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MODELLING OF STREAM FLOW IN HIMALAYAN BASIN UNDER CLIMATE CHANGE

Major Project Thesis

Submitted by

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DECLARATION

This is to certify that the work that forms the basis of this project "**Modelling of stream flow in Himalayan basin under climate change**" is an original work carried out by me and has not been submitted anywhere else for the award of any degree.

I certify that all sources of information and data are fully acknowledged in the project thesis.

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CERTIFICATE

I hereby certify that the project work entitled "**MODELLING OF STREAM FLOW IN HIMALYAN BASIN UNDER CLIMATE CHANGE**" carried out by Miss. Chanchal, M.Sc. (Geoinformatics), TERI University, New Delhi is an authentic record of work carried out by her from January 4th, 2016 to May 10th, 2016 under my guidance.

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LIST OF ABBREVIATION

TM : Thematic Mapper

ETM^+ : Enhanced Thematic Mapper

DEM : Digital elevation Model

ASTER : Advanced Space borne Thermal Emission and Reflection Radiometer

LULC : Landuse and Landcover

GCM : Global climate model

SWAT : Soil and water assesment tool

HRU,s : Hydrological response unit

SWAT CUP : SWAT calibration uncertainity procedures

IM : Inverse Modelling

GLUE : Generalized likelihood uncertainty estimation

ParaSol : Parameter solution

SUFI-2: Sequential uncertainty fitting

95PPU: percent prediction Uncertainty

P-factor : Percentage of observations covered by 95ppu

R-factor : Relative width of 95% probability band

NSE : Nash Sutcliffe efficiency

RSR : Ratio of the root mean square

PBIAS : Percent bias

T-stat : Provides a measure of sensitivity (larger absolute values)

P-value : Determine the significance of the sensitivity (close to zero)

ABSTRACT

Stream flow modelling is vital for agricultural watershed management and its effect on many aspects of change in climate variability. For Soil and Water Assessment Tool (SWAT) model has been used to simulate stream flows in Bhuntar River basin which is located Himachal Pradesh in N-W Himalaya region, India. Daily stream flow was simulated for the period of 1990-2000, and validated for 2001-2010. As it is difficult to manually calibrate such a complex model with many parameters, the sensitivity analysis have been carried out to find the sensitive parameter which is used as a input for the model calibration and the Sequential Uncertainty Fitting (SUFI2) algorithm was used for calibration and to quantify uncertainty. Performance SUFI2 was evaluated to reach the objective of the Bhuntar Basin. For the calibration period, the values of P-factor and R-factor, R^2, NS, bR^2 and PBIAS were found to be 0.27, 0.11, 0.6, 0.6, 0.352 and 3.7 respectively in Bhuntar basin. For validation data, values are found to be 0.14, 0, 0.57, 0.48, 0.258 and 25.3 respectively at the Bhuntar outlet. It demonstrates the efficiency and suitability of the SUFI2 method for the Bhuntar catchment.

Investigation the potential changes in climatic variability, The predictors of two global climate models (GCMs) that are used to predict Present and future time. The data contains series of temperature minimum and maximum, precipitation. The simulation values were generated and investigated climate change effect for the year 1992 to 2060s. The results of climate change prediction in present and future scenario were estimated. The simulated stream flow is continuously increased with the time. In the end of 2040's to 2060's the stream flow will increase which shows the instability in climate. The study shows the changes in climate condition. hence, The climate is continuously changing due to instability in the climate as the glacier and snow are continuously shrinking and melting down in the downstream and effect the water budget component etc.

Keywords:

Stream flow, Sensitivity analysis, Uncertainty analysis, Calibration, Validation, Climate change prediction, SWAT, SWATCUP -SUFI-2.

CHAPTER 1

INTRODUCTION

1.1 General

The concerns over the rich Himalayan resource depletion have manifested in various forms. Himalaya is unique and highest mountain chain of the world. It referred to the third pole (Schild, 2008) and the "water tower of Asia" (Xu et al., 2009). The Himalayan region affects, directly or indirectly, the living of over 300 million people of the Indian subcontinent (Schild, 2008). Concerns over impoundment of rivers for energy generation and its correlates to the impact of climate change on the livelihood and the natural resources especially the Glacial retreat have emerged to be very crucial area of focus. Glaciers are dynamic bodies of ice and Snow normally present above the snow line. Glaciers are one of the most important natural resources of fresh water and act as a source of water for various purposes like hydropower, agriculture and drinking etc. "About 30% of the Earth's land surface is covered by glaciers; 10% of land is permanently ice-covered at present, and 10% is permanently frozen; about 50% of the land is covered by snow and ice in northern hemisphere winter and around 75% of the world fresh water is contained in glacier, which is provide irrigation water for the populated areas of the world (Knight, 1999)."

The Himalaya has the largest collection of the glaciers outside the polar region with a total glacier cover of around 33000 km^2 and the total number of approximately 9600 glaciers in the Indian Himalaya (Bhambari et al., 2011) Glaciers play significant role in maintaining ecosystem stability as they act as a buffer and also regulate the water supply from High Mountain to the plain. Most of the glaciers in the Himalayas are of winter accumulation type and ablation takes place simultaneously during summer (Fujita et al., 1997). A broad classification can be done on their distinct characteristics and each class has unique properties. The classification of glacier based on three main category viz. Thermal, dynamic and morphological characteristics. Temperate glacier, warm glaciers (Himalayan glacier) and cold glacier comes under thermal characteristics. In dynamic category glaciers can be active, passive or dead and morphological characteristics is basically based on size and shape and their relationship to the topography upon which they flow (knight, 1999). On the basis of their mode of occurrence and dimension, glaciers have been classified into three categories: valley glaciers, piedmont glaciers and continental glaciers. Himalayan glaciers are mainly valley glacier.

Stream flow simulation is main Challenge in mountainous watersheds because of the rugged topography and complex hydrological processes. It is the main hydrological factor which influences the hydrological characteristics in many ways to shows their importance in balanced agriculture watershed. Stream flow is the volume of water passing a fix point over a unit of time and is usually explicit in cubic meters per second/cumec. It reflects the total amount of water moving off the watershed and into the channel and the amount being removed from the stream (singh et, al.). Stream flow is affected natural and human factors. Evaporation and water use by plants significantly affect stream flow. Vegetation has the largest impact on flow during summer months when temperatures are high and streamside vegetation uses the most water. The flow is also being influenced by subsurface water flow which response to change many factors. Concerns over impoundment of rivers for energy generation and it correlates to the impact of climate change on the livelihood and the natural resources especially the Glacial retreat have emerged to be very crucial area of focus. The region controls flow to the three Major River in the Himalayan mountainous system; Ganga Brahmaputra and Indus. These river systems play a main role in the economy of many countries including India which depends greatly on it for hydropower, water supply, agriculture and tourism. These Himalayan resource are highly prone to natural hazards, leading to serious concern especially about current and future climate change impacts on the water stored in snow and glaciers (Cruz et al.,2007). In the region, the climate change concerns are multifaceted encompassing lead to an intensification of the global water cycle as a result of changes in hydrological variables such as precipitation and temperature. The rise consequently leads to the melting of the glaciers .The alarming rate of retreat in up to Bhuntar glacier at 52 m per year (Kulkarni et.al 2005) raises questions of regional stress for water resources., snow cover changes, glacier retreat, expansion of glacier lakes and glacier lake outburst floods, droughts, landslides, flash floods, (Barnett et al.2005).. Many rivers, springs and lakes in the mountain regions are fed by significant contribution of snow and ice melt runoff. Most of the rivers in the Himalayan region such as the Ganga, the Indus, and the Brahmaputra, have their upper catchment in the snow covered areas. Snowfall is temporarily stored in high hills and the melt water reaches the river later in the hot season. Snow and glacier runoff are vital in making big Himalayan Rivers perennial, whereas the rainfall contribution during the monsoon season is important for high flow volumes in rivers. Snow accumulates in Himalayas generally from November to March, while melt season spans the months April to September. Snowmelt is the predominant component of runoff in mountains in April to June months and it forms a significant constituent of stream flows during July - September.

It is important to assess snow and glacier contribution in the flow of various Himalayan rivers to efficiently manage water resources. Reliable estimation of snow and glacier melt runoff is very much required for planning of new river. However, in spite of well-recognized importance and potential of such studies, very few attempts have been made to assess snow and glacier contributions in these rivers.

Snow and ice are converted into water by using energy (heat). Therefore, snowmelt depends on the flow and storage of energy into and through the snowpack (USACE, 1998). Snowmelt models follow either of two methods to compute snowmelt from a snowpack: a) energy budget method and b) temperature index method. The energy budget approach is physically based and attempts to simulate all energy fluxes for the snowpack to give a realistic account of snowmelt in response to each of the energy fluxes over time and space. However, this approach requires vast amounts of data to run a model or to calibrate a model using historical data. Often, application of this approach faces inadequate data. Since the data requirements for the energy budget approach are large, an alternative method, known as the temperature index or degree day approach, is frequently followed. This allows calculating snowmelt with less input data by assuming that there is a high correlation between snowmelt and air temperature because of high correlation between air temperature and the components of the energy budget equation (Semádeni- Davies, 1997; Ohmura, 2001; Hock, 2003).

High spatial and temporal variability in hydro-meteorological conditions in mountainous environments requires spatial models that are physically realistic and computationally efficient (Liston and Elder 2006b). Among the models developed to simulate hydrological response of mountainous basins, the most common approach followed for distributed snowmelt Modelling in the absence of detailed measured data is to subdivide the basin into zones and/or bands based upon elevation, allowing the model to discretize the snowmelt process based on watershed topography (Hartman *et al.*, 1999; Li et al., 2013). The SWAT model (Arnold et al. 1996; Neitsch et al. 2001) contains a snowmelt estimation procedure which is based on a simple temperature index approach. Initially, SWAT model was developed to assist water resource managers in assessing water supplies and non-point source pollution in watersheds and large river basins. But it has been widely applied for snowmelt runoff estimation also.

SWAT model allows defining up to ten elevation bands in each sub basin to consider orographic effects on precipitation, temperature and solar radiation, (Neitsch et al. 2001). In the model, snow accumulation, sublimation and melt are computed in each elevation band and weighted average is computed sub basin wise. Snowmelt depth is in the same elevation band is assumed to be the same in all sub basins. However, it is often argued that elevation is not the only variable that dictates snowmelt in a sub basin and other dominant factors such as land use/land cover, aspect and slope also influence snowmelt (Morid et al. 2002; LaMalfa and Ryle 2008).

Remote sensing provide multi sensor, spatial and multi temporal data for monitoring and mapping various properties such as glacier area, length, surface elevation, albedo, equilibrium line altitude, terminus position, volume, accumulation/ ablation rates and accumulation area ratio from which glacier mass balance can be inferred. These techniques are very useful for inaccessible areas (Lakhman et al., 2014). Remotely sensed data provide valuable and real time spatial and temporal information on natural resources and physical parameter. Multispectral and multi temporal data provide abundant potential for mapping and monitoring the large spatial coverage of glacier at regular temporal intervals. Stream flow Modelling studies from the Indian Himalaya are based on a comparison of satellite data with topographic maps (Bhambri et al., 2011). GIS is very important and effective technique for assessing the climate change condition and stream flow runoff modeling which is relationship between rainfall and stream flow it is established to measure based on discharge relationship due to hydraulic tends, as remote sensing derived information can be well integrated with the database for evaluating and identified the climate changes prediction for present and future scenario. It is confirmed that northwest Himalaya region has warmed significantly at a higher rate than the global average. A significant rise of 1.6^0c from 1998-2002 has been reported in the northwest Himalaya (Bhutiyani et al., 2007).

