.48
Aug-04	3386	3980	283.68	6.39	277.28	16.47	43.23	43.22	29.09	71.75	249.56	4.80	254.36	65.45	15.39	0.49
Sep-04	2495	2990	226.08	8.41	217.67	15.70	41.96	44.22	24.17	64.14	195.90	4.91	200.81	66.81	7.05	0.48
Oct-04	606	1630	59.12	9.82	49.30	11.96	41.76	39.80	5.62	42.64	44.37	4.42	48.79	76.14	0.49	0.42
Nov-04	146	724	12.15	3.08	9.07	9.45	41.77	35.82	1.13	32.23	8.16	3.98	12.14	78.99	0.23	0.37
Dec-04	49	464	1.63	1.06	0.57	7.65	41.83	32.24	0.08	25.53	0.51	3.58	4.10	79.96	0.09	0.34
Jan-05	281	360	35.16	12.74	22.42	4.95	41.96	29.01	2.41	21.16	20.18	3.22	23.40	92.40	0.30	0.30
Feb-05	144	277	17.78	9.01	8.76	6.94	42.07	26.11	1.73	25.10	7.89	2.90	10.79	100.44	0.97	0.32
Mar-05	293	251	29.28	5.96	23.32	10.69	43.43	23.50	6.33	42.55	20.99	2.61	23.60	101.04	5.36	0.40
Apr-05	266	290	23.17	2.08	21.08	13.33	43.68	21.77	8.87	60.12	18.97	2.42	21.39	95.43	7.69	0.44
May-05	696	508	65.27	3.72	61.55	14.40	43.01	22.08	12.65	74.52	55.40	2.45	57.85	90.56	8.59	0.46
Jun-05	2202	1070	200.42	2.20	198.22	17.61	43.28	42.95	24.76	96.34	178.40	4.77	183.17	61.92	30.85	0.49
Jul-05	4169	3720	384.89	5.79	379.10	16.78	43.72	50.36	40.16	89.73	341.19	5.60	346.78	52.02	15.69	0.49
Aug-05	3434	4230	284.77	4.93	279.84	16.75	43.45	54.73	29.91	73.70	251.85	6.08	257.93	44.84	12.11	0.49
Sep-05	1313	2210	113.34	2.74	110.60	16.39	41.57	55.03	14.16	67.08	99.54	6.11	105.66	39.93	7.65	0.49
Oct-05	2036	1300	196.74	20.78	175.96	13.35	42.08	49.93	18.76	47.77	158.36	5.55	163.91	58.60	2.11	0.44
Nov-05	63	726	0.42	0.11	0.31	9.08	41.93	44.93	0.20	31.28	0.28	4.99	5.27	58.69	0.02	0.37
Dec-05	71	410	3.25	1.72	1.53	7.00	41.94	40.44	0.22	23.92	1.38	4.49	5.87	60.34	0.07	0.33
Jan-06	58	293	1.68	0.83	0.86	6.64	41.94	36.40	0.15	24.23	0.77	4.04	4.81	61.11	0.06	0.32
Feb-06	57	248	1.15	0.43	0.71	8.18	41.96	32.76	0.31	28.83	0.64	3.64	4.28	61.29	0.26	0.35

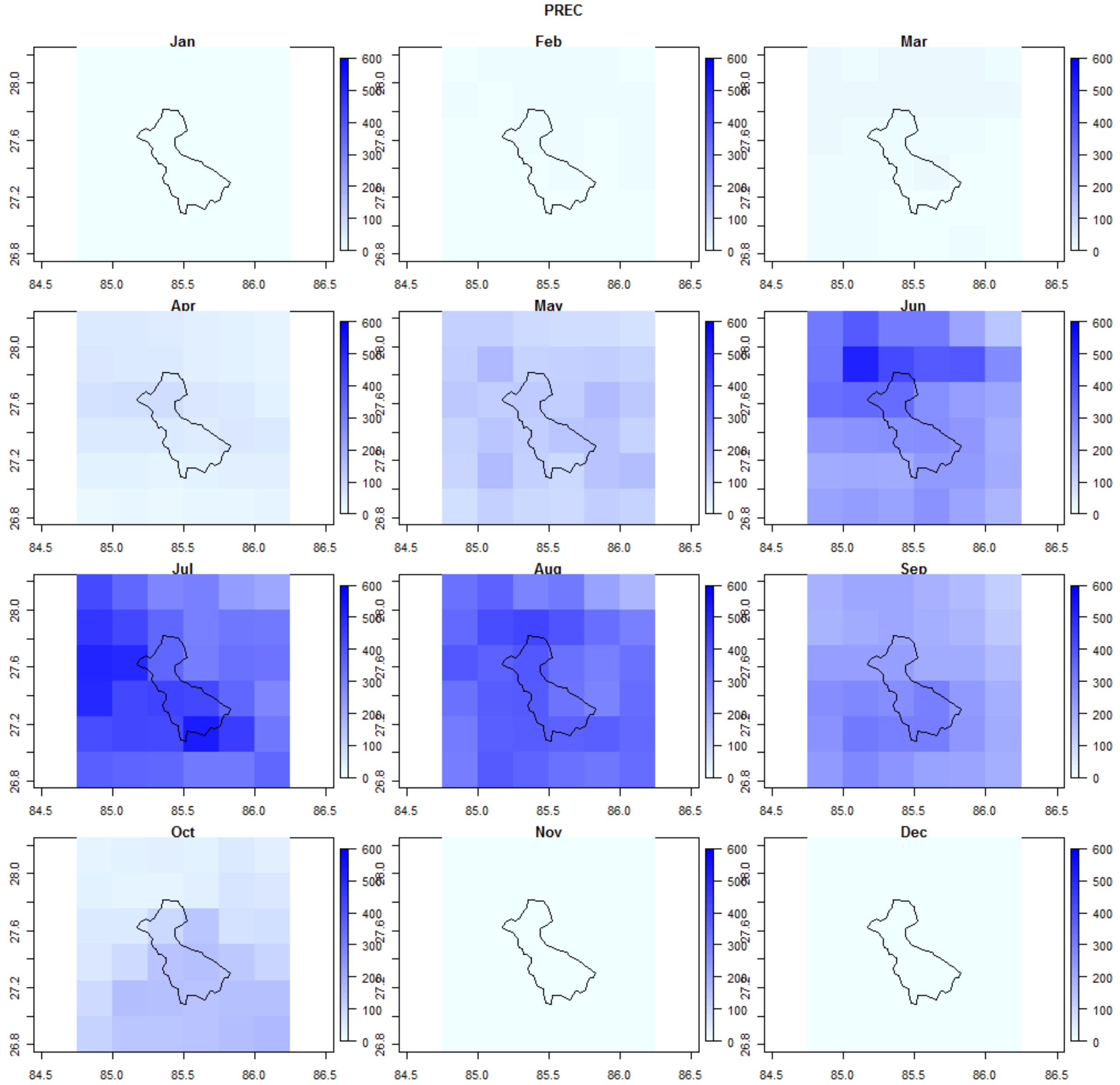
Date	Q sim (m³/s)	Q obs (m³/s)	Precipitation (mm)			Temp °C	Soil moisture storage	Surplus storage	Evapotranspiration		Runoff			Snow Accum ulation	Snow Melt	Snow Melt Factor
			Total	Snow	Rain				Actual	Potential	Direct	Surplus	Total			
Mar-06	214	219	18.91	3.42	15.49	9.09	41.94	29.48	2.11	37.80	13.94	3.28	17.22	64.15	0.55	0.37
Apr-06	316	255	27.16	2.14	25.02	11.97	41.91	26.53	3.97	54.03	22.52	2.95	25.47	64.87	1.43	0.42
May-06	853	714	78.74	3.23	75.51	15.25	42.87	26.77	11.81	78.93	67.96	2.97	70.93	59.67	8.43	0.47
Jun-06	2297	1530	211.23	3.19	208.05	16.74	42.50	34.46	24.79	91.60	187.24	3.83	191.07	47.73	15.13	0.49
Jul-06	3057	3390	281.00	3.69	277.31	17.35	41.76	42.16	30.58	92.71	249.58	4.68	254.26	36.93	14.49	0.49
Aug-06	2465	3180	201.67	1.83	199.84	17.78	40.70	47.57	22.55	78.22	179.85	5.29	185.14	26.55	12.21	0.49
Sep-06	1607	2690	141.53	3.51	138.02	16.37	39.56	46.33	15.81	67.01	124.22	5.15	129.37	25.28	4.78	0.49
Oct-06	306	1080	25.43	3.21	22.22	13.45	38.18	41.80	3.85	48.04	20.00	4.64	24.65	28.13	0.36	0.44
Nov-06	82	556	3.90	0.95	2.95	9.06	38.18	37.62	0.36	31.24	2.66	4.18	6.84	29.01	0.07	0.37
Dec-06	70	369	3.61	1.28	2.33	5.55	38.18	33.86	0.27	21.87	2.10	3.76	5.86	30.26	0.04	0.31

