ESTIMATION OF EVAPOTRANSPIRATION USING TEMPERATURE AND RADIATION BASED TECHNIQUES OVER BEAS BASIN AND ITS IMPACT ON SNOWMELT RUNOFF

A DISSERTATION

Submitted in partial fulfillment of the

requirements for the award of the degree

of

INTEGRATED MASTER OF TECHNOLOGY

In

GEOPHYSICAL TECHNOLOGY

By

SHUBHAM NAYAK

DEPARTMENT OF EARTH SCIENCES

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

ROORKEE–247667 (INDIA)

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CANDIDATE'S DECLARATION

I hereby declare that the work which is has been presented in this dissertation entitled, "Estimation of Evapotranspiration using temperature and radiation based techniques over Beas basin and its Impact on Snowmelt runoff Basin " in partial fulfillment of the requirements for the award of the degree of **INTEGRATED MASTER OF TECHNOLOGY in GEOPHYSICAL TECHNOLOGY**, submitted in the Department of Earth Sciences, Indian Institute of technology, Roorkee, is an authentic record of my own work carried out under the guidance of Prof. Ajanta Goswami, Department of Earth Sciences, IIT Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree or diploma of this institute or any other university/institute.

Date: 16th May, 2019
Place: Roorkee

(SHUBHAM NAYAK)
Integrated M.Tech, Final Year
Geophysical Technology
Department of Earth Sciences
I.I.T Roorkee
Roorkee-247667, India

CERTIFICATE

This is to certify the work presented in this thesis entitled "**Estimation Of Evapotranspiration Using Temperature And Radiation Based Techniques Over Beas Basin And Its Impact On Snowmelt Runoff**" submitted by Mr. Shubham Nayak to Indian Institute of Technology, Roorkee, India, in partial fulfillment of the requirements for the award of the degree of **INTEGRATED MASTER OF TECHNOLOGY** in **GEOPHYSICAL TECHNOLOGY** is a record of bona fide original work carried out by his under our supervision during the academic year 2018 - 19.

Dr. Ajanta Goswami
Assistant Professor, Department of Earth Sciences
Indian Institute of Technology Roorkee,
Roorkee-247667, India

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CONTENTS

ABSTRACT

In this regularly changing habitat, the availability and distribution of water will differ everywhere in the world. Water availability, both as surface water and groundwater, is vital for agriculture, human consumption, industry, and energy generation. In order to keep the track of water is it mandatory and necessary to know the scow cover area and water discharge and it will be a key factor in future projects. As a research student it is our duty to make sure that our future generation will be in no danger so we need to make sure that the rate of water through discharge is sufficient so that it could provide help to the everywhere living in India. This could only be possible if proper management is done. So looking at the water budget equation to most important terms are discharge and evapotranspiration and this thesis work will show the trend of both by using different methods. In order to manage the water resources, an assessment of the quantity and quality of available water is important. For the assessment studies, water balance approach is needed. To solve the water budget equation with minimum error, all the components must be perfectly estimated. Water balance components such as Runsoff, Evapotranspiration, Soil generating the liquid moisture, Base flow can be computed from respective methods.

Since evapotranspiration (ET) is one of the important element in water balance equation, we will be majorly focusing on ET as it is our prime interest.

There are several methods of calculating the evapotranspiration but the one which will be focused in this thesis are Thornwaite, Hargreaves, Hamon, Priestley and Penman methods. Thornwaite and Hamon are Temperature based techniques whereas Hargreaves and Priestley are radiation-based techniques which require radiation data (i.e. solar radiation).

The impact of snowmelt runoff on basin hydrology is perceived by SRM technique. The work done will show some trend of water balance terms in different months and where it is maximum and minimum. The month in which will be maximum will be the month where we as a team need to keep the projects aside so that there is no harm and no loss of cost.

During the course of study we have use Modeling of Snowmelt Runoff in the region of Beas basin by using data of MODIS and SRTM digital elevation model (DEM) finally into the desktop software of snowmelt runoff model WinSRM.

The results shown will be in the form of evapotranspiration during a particular time period. And our objective will be to relate evapotranspiration with the impact on Snowmelt runoff.

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INTRODUCTION

Water is one of the most important natural assets and a major element in the socioeconomic development of north Indian hilly states like Himachal Pradesh, Uttarakhand, etc. Due to increased demands and limitation of available quantity of water the whole world including India is in stress. If some orthodox method isn't applied for the conservation/utilization of water, a serious problem could arise. That's why a proper study, planning and management need to be done in order to keep our future generation stress free. "Sustainable water management of a river basin is quite essential to maintain stability and flexibility in water supply to meet the crop water and growing municipal and industrial water demands".

Himalaya has also termed as the "third pole" because the North Pole and the South Pole are both covered by snow and our Himalaya Mountain is the mountain chain covered by snow and glaciers. Most of the peaks in Himalayas are above eight thousand and it contains world's top mountains, Mt. Everest being one of the peaks. If there will be any climatic changes in these mountains it will directly affect the people living near these mountains.

Himalayan snow cover has an enormous amount of water embedded in the form of snowpack/glacier and this is also a everlasting source of major river systems like the Indus, Ganga and Brahmaputra, all originating from the high glaciers of the Himalayan region. "These rivers receive substantial amounts of snow/glacier melt water and are considered as the lifeline of the Indian subcontinent. Snowmelt during summer forms an important component of stream runoff" (Kulkarni et al. 2010). The rivers receiving water from the glaciers are lifelines to many people in the North India but still research need to be done in these rivers to know the future aspects quantitatively. Snow/ glaciers will affect the quantity of water in all the rivers in the north India so a detailed study of Snow Cover area with respective time/ season need to be assess.

However, some such studies have been made for a few river basins in the western Himalayan region on an annual basis. Singh et al. (1997) estimated the average annual contribution of snow/ glaciers to be about 28% at Devprayag (830 m above mean sea level (amsl)) and 49% at Akhnoor (301 m amsl) in the Ganga and Chenab Rivers. Similarly, Singh & Jain (2002) estimated 60% snowmelt contribution at the Bhakra Dam site (for the Satluj River basin). Shashi Kumar et al. (1993) applied snowmelt runoff model for some parts of the study area, viz. the Beas Basin up to Thalot and the Parwati River up to the Phulga dam site. The snowmelt model (SNOWMOD) has been applied to Himalayan basins such as Satluj, Beas and Chenab (Jain et al. (1997); Jain & Singh 2003; Singh & Bengtsson, 2004; Arora et al. 2008; Jain et al. 2010). In addition, Ahluwalia et al. (2013) estimated 50% snow/glacier melt contribution in the Beas River at Manali. However, snow/glacier melt contribution for a small scale catchment and its seasonal variation are still not well studied. The present study is an attempt to estimate the contribution of snow/glacier melt, rainfall and groundwater subsurface flow, using a conventional approach and the Snowmelt Runoff model for the Beas River basin at Manali (1,980 m amsl). This region represents the head watershed of the Beas River basin.

Study from last 50 years in Evapotranspiration has proposed some methods to calculate it but new techniques need to work by researchers so that ET can be calculated easily. Methods for estimating crop Evapotranspiration can be used in Water management and crop yields which ultimately is the need of the hour.

SNOW AND GLACIER MELT RUNOFF

A major source of runoff and groundwater recharge in Himachal's middle and higher elevation areas are contributed through snowmelt from seasonal snow covered areas of the Earth's mountain region. Freshwater is the basic need of humans and the Himalayan mountain system is the source of one of the world's largest suppliers for water. All the major south Asian rivers (eg. Ganga, Bhramaputra, etc) originate in the Himalayas and their upper catchments are covered with snow and glaciers at higher elevations. The people living in the Indian subcontinent are totally dependent on the river water system such as Ganga, Bhramaputra and Indus that is being received by the glaciers of Himalaya. The water received by North-eastern India comes from Bhramaputra. There is a study done which shows that water from Himalayas is approx. twice that of water receiving in south - Peninsular India, the reason being snow and glaciers available in North India and the major source for water in South is collection of rains in river in monsoon which is collected and stored by dam. So we need to daily asses the snow area in the Himalayas which will give us the idea and trend so that we can start any Hydrological projects like building dam etc.