The present study was undertaken on the stream flow modeling, climate change prediction in past, present and future climate scenario in Himalayan region of Beas river basin up to Bhuntar which is located in western Himalaya. Beas river originate from the eastern slopes of rohtangpass of Himalayas at an elevation of 3900 above mean sea level and flows in nearly north-south direction up to Larji, where it takes a nearly right angle turn and flows towards west up to the Bhuntar which is situated kullu district, Himachal Pradesh. The Bhuntar river catchment as a whole receives good amount of rainfall throughout the daily and has great significance in terms of economic and ecological diversity point of view in the western Himalayan. Various remotely sensed images, metrological data; topographic data has been used to conduct the present study. In the last few decades, the SWAT model has been applied to numerous catchments under varied climate, topography, and land use/land cover. Some of the prominent studies carried out in mountainous catchments. ERDAS Imagine, ArcGIS, Arc SWAT, SWAT cup, PCPstat, DEW point software have been used in present study.

1.2 SWAT Model

SWAT is the acronym for SOIL AND WATER ASSESMENT TOOL, that required a diversity information. SWAT is physically based and semi distributed hydrological and water quality model designed to calculate runoff, sediments and contaminants from subbasin drainage units throughout a river basin towards its outlet. sub watersheds connected with the river network and smaller units called HRU,s (Hydrological response unit) semi distributed process based on river basin or watershed scale model developed by Dr. jeff Arnold and jointly developed by the USDA-ARS and agriculture experiment station in Temple, TEXAS.The model was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watershed with varying soil, land use and management condition over a long period of time.

SWAT can be grouped into different divison viz; hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticide and agricultural management (SWAT Theoretical Documentation,2012). The SWAT model uses in physically based inputs such as weather variables, soil properties, Elevation, vegetation and land management practices that occures in the catchment area. This process associated derived from water flow, sediment transport, crop growth, nutrients cycle etc. that directly modeled in SWAT. The hydrological cycle as simulated by SWAT is based on water balance equation (all water units is shown in depth term in mm):

$$SW_t = SW_0 + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right) \qquad \ldots. (1)$$

where,

SWt : The final soil water content,

SWo : The initial soil water content,

T : Time in days,

Rday : The amount of precipitation on day i,

Qsurf : The amount of surface runoff on day i,

Ea : The amount of evapo-transpiration on day i,

Wseep : The amount of percolation and bypass exiting the soil profile bottom on day i,

Qgw : The amount of return flow on day i

SWAT is a weather simulation model which generates the daily rainfall, solar radiation, relative humidity, wind speed and temperature from the average monthly data. This is usefull tool to provide the facilities to fullfill the mising daily data in the observed records. SWAT model uses hourly and daily time series data to calculate surface runoff. The Green &Ampt method is used for hourly data and an empirical SCS Curve number is used for daily computation. SCS method stands for Soil Conservation Service method which is widely used for estimating flood on small to medium sized unguaged drainage basins. It was developed originally as a procedure to estimate runoff volume and peak discharge for design of soil conservation works and flood control project (Maidment, The Handbook of Hydrology). The surface runoff method based on SCS equation:

$$Q = \frac{(P - Ia)^2}{(P - Ia) + s} \quad ..(2)$$

Where,

Q: Runoff depth (mm),
P: Rainfall depth (mm,)
S: Maximum potential retention depth,
IA: Initial abstraction

S is the maximum potential retention depth after runoff begins and IA is the initial abstraction which represents all losses before runoff begins. IA includes retention in surface depressions, water intercepted vegetation, evaporation and infiltration. IA is highly variable but it has been approximated by the following empirical formula:

$$IA = 0.2 * S \quad .....(3)$$

By eliminating IA as an independent parameter, the combination of S and P produce a unique runoff amount given by the following equation:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad ....(4)$$

Where the parameter S is related to the soil and cover condition through the curve number. CN has a wide range for different land use over different soil types and S is related to CN by the following equation:

$$S = \frac{25400}{CN} - 254 \quad .... (5)$$

Basically, S is related to the soil and cover condition of the watershed trough the curve number , that form for soil type, land use, hydrological condition, antecedent moisture condition initial abstraction, Rainfall intensity. For SCS method application, all soil has been classified into four hydrological soil groups which are based on the infiltration rate. SWAT model, runoff occurs when the rainfall is greater than the initial abstraction. In the present study, the SCS method has been used to estimate the water balance or water budget. SWAT has been succesfully applied all over the world for solving various environmental issues for water quality studies like diffuse surface water pollution (panagopoulos et al,2011.) but relatively less in snow and glacier dominated mountanious terrain. However, several studies have been performed and a few studies are ongoing to explore hydrological fluxes in mountain region (Abbaspour et al, 2007.)

SWAT snowmelt hydrology process is represented at the sub-basin level .which is generated in SWAT that can be divided into 10 elevation bands in order to integrate temperature and precipitation variations with respect to altitude (Hartman et al, 1999.) for each subbasin shows different precepitation and temperature laps rates, P_{laps} (mmH_2O/km) and t_{laps}(degree C/ km), it is defined difference between elevation band in precipitation and temperature.

$$P_B = P + (Z_B - Z)\frac{p_{laps}}{days_{pcp,yr} \times 1000} \text{ and } T_B = T + (Z_B - Z)\frac{t_{laps}}{1000}$$

..(6)

Where (mm H2O), T (ºC) and Z (m) are derived sub-basin precipitation, temperature and recording gauge elevation, that PB, TB and ZB are the adapt precipitation, temperature and middle elevation for each elevation band. The variable days PCP per year this represents the mean annual number of days with precipitation.

In SWAT the snow pack is represented the variable snow water equivalent/SWE, which increases snowfall/SF , snowfall derived the daily mean temperature is below the critical temperature SFTMP, degree Celsius and decreases with snowmelt/SM or sublimation Is.

$$SWE_{day} = SWE_{(day-1)} + SF - SM - Es \qquad \ldots\ldots (7)$$

Snowmelt hydrology in SWAT is modeled on the basis of HRUs. Mean daily air temperature SFTMP is the indicator of snowfall accumulation and snow pack in SWAT. The classification of precipitation is based on a threshold value of mean air temperature. If the average daily air temperature is below the snowfall temperature, the precipitation in a HRU is taken as solid and the liquid water equivalent of the snowfall is added to snowpack. The snowpack is depleted by snowmelt or sublimation. The mass balance for the snowpack for a HRU is:

$$SNO_i = SNO_{i-1} + P_s - E_{subi} - SNO_{mlti} \qquad \ldots (8)$$

Where, SNO_i is the water content of the snowpack (mm H_2O), P_s is the water equivalent of snow precipitation (mm H_2O), E_{subi} is the amount of snow sublimation (mm H_2O), and SNO_{mlti} is the water equivalent of snow melt (mm H_2O), all for day *i*.

The snowpack is not uniformly distributed over the entire watershed. This is the result of fraction of the sub basin area that is bare of snow. The spatial non-uniformity of the areal snow coverage over the HRU area is taken account through an area depletion curve which describes the seasonal growth and recession of the snowpack (Anderson, 1976). Two addition parameters defined at the watershed scale, SNOCOVMX and SNO50COV, control the areal depletion curve by accounting for the variable snow coverage. An area depletion curve is calculated as:

$$SNO_{cov\,i} = \frac{SNO_i}{SNOCOVMX}\left[\frac{SNO_i}{SNOCOVMX} + \exp\left(\mathrm{cov}_1 - \mathrm{cov}_2 \cdot \frac{SNO_i}{SNOCOVMX}\right)\right]^{-1} \qquad . (9)$$

where SNO_{covi} is the fraction of HRU area covered by snow on the day *i*, $SNO_i$is the water content of the snow pack on day *i*, SNOCOVMX is the minimum snow water content that correspond to 100% snow cover (mm H_2O), and cov_1 and cov_2 are coefficients that control the shape of the curve. The values of cov_1 and cov_2 are found by determining two known points: 95% coverage at 95% SNOCOVMX and 50% coverage at a fraction of SNOCOVMX, specified by the variable SNO50COV.

When the volume of water contained in the snowpack exceeds SNOCOVMX, snow depth over the HRU is assumed to be uniform, or SNOCOVMX = 1.0. The areal depletion curve affects snowmelt only when the snowpack water content is in the range 1.0 to SNOCOVMX. Due to this, if SNOCOVMX is set to very small value, the impact of the areal depletion curve on the snowmelt will be minimal. As the value of SNOCOVMX increases, the influence of areal depletion curve becomes more important in snowmelt process.

In addition to the areal coverage, snowmelt is also controlled by the snowpack temperature and melting rate. Anderson (1976) found that snowpack is the function of the mean daily temperature of the preceding days and varies as a dampened function of air temperature. A lagging variable, TIMP, controls the influence on current day snowpack temperature by the temperature of the previous day. It shows how rapidly the snowpack temperature is affected by air temperature. The lagging factor inherently accounts for snowpack density, snow pack depth, exposure and other factors affecting snow pack temperature. The snowpack temperature is computed as:

$$T_{snow\,i} = T_{snow(i-1)}\left(1 - TIMP\right) + \overline{T_{air\,i}} \cdot TIMP \qquad \ldots (10)$$

Where $T_{snow\,(i-1)}$ is snowpack temperature on day *i-1* and $\overline{T_{air\,i}}$ is the mean air temperature on day *i*. As the lagging factor, TIMP approaches unity, the mean air temperature $\overline{T_{air\,i}}$ on the current day exerts an increasingly greater influence on the snowpack temperature and snowpack temperature of previous day has less influence. Weather, soil properties, topography, vegetation and land management practices are the most important inputs for SWAT to model hydrology and water quality in a watershed (Neitsch, 2002).

1.2.1. Temperature-index approach

In temperature index method, temperature is considered as a major controlling factor for snowmelt (Hock 2003). The snowmelt runoff will not take place until its temperature exceeds a threshold value, which is known as snowmelt base temperature SMTMP. In SWAT, the snowmelt is estimated as a linear function of the difference between the average of snowpack temperature- maximum air temperature and the threshold temperature for snowmelt. A temperature index is used to estimate snowmelt based on the following relationship

$$SNO_{mlti} = b_{mlti} \cdot SNO_{cov\,i}\left[\frac{T_{snowi} + T_{\max i}}{2} - SMTMP\right] \quad ..(11)$$

WhereSNOmlti is the amount of snowmelt on day i (mm H_2O), T_{maxi} is the maximum air temperature on day i (^oC), SMTMP (^oC) is snowmelt base temperature above which snow will be allowed to melt and b_{mlti} is the melt factor on day i (mm H_2O-day).