Bagmati Basin

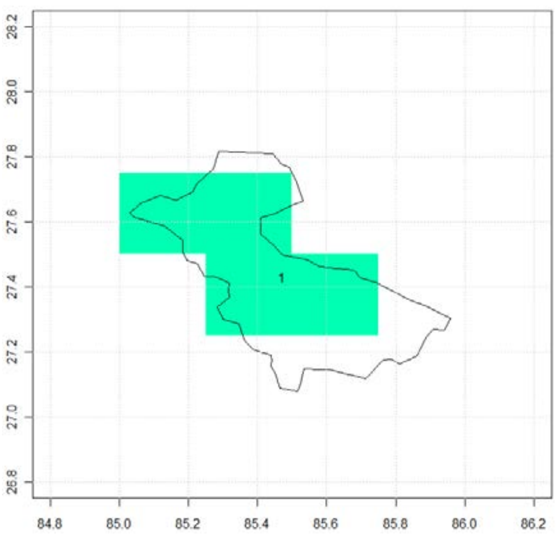
Average Temperature



Average Precipitaion



Pixel selection



Model output results

Date	Q sim (m³/s)	Q obs (m³/s)	Precipitation (mm)			Temp °C	Soil moisture storage	Surplus storage	Evapotranspiration		Runoff			Snow Accumu lation	Snow Melt	Snow Melt Factor
			Total	Snow	Rain				Actual	Potential	Direct	Surplus	Total			
Jan-01	6	18	0.72	0.00	0.72	12.45	93.67	45.00	36.54	36.54	0.50	5.00	5.50	80.00	80.00	0.50
Feb-01	10	16	5.90	0.00	5.90	13.66	95.54	40.50	39.90	39.90	4.13	4.50	8.63	40.00	40.00	0.50
Mar-01	12	15	9.88	0.00	9.88	17.01	58.84	36.45	59.66	59.66	6.92	4.05	10.97	20.00	20.00	0.50
Apr-01	53	15	61.71	0.00	61.71	20.67	26.87	32.81	60.49	85.11	43.19	3.65	46.84	10.00	10.00	0.50
May-01	98	41	123.24	0.00	123.24	22.73	5.03	29.52	63.82	110.25	86.27	3.28	89.55	5.00	5.00	0.50
Jun-01	238	125	306.53	0.00	306.53	24.68	3.43	26.57	96.06	129.87	214.57	2.95	217.53	2.50	2.50	0.50
Jul-01	334	320	432.08	0.00	432.08	25.61	14.08	23.91	120.21	133.84	302.45	2.66	305.11	1.25	1.25	0.50
Aug-01	317	474	369.40	0.00	369.40	25.03	26.68	21.52	98.85	106.87	258.58	2.39	260.97	0.63	0.63	0.50
Sep-01	203	355	253.12	0.00	253.12	24.35	20.12	19.37	82.81	96.64	177.19	2.15	179.34	0.31	0.31	0.50
Oct-01	88	104	107.70	0.00	107.70	22.19	7.28	17.43	45.30	74.23	75.39	1.94	77.33	0.16	0.16	0.50
Nov-01	2	52	0.19	0.00	0.19	18.12	1.02	15.69	6.40	53.16	0.13	1.74	1.88	0.08	0.08	0.50
Dec-01	2	38	0.06	0.00	0.06	12.85	0.10	14.12	0.98	36.22	0.04	1.57	1.61	0.04	0.04	0.50
Jan-02	23	33	27.61	0.00	27.61	11.27	0.01	12.71	8.39	33.95	19.33	1.41	20.74	0.02	0.02	0.50
Feb-02	10	30	9.96	0.00	9.96	13.72	0.00	11.44	3.00	40.04	6.97	1.27	8.24	0.01	0.01	0.50
Mar-02	28	25	34.12	0.00	34.12	18.21	0.00	10.29	10.24	64.07	23.88	1.14	25.03	0.00	0.00	0.50
Apr-02	36	26	43.87	0.00	43.87	20.33	0.00	9.27	13.16	83.44	30.71	1.03	31.74	0.00	0.00	0.50
May-02	117	57	150.77	0.00	150.77	22.64	0.00	8.34	45.23	109.63	105.54	0.93	106.47	0.00	0.00	0.50
Jun-02	202	107	261.86	0.00	261.86	24.98	0.00	7.50	78.56	132.07	183.30	0.83	184.14	0.00	0.00	0.50
Jul-02	651	897	847.22	0.00	847.22	25.31	122.60	6.75	131.56	131.56	593.05	0.75	593.80	0.00	0.00	0.50
Aug-02	385	235	452.83	0.00	452.83	25.19	150.64	6.08	107.81	107.81	316.98	0.68	317.66	0.00	0.00	0.50
Sep-02	141	195	177.59	0.00	177.59	23.72	110.66	5.47	93.25	93.25	124.31	0.61	124.92	0.00	0.00	0.50
Oct-02	24	72	29.76	0.00	29.76	21.27	49.18	4.92	70.41	70.41	20.83	0.55	21.38	0.00	0.00	0.50
Nov-02	3	30	3.28	0.00	3.28	16.84	17.00	4.43	33.17	49.25	2.30	0.49	2.79	0.00	0.00	0.50
Dec-02	3	19	2.99	0.00	2.99	13.16	5.61	3.99	12.29	36.92	2.09	0.44	2.53	0.00	0.00	0.50
Jan-03	9	16	11.81	0.00	11.81	10.55	0.44	3.59	8.71	32.44	8.26	0.40	8.66	0.00	0.00	0.50