Today's demand is proper infrastructure everywhere infact in the areas closer to river dams so we need to find a method that can tell us whether the time we are building the dam or any electric generating machines near the dam or on the dam will be effective or not. So keeping in mind all these facts it will be easier for the engineers and company to start building the projects like dam on a suitable time period. If rainfall is maximum in the time month of July – August so it will not be a good idea to construct the necessary infrastructure on that month because building in that month will be a huge risk as the machines are electric powerful which will create damage to the machines. So we need to forecast the flood by looking at the trend of previous years and work accordingly. Again we need to assess when is the time where maximum discharge is happening so that rivers are on the highest speed and it is impossible for the construction to go on. And where the slope is high he flow of river water will be high and it's impossible to construct dam and work on that river in that period of time.

The Himalayan water system is highly dependent on snow storage and hence susceptible to suffer from the effects of global warming. This region having a large fraction of runoff driven by snowmelt would be especially susceptible to changes in temperature, because temperature determines the fraction of precipitation that falls as snow and is the most important factor determining the timing of snowmelt. Increased snow melt could cause extreme floods in the beginning followed by reduced flow during dry season.

The work of WRA is to measure, collect and analyze parameters for development and a better management of water resources on the quantity and quality of water resources, the task of collecting data is a challenging and it requires some sort of skills.

Basins of all major Himalayan rivers (eg. Ganga) have combination of both glaciated and non-glacial watersheds. There are some features for glacial watersheds such as they have high energy, they are generally located on higher elevation and steep slope. This region has the maximum presence of ice and snow and here you could find less biotic activities. For the non-glacial watersheds biotic activities are intense also the soil quality are pretty good over here and it is found at lower elevation and gentle slope.

Also it is generally seen that on the basis of elevation basins are divided into **Rainfed** basin which is generally considered area which is below 2000 meters where only rain is seen. The second one is **Snowfed** Basin which comes in the range between 2000 and 4000 meters where both snow and rain is seen and the last one is **Glacierfed** basin which is above 4000 meters where only Snow is seen.

THE STUDY AREA

The upstream of the Beas River basin in the western Himalayas of Himachal Pradesh was selected for snowmelt runoff modeling (Figure 1). Beas Kund (3,505 m amsl) and the Rohtang pass (3,977m amsl) are the major contributors of the water in the Beas River. The water originating from both places meets at Palchan, which is situated 10 km north of Manali (Figure 1). Beas River is one of the major tributaries of the Indus River system. The Beas Basin covers an area of 362 km2 up to Manali town, with an elevation range of 1,913–5,821 m. The upper reaches of the Beas River basin fall within Kullu district, with an estimated population of 437,903 (Census 2011). The study area experiences a severe winter (December– March) characterized by the occurrence of severe snowfall at higher altitudes. The winter season is followed by the pre-monsoon season (April–June), having an average maximum temperature of 14.1 °C to a minimum 0.22 °C, with average rainfall during this period of 106.12mm. In the summer season, temperature varies from a maximum 24.6 °C to a minimum 8.9 °C, and rainfall during this season averages 86.83mm in Manali. The majority of the precipitation, over 70% of the annual rainfall, is concentrated in the monsoon months (June– September) (Das 2013). The upper reaches of the basin are snow covered and glaciated, which contributes melt water to the streamflow. The post-monsoon season during October– November is generally the driest, with scanty amounts of rainfall.

So our study area lies in the Indus Region, in the state of Himachal Pradesh. Our area of interest is the Beas Basin where the data of temperature, rainfall and snow cover are provided by these stations namely Pandoh, Manali, Largi and Bhantar. So during our modeling we have divided the Beas into 9 zones based upon different elevation. Our stations lies in this zones.

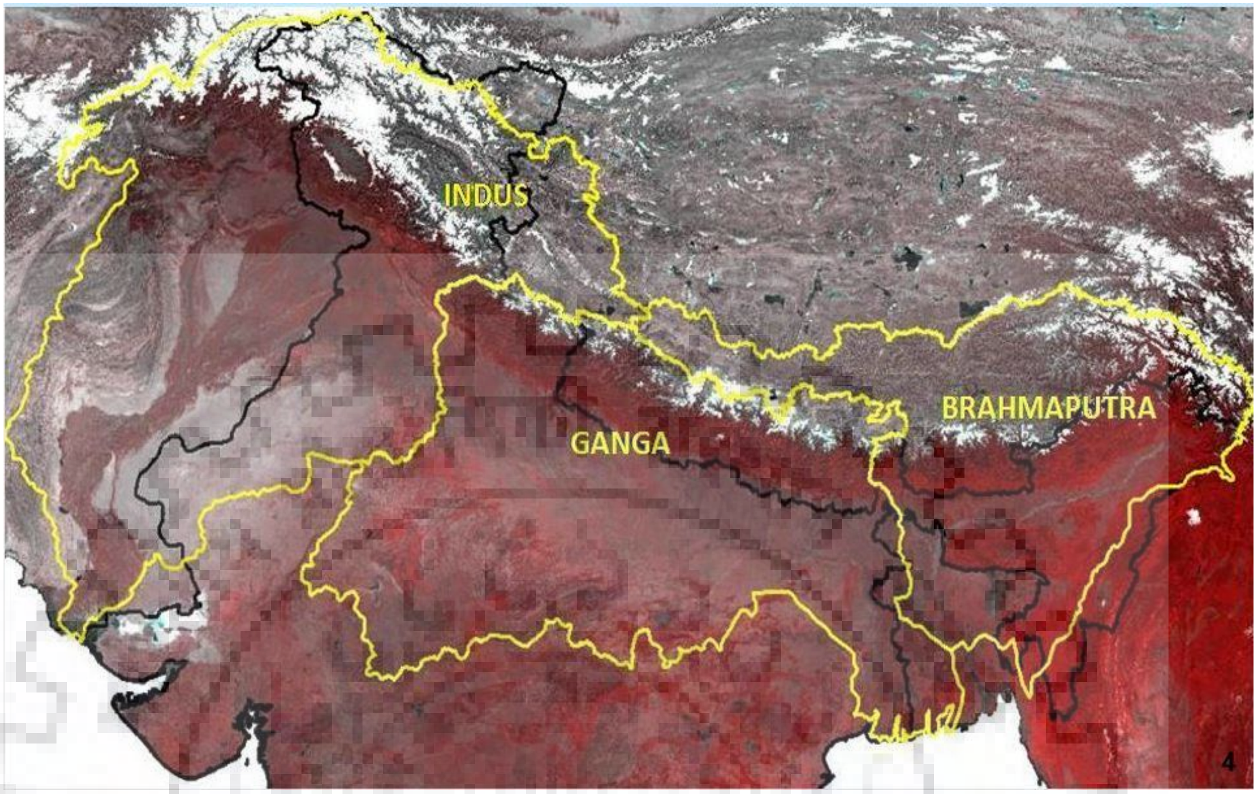

Figure 1 The Map of Indian Region divided into Indus, Ganga and Brahmaputra

The Beas River is the second easternmost of the rivers of the Punjab. The river begins at the Rohtang Pass in Himachal Pradesh in Kullu district at an elevation of 4361m. The computation of balance water availability is essential for Beas River for proper water management. It is well known that water resources structures need appropriate planning to fulfill the goals of water management. To minimize the gap between the demand and supply we should establish a sustainable water management of the river basin to ensure a long-term stable and flexible water supply to meet the crop water, municipal and industrial water demand.

The total area of Beas Basin is 5728 km^2 and the range of elevation up to which it can vary is 600 to 5400 meters but our stations lies in the altitude of 900-1500 meters.