1.3 SWAT-CUP

SWAT-CUP (SWAT CALIBRATION UNCERTAINITY PROCEDURES) is a computer program for calibration of SWAT models. It is developed by Eawag, swiss Fedral institute which analyze prediction uncertainty of SWAT model . this model is calibrated parameters are conditioned on the choice of objective function, type, and numbers of data points and the procedure used for calibration. In a previous study (Abbaspour et al. 1999), we investigated the consequences of using different variables and combination of variables from among pressure head, water content, and cumulative outflow on the estimation of hydraulic parameters by inverse modeling (IM). The inverse study combined a global optimization procedure with a numerical solution of the one-dimensional variably saturated Richards flow equation IM used for finding best parameters , it concerned with the problem of making inferences about physical systems from measured output variables of the model like; river discharge, sediment concentration).SWAT CUP procedures include GLUE (Generalized likelihood uncertainty estimation) is defined partly to allow for the possible non uniqueness, Parasol (Parameter solution), SUFI-2 (Sequential uncertainty fitting) is the method to define aggregates objective functions into a global optimization criterion that is using SCE-UA algorithm.

Model parameterization in SWAT- CUP of a watershed model is consider a soil map which is similar soils in different parameters in different places because it is in a different climatic region or under a different land use or soil management. The interface linking SWAT to various calibration programs allows parameter aggregation on the basis of hydrologic group, soil, land use, and sub basin specifications formulated as: (Abbaspour et al.)

x__<parname>.<ext>__<hydrogrp>__<soltext>__<land use>__<subbsn> ... (12)

Where,

x__ is a code to indicate the type of change to be applied to the parameter

v__ means the default parameter is replaced by a given value

a__ means a given quantity is added to the default value

r__ means the existing parameter value is multiplied by (1+a given value)

<parname>: SWAT parameter name

<ext>: SWAT files extension code for the file containing the parameter

<hydrogrp>: soil hydrological group (A, B, C or D)

<soltest>: soil texture

<land use>: land use category

<subbsn>: sub basin number, crop index or fertilizer index.

1.3.1 Uncertainty Aspects in Hydrologic Modeling

Reliability of results obtained from model is checked on the basis of performance of the calibration and validation. Through model calibration parameter values have to modify and comparison of predicted output of interest to measured data until a defined objective is achieved (James and Burges, 1982). Before calibration, sensitivity analysis is usually done in model calibration and it provides identify and rank parameters that have significant impact on modeling.

There are five sources of uncertainties in hydrologic modeling: 1) natural uncertainties associated with random temporal and spatial fluctuations in natural processes, 2) model structure uncertainty, reflecting the inability of the model to precisely represent the system, 3) parameter uncertainty, reflecting non-uniqueness of model parameters and inability to determine their right values, 4) data uncertainties arising from measurement inaccuracy and inadequacy of gauging networks, and 5) computational uncertainties (Singh et al. 2007).

Uncertainties in input data are important because input data are measured at fixed points but data are used to represent large areas in most hydrologic models. This may introduce large errors, particularly in mountainous areas. In the model, for every basin climate data is provided by the station nearest to the centroid of the sub basin. Direct accounting of rainfall or temperature distribution error is quite difficult because information from many stations would be required.

The SWAT-Calibration and Uncertainty Program (SWATCUP) is an interface for calibration, validation, uncertainty analysis, and sensitivity analysis of SWAT model. The Sequential Uncertainty Fitting (SUFI2) algorithm developed by Abbaspour et al. (2004; 2007) was used in this study because it converges with relatively smaller number of iterations and provides possibility of restarting an unfinished iteration and splitting iteration into several runs.

1.3.2 Sequential Uncertainty Fitting (SUFI2)

SUFI2 is a multi-site, semi-automated global search procedure which can be used for model calibration and uncertainty analysis. All sources of uncertainties such as input variables (e.g., temperature, rainfall), conceptual model, parameters and measured data are accounted by parameter uncertainty in SUFI2. SUFI2 considers the uniform distribution to describe the uncertainty of input parameters and the model output uncertainty is quantified by the 95% prediction uncertainty (95PPU) which is calculated at the 2.5% and 97.5% levels of the cumulative distribution of output variables that is obtained through Latin hypercube sampling. Uncertainty analysis of SUFI2 is based on the premise that a single parameter value gives a single model response while propagation of the uncertainty in a parameter leads to 95PPU. With increase in parameter uncertainty, the uncertainty of output also increases.SUFI2 uses P-factor, the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU), to assess uncertainty. Another measure used in SUFI2 to measure the strength of a calibration/ uncertainty analysis is the R-factor

This is the average width of the 95PPU band divided by the standard deviation of the measured data.

SUFI2 seeks to bracket most of the measured data with the smallest uncertainty band. The value of P-factor ranges between 0 and 100%, while that of R-factor ranges between 0 and infinity. A simulation whose P-factor is 1 and R-factor is zero exactly corresponds to measured data. The degree to which the result deviates from these numbers is used to judge the strength of the calibration. The parameter uncertainties are desired parameter ranges when acceptable values of R-factor and P-factor are reached. A larger P-factor can be reached at the expense of a larger R-factor. After getting acceptable values of R-factor and P-factor, the goodness of fit is quantified by r^2 and/ or NSE between the observation and the best final simulation. Plotting the measured data with the 95PPU can guide about the parameter uncertainty ranges. For example, when the parameters are at their maximum physical limits and the 95PPU does not bracket the measured response, it shows some weakness in the model which must be looked again.

In SUFI2 initially a large parameter uncertainty is assumed, so that the measured data initially falls within the 95PPU, after that this uncertainty may be decreased in steps until two rules are satisfied: (1) the 95PPU band brackets 'most of the observations' and (2) the average distance between the upper (at 97.5% level) and the lower (at 2.5% level) parts of the 95PPU is 'small' (Abbaspour et al. 2007). The quantification of the two rules depends on the problem. In case of high quality measurements, 80–100% of the measured data should be bracketed within 95PPU, while in case of low quality data containing many outliers and it may be adequate to account only for 50% of the data in the 95PPU. For second rule, a practical measure is that the average distance between the upper and the lower 95PPU be smaller than the standard deviation of the measured data. A balance between the two rules ensures bracketing most of the data within the 95PPU, while seeking the smallest possible uncertainty band. These two measures can be adopted to quantify the strength of calibration and accounting of the combined parameter, model, and input uncertainties. Abbaspour et al. (2007) have given a more detailed step-by-step description of SUFI2 algorithm parameter sensitivity analysis and calibrate stream flow correlation between simulated and observed data.3

1.4 Study Area

Beas River basin up to Bhuntar site were consider for the present study, which is located in territory of Kullu district of Himachal Pradesh, it is a part of western Himalaya. Beas River is the main river of Northern India rises in the Himalaya in central Himachal Pradesh its originate from the eastern slopes of Rohtang pass of Himalayas at an elevation of 3900 above mean sea level and flows in nearly north-south direction up to Larji, where it takes a nearly right angle turn and flows towards west up to the Bhuntar. The length of the Beas River is 80 km and the total area of the Beas River basin is 3384 km^2 up to the Bhuntar. The Beas River basin lies between 31° 43′ 12″ to 32° 26′ 24″ N and 76° 55′ 12″ to 77° 52′ 12″ E. The basin area comprises of steep slopes and the rocks are mainly bare and altitude varies from 1080 amsl near Bhuntar to more than 6000 amsl near Beo-Toibba.

The State has utilized the well hydropower strength from the massive river. There is geothermal spring near the banks of the Parvati river basin at Manikaran and Kasol spread on the banks of the river basin. The river passes through deep gorge with an approximate 25-30 m near gwacha. The valley is situated in the lesser Himalaya. The basin falls within altitude range 5200m above mean sea level (R.N. Prashad, 2013).

The Bhuntar basin is selected as a basic unit of study for assessing the stream flow modeling and climate change scenario within particular time frame.

The location of the study area is shown in Figure 1.

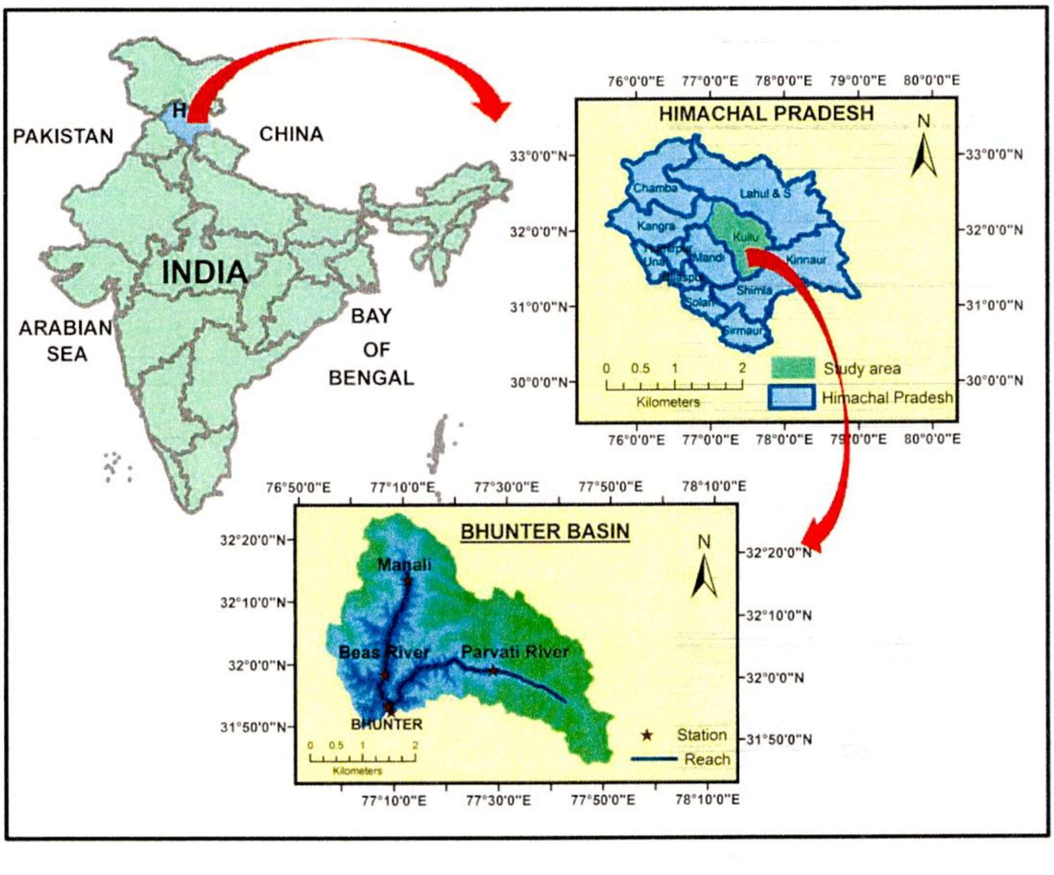


Figure 1: Location of Study Area

CHAPTER 2

AIMS & OBJECTIVES

SWAT hydrological model was applied to the current research work, identify several key questions related to Stream flow modeling in Himalayan basin under climate change within the Bhuntar basin, Himachal Pradesh, India using Multi spectral or temporal datasets have been used to conduct the study. The main objectives of the present study are as follows:

1) To apply the Soil and Water Assessment Tool (SWAT) for simulation of stream flow in Bhuntar Basin.