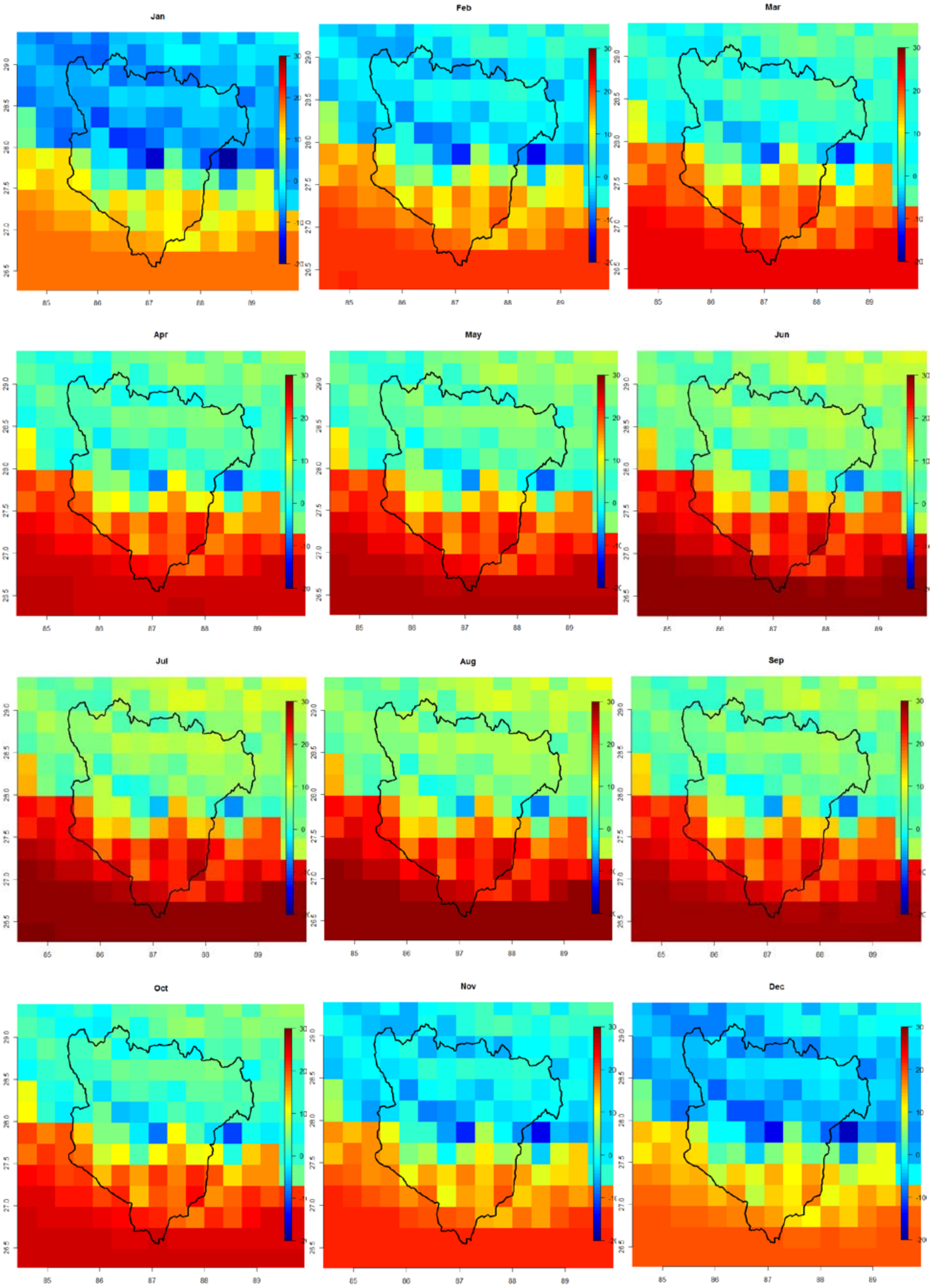
Date	Q sim (m³/s)	Q obs (m³/s)	Precipitation (mm)			Temp °C	Soil moisture storage	Surplus storage	Evapotranspiration		Runoff			Snow Accumu lation	Snow Melt	Snow Melt Factor
			Total	Snow	Rain				Actual	Potential	Direct	Surplus	Total			
Feb-03	37	21	42.61	0.00	42.61	13.19	0.03	3.23	13.19	38.77	29.82	0.36	30.18	0.00	0.00	0.50
Mar-03	24	18	30.39	0.00	30.39	16.77	0.00	2.91	9.14	58.82	21.28	0.32	21.60	0.00	0.00	0.50
Apr-03	39	18	48.32	0.00	48.32	21.55	0.00	2.62	14.50	89.56	33.82	0.29	34.12	0.00	0.00	0.50
May-03	63	17	81.27	0.00	81.27	22.20	0.00	2.36	24.38	106.94	56.89	0.26	57.15	0.00	0.00	0.50
Jun-03	226	96	294.80	0.00	294.80	25.31	0.00	2.12	88.44	134.52	206.36	0.24	206.60	0.00	0.00	0.50
Jul-03	467	451	609.19	0.00	609.19	25.39	50.56	1.91	132.20	132.20	426.43	0.21	426.64	0.00	0.00	0.50
Aug-03	289	343	352.46	0.00	352.46	25.37	43.49	1.72	112.81	112.81	246.72	0.19	246.91	0.00	0.00	0.50
Sep-03	111	213	140.19	0.00	140.19	24.45	17.43	1.55	68.11	97.21	98.13	0.17	98.30	0.00	0.00	0.50
Oct-03	19	68	24.02	0.00	24.02	21.57	3.13	1.39	21.51	71.63	16.82	0.15	16.97	0.00	0.00	0.50
Nov-03	0	29	0.05	0.00	0.05	17.35	0.45	1.25	2.70	50.77	0.03	0.14	0.17	0.00	0.00	0.50
Dec-03	11	16	14.41	0.00	14.41	13.22	0.04	1.13	4.73	37.06	10.08	0.13	10.21	0.00	0.00	0.50
Jan-04	14	15	18.27	0.00	18.27	11.40	0.00	1.01	5.52	34.22	12.79	0.11	12.90	0.00	0.00	0.50
Feb-04	0	12	0.32	0.00	0.32	13.72	0.00	0.91	0.10	41.48	0.22	0.10	0.33	0.00	0.00	0.50
Mar-04	23	10	28.45	0.00	28.45	19.82	0.00	0.82	8.54	70.77	19.92	0.09	20.01	0.00	0.00	0.50
Apr-04	94	12	118.77	0.00	118.77	21.30	0.00	0.74	35.63	88.64	83.14	0.08	83.22	0.00	0.00	0.50
May-04	160	22	208.58	0.00	208.58	24.00	0.00	0.67	62.58	118.82	146.01	0.07	146.08	0.00	0.00	0.50
Jun-04	237	78	308.31	0.00	308.31	24.35	0.00	0.60	92.49	127.55	215.82	0.07	215.89	0.00	0.00	0.50
Jul-04	552	676	719.07	0.00	719.07	24.68	88.94	0.54	126.78	126.78	503.35	0.06	503.41	0.00	0.00	0.50
Aug-04	248	100	292.07	0.00	292.07	25.36	68.09	0.48	108.47	108.47	204.45	0.05	204.51	0.00	0.00	0.50
Sep-04	194	142	244.67	0.00	244.67	24.68	43.47	0.44	98.02	98.02	171.27	0.05	171.32	0.00	0.00	0.50
Oct-04	81	109	101.65	0.00	101.65	20.66	22.48	0.39	51.49	67.65	71.16	0.04	71.20	0.00	0.00	0.50
Nov-04	12	40	15.78	0.00	15.78	16.56	7.55	0.35	19.66	48.27	11.05	0.04	11.09	0.00	0.00	0.50
Dec-04	0	26	0.03	0.00	0.03	13.68	0.82	0.32	6.75	38.10	0.02	0.04	0.06	0.00	0.00	0.50
Jan-05	47	23	60.86	0.00	60.86	12.13	0.04	0.29	19.03	35.82	42.60	0.03	42.63	0.00	0.00	0.50
Feb-05	7	18	8.05	0.00	8.05	13.83	0.00	0.26	2.45	40.31	5.64	0.03	5.67	0.00	0.00	0.50
Mar-05	46	17	57.83	0.00	57.83	18.47	0.00	0.23	17.35	65.09	40.48	0.03	40.50	0.00	0.00	0.50
Apr-05	43	14	54.13	0.00	54.13	20.62	0.00	0.21	16.24	84.88	37.89	0.02	37.92	0.00	0.00	0.50