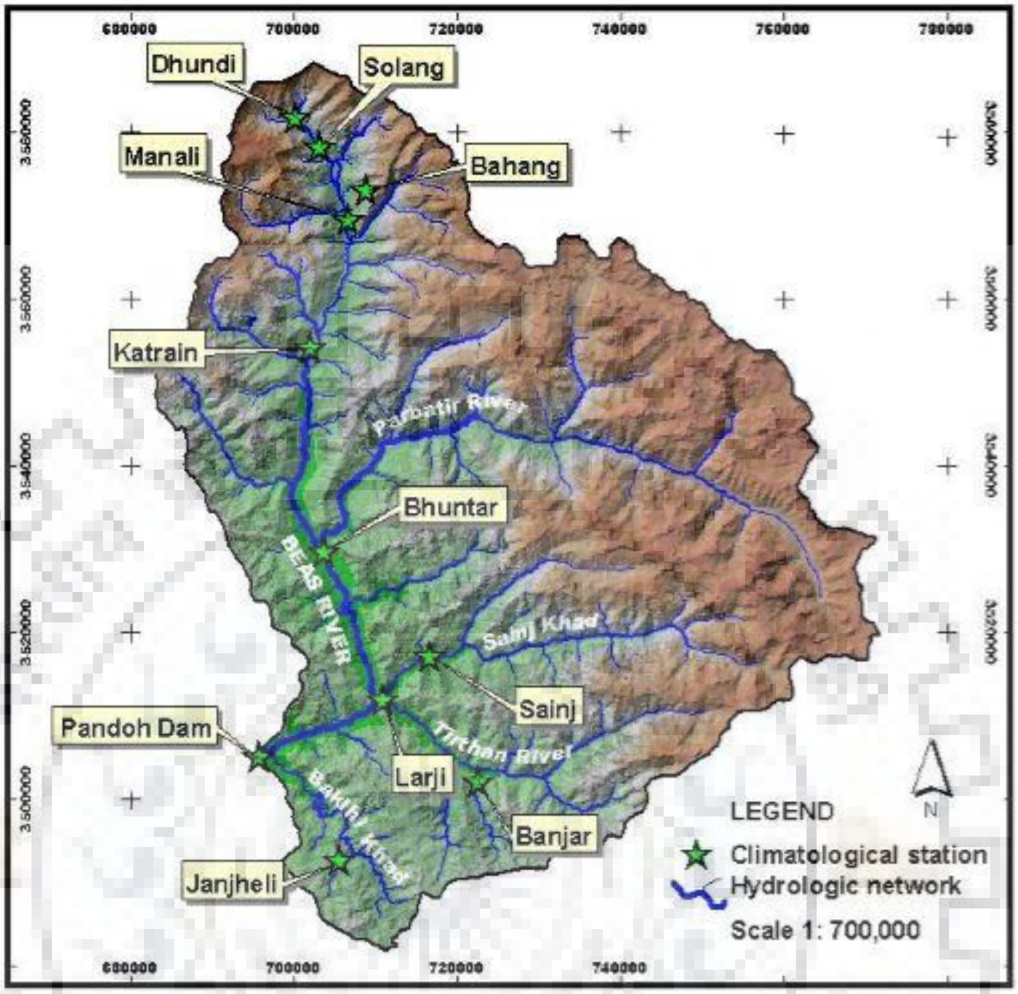

Figure 2 Different Stations of Beas Basin

Following is the list of total area and there maximum and minimum snow cover area.

Basin	Site	Total Area(km^2)	Maximum SCA (km^2)	Minimum SCA (km^2)
Chenab Basin	Akhnoor	22,200	15,590(70%)	5,400(24%)
Satluj Basin	Bhakra Dam	22,275	14,498(65%)	4,528(20%)
Beas Basin	Pandoh Dam	5,278	2,700(21%)	780(14%)
Ganga Basin	Devprayag	19,700	7,080(46%)	3,800(19%)

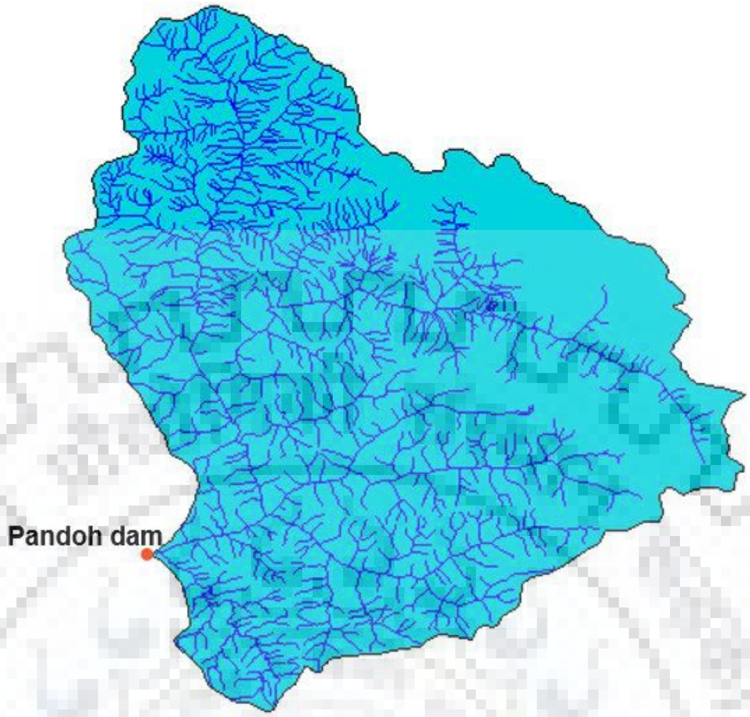

Figure 3 Drainage pattern of the Beas Basin.

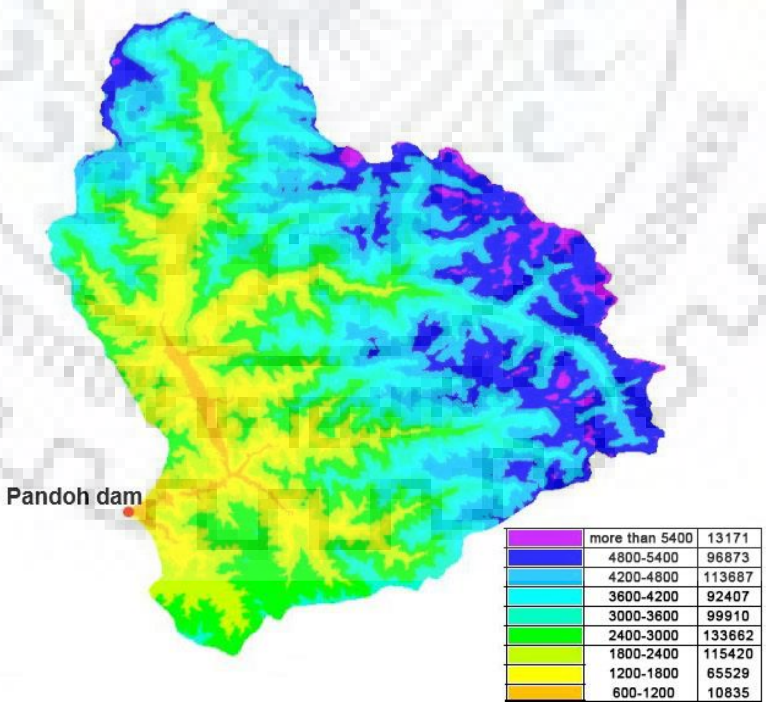

Figure 4 Beas Basin divided into different zones depending upon elevation.

Zones	Elevation range (m)	Area (km^2)	Percentage	Raingauge Station	Temperature Station
1	600-1200	77.34	1.46	Pandoh	Pandoh
2	1200-1800	467.56	8.84	Largi	Bhunter
3	1800-2400	823.90	15.57	Manali	Largi
4	2400-3000	954.12	18.03	Manali	Manali
5	3000-3600	713.2	13.47	Manali	Manali
6	3600-4200	659.63	12.46	Sainj	Manali
7	4200-4800	811.53	15.33	Sainj	Manali
8	4800-5400	691.51	13.06	Sainj	Manali
9	>5400	94.10	1.78	Sainj	Manali

Table Zones with their detailed parameter and station.