2) To find out the sensitive parameters of model for simulation of stream flow.

3) To test the performance and feasibility of SWAT model by examining the influence of topographic, land use, soil and climatic conditions on stream flow.

4) To apply SWAT-CUP (SWAT Calibration and Uncertainty Procedures) for calibration, validation and uncertainty analysis of the model.

5) To investigate the present and future climate change scenario.

The goal of this study is to provide answers to these and related questions through a better understanding of the variation in temperature, precipitation, and snow/glacier cover area, river discharge in the Western Himalaya, India. Remote sensing information and GIS (Geographical information System) plays the most important role to achieve all the objectives of the present study.

CHAPTER 3

LITERATURE REVIEW

Recent Applications of the SWAT Model to Mountainous Basins have been study Spruill et al. (2000) applied the SWAT model to simulate daily stream flow over a two year period in a small watershed in Kentucky covering an area of 5.5 km^2. The Nash-Sutcliffe efficiency (NSE) for monthly flows was 0.58 for 1995 and 0.89 for 1996 whereas for the daily flows, NSE was much less, -0.04 and 0.19. Fontaine et al. (2002) developed a snowfall-melt routine for mountainous terrain for the SWAT model. This study increased the scope of the SWAT model and simulation of mountainous region with a large snowmelt component was added. For snowed catchments, the development of new snowmelt algorithms improved the correlation between observed and simulated stream flow. Wang and Melesse (2005) applied the SWAT model for the 433,497 ha Wild Rice River watershed, located in north western Minnesota (USA) and obtained satisfactory monthly and seasonal performances. Also performance of the model for daily stream flow predominantly generated from melting snows was satisfactory.

Remote sensing and GIS is a very useful technique which has a capability to solve various issue for conservation of natural resources. Present days, there is a various kind of concern about the glacier. Glaciers are continuously melting and disappear due to global warming and climatic variability. Now a days glacier study become important and necessary to know about how much climate change effect due to continuously glacier shrinking in N-W Himalayan region . As we know that remote sensing information can be well integrated with the GIS system to solve numerous spatial problems. Stream flow modeling study is important because glaciers are rapidly disappear and melting down due to the climatic condition. It is the main source of fresh water and has a use in different sectors like hydropower and Agriculture A part from this, many rivers fed by the Glacier. Several studies have been done on Himalayan glaciers to assess the climate change and retreat rate of glacier using remote sensing and GIS.

Thus, regular monitoring of Himalayan cryosphere is important for improving our knowledge of its response to climate change. In Hydrological stream flow modelling on Tungabhadra catchment which is situated Tungabhadra sub basin of the Krishna river basin in India. Its derives two tributaries, viz. Tunga and bhadra in Western Ghats Karnataka. In this measurement the stream flow for agricultural watershed management and its effect on many aspects of water balance parameters. For this SWAT model was used to conduct the study of Tungabhadra catchment. SWAT cup model parameters are applied to find out the global sensitivity parameters for stream flow calibration that shows variation in observed and simulated flows at this catchment area. The whole model can be used for future prediction and assessment of water balance and climate change studies (Singh et al., 2013). As well as impact of climate change on water resources in a hilly river basin .another research work on sub basin of Sutlej basin which is located hilly terrain basin in North West Himalayan. He investigated for hydrologic response to potential changes in climate variability. In this study SWAT model was predicted from calibration and validation used with ten sensitive parameters and climate change were also performed in Sutlej basin through GCM data to define future time series of temperature and precipitation is generated through SDSM that model is predicted from present and future climate scenario (Dharamveer et al., 2015).stream flow modelling in a highly managed mountainous glacier watershed because of irregular topography and complex hydrological processes. Changes in precipitation and temperature with respect to elevation that reproduce stream runoff by hydrological models. In this study, results representation based on the historic discharge analysis for hydropower storage reservoirs having very strong influences on the downstream catchment that can be affected basin for water transaction (Rahman et al., 2012). Spruill et al. (2000) applied the SWAT model to simulate daily stream flow over a two year period in a small watershed in Kentucky covering an area of 5.5 km^2. The Nash-Sutcliffe efficiency (NSE) for monthly flows was 0.58 for 1995 and 0.89 for 1996 whereas for the daily flows, NSE was much less, -0.04 and 0.19. Fontaine et al. (2002) developed a snowfall-melt routine for mountainous terrain for the SWAT model. This study increased the scope of the SWAT model and simulation of mountainous region with a large snowmelt component was added. For snow fed catchments, the development of new snowmelt algorithms improved the correlation between observed and simulated stream flow. Wang and Melesse (2005) applied the SWAT model for the 433,497 ha Wild Rice River watershed, located in north-western

Minnesota (USA) and obtained satisfactory monthly and seasonal performances. Also performance of the model for daily stream flow predominantly generated from melting snows was satisfactory.

Lemonds et al. (2007) applied SWAT model to the Blue River basin (867 km^2) in Colorado (USA). Beside the snowmelt and snow formation parameters, several ground-water parameters were used in model calibration. Comparison of stream flow hydrographs at two U.S. Geological Survey gauging stations with simulated hydrographs showed good fits to average monthly values (NSE = 0.71). Zhang *et al.* (2008) combined the SWAT Model with different snowmelt algorithms to simulate monthly runoff of a mountainous river basin (114,345 km^2) in the headwaters of the Yellow River, China. To evaluate the performance of SWAT with different snowmelt algorithms, monthly runoff data of two time periods (1975-1985 and 1986-1990) were used. Model performance was found to be satisfactory.

Jain et al. (2010) applied the SWAT model to simulate runoff for the Sutlej River located in Western Himalayan region. Runoff was estimated from the intermediate catchment between two gauging sites, Sunni and Kasol. The model was calibrated with the observed discharges for years 1993 & 1994 and validated by using the observed hydrographs for the years 1995 to 1997. Statistical and graphical methods were employed to evaluate the performance of the model. The coefficients of determination (R^2) for the daily and monthly runoff were 0.53 and 0.90 respectively for the calibration period and 0.33 and 0.62 respectively for the validation period. These results show the difficulties in obtaining a good calibration for daily flows. Tyagi et al. (2013) examined the applicability of SWAT model in estimating daily discharge and sediment delivery from mountainous forested watersheds and assessed the impact of forest cover types on stream discharge pattern and sediment load. The study watersheds, Arnigad and Bansigad, comprising of dense Oak forest (80%) and degraded Oak forest (83%) respectively, are located in Lower Himalaya (India). Calibration results for Arnigad watershed showed very good agreement between observed and simulated daily discharges, with r^2 of 0.91 and NSE of 84.48%, and r^2 of 0.89 and NSE of 83.11% in sediment simulation. The model also exhibited high performance on Bansigad watershed with r^2 of 0.91 and NSE of 89.74% in discharge simulation; and r^2 of 0.86 and NSE of 82.07% in sediment simulation. The authors concluded that SWAT is capable of estimating discharge and sediment yield from

Himalayan forested watershedsHowever, the degradation of the river water quality in Canadian rural catchment, understand the problems related to diffuse pollution with the help of SWAT model. As stream flow observations under ice-cover conditions are known to be less reliable than ice free ones. This, current snowmelt component model structure regarding routing of snowmelt events that explain systematic tendency to underestimate predicted winter volume (Levesque et al., 2008).Thus, the Model evaluation guidelines for systematic quantification of accuracy in watershed simulations study describe watershed models are powerful tools for simulating the effect of watershed processes and management on soil and water resources. In this study, it is defined model evolution in terms of the accuracy of simulated data compared to the measured flow and constituent value and recommended model evaluation statistics and their respective performance ratings, and the step description is established a platform for model evaluation (Moriasi et al., 2006). In SWAT model snow accumulation and snowmelt dynamics play an important role to measurements of snow coverage, remotely sensed snow cover information with combined discharge time series in order to validate the model representation of stream hydrology and spatial snow cover extent (Stehr et al., 2009). Hydrologic modeling of the bouregreg watershed (Morocco) using GIS and SWAT Model describe water balance in the watershed and estimate the monthly volume inflow to SMBA dam and the model parameters were analyzed, ranked and adjusted for hydrologic Modelling purposes using daily temporal data series. They were calibrated and validated based on statistical indicators and SWAT model used and define efficiently in semi-arid regions to support water management policies (Fadil et al., 2011). In water balance studies of Narmada River Basin an integrated approach using remote sensing and GIS tools and techniques. In their study, he estimated of water resources availability in large river basin. In this study, he describes simulation and these impacts on long –term. Daily metrological data was used as input for calibration. Calibration and validation was done which indicates decrease in average annual water yield (Gupta et al., 2014). For using SWAT model it's define prediction of water yield and water balance: case study of upstream catchment of jebba dam in Nigeria. In this study, they were discussed estimation of water yield and water balance in a river catchment is critical to sustainable management of water resource. SWAT and GIS tool was applied to examine these process and found the results. (Adeogun et al. 2014). Another study was formulated on SWAT application on the Simulation of surface runoff for upper Tapi sub catchment area (Burhanpur watershed) using SWAT. In this study, he simulated the surface runoff for the Tapi basin and compared it with the observed value of runoff for the basin. Lastly, he has calculated the co-efficient of determination (R^2) which indicated the efficiency of the model (Shivhare, V. et al., 2014). In hydrological Modelling of the simply dam watershed (Pakistan) using GIS and SWAT model apply to define modern mathematical models have been developed for studying this complex hydrological processes of a watershed that shows the direct relation of weather, topography, geology and land use and lastly validate and calibration was performed to generate the result (Ghoraba et al., 2015).The climate change effect on the hydrological cycle and water resource management impact in arid and semi-arid regions as well defined with the help of SWAT model, in SWAT calibration and validation was simulated and investigate the climate change scenario (Wang et al., 2011). It can be noted from the above that a number of studies in mountainous catchments have been carried out by using the SWAT model and the results have been quite good. However, only limited studies have been carried out in the Himalayan region. Nearly 2 billion people depend on water of Himalayan Rivers which have huge hydropower potential but water triggered disasters are also frequent in these basins. Further, climate change is likely to significantly impact hydrological response of these river basins. Thus there is a need for better understanding of the hydrologic response of Himalayan Rivers. Therefore, the objective of this study was to evaluate the applicability of the SWAT model in simulating stream flow in Himalayan basins with high altitude and permanent snow/glacier cover and carry an uncertainty analysis. Successful modeling of this basin will help in improved management of water resources and partly overcome problems due to data scarcity.

These studies were referred to estimate stream flow modeling under climate change for the present study. These are the main study which provides the general overview for conduct the present study.