APPENDIX 5: Model Results

Date	Q sim (m³/s)	Q obs (m³/s)	Precipitation (mm)			Temp °C	Soil moisture storage	Surplus storage	Evapotranspiration		Runoff			Snow Accumu lation	Snow Melt	Snow Melt Factor
			Total	Snow	Rain				Actual	Potential	Direct	Surplus	Total			
May-05	63	27	82.33	0.00	82.33	22.54	0.00	0.19	24.70	109.03	57.63	0.02	57.65	0.00	0.00	0.50
Jun-05	180	49	234.03	0.00	234.03	25.80	0.00	0.17	70.21	138.31	163.82	0.02	163.84	0.00	0.00	0.50
Jul-05	283	282	369.32	0.00	369.32	25.69	0.00	0.15	110.80	134.37	258.52	0.02	258.54	0.00	0.00	0.50
Aug-05	378	396	445.03	0.00	445.03	25.40	24.39	0.14	109.11	109.11	311.52	0.02	311.54	0.00	0.00	0.50
Sep-05	57	72	72.42	0.00	72.42	25.27	6.11	0.12	40.01	101.75	50.69	0.01	50.71	0.00	0.00	0.50
Oct-05	160	40	201.73	0.00	201.73	21.74	10.84	0.11	55.78	72.35	141.21	0.01	141.22	0.00	0.00	0.50
Nov-05	0	22	0.03	0.00	0.03	16.60	1.46	0.10	9.40	48.56	0.02	0.01	0.03	0.00	0.00	0.50
Dec-05	0	15	0.19	0.00	0.19	13.91	0.16	0.09	1.36	38.67	0.13	0.01	0.14	0.00	0.00	0.50
Jan-06	0	12	0.04	0.00	0.04	12.40	0.02	0.08	0.15	36.42	0.03	0.01	0.04	0.00	0.00	0.50
Feb-06	0	11	0.04	0.00	0.04	16.66	0.00	0.07	0.02	47.86	0.03	0.01	0.03	0.00	0.00	0.50
Mar-06	14	14	17.63	0.00	17.63	18.24	0.00	0.07	5.29	64.20	12.34	0.01	12.35	0.00	0.00	0.50
Apr-06	30	11	37.52	0.00	37.52	20.32	0.00	0.06	11.26	83.39	26.26	0.01	26.27	0.00	0.00	0.50
May-06	95	25	123.24	0.00	123.24	23.18	0.00	0.05	36.97	113.07	86.27	0.01	86.27	0.00	0.00	0.50
Jun-06	285	131	372.07	0.00	372.07	25.73	0.00	0.05	111.62	137.78	260.45	0.01	260.46	0.00	0.00	0.50
Jul-06	225	169	293.43	0.00	293.43	25.84	0.00	0.04	88.03	135.51	205.40	0.00	205.40	0.00	0.00	0.50
Aug-06	199	158	234.36	0.00	234.36	25.62	0.00	0.04	70.31	110.44	164.05	0.00	164.06	0.00	0.00	0.50
Sep-06	303	406	382.89	0.00	382.89	24.49	17.48	0.03	97.39	97.39	268.03	0.00	268.03	0.00	0.00	0.50
Oct-06	15	52	18.90	0.00	18.90	22.40	4.10	0.03	19.05	75.14	13.23	0.00	13.23	0.00	0.00	0.50
Nov-06	4	21	4.81	0.00	4.81	17.30	0.70	0.03	4.84	50.63	3.36	0.00	3.37	0.00	0.00	0.50
Dec-06	3	16	3.84	0.00	3.84	15.44	0.11	0.03	1.75	42.45	2.69	0.00	2.69	0.00	0.00	0.50