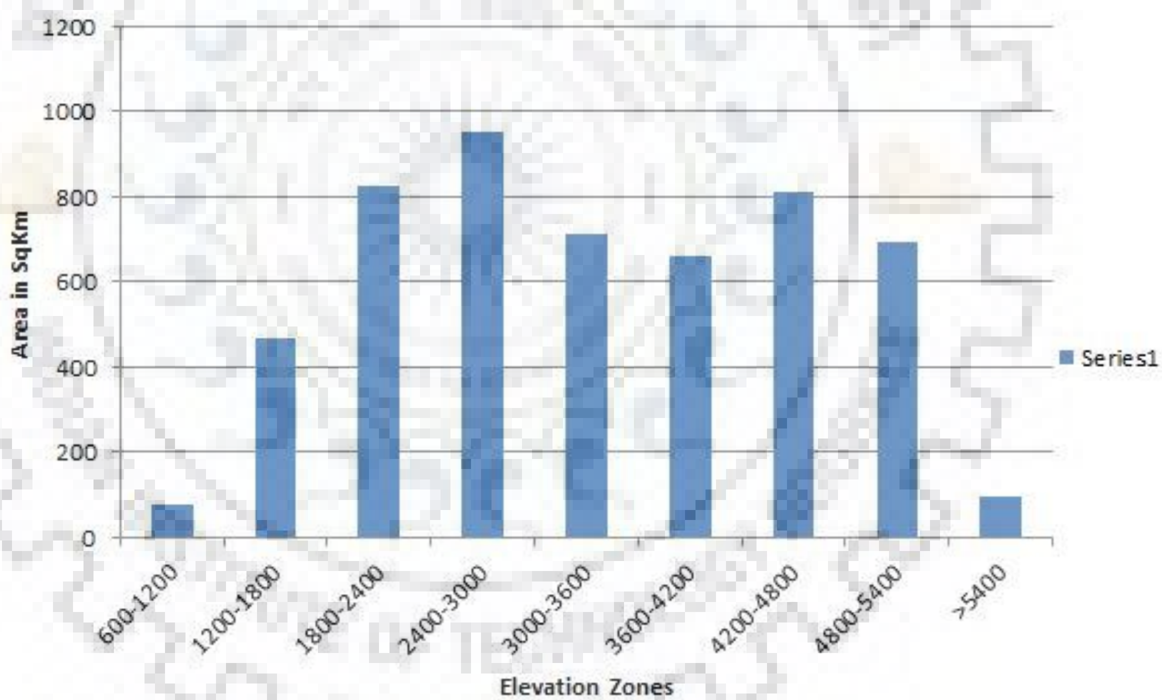

Figure 5 Area elevation curve of Beas Basin

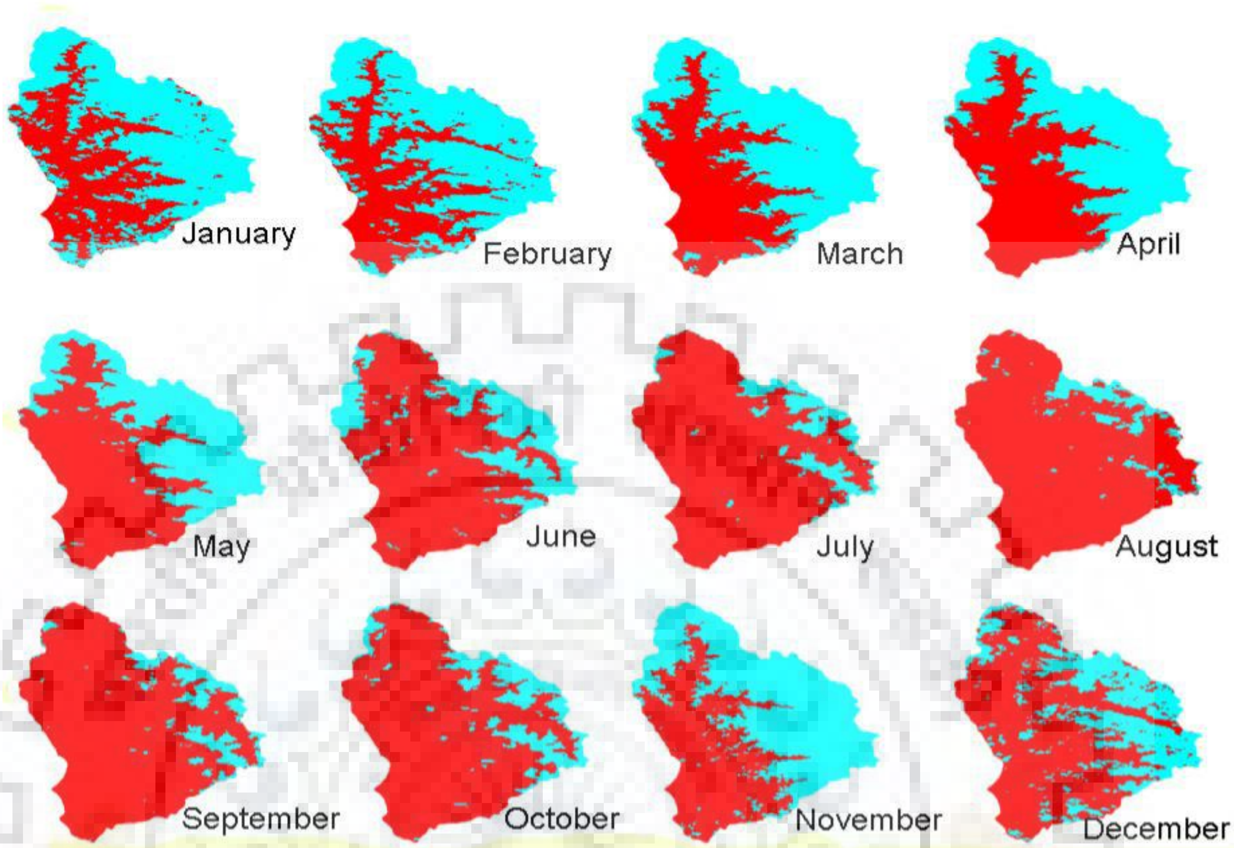

Figure 6 Snow Cover Area trend

Evapotranspiration

Evapotranspiration is closely related to the evaporation from the plants and its interaction with the atmosphere. It is basically the losses of water due to evaporation loss and plant transpiration, as we all know evaporation is basically escape of the water particles in the air. Water that is used in photosynthesis and plant growth is basically the plant transpiration and it also goes in the air due to heat as losses. There are two kind of evapotranspiration, the potential evapotranspiration is basically the ability of atmosphere to remove water or we can define it as maximum water that can be taken away by the atmosphere when a crop is completely yield with water. Secondly, actual evapotranspiration is the quantity which is actually removed. So actual evapotranspiration is always less than the potential evapotranspiration and in our beas region it is basically computed by multiplying Potential ET by 0.4. It all depends on wind direction and intensity, it can also be effected by sunshine temperature and humidity. Lysimeter is generally used in direct estimation of ET.

Since Evaporation and transpiration both processes depend on solar radiation, air temperature, relative humidity and wind speed therefore they occur simultaneously. Crop characteristics, environmental aspects, and cultivation practices are the factors that influenced the Transpiration rate. Obviously different plants have different transpiration rate in different environmental conditions, crop development process and management steps.

We have basically used few methods to calculate the evapotranspiration, few of them are Thornwaite one is penman which are most popular and they are being used by many both of them have different formula. One can be computed by temperature based data and the second one is radiation based technique. They give the monthly ET and which we can convert into annual by using specific method. For penman we need to use wind data and humidity data in order to compute Evapotranspiration and that is all we want.

The Water Budget equation can be written as:

Precipitation = Runoff + Baseflow + Evapotranspiration + Soil Moisture ± ΔTW + (other components)

Where,

ΔTWS = Change in Terrestrial Water Storage and other components include interception, shallow and deep groundwater storage, snow and glaciers, etc.

So the terms in the Water Budget equation are precipitation which is the total water that is coming from different sources

Thronwaite Method

Thornwaite method is a temperature based technique to delineate the evapotranspiration, it uses temperature data from 2001-2005. Monthly Heat index is calculated from the monthly mean temperature, mean temperature can be calculated be averaging the minimum and maximum value of the temperature.