CHAPTER 4

METHODOLOGY

4.1 Database Development for the Study Area

Multispectral, Multi-temporal and dynamic data have been collected for the study area (Bhuntar River Basin). The satellite imageries, ASTER DEM, Metrological data, GCM data, Discharge data, and various physical parameters of soil have been obtained from various sources. The basin DEM has been obtained at 30 m resolution from the ASTER Data which is freely available on the web (USGS)and the GCM data have been provided by the NIH, Roorkee, Metrological data such as rainfall, temperature and relative humidity were obtained from Bhakra Beas Management Board (BBMB), India. Solar radiation and wind speed data were downloaded from the link http://globalweather.tamu.edu/ . .LULC map was prepared from Landsat-8 satellite imagery. The soil map was prepared from the soil map sheet of NBSS & LUP, Nagpur. Daily stream flow data (1990-2010) was also obtained from BBMB, India for gauging station located at the Bhuntar on Beas River.

Table 1: The details of the datasets used in the present study are discussed below

Data Type	Source	Spatial/ Temporal Resolution	Description
Topography	http://gdem.ersdac.jspacesystems.or.jp	30 m	ASTER Digital Elevation Model
Land use/Land cover data prepare	Landsat-8 satellite imagery (Earth explorer)http://usgc.earthexplorer	30 m	Land-use Classification
Soils	NBSS& LUP, Nagpur (Hardcopy of soil map was converted into digital form)	-	Soil Classification

Weather Data	BBMB, India	Daily	Rainfall , minimum and maximum temperature, Relative Humidity
	http://globalweather.tamu.edu/	Daily	Solar Radiation, Wind Speed
Stream Flow Data	BBMB, India	Daily	Daily stream flows measured at the gauging stations
GCM	NIH (Provide)	Daily	Present and future scenario

4.2 MODEL INPUTS

In the setup of SWAT model, the first step is identification and delimitation of hydrological response units (HRUs) for the study area. River network for basins up to Bhuntar was delineated from ASTER DEM by using the analytic technique of the Arc SWAT 2009 GIS interface. To obtain a reasonable numbers of HRUs within each sub basin, a unique combination of land use and soil (thresholds of 10% in land use/cover, 10% in soil type and 15% in slope) were used. In this procedure, the Beas basin up to Bhuntar was divided into six sub-basins and 100 HRUs. These configurations ensure a satisfactory stream network description regarding the management of dominant land uses, soils within each sub basin, and a reasonable number of HRUs per sub-basin.

4.2.1 ASTER Digital Elevation Model

A DEM generated using the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) sensor was used in this study. ASTER is an imaging instrument on board the Terra satellite launched in December 1999 as a part of NASA's Earth Observing System (EOS). ASTER resolution ranges from 15 to 90 m depending on the wavelength. The instrument records in three bands – the visible/near infrared (VNIR), the shortwave infrared (SWIR) and the thermal infrared (TIR) oriented on the nadir and looking backward. There are 14 spectral bands altogether spanning the visible and infrared spectra and so the sensor is susceptible to cloud cover and cannot record images at night. Because of it's off nadir sensor pointing capability, ASTER can collect the stereo pairs necessary to generate high-resolution DEMs (Bands 3N and 3B). The ASTER on board the Terra satellite has produced 30 m resolution elevation data. There is a fairly complete coverage of the Earth at this high resolution and the data are free.

In present study The ASTER DEM was downloaded for the Himachal Pradesh from the web at the 30 m resolution. The basin was covered in different multi tile; mosaic application was used to mosaic all the tiles to extract the Bhuntar river basin. The Bhuntar River is the main tributary of river Beas. The Bhuntar River Basin was extracted out from the Beas DEM. A view of the ASTER DEM for the study area shown in figure 2.

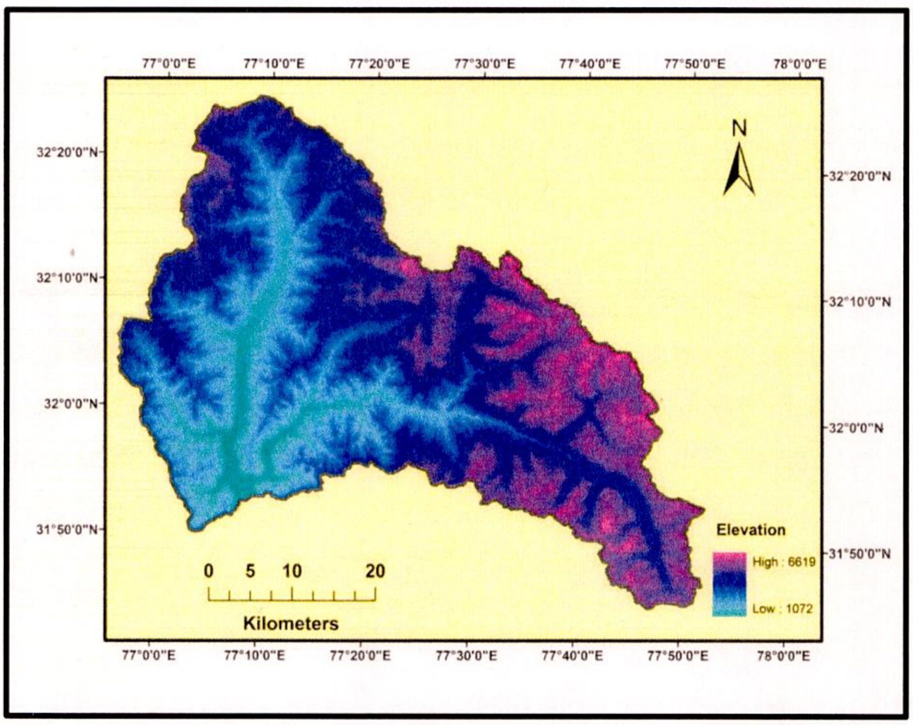


Figure 2: ASTER DEM of Bhuntar River Basin

4.2.2 Soil Map

Soil and its physical properties is the critical input for the SWAT. It plays an important role in various process of hydrological Modelling. In Arc SWAT model, soil physical properties like soil texture, hydraulic conductivity, bulk density, water availability etc. are essential input to fulfill the model requirement. The soils map was digitized from the map of National Bureau for Soil Survey & Land Use Planning (NBSS & LUP), Nagpur. Soil class name defined as (CL-LS-C, GL-SS-RO-D, LS-RO-D, LS-RO-DE-D, SS-RO-DE-D, SS-RO-LS-DE-D) 7 category of soil was considered up to Bhuntar basin.

The soil map is shown in figure.3

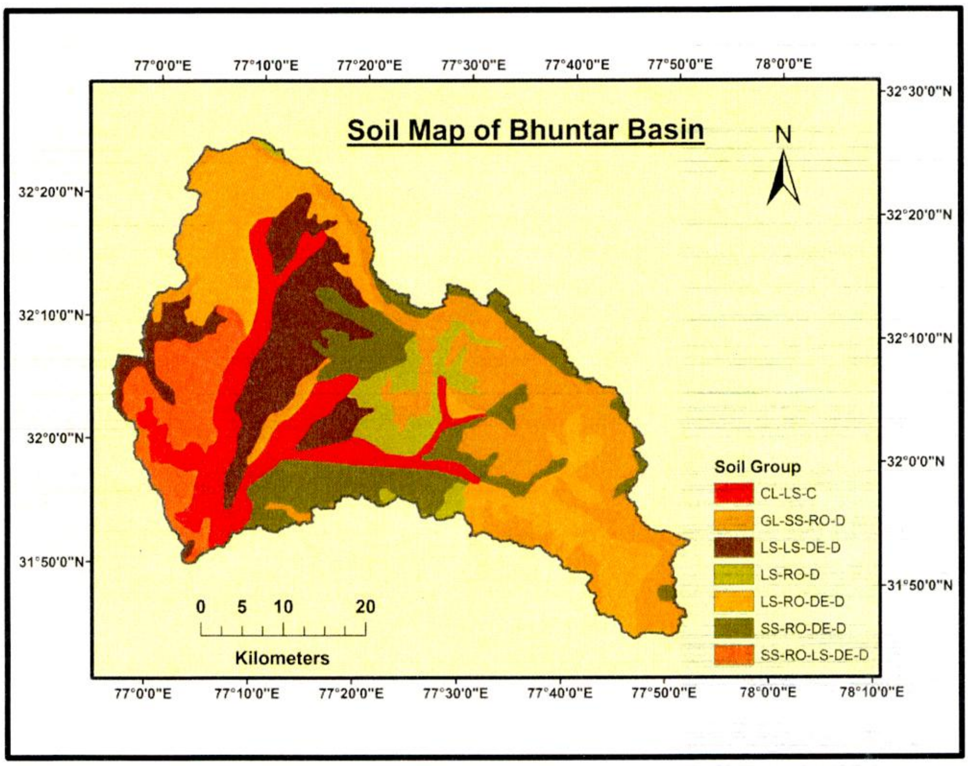


Figure 3: Soil map of Study Area

4.2.3 Land use an land cover map

Land use is one of the most important factors affecting runoff, soil erosion and evapotranspiration in a watershed (Neitsch et al., 2005). As per the land use/ land cover map has been prepared from the landsat-8 satellite imagery. Land use map is important consideration in the hydrological model to fulfill the model requirement. It is basically affects the generation of land flow, soil water storage, water demands for irrigation etc. Five LULC Categories have been identified such as Evergreen forest, Open forest, Rangeland/debris, Snow and Water bodies. A view of the LULC map of Bhuntar Basin is showing in Figure.4

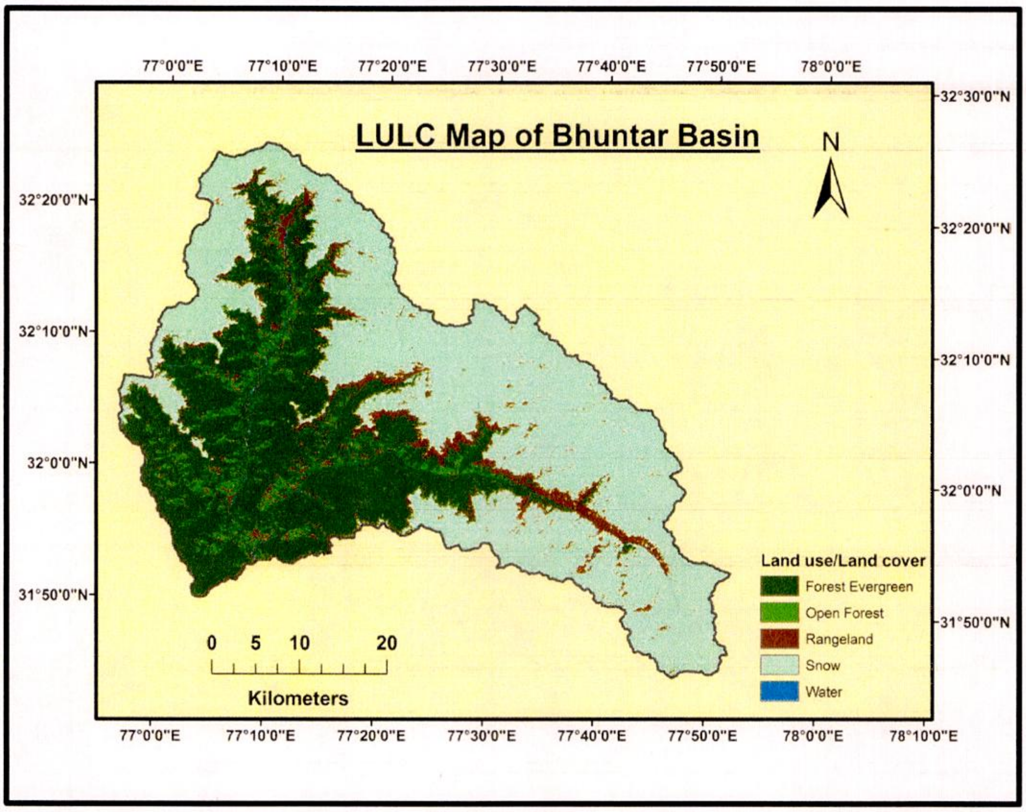


Figure 4: LULC Map of Bhuntar Basin

4.2.4 Climatic data

Various climatic data like precipitation, min. Max. Temperature, solar radiation, relative humidity, wind speed, daily discharge data were considered in the present study and temperature, precipitation, daily discharge data has been obtained from the NIH and wind speed, relative humidity, solar radiation data was obtained from global weather that is freely available in public domain. The model requires daily data of weather parameter. These values used as in Input which records from the observed data or they may be generated through the weather generator. These climatic data for the year 1990 to 2010 were prepared in a SWAT supported format and calculated all parameters through **PCP stat** and **dew point** generator India. Solar radiation and wind speed data were downloaded from the link http://globalweather.tamu.edu/. .LULC map was prepared from Landsat-8 satellite imagery. The soil map, six weather stations were identified across the entire basin through centroid method.