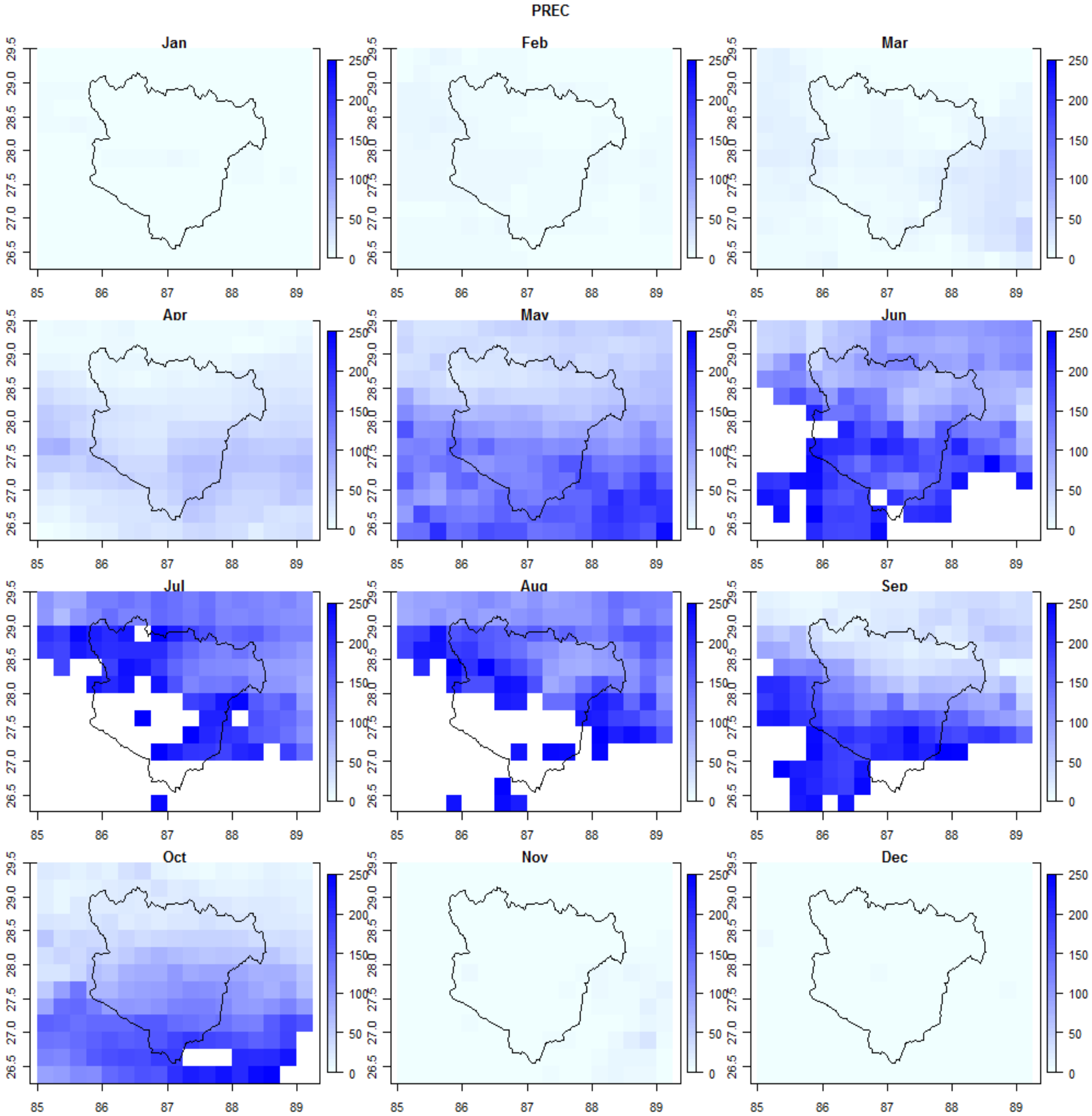
Saptakoshi Basin

Average Temperature

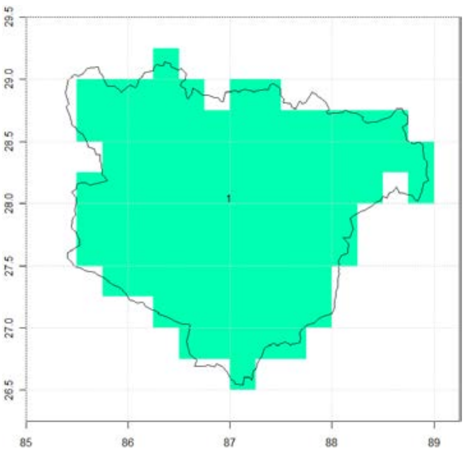


APPENDIX 5: Model Results

Average Precipitaion



Pixel selection



Model output results

Date	Q sim (m³/s)	Q obs (m³/s)	Precipitation (mm)			Temp °C	Soil moisture storage	Surplus storage	Evapotranspiration		Runoff			Snow Accumu lation	Snow Melt	Snow Melt Factor
			Total	Snow	Rain				Actual	Potential	Direct	Surplus	Total			
Jan-01	172	312	0.86	0.64	0.22	0.26	203.31	42.69	12.82	12.82	0.19	7.53	7.72	283.67	66.33	0.19
Feb-01	250	260	4.06	2.17	1.89	3.74	214.12	48.16	17.56	17.56	1.60	8.50	10.10	243.79	42.06	0.21
Mar-01	251	248	6.76	2.78	3.98	6.11	235.12	42.49	30.13	30.13	3.38	7.50	10.88	194.22	52.35	0.30
Apr-01	682	326	29.17	3.78	25.39	9.08	250.83	45.03	45.82	45.82	21.58	7.95	29.52	129.80	68.20	0.42
May-01	1577	830	81.98	9.62	72.36	9.35	232.15	51.47	54.11	54.18	61.51	9.08	70.59	99.32	40.10	0.43
Jun-01	2713	2460	142.71	10.66	132.05	11.37	215.79	51.90	62.12	66.26	112.24	9.16	121.40	74.45	35.53	0.46
Jul-01	4123	3530	219.32	13.86	205.46	11.93	201.06	55.93	56.50	67.30	174.64	9.87	184.51	63.45	24.86	0.47
Aug-01	4496	5790	217.25	15.30	201.96	11.45	191.75	57.04	43.45	53.68	171.66	10.07	181.73	63.72	15.02	0.47
Sep-01	2319	3890	117.27	9.56	107.71	10.22	178.87	50.45	32.92	46.10	91.55	8.90	100.46	67.08	6.20	0.45
Oct-01	1414	2260	73.84	10.74	63.10	8.40	169.51	43.17	20.72	34.48	53.63	7.62	61.25	75.59	2.24	0.40
Nov-01	155	742	0.95	0.41	0.54	5.05	163.01	36.70	6.78	21.62	0.46	6.48	6.93	75.81	0.19	0.25
Dec-01	124	414	0.27	0.21	0.06	1.57	161.54	31.19	1.50	13.46	0.05	5.50	5.56	75.99	0.03	0.19
Jan-02	217	284	8.91	3.01	5.90	0.22	160.54	26.51	1.92	12.79	5.02	4.68	9.69	78.97	0.04	0.19
Feb-02	170	240	7.53	4.10	3.43	4.62	156.79	22.54	4.73	19.99	2.91	3.98	6.89	82.60	0.46	0.24
Mar-02	536	231	28.43	5.11	23.32	7.45	148.57	19.16	14.37	35.00	19.82	3.38	23.20	85.05	2.66	0.36
Apr-02	522	334	30.79	7.60	23.18	6.97	139.41	16.39	14.66	38.86	19.71	2.89	22.60	90.51	2.15	0.34
May-02	1335	722	79.52	12.24	67.28	8.44	130.38	14.53	23.20	50.12	57.19	2.56	59.75	97.96	4.79	0.40
Jun-02	2317	1900	131.15	13.20	117.95	10.60	121.08	19.54	31.73	62.35	100.26	3.45	103.70	97.97	13.20	0.45
Jul-02	5020	5300	279.17	20.13	259.04	10.88	114.28	25.46	48.40	62.60	220.18	4.49	224.68	104.95	13.15	0.46
Aug-02	5173	5620	269.71	29.90	239.81	10.45	114.93	29.97	35.73	49.81	203.84	5.29	209.13	124.64	10.21	0.45
Sep-02	1256	2820	69.51	10.96	58.55	8.64	106.90	26.13	18.31	40.53	49.77	4.61	54.38	133.34	2.26	0.41
Oct-02	395	1300	22.85	7.35	15.50	6.23	102.41	22.28	7.47	27.89	13.18	3.93	17.11	139.95	0.74	0.31
Nov-02	92	670	3.85	2.95	0.90	2.84	102.25	18.94	0.32	15.87	0.77	3.34	4.11	142.87	0.03	0.20
Dec-02	72	421	1.64	1.18	0.45	2.28	102.27	16.10	0.07	14.06	0.38	2.84	3.22	144.04	0.01	0.19
Jan-03	158	306	10.26	4.77	5.49	0.30	102.27	13.68	0.86	12.85	4.66	2.41	7.08	148.78	0.03	0.19