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

After calculating the Monthly Heat Index then using the formula we can compute the Annual Heat Index which is basically the sum of temperature of all twelve months starting from January to December.

$$I = \sum_{i=1}^{12} i$$

Before calculating the actual evapotranspiration we need to calculate the potential evapotranspiration using the formula where alpha depends on the Annual Heat Index.

$$PET_{non\ corrected} = 16 \cdot \left(\frac{10 \cdot t}{I}\right)^{\alpha}$$

$$\alpha = 675 \cdot 10^{-9} \cdot I^3 - 771 \cdot 10^{-7} \cdot I^2 + 1792 \cdot 10^{-5} \cdot I + 0.49239$$

Now the corrected evapotranspiration can be calculated which will depend the length of the day and sunshine hours.

$$PET = PET_{non\ corrected} \cdot \frac{N}{12} \cdot \frac{d}{30}$$

Result obtained from this method will be correlated with the different temperature based technique and radiation based technique.

Haman Method

Haman method will also be using daily sunshine duration and daily mean temperature from 2001-2005. The unique parameter used in this technique is Hargreaves Method

The following methods are used to delineate the Potential Evapotranspiration

Comparison of all three methods is done by comparing the trend and which show maximum similarity to the observed data that will be the best method for that particular basin which thus will be important to analyze the source data in future.

Hargreaves Method

Hargreaves equation is basically used in calculating Evapotranspiration or we can analyze the result in future of ET with this method, so this method can lead to improvement in irrigation field which were done by other methods previously.

$$ET_o = 0.0023 \; R_a \; (TC + 17.8) \; TR^{0.50}$$

TR is basically the difference between maximum and minimum value of daily average temperature, which can be easily done in excel when we have lots of data (2001-2005), Ra is extraterrestrial radiation which can be computed with the help of sunshine hour duration, which we have generated the code (appendix). Tc used in the equation is normal temperature in degree Celsius.

Sunshine Duration

Sunshine duration is basically the duration where sun is brightening with certain energy, the energy which it should radiate should be more than One hundred and twenty Watt per meter square. The sunshine duration will basically help in delineate the evapotranspiration as it is used in different techniques such as Thornwaite and Haman as the ET is mostly effective in daytime. In winters the sunshine duration is generally less and in summers as practically the time for which we can see the sun is more so sunshine duration is more. So according to the trend we have noticed in May-June-July the sunshine duration is maximum. So we have generated Sunshine duration for every day and one thing to keep in mind is basically the leap year where it has 366 days so need to change in the formula.

Fig.4 Instrument for measuring the brightness “Pyranometer”.

The algorithm of Glover & Mc.Gulloch is used in estimating the Sunshine duration which will be further used in different methods and techniques for delineating the evapotranspiration.

From the temperature data we have minimum and maximum value of temperature ranging from 1985 to 2005 from that we need to find out the mean value and difference of temperature because these will be directly used in the formula with the corresponding date. So for Haman and Hargreaves, ET comes out for every day which is then converted to monthly basis and can be found out for yearly basis.

From all the methods and techniques such as thornwaite and Hargreaves, potential evapotranspiration is calculated but we want the actual evapotanspiration which can be found by multiplying the potential ET by a multiplying factor of 0.4 (for the Beas Basin).

In the formulas Leap year is also taken into consideration, the places where 365 days are used for the normal year, need to change with 366 for the leap year.

Following is the code written for delineating the Sunshine duration in Java using netbeans.

Penman-Monteith Method

The Penman-Monteith Equation is considered as the exclusive method for deriving reference Evapotranspiration (ET_O) from meteorological data. Over the last five decades, large number of methods was developed by scientists to estimate ET with the help of different climatic variables. Accuracy was then calibrated for different methods but were time consuming and costly. The radiation methods such as Penman and Priestley show good results in humid, but performance in arid conditions are erratic and tends to underestimate evapotranspiration.

Priestley – Taylor Method

Priestley – Taylor method is a radiation based techniques to assess the evapotranspiration, this equation further has been widely used in Hydrologic modeling and ecological applications. For

$$\mathrm{ET}_{o\mathrm{PT}} = \alpha \frac{\Delta}{\Delta + \gamma} \frac{R_n}{\lambda}$$

For all the methods, the code was written in Java (netbeans) because it was easier to read the daily data from 2001-2005, and the work was easier rather to put the formula in excel. I think that was time consuming.

ESTIMATION OF SNOWMELT

SRM – Snowmelt Runoff Model

The snowmelt runoff model (SRM) has been widely used in calculating the water discharge and forecast of stream flow in snow-dominated mountainous basins around the world. A watersheds describes an area of region that contains a set of stream and river that all collect into a single larger bodies of river.

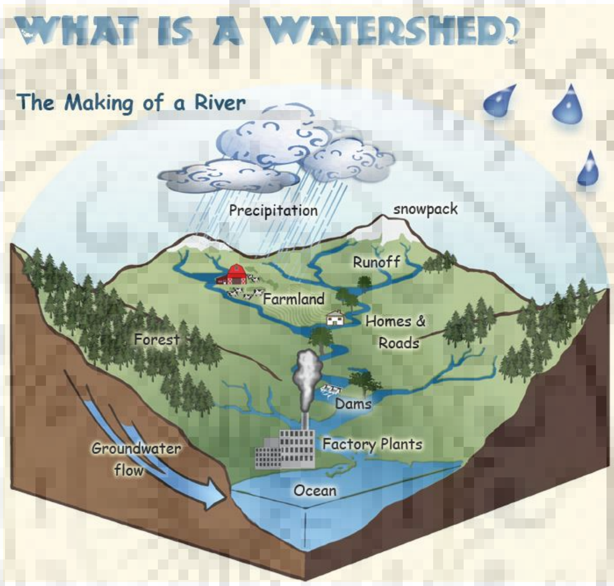

Figure 7 Watershed

Water Cycle is the process in which there is inflow of water through different process and outflow with different process, so together and collectively the sum remains constant and there can be quite error in the cycle due to some losses like evapotranspiration and discharge and which is basically what we are going to study in this thesis and their relation is important factor for studying the future aspect of engineering and climatic aspects. Water outflow in the water cycle is basically because of the evaporation and it is maximum in the summers and less in the winters. So snow cover area is really an important tool to see the cover of snow and we can compare the area of snow of different months and study them in detail.

Snowmelt runoff model is basically used to extract the discharge of water from the mountains with using many mathematical constant which is need to derive before putting in the final formula. Precipitation is anything that is coming to the earth and it can be in any form and when the weight of that cloud of water is heavier than atmospheric temperature or conditions it comes on the surface of earth with the help of gravity.

SRM calculates the daily discharge of a basin and the methodology for delineating the runoff discharge is as follows:

$$Q_{n+1} = [c_{Sn} \cdot a_n (T_n + \Delta T_n) S_n + c_{Rn} P_n] \frac{A \cdot 10000}{86400} (1\text{-}k_{n+1}) + Q_n k_{n+1}$$

In the above equation Q is the abbreviated as daily runoff discharge ($m^3 s^{-1}$);

c is the runoff coefficient denoting the losses as runoff / precipitation;

c_S denoting snowmelt and c_r to rains;

a is the degree-day factor (cm°$C^{-1}d^{-1}$), which shows the snow that is melted to depth resulting from a single degree-day;

T is the number of degree-days (°C d);

ΔT is the calculated by temperature and elevation by taking the difference of two heights and their respective temperature (°C d);

S is the ratio of the snow cover area (SCA) to the overall area;

P is the precipitation taking part in runoff , which is calculated by the defined threshold temperature TCRIT: if rainfall is determined to be new snow, it is kept in storage over the snow-free region until melting conditions occur; A is the area of the basin or zone (square kilometers);

k is the recession coefficient indicating the decreasing of discharge in a period without precipitation:

$K = Q_{z+1} / Q_z$

(z and z+1 are the sequence of days during a true recession flow period);

and n is the sequence of days during the discharge calculated period.