Same process was applied for the GCM data. This is used as an input in present study to estimate or investigate present and future scenario of climate change for Bhuntar basin. There are two data forms were available viz. EC_earth in year 2001 to 2040 and IPSLSD in year 2001 to 2060. All parameter was calculated and generated into the swat supported format to evaluate the model performance and estimate the climatic variability.

4.3 Model Setup

The entire database required for the SWAT model for the Stream flow modeling in Himalayan basin under climate change was developed and used as an input to achieve main goals of study. The main procedure and various step followed in model application are explained below:

- SWAT Project set up
- Automatic watershed delineation
- HRU Analysis
- Write input tables
- Edit SWAT inputs

- SWAT simulation

4.3.1 SWAT Project Setup

This module is basically used to define the location of the project and its geo database. In this project, its name and associated database file are stored in the defined project location.

4.3.2 Data Processing

The entire required database was generated for the model application to estimate stream flow climate change trends. PCP stat and Dew point software was used to calculate the weather parameter. The entire databases required for the stream flow modeling and climate change study for Bhuntar River Basin have been developed to achieve all the objectives of the current study. The main procedures and the various step followed for the main concern of the study area explained in sequential way. The flow chart of the Methodology for stream flow modeling in Bhuntar River Basin is depicted below:

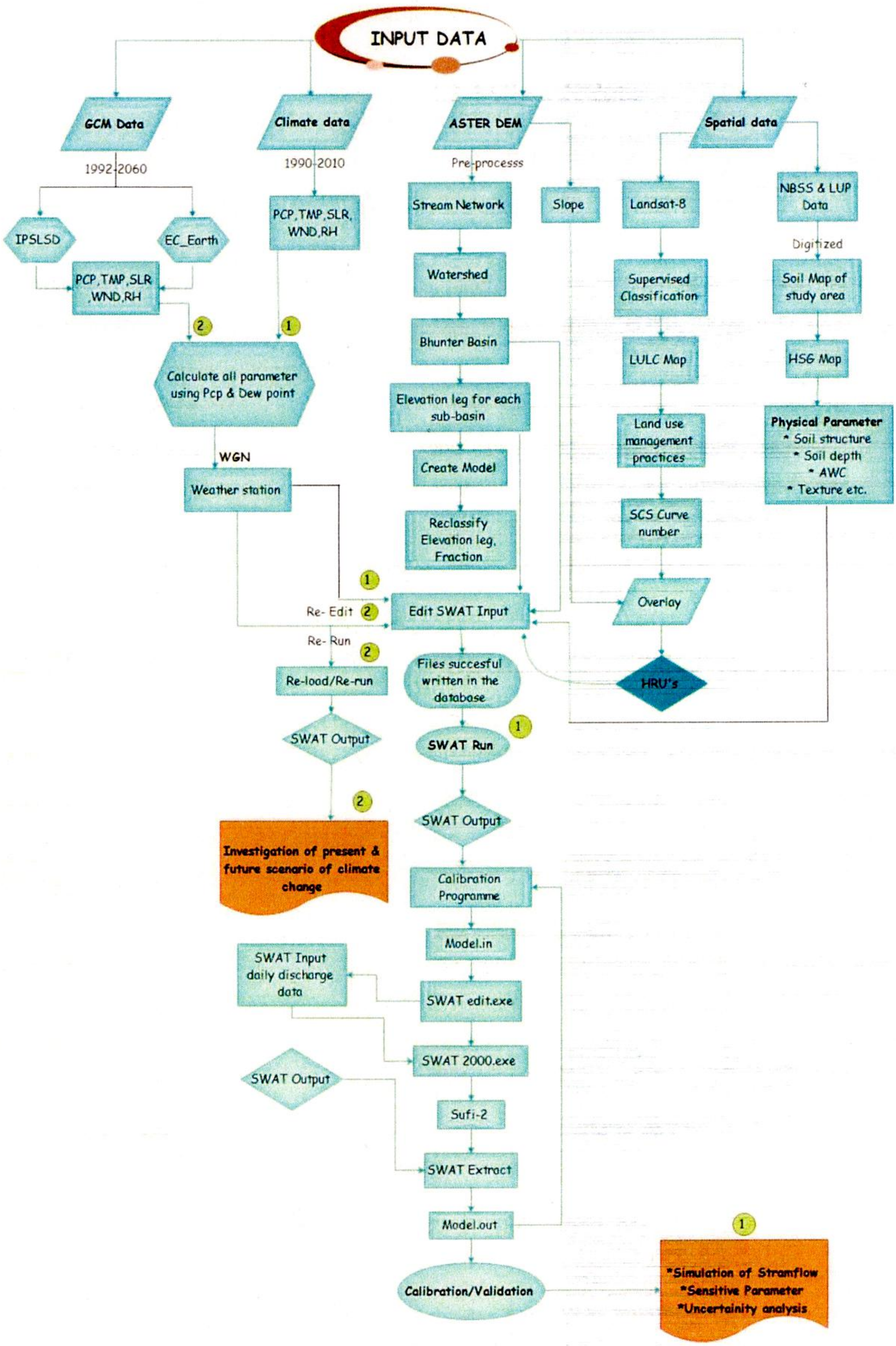


Figure 5: Flow chart of Methodology

4.3.3 Automatic Watershed Delineation

This module is used for delineate the watershed of the study area using digital Elevation model. DEM was used as an input to delineate the watershed for the study area. The DEM have been pre-processed and 3000 ha. Threshold areas were defined to the model to generate the detailed stream network in the basin. Various junction points were generated of the stream which is acting as individual outlets of the sub – tributaries. Common outlet of Bhuntar river basin was defined at the Beas Basin up to Bhuntar district in Kullu to generate the whole watershed of the study area. 6 sub watersheds also were generated and calculated all the sub basin parameter for the study area. The geographical area delineated by the model was found to be 3129670800 area sqm. The Bhuntar Basin watershed is shown in Figure 6.

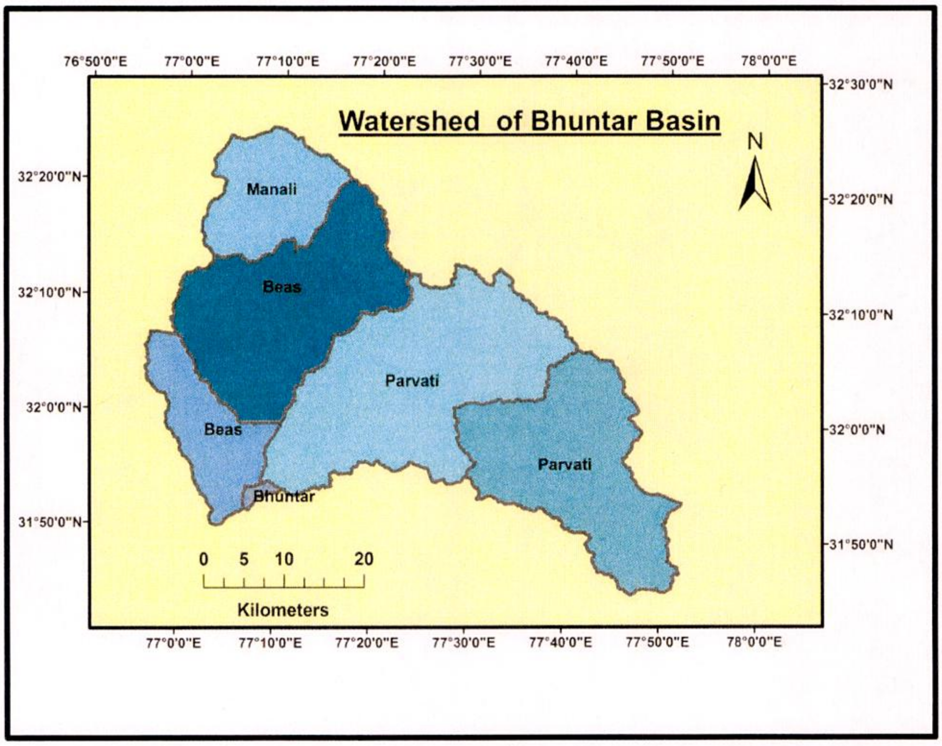


Figure 6: Sub watershed of the Bhuntar River Basin

4.3.4 HRU analysis

HRUs stands for hydrological response unit that divides the watershed into various homogeneous units based on the land use, soil type, and slope at each grid. SWAT requires the land use and soil data to generate the HRUs for each sub basin. The LULC and soil map have been imported in SWAT model. The characteristics of Land use and soil category or look up table are imported to the model. These datasets have been linked to the SWAT geo database to generate the HRU's. These datasets were reclassified according to the codes which have been assigned to the respective category of the spatial datasets and linked to the SWAT Geo database, the slope map were generated by assigning the range of slope which is 0-25, 25-55, 55-80 and 80 above in percentage. These LULC, soil and Slope map were overlaid to generate the multiple HRU's of the Bhuntar river basin which is basically divide the watershed in the homogenous geographic unit of similar land use, soil and slope. For generating the minor land use, soil and the slope the threshold percentage method were selected and 10% for the Land use, 10% for the soil and 15% for the soil is used for the present study. The multiple HRU's and associate report were generated successfully which specified the area of different HRUs in various sub basins. LULC Map and soil map are shown in figure 3, 4. The slope map of Bhuntar basin is shown below:

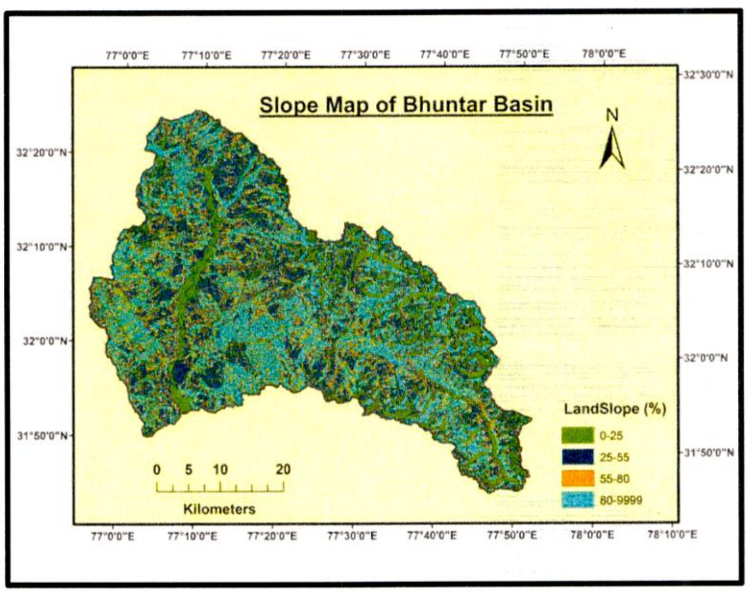


Figure 7: Slope Map of Bhuntar Basin

4.3.5 Write Input Tables

This model requires weather data on daily basis which is recorded from the observed value or they may be generated using weather generator of the SWAT. The climatic data which is used in the present study are daily precipitation, min. Max. Temperature, solar radiation, wind speed, relative humidity. Precipitation and temperature was calculated through PCP stat and DEW Point software to generate all the parameter that is required for the SWAT. The total record of the day by day were calculated through the PCP Stat and Dew Point in which PCP (mm), PCPSTD, PCPSKW, PR W1, PR W2, PCPD, temperature max, temperature minimum, solar radiation, wind speed and relative humidity, dew point parameters on monthly basis were successfully generated. These parameters were used in swat weather input databases. All parameters have been prepared in swat supported format and imported in the model. 6 weather stations were identified across Bhuntar river basin and used as an input for the swat weather generator after this process weather station was successfully imported in the model. The locations of weather station in the basin are shown in the map given below:

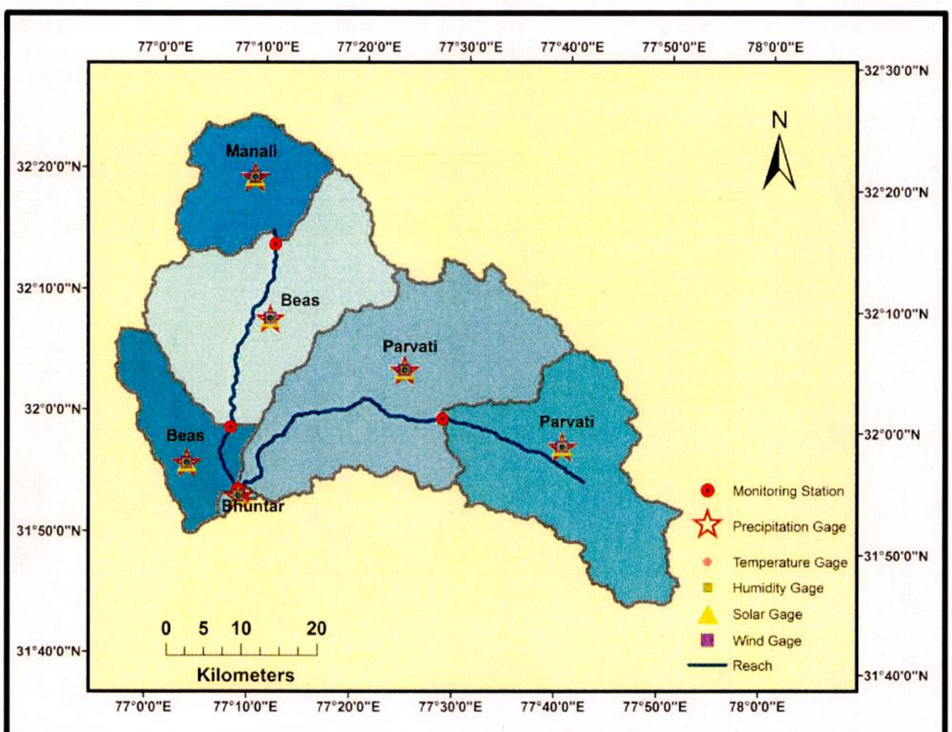


Figure 8: Location of weather station in the Beas up to Bhuntar River Basin

4.3.6 Edit SWAT Input

This module allows the user to edit the database file in the model. It is used to setup additional inputs for running the SWAT model. The characteristics of soil and the physical properties of the soil have been assigned to the model and LULC data and its characteristics also were edited and have been assigned the curve number and elevation leg etc. And the manning's roughness number of the particular class of the LULC data as per the requirement. The files were successfully rewritten and stored in personal Geo database of the model. After this step, the model was ready to be run.

4.3.7 SWAT Simulation

SWAT has been run successfully for the defined duration. The model output like HRU, RCH, and SUB. Stream flow simulation were successfully generated for the simulation on the monthly or annual basis after that manually calibration has been performed .The results and its associate reports of the Bhuntar River basin have been generated successfully.

4.4 SWAT CUP Model (Sufi-2)

The SWAT model has a large number of parameters to describe the different hydrological conditions and features across the basin. After pre-processing this step SWAT cup model was used to calibrate the model finding with the ground observed data. In the SWAT cup, SWAT simulated results and daily observed ground stream flow data from year 1990 to 2000 were imported as an input to calibrate the model output with the discharge data which is recorded on the ground on a daily basis and then validation was performed by using the data from the year 2001 to 2010. Data for the first two years (1990 and 1991) were reserved as "warm-up" period for initial model set-up. These two years were excluded for the evaluation of the model performance. Thus the for model calibration statistics was evaluated for the period 1992-2000.

CHAPTER 5

RESULTS & DISCUSSION

5.1 Calibration and Validation of the SWAT

The SWAT model has a large number of parameters to describe the different hydrological conditions and features across the basin. Calibration and validation of SWAT model are two critical issues in hydrological modeling. During the calibration and validation process, the daily time series data have been used for year 1990-2010. In the calibration 10 years of data has been used in the study (1992-2000) in which 2 year excluded as a "warm up period" likewise validation were performed on the daily time series data for the duration of 10 year (2001-2010). This warm up period is used for the estimation of several parameters of the model, the initial values which are not known (Bekiaris et al. 2005).The calibration and validation parameters were systematically adjusted to obtain results which provide the best match with the observed values across the basin. The catchment response was simulated with the final parameter which was set during the calibration without any change. Calibration was carried out in both ways manually and automatically using SWAT-CUP. The statistical criteria were defined and used to evaluate model performance with the **goodness-of-fit (R^2)** and the **Nash-Sutcliffe efficiency index (NSE)**. The evaluation of model performance was considered better if the values of R^2 and NSE are close to unity.

In the current study, a program developed by Abbaspour et al. (2004) called as SUFI2 optimization program has been used for calibration and validation of the SWAT. Uncertainty analysis and sensitivity analysis have been carried out to find out the sensitive parameter and uncertainty on the basis of measured river discharge data. Global sensitivity analysis was performed and calculation has been made using multiple regression system, it regress the Latin hypercube generated parameters against the objective function values. 18 calibrated parameters including 9 snowmelt related parameters have been used as an input for Global sensitivity analysis.

SWAT-CUP stream flow parameters description and value which is used to estimate the calibration and validation are shown in Table.2

Table 2: Description of stream flow calibration parameters

Parameters selected for the calibration	Description of parameters
R__CN2.mgt	Initial SCS runoff curve number for moisture condition II
V__ALPHA_BF.gw	Base flow alpha factor (days)
V__GW_DELAY.gw	Groundwater delay (days)
R__SOL_AWC (...).sol	Available water capacity of the soil layer (mm/mm)
R__SOL_K (...).sol	Saturated hydraulic conductivity of soil (mm/hr.)
V__ESCO.hru	Soil evaporation compensation factor
V__CH_K2.rte	Effective hydraulic conductivity in main channel alluvium(mm/h)
V__RCHRG_DP.gw	Deep aquifer percolation fraction
V__CANMX.hru	Maximum canopy storage (mm H2O)
V__PLAPS.sub	Precipitation Lapse Rate
V__TLAPS.sub	Temperature Lapse Rate
V__SFTMP.bsn	Snowfall Temperature (^oC)
V__SMTMP.bsn	Snowmelt base Temperature (^oC)
V__SMFMN.bsn	Minimum melt rate for snow during year (mm $H_2O/^oC$ -day)
V__SMFMX.bsn	Maximum melt rate for snow during year (mm $H_2O/^oC$ -day)
V__TIMP.bsn	Snow pack temperature lag factor
V__SNOCOVMX.bsn	Minimum snow water content corresponds to 100% snow cover, SNO100 (SNOCOVMX- mm H_2O)
V__SNO50COV.bsn	Snow water content corresponds to 50% snow cover

Table 3: Stream flow parameter uncertainties for SUFI-2 of Bhuntar basin

Parameter	Fitted value	Min value	Max value
R__CN2.mgt	-0.157105	-0.198882	-0.134609
V__ALPHA_BF.gw	0.024675	0.02267	0.026316
V__GW_DELAY.gw	15.849224	15.307833	26.135664
V__RCHRG_DP.gw	0.014472	0.014241	0.014597
V__REVAPMN.gw	132.327774	104.989021	134.81311

R__SOL_AWC (...).sol	0.248831	0.184231	0.266699
R__SOL_K (...).sol	-0.291881	-0.339435	-0.262321
V__PLAPS.sub	99.156166	89.873993	100
V__TLAPS.sub	-9.240855	-9.179295	-9.244095
V__CH_K2.rte	77.333336	50	90
V__ESCO.hru	0.179252	0.179251	0.179259
V__SFTMP.bsn	-0.702976	-0.702975	-0.702976
V__SMTMP.bsn	2.863735	2.815472	2.953367
V__SMFMX.bsn	1.942877	1.941232	1.948826
V__SMFMN.bsn	0.126696	0.060043	0.130204
V__TIMP.bsn	0.338256	0.338254	0.338267
V__SNOCOVMX.bsn	498.053314	470.741821	500.536163
V__SNO50COV.bsn	0.444373	0.340361	0.446136

The ranges of the parameters have been fitted for the calibration in the SUFI2 technique is defined above in the Table.3 for Bhuntar site. The remaining parameters did not affect much change in the model output. The parameters have been given rank for their sensitivity to the model calibration.