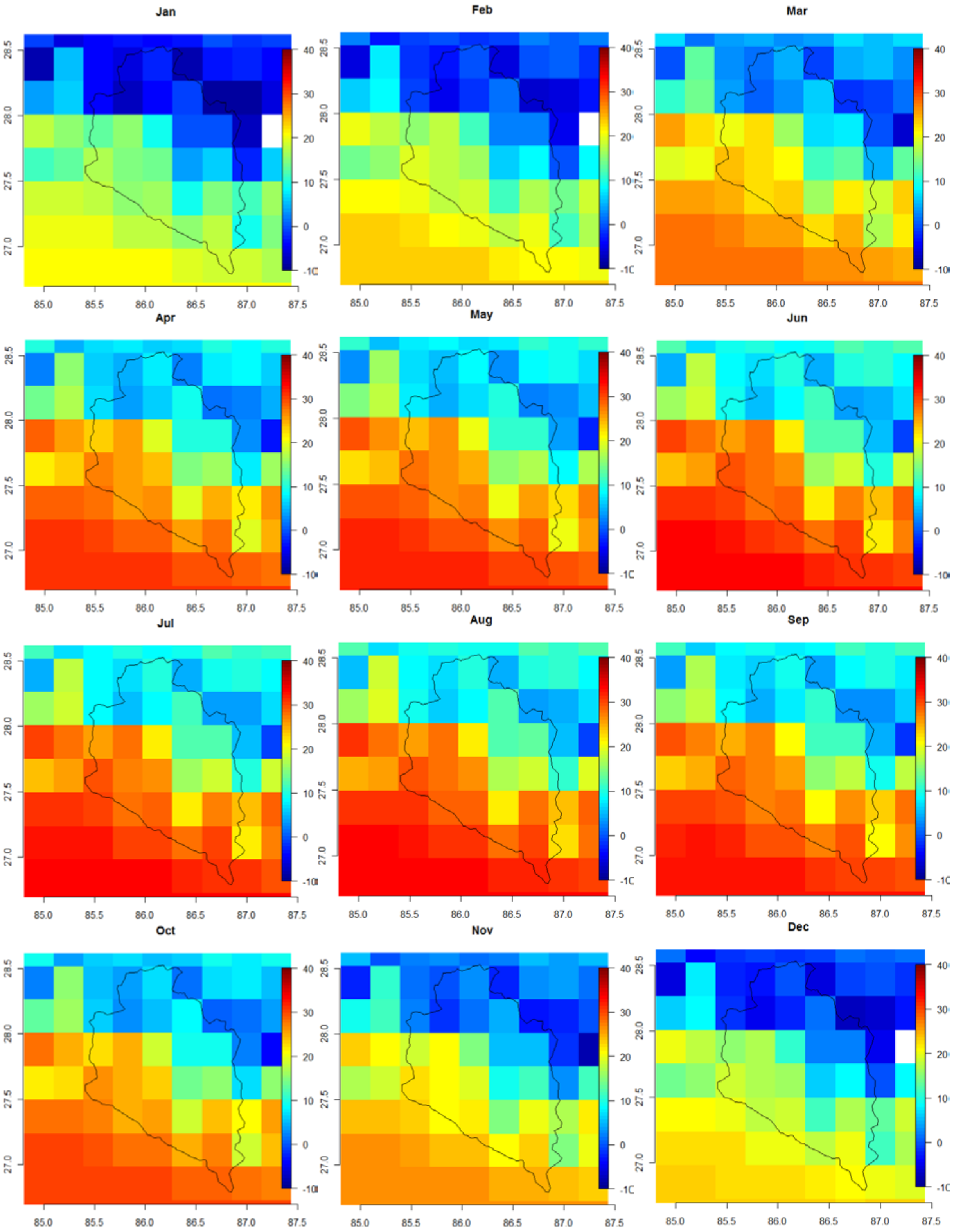
APPENDIX 5: Model Results

Date	Q sim (m³/s)	Q obs (m³/s)	Precipitation (mm)			Temp °C	Soil moisture storage	Surplus storage	Evapotranspiration		Runoff			Snow Accumu lation	Snow Melt	Snow Melt Factor
			Total	Snow	Rain				Actual	Potential	Direct	Surplus	Total			
Feb-03	305	282	23.36	11.28	12.09	1.77	102.28	11.63	1.85	14.26	10.27	2.05	12.32	160.01	0.05	0.19
Mar-03	150	268	8.16	2.56	5.60	5.12	100.98	9.89	4.44	26.47	4.76	1.74	6.51	160.27	2.29	0.26
Apr-03	600	418	30.88	3.11	27.77	10.02	98.89	13.48	16.43	49.55	23.60	2.38	25.98	147.22	16.15	0.44
May-03	549	485	28.78	2.98	25.80	10.12	92.04	14.99	17.76	57.39	21.93	2.64	24.57	139.02	11.19	0.44
Jun-03	2546	2580	136.22	7.38	128.84	11.53	85.29	25.24	31.21	66.89	109.51	4.45	113.96	126.55	19.85	0.47
Jul-03	4494	6180	242.88	13.51	229.37	11.88	81.60	35.03	40.56	67.10	194.97	6.18	201.15	121.62	18.44	0.47
Aug-03	3649	5800	182.29	11.23	171.05	12.04	77.96	41.74	30.71	57.86	145.40	7.37	152.76	117.35	15.49	0.47
Sep-03	1463	5300	70.54	4.31	66.23	11.22	71.82	40.11	18.12	49.69	56.29	7.08	63.37	114.17	7.50	0.46
Oct-03	931	1610	47.98	7.68	40.30	9.02	68.07	34.25	10.80	36.40	34.26	6.04	40.30	120.68	1.17	0.42
Nov-03	125	772	1.09	0.55	0.54	5.10	67.69	29.11	0.49	21.67	0.46	5.14	5.59	121.19	0.04	0.26
Dec-03	203	522	10.67	5.14	5.53	1.31	67.69	24.74	0.84	13.24	4.70	4.37	9.07	126.32	0.01	0.19
Jan-04	167	409	10.32	5.92	4.40	-0.50	67.69	21.03	0.70	12.23	3.74	3.71	7.45	132.20	0.04	0.19
Feb-04	80	344	0.58	0.36	0.21	1.31	67.69	17.88	0.08	14.35	0.18	3.15	3.34	132.52	0.05	0.19
Mar-04	229	346	11.54	3.02	8.52	6.70	65.31	15.20	6.50	32.94	7.24	2.68	9.92	132.71	2.84	0.33
Apr-04	883	437	54.72	12.44	42.28	7.30	63.39	13.04	11.73	39.84	35.94	2.30	38.24	141.55	3.60	0.36
May-04	1164	795	69.34	10.51	58.83	8.94	61.82	11.82	15.58	52.44	50.00	2.09	52.09	146.02	6.04	0.41
Jun-04	1997	1580	111.65	9.26	102.40	10.15	60.34	13.27	21.74	60.67	87.04	2.34	89.38	146.58	8.69	0.44
Jul-04	4714	3800	274.61	29.59	245.02	9.89	62.00	15.31	38.28	57.96	208.26	2.70	210.97	168.23	7.94	0.44
Aug-04	3122	3870	156.03	12.54	143.49	10.93	61.36	23.94	24.33	51.58	121.97	4.22	126.19	165.76	15.01	0.46
Sep-04	1519	2960	80.83	8.04	72.79	9.56	60.40	22.10	13.81	43.64	61.87	3.90	65.77	169.79	4.00	0.43
Oct-04	622	1640	38.48	10.72	27.76	6.64	60.22	18.88	5.34	29.45	23.60	3.33	26.93	179.40	1.11	0.33
Nov-04	169	755	7.36	1.81	5.56	3.04	60.23	16.05	0.88	16.20	4.72	2.83	7.55	181.15	0.06	0.20
Dec-04	55	503	0.28	0.20	0.07	0.48	60.23	13.64	0.01	12.57	0.06	2.41	2.47	181.36	0.00	0.19
Jan-05	236	395	20.41	10.40	10.01	-1.71	60.27	11.59	1.64	11.15	8.51	2.05	10.55	191.59	0.18	0.18
Feb-05	103	339	6.51	3.68	2.83	1.73	60.24	9.85	0.80	14.22	2.41	1.74	4.15	194.91	0.35	0.19
Mar-05	330	350	22.16	7.10	15.06	5.05	60.60	8.38	4.02	25.92	12.80	1.48	14.28	199.90	2.12	0.25
Apr-05	461	379	26.41	4.50	21.90	7.64	60.25	7.63	9.73	40.76	18.62	1.35	19.97	197.70	6.71	0.37

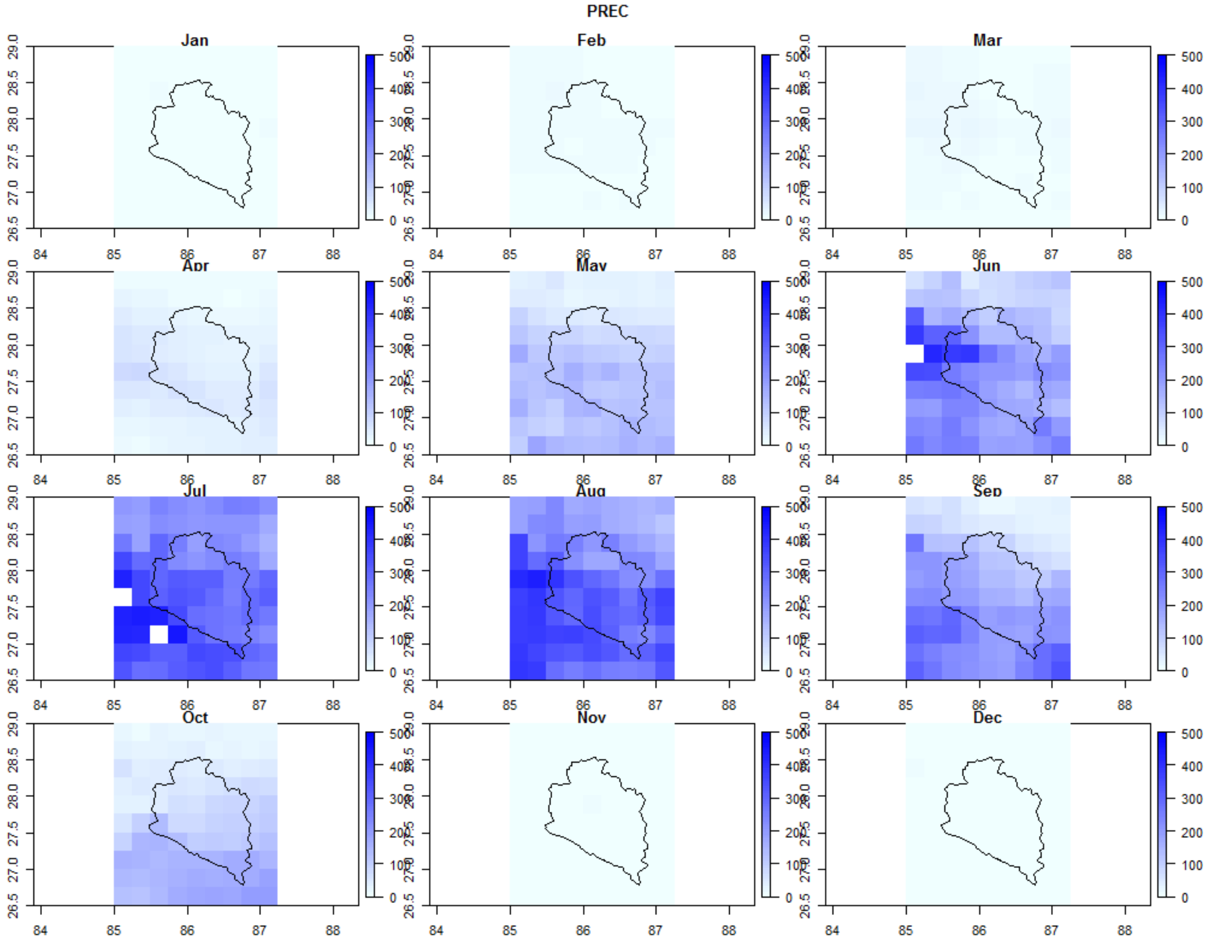
Date	Q sim (m³/s)	Q obs (m³/s)	Precipitation (mm)			Temp °C	Soil moisture storage	Surplus storage	Evapotranspiration		Runoff			Snow Accumu lation	Snow Melt	Snow Melt Factor
			Total	Snow	Rain				Actual	Potential	Direct	Surplus	Total			
May-05	635	569	39.17	7.30	31.87	8.11	59.55	7.56	10.39	48.56	27.09	1.33	28.42	198.82	6.17	0.39
Jun-05	1336	1170	72.84	5.67	67.18	10.64	59.24	15.29	17.40	63.10	57.10	2.70	59.80	187.04	17.45	0.45
Jul-05	2957	3050	170.06	18.14	151.92	10.05	59.16	18.12	26.58	58.96	129.13	3.20	132.33	195.44	9.74	0.44
Aug-05	3939	4060	198.13	15.79	182.34	10.50	59.41	23.99	28.99	49.95	154.99	4.23	159.22	199.25	11.99	0.45
Sep-05	1054	2190	52.67	4.21	48.47	10.32	58.30	25.15	11.01	46.39	41.20	4.44	45.63	195.21	8.24	0.45
Oct-05	705	1270	43.50	12.02	31.48	6.91	58.38	21.44	5.86	30.49	26.76	3.78	30.54	205.95	1.28	0.34
Nov-05	73	681	0.31	0.27	0.04	3.10	58.39	18.22	0.01	16.31	0.04	3.22	3.25	206.21	0.01	0.20
Dec-05	63	459	0.79	0.67	0.12	0.58	58.39	15.49	0.02	12.65	0.10	2.73	2.84	206.89	0.00	0.19
Jan-06	53	347	0.26	0.21	0.05	1.14	58.39	13.17	0.01	13.55	0.04	2.32	2.36	207.09	0.00	0.19
Feb-06	54	310	0.40	0.17	0.23	5.77	58.35	11.19	0.53	23.64	0.19	1.97	2.17	206.80	0.47	0.29
Mar-06	119	291	6.60	2.52	4.08	6.46	58.14	9.53	1.71	31.24	3.46	1.68	5.15	208.40	0.92	0.32
Apr-06	355	349	22.14	5.72	16.42	6.38	57.94	8.14	3.80	35.76	13.95	1.44	15.39	212.94	1.18	0.31
May-06	1009	635	61.89	10.28	51.61	7.85	57.61	7.29	11.30	47.50	43.87	1.29	45.15	219.56	3.67	0.38
Jun-06	1584	2080	94.35	12.51	81.84	8.57	57.33	7.60	16.20	53.33	69.56	1.34	70.90	226.78	5.29	0.40
Jul-06	3108	3350	170.15	11.67	158.48	11.34	57.53	25.02	28.04	64.65	134.70	4.42	139.12	212.15	26.30	0.46
Aug-06	2333	3080	118.93	12.91	106.03	9.60	57.43	23.83	18.91	47.06	90.12	4.21	94.33	219.14	5.92	0.43
Sep-06	2341	2820	132.16	17.25	114.91	8.08	57.68	21.09	18.84	38.48	97.67	3.72	101.40	233.54	2.85	0.39
Oct-06	277	1330	14.35	3.98	10.38	6.21	57.67	18.04	2.13	27.84	8.82	3.18	12.00	236.83	0.69	0.31
Nov-06	102	688	4.85	2.65	2.20	2.42	57.68	15.34	0.33	15.12	1.87	2.71	4.58	239.47	0.01	0.20
Dec-06	82	472	3.37	1.78	1.59	0.28	57.68	13.04	0.26	12.42	1.35	2.30	3.65	241.23	0.02	0.19