Equation is written for a time difference between the daily temperature cycle and the respective discharge cycle of eighteen hours. The number of degree-days measured on the zth day corresponds to the discharge on the (z+1)th day. The conversion from $cmkm^2d^{-1}$ to m^3s^{-1} (conversion from runoff depth to discharge) is 10,000/ 86,400. Runoff computations by SRM can easily calculate and can interpreted by anyone. There are three model input variables: temperature, precipitation, and SCA, and eight model parameters: temperature lapse rate, runoff coefficient (for rain and snow), degree-day factor, recession coefficient, critical temperature, rainfall-contributing area, and lag time.

$$Q_{n+1} = \Big\{ \big[c_{SAn} a_{An} (T_n + \Delta T_{An}) S_{An} + c_{RAn} P_{An} \big] \frac{A_A \cdot 1000}{86400} + \big[c_{SBn} a_{Bn} (T_n + \Delta T_{Bn}) S_{Bn} + c_{RBn} P_{Bn} \big] \frac{A_B \cdot 1000}{86400} + \big[c_{SCn} a_{Cn} (T_n + \Delta T_{Cn}) S_{Cn} + c_{RCn} P_{Cn} \big] \frac{A_C \cdot 1000}{86400} \Big\} (1 - k_{n+1}) + Q_n k_{n+1}$$

The above equation is used when the basin is divided into different zones and here formula is shown only for three zones.

Initial estimation of model parameters - When SRM parameters cannot be calibrated by historical data, they can be measured or estimated by hydrological judgment taking into account the basin characteristics, physical laws, theoretical relations, and empirical regression relations. Usually, the parameters of the temperature lapse rate, degree-day factor, and recession coefficient can be evaluated more accurately by on-site measurements, weather records, and hydrological data analysis with certain empirical formulas.

The estimation of the runoff coefficient, critical temperature, rainfall-contributing area, and lag time is more directly derived from basin characteristics such as geographical location, vegetation cover, topography, soil condition, evapotranspiration, physical laws, and complex interactions between them. When performing the extrapolation of temperature and precipitation, close attention should be paid to validating proper lapse rate and altitude gradient. The processing of satellite images is another major issue in the snowmelt runoff modeling. Locations where SRM has been tested in India are: Beas, Duwara, Himachal Pradesh, India.

Calibration Parameter used in SRM for beas Basin:

Sr. No.	Parameter	Value
1	Temperature Lapse Rate(°C/100m)	0.64
2	T_{crit}(°C)	0
3	Degree Day factor (cm $c^{-1}d^{-1}$)	0.3-0.75
4	Lag Time (hr)	18
5	Runoff Coefficient for Snow	0.03-0.45
6	Runoff Coefficient for Rain	0.05-0.48
7	RCA	0-1
8	Reference Elevation	3060
9	Initial Discharge(m^3/s)	85.47
10	Rainfall Threshold (cm)	6
11	Recession Coefficient	X = 1.08-1.9 Y = 0.02

The data used in the Snowmelt Runoff Modeling is the MODIS LST (Land Surface Temperature) which is derived from satellite data and is continuous datasets with better spatial and temporal resolution. The MODIS LST product parameters are achieved in Hierarchical Data format which is saved in Earth Observing System (HDF – EOS) format files. The algorithm used is split window algorithm developed by Wan and Dozier (1996) for generating the MODIS LST data.

Earth Science Data Type (ESDT)	Spatial Resolution	Temporal Resolution	Period
MOD11A2	1km(actual 0.927 km)	Eight days	2000 to 2009

DATA USED

The weather variables for driving the hydrological balance are precipitation, air temperature, solar radiation, wind speed and relative humidity were used of the station Bhuntar, Pandoh, Manali and Largi. The data of relative humidity was given of three time duration, for 4PM, 8AM and 12PM for all the stations of Beas Basin. The needed climatic or meteorological data for the calculation of month-wise potential evapotranspiration have been acquired for Beas region for periods varying from 1985-2005. The sources of data are the Monthly Weather Reports of the India Meteorological Department and the Monthly Climatic Data for the World (NOAA/WMO).

RESULTS

In manali we have derive the evapotranspiration for all methods and trend of each method can be seen as follows:

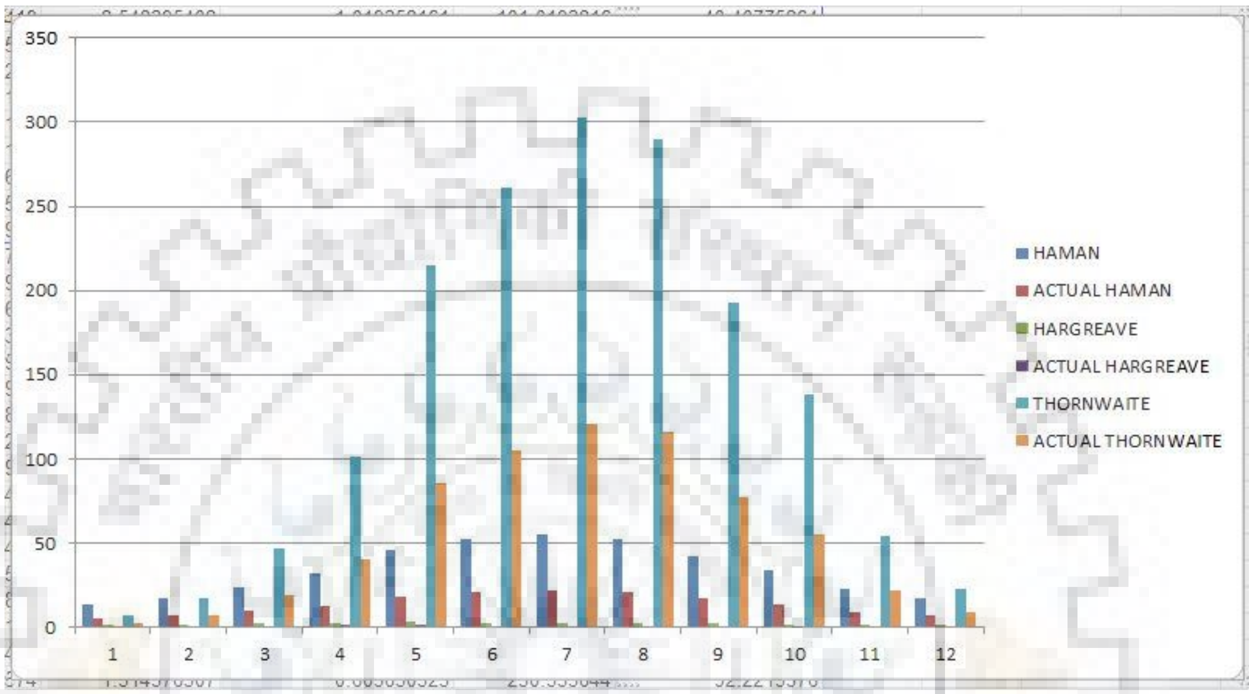

Figure 8 Trend of different Methods in Manali Area.

For the Bhantar region trend goes like this :