5.2 Sensitivity Analysis

Sensitivity analyses have been performed for the current study to find out the sensitive parameter for the study. Sensitivity analysis was implemented for all 18 SWAT parameters which influence land phase and routing phase of water cycle. In the present study, SUFI-2 has been used for parameter optimization. SUFI-2 algorithm gives the comparable results with mostly used in auto calibration which applied for the sensitivity parameters, calibration, validation and the uncertainty analysis. Total 18 parameters which mainly lead the stream flow cognitive process has been shown in table.2 used for the model parameterization and the sensitive parameter used in the calibration and validation are shown in Figure below:

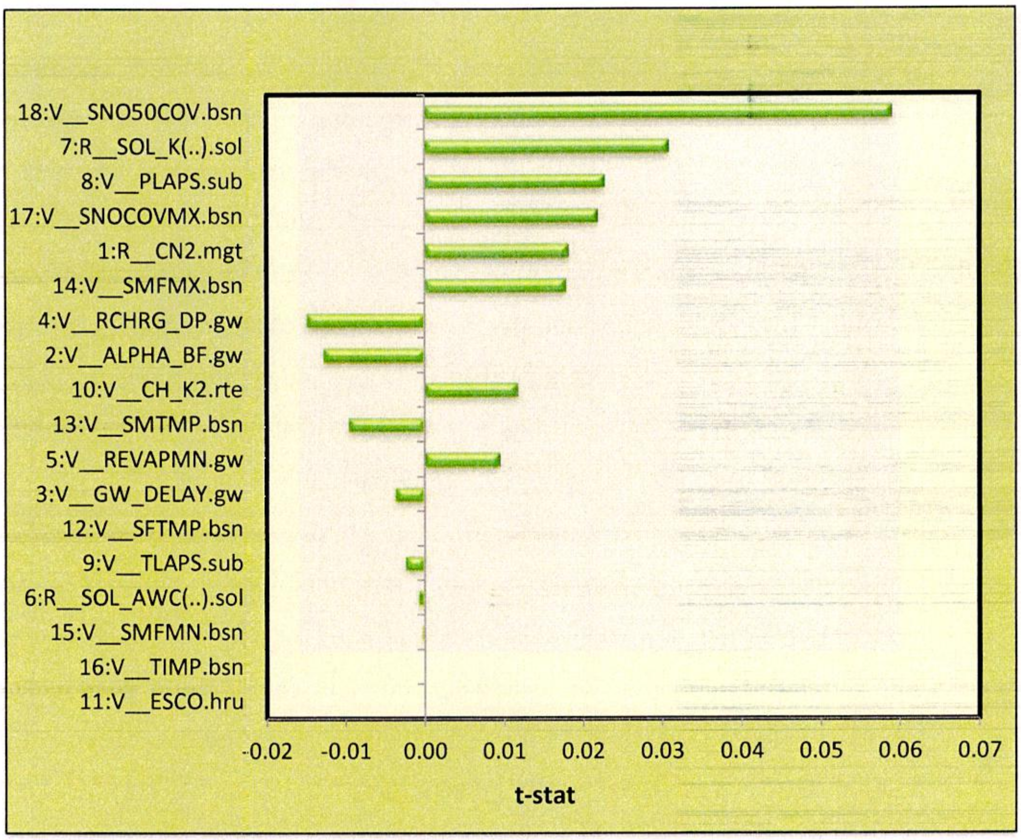


Figure 9: Graphical representation of t-stat showing sensitivity of the parameter

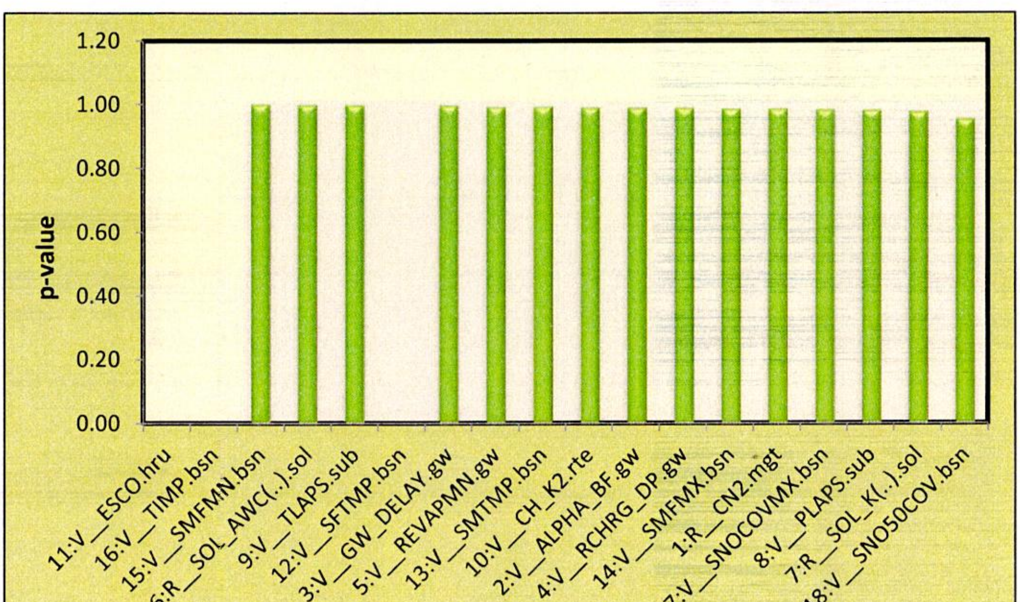
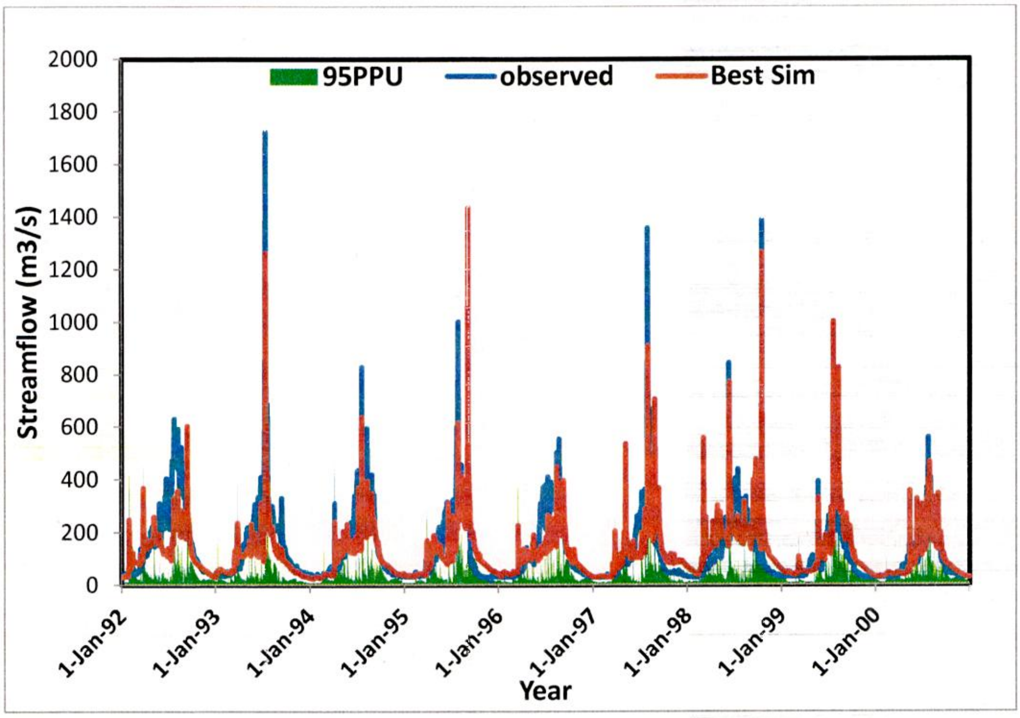


Figure 10: Graphical representation of p-value showing sensitivity of the parameter

These sensitive parameters were mostly responsible for the model calibration and parameter changes during model iteration processes. **The values of P factor and R factor reflect the uncertainty about the model parameters** which takes into account the discharge observations. These two measures also specify the termination rules for SUFI iterations. When more than half of the observations can be bracketed inside the uncertainty bound and the R factor value reaches a small ratio – generally below 1, this is a state of being sufficiently calibrated. The sampling run will be iterated several times by resettling, usually narrowing the parameter space though the posterior parameter distribution, until the calibration goal is achieved. The number of iterations carried out for Bhuntar site **500-600**. For each iteration, **400-600** simulations were performed. A comparison of simulated daily stream flow with observed data have been evaluated at the outlet of the each sub basin (Bhuntar) for both calibration and validation. These are shown in Table.4 the simulated daily flow shows in better agreement with the observed values for the calibration period with **R^2= 0.6013, NS = 0.60, Br^2 = 0.352** respectively. Calibration and validation periods indicate that the stream flow is under predicted by SWAT model. Precipitation and observed stream flow is showing the good fitness especially during high flows (Shrestha et al. 2013).

Table 4: Statistical performance indicators for calibration and validation for the Bhuntar River Basin.

STATISTICAL INDICATOR	calibration(1992-2000)	Validation(2001-2010)
P-Factor	0.27	0.14
R-Factor	0.11	0
R^2	0.6	0.57
NS	0.6	0.48
Br^2	0.352	0.2589



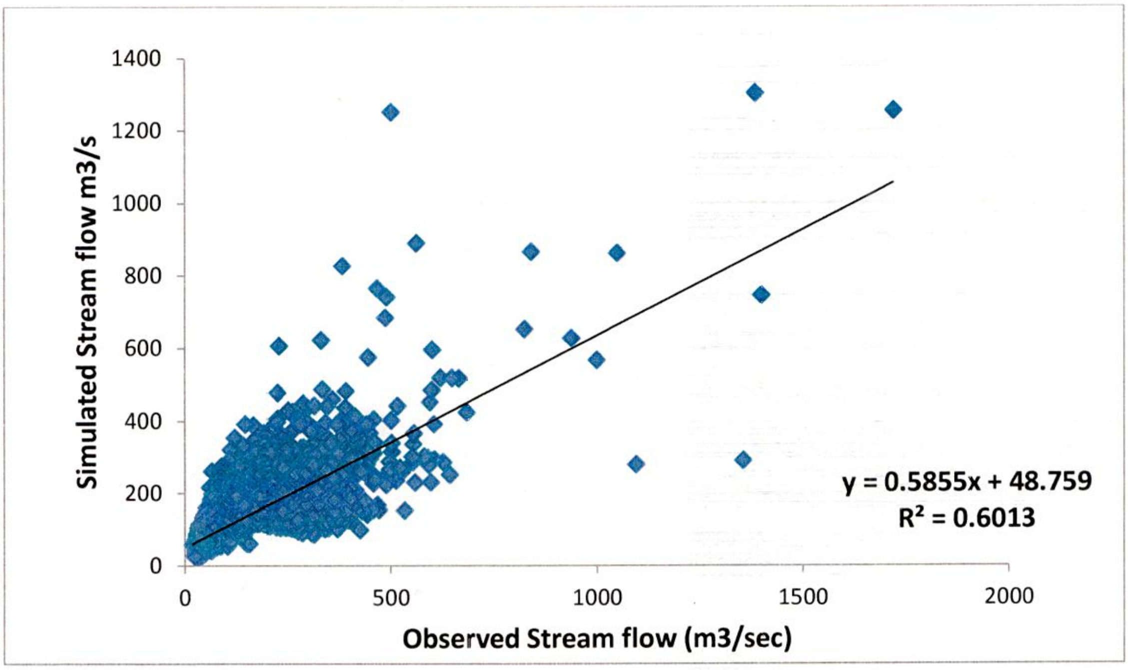