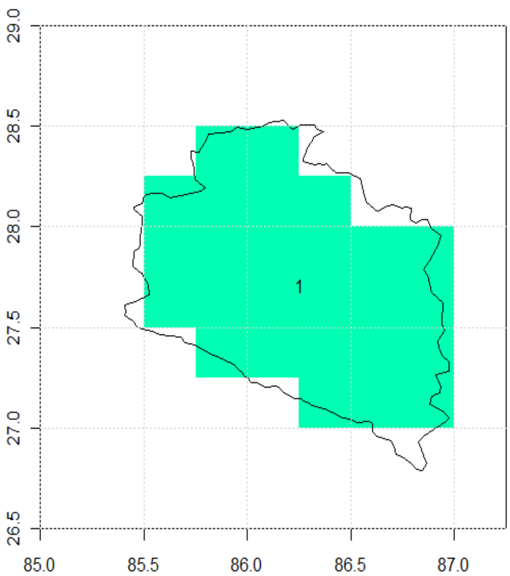
Sunkoshi Sub-basin

Average Temperature



Average Precipitaion





Model output results

Date	Q sim (m³/s)	Q obs (m³/s)	Precipitation (mm)			Temp °C	Soil moisture storage	Surplus storage	Evapotranspiration		Runoff			Snow Accumu lation	Snow Melt	Snow Melt Factor
			Total	Snow	Rain				Actual	Potential	Direct	Surplus	Total			
Jan-01	13	151	1.39	0.83	0.56	6.73	246.59	71.41	24.56	24.56	0.51	1.46	1.97	306.03	143.97	0.32
Feb-01	44	125	5.49	1.40	4.09	10.08	269.79	116.45	32.65	32.65	3.76	2.38	6.14	204.49	102.94	0.39
Mar-01	59	109	7.26	0.69	6.57	14.02	281.40	135.31	54.82	54.82	6.04	2.76	8.80	117.67	87.51	0.47
Apr-01	233	110	34.25	0.00	34.25	17.92	244.43	151.45	79.30	79.30	31.51	3.09	34.60	58.83	58.83	0.50
May-01	642	209	103.61	0.00	103.61	18.02	185.45	156.45	88.50	91.78	95.32	3.19	98.52	29.42	29.42	0.50
Jun-01	1245	694	204.19	0.00	204.19	19.11	143.07	155.28	71.43	103.14	187.85	3.17	191.02	14.71	14.71	0.50
Jul-01	1674	1310	275.98	0.00	275.98	19.96	114.83	152.35	57.49	105.87	253.90	3.11	257.01	7.35	7.35	0.50
Aug-01	1878	2420	279.75	0.00	279.75	18.70	99.30	149.30	41.58	81.26	257.37	3.05	260.42	3.68	3.68	0.50
Sep-01	1024	1380	162.05	0.00	162.05	17.55	87.03	146.31	27.08	71.36	149.09	2.99	152.07	1.84	1.84	0.50
Oct-01	531	636	84.29	1.78	82.52	15.46	77.89	143.39	17.16	54.82	75.92	2.93	78.84	2.20	1.42	0.49
Nov-01	23	277	0.88	0.10	0.78	11.65	72.27	140.52	5.95	37.88	0.72	2.87	3.59	2.03	0.27	0.42
Dec-01	19	184	0.42	0.28	0.13	7.24	71.02	137.71	1.35	24.51	0.12	2.81	2.93	2.22	0.09	0.33
Jan-02	88	141	15.30	3.63	11.67	6.13	71.09	134.96	0.96	22.48	10.74	2.75	13.49	5.76	0.09	0.31
Feb-02	63	122	9.61	3.01	6.60	9.08	68.49	132.26	3.88	30.70	6.07	2.70	8.77	8.02	0.75	0.36
Mar-02	280	111	45.96	3.62	42.34	12.93	63.58	129.61	10.62	49.88	38.96	2.65	41.60	9.31	2.33	0.45
Apr-02	171	124	25.28	0.55	24.73	15.73	55.33	127.02	14.23	69.81	22.75	2.59	25.35	5.86	4.00	0.49
May-02	674	216	109.73	0.00	109.73	17.25	47.37	124.57	19.58	87.78	100.95	2.54	103.50	2.93	2.93	0.50
Jun-02	1115	502	183.25	0.00	183.25	18.29	40.69	122.08	22.81	98.36	168.59	2.49	171.08	1.47	1.47	0.50
Jul-02	2286	2340	378.77	0.00	378.77	18.62	35.54	119.64	36.18	98.03	348.47	2.44	350.91	0.73	0.73	0.50
Aug-02	2322	2980	347.24	0.00	347.24	19.46	32.81	117.24	30.88	84.86	319.46	2.39	321.85	0.37	0.37	0.50
Sep-02	682	1180	107.55	0.00	107.55	18.21	27.46	114.90	14.13	74.15	98.95	2.34	101.29	0.18	0.18	0.50
Oct-02	235	553	35.49	0.08	35.41	16.78	23.67	112.60	6.75	59.25	32.58	2.30	34.87	0.14	0.12	0.50
Nov-02	32	321	3.51	0.62	2.90	12.75	22.27	110.35	1.68	41.13	2.66	2.25	4.92	0.70	0.05	0.44
Dec-02	19	237	1.27	0.44	0.83	9.17	22.27	108.14	0.09	29.45	0.76	2.21	2.97	1.11	0.03	0.36
Jan-03	72	190	15.10	5.37	9.72	6.24	22.37	105.98	0.76	22.64	8.95	2.16	11.11	6.40	0.09	0.31