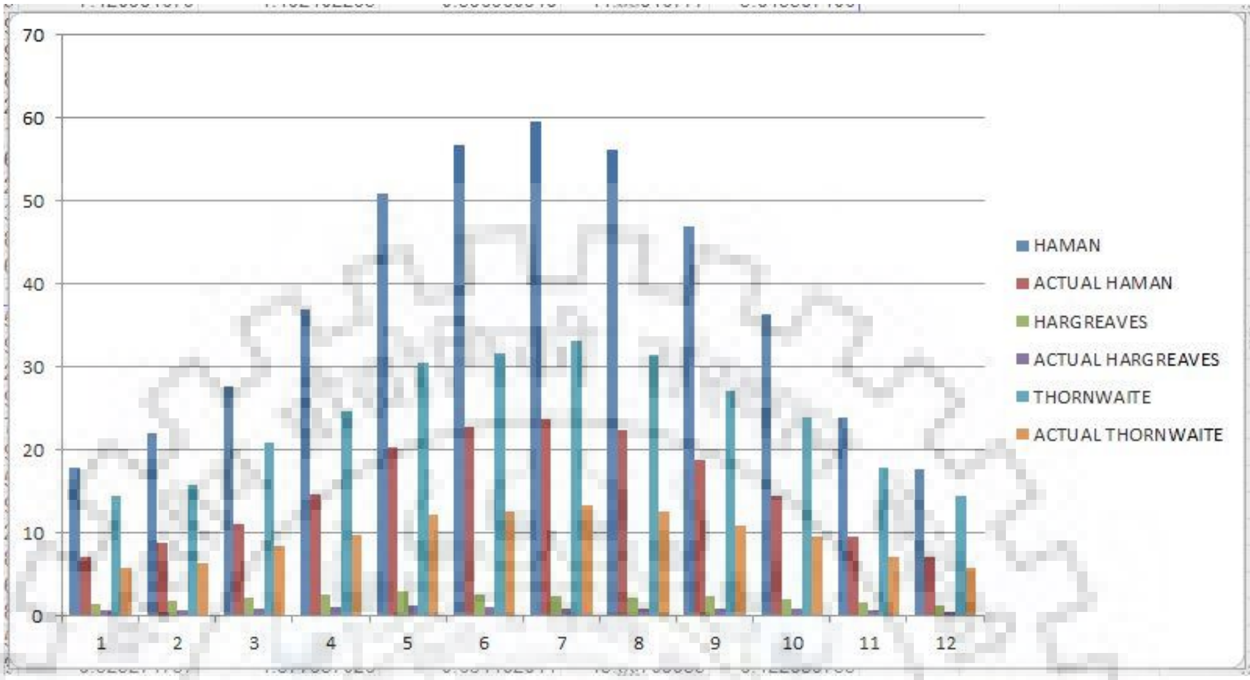

Figure 9 Trend of Bhantar region

Largi trend is as follows:

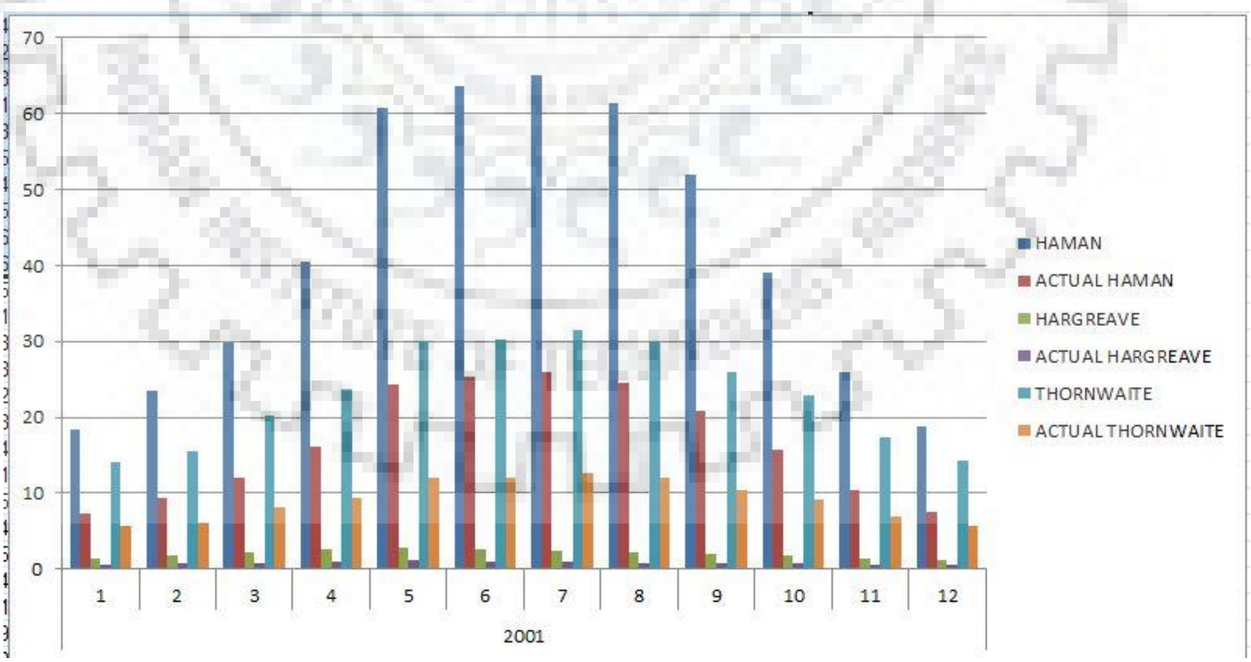

Figure 10 Largi ET using different techniques

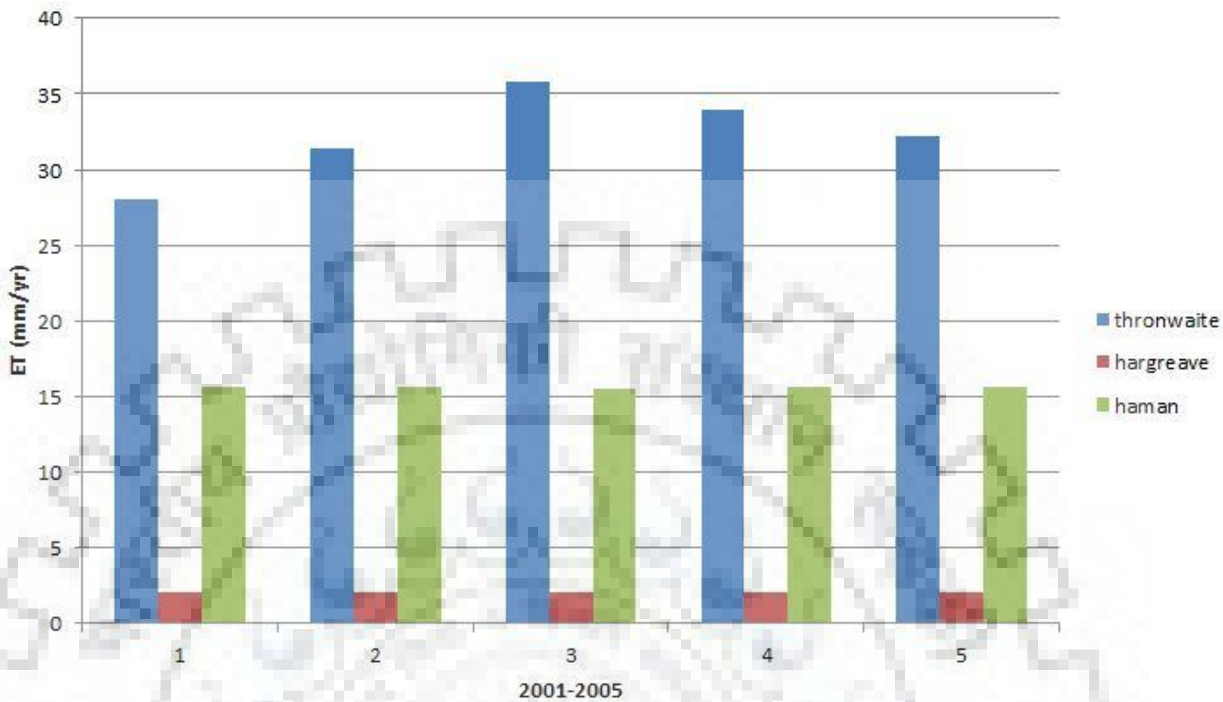

Figure 11 Evapotranspiration with respect to year 2001-2005

Beas	thronwaite	hargreave	haman
2001	28.0182	2.056116	15.65326
2002	31.39273	2.053676	15.6427
2003	35.81055	2.039955	15.55676
2004	33.98721	2.042044	15.5794
2005	32.24486	2.056824	15.65659

As we can see that Thornwaite has the maximum value according to the formula/equation applied and we can see the trend of 2001-2005 that in 2003 it is showing maximum value. Hargreaves showing the lesser value but trend is quite constant and there is little variation. Haman on the other hand shows a moderate value of around 15 mm/yr.

Discharge delineated from Snowmelt Runoff modeling has a trend which shows that it is maximum in the month July- August Period for the year 2001-2005. Also there is the possibility that discharge can be very high compared to surrounding

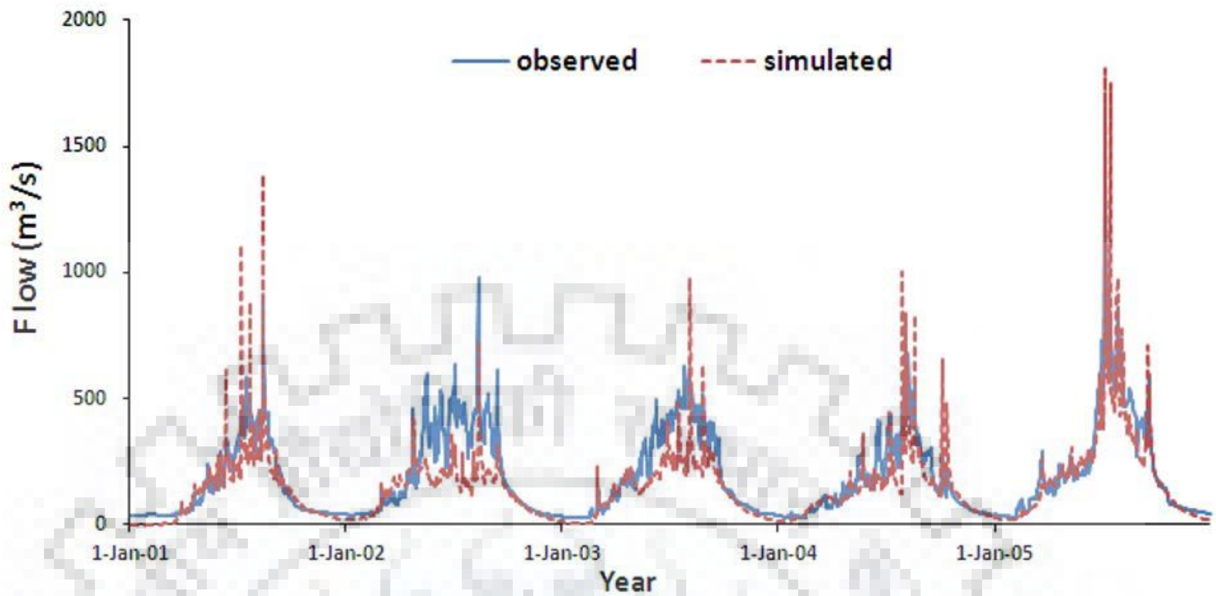

Figure 12 Comparison of daily observed and simulated stream flow hydrograph of Beas basin up to Thalout during validation period (2001-2005)

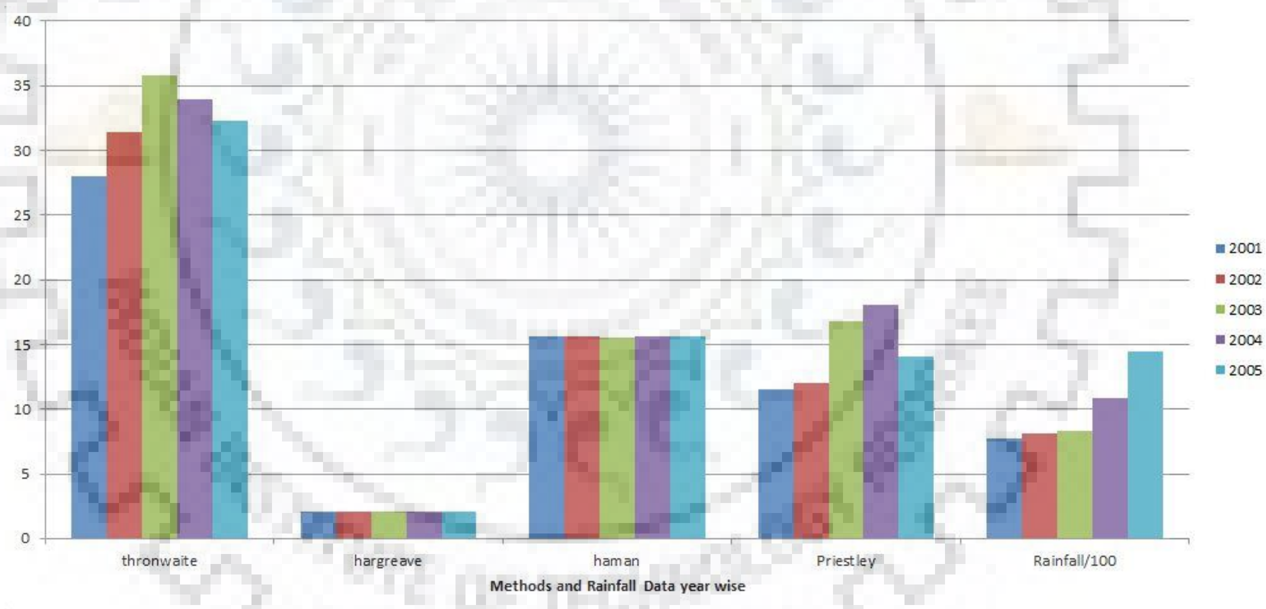

Figure 13 Trend of 2001-2005 of ET with precipitation

CONCLUSIONS

The trend which can be seen from the curves shows that ET (mm/month) is being maximum in the June July August month when we have used temperature based technique such as Thornwaite, Hargreaves and Hamon but the trend is different for the radiation based technique which is Penman and Priestley, here trend is maximum in May June month.

From the literature review and observed data, Priestley Taylor method is best method because it is showing increasing trend and radiation based techniques is the best for beas basin.

Since both Evapotranspiration and discharge are the components of water budget equation, will be focusing on the relation. When discharge is maximum, the trend of Evapotranspiration is the noticed whether is it increasing or decreasing and in which month its correlation is maximum. Discharge is compared with the output of all these methods.

Mountain river hydrology is need to study and will be crucial in order to control the water management, drinking water, agricultural irrigation and power generation. In Himalayan Region, simulation and forecast of snowmelt runoff has found to become a real necessity. Snowmelt Runoff Research is considered really fascinating to predict water resources availability, programing water usage and management due to global climate change and global warming. More research should be encouraged on the usability of snowmelt modeling in remote mountain watersheds by using data of snow cover remote sensing data, GIS tools and innovative way of parameterizing the model.

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APPENDIX

1. Code for calculating the Sunshine hours is as following written in Java which is for only January month and similarly sunshine duration can be calculated for different months too.

```
public class Sunsh {

    public static void main (String[] args){
    double Shi = 31.7225;
    double radshi = Math.toRadians(Shi);
    for (double n=1.0; n<=31.0; n++){


    double Day = 31.0;
    double prevald = Math.toRadians((360.0/365.0)*(284.0+n));
    double predel = Math.sin(prevald);
    double Delv = Math.toRadians(23.45*predel);
    double Sval = (2.0/15.0)*((180/3.14)*Math.acos((-1)*(Math.tan(Delv))*Math.tan(radshi)));
    System.out.println(Sval);


    }
```

Figure 14 Sunshine Duration.

2. Code written as to collect information from excel and directly run into java netbeans and the output result can be further processed to calculate the actual evapotranspiration.

```
Cell ui = s.getCell(21,i);
String yh = ui.getContents();
al = Double.parseDouble(yh);  // alpha
//System.out.println(al);

//double alpha = 675*Math.pow(10, -9)* Math.pow(Sumi,3) - 771*Math.pow(10, -7)* Math.pow
for (int k =13;k<25;k++){

Cell c = s.getCell(12,k);
String a = c.getContents();
td = Double.parseDouble(a);

double pnc = 16.0* Math.pow((10.0*td)/Sumi, al);
//System.out.println(alpha);
System.out.println(pnc);
}
```

Figure 15 Thornwaite code

3. Code written for Haman

```
//System.out.println(z);
Cell h = s.getCell(6,i);
String u = h.getContents();
x = Double.parseDouble(u);

//System.out.println(x);

double kp = 1.2;//calibration constant
double esat = 6.108 * Math.exp((17.27* z)/(z+273.3));


double rho = 216.7 * (esat/(t + 273.3));

double pet = 0.1651 * (x/12) * rho *kp; //potential evapotranspiration

System.out.println(pet);
```

Figure 16 Haman Code for finding out Evapotranspiration