Date	Q sim (m^3/s)	Q obs (m^3/s)	Precipitation (mm)			Temp °C	Soil moisture storage	Surplus storage	Evapotranspiration		Runoff			Snow Accumu lation	Snow Melt	Snow Melt Factor
			Total	Snow	Rain				Actual	Potential	Direct	Surplus	Total			
Feb-03	180	180	34.70	9.86	24.84	8.76	22.59	103.86	3.00	28.89	22.85	2.12	24.97	15.04	1.23	0.36
Mar-03	79	169	11.31	0.78	10.53	12.47	21.91	101.78	5.39	48.54	9.69	2.08	11.76	11.95	3.87	0.44
Apr-03	261	190	40.14	0.19	39.95	16.59	21.95	99.75	9.02	73.40	36.75	2.04	38.79	6.28	5.86	0.50
May-03	203	202	31.69	0.00	31.69	17.62	19.22	97.75	8.41	89.70	29.16	1.99	31.15	3.14	3.14	0.50
Jun-03	1161	754	191.52	0.00	191.52	19.33	16.70	95.80	19.41	104.46	176.20	1.96	178.15	1.57	1.57	0.50
Jul-03	2003	2230	332.09	0.00	332.09	19.39	14.72	93.88	29.33	102.50	305.52	1.92	307.44	0.79	0.79	0.50
Aug-03	1596	2260	247.04	0.00	247.04	19.36	13.63	92.00	21.24	87.41	227.28	1.88	229.16	0.39	0.39	0.50
Sep-03	630	1900	99.77	0.00	99.77	18.64	12.00	90.16	9.81	76.01	91.79	1.84	93.63	0.20	0.20	0.50
Oct-03	262	673	40.64	0.37	40.27	16.50	10.79	88.36	4.69	58.27	37.05	1.80	38.85	0.31	0.26	0.50
Nov-03	17	305	1.09	0.25	0.83	12.18	10.79	86.59	0.09	39.12	0.77	1.77	2.53	0.54	0.02	0.43
Dec-03	71	223	13.21	3.29	9.93	8.66	10.88	84.86	0.97	27.38	9.13	1.73	10.87	3.57	0.26	0.35
Jan-04	60	181	13.49	5.24	8.25	6.35	11.00	83.16	0.64	22.79	7.59	1.70	9.29	8.70	0.11	0.31
Feb-04	14	153	0.61	0.19	0.42	9.49	10.84	81.50	1.26	32.61	0.38	1.66	2.05	7.83	1.06	0.37
Mar-04	132	147	20.25	0.67	19.59	14.98	10.08	79.87	5.77	58.29	18.02	1.63	19.65	5.06	3.44	0.48
Apr-04	478	146	75.48	0.10	75.38	16.94	9.48	78.27	9.18	75.25	69.35	1.60	70.94	2.61	2.55	0.50
May-04	689	219	113.30	0.00	113.30	17.81	8.10	76.71	11.74	90.94	104.24	1.57	105.80	1.30	1.30	0.50
Jun-04	1117	530	184.66	0.00	184.66	19.14	6.26	75.17	17.27	103.38	169.88	1.53	171.42	0.65	0.65	0.50
Jul-04	2324	2070	386.05	0.00	386.05	18.27	5.14	73.67	32.33	95.90	355.16	1.50	356.67	0.33	0.33	0.50
Aug-04	1545	1970	231.26	0.00	231.26	19.24	3.89	72.20	19.91	83.50	212.76	1.47	214.23	0.16	0.16	0.50
Sep-04	850	1280	135.66	0.00	135.66	18.30	2.46	70.75	12.36	74.20	124.81	1.44	126.25	0.08	0.08	0.50
Oct-04	351	673	57.19	2.11	55.08	15.05	1.72	69.34	5.83	53.25	50.67	1.42	52.08	1.51	0.69	0.48
Nov-04	99	314	17.12	2.12	15.01	11.18	1.72	67.95	1.33	36.70	13.81	1.39	15.19	3.50	0.13	0.41
Dec-04	10	221	0.48	0.23	0.25	9.21	1.73	66.59	0.04	29.52	0.23	1.36	1.59	3.71	0.02	0.37
Jan-05	165	172	39.00	12.90	26.10	6.45	1.87	65.26	2.19	23.54	24.01	1.33	25.34	16.36	0.25	0.32
Feb-05	48	147	8.48	2.59	5.89	9.24	1.75	63.95	2.30	31.01	5.42	1.31	6.72	17.24	1.70	0.37
Mar-05	220	141	35.85	1.79	34.05	13.69	2.60	62.67	7.82	52.97	31.33	1.28	32.61	13.10	5.94	0.46
Apr-05	213	128	33.26	0.24	33.02	16.31	3.25	61.42	8.18	72.20	30.38	1.25	31.63	7.15	6.19	0.49

Date	Q sim (m³/s)	Q obs (m³/s)	Precipitation (mm)			Temp °C	Soil moisture storage	Surplus storage	Evapotranspiration		Runoff			Snow Accumu lation	Snow Melt	Snow Melt Factor
			Total	Snow	Rain				Actual	Potential	Direct	Surplus	Total			
May-05	300	246	48.92	0.22	48.70	16.59	3.08	60.19	7.60	84.47	44.80	1.23	46.03	3.83	3.54	0.50
Jun-05	747	534	123.24	0.00	123.24	18.93	1.88	58.99	12.98	102.10	113.38	1.20	114.59	1.91	1.91	0.50
Jul-05	1428	1710	236.91	0.00	236.91	18.31	0.79	57.81	21.00	96.32	217.96	1.18	219.14	0.96	0.96	0.50
Aug-05	1982	2580	297.48	0.00	297.48	19.25	0.22	56.65	24.85	83.83	273.68	1.16	274.83	0.48	0.48	0.50
Sep-05	448	1250	71.18	0.00	71.18	18.31	0.02	55.52	6.13	74.61	65.48	1.13	66.62	0.24	0.24	0.50
Oct-05	515	697	84.53	2.60	81.93	15.26	0.08	54.41	7.48	54.17	75.38	1.11	76.49	1.85	0.99	0.48
Nov-05	8	398	0.28	0.11	0.17	11.15	0.08	53.32	0.03	36.76	0.16	1.09	1.25	1.95	0.02	0.41
Dec-05	9	291	0.82	0.51	0.31	9.44	0.08	52.26	0.04	29.95	0.28	1.07	1.35	2.44	0.02	0.37
Jan-06	7	219	0.60	0.50	0.10	6.36	0.10	51.21	0.01	22.81	0.10	1.05	1.14	2.92	0.01	0.32
Feb-06	9	190	0.53	0.26	0.27	9.24	0.09	50.19	0.10	31.01	0.24	1.02	1.27	3.11	0.07	0.37
Mar-06	78	184	12.84	1.33	11.51	13.69	0.15	49.18	1.79	52.97	10.59	1.00	11.60	3.50	0.93	0.46
Apr-06	205	209	32.28	0.22	32.06	16.31	0.01	48.20	4.38	72.20	29.50	0.98	30.48	2.05	1.67	0.49
May-06	478	356	79.11	0.33	78.78	16.59	0.00	47.23	7.43	84.47	72.47	0.96	73.44	1.26	1.12	0.50
Jun-06	892	973	147.78	0.00	147.78	18.93	0.00	46.29	12.45	102.10	135.96	0.94	136.91	0.63	0.63	0.50
Jul-06	1607	1940	267.10	0.00	267.10	18.31	0.00	45.36	21.68	96.32	245.73	0.93	246.66	0.32	0.32	0.50
Aug-06	1100	1770	164.84	0.00	164.84	19.25	0.00	44.46	13.34	83.83	151.65	0.91	152.56	0.16	0.16	0.50
Sep-06	1347	1440	216.52	0.00	216.52	18.31	0.00	43.57	17.40	74.61	199.19	0.89	200.08	0.08	0.08	0.50
Oct-06	126	673	20.23	0.75	19.47	15.26	0.00	42.70	1.83	54.17	17.92	0.87	18.79	0.56	0.27	0.48
Nov-06	26	383	3.76	0.42	3.35	12.92	0.04	41.84	0.32	41.55	3.08	0.85	3.93	0.89	0.09	0.45
Dec-06	23	260	5.94	2.94	3.00	8.85	0.04	41.01	0.42	28.29	2.76	0.84	3.60	3.65	0.18	0.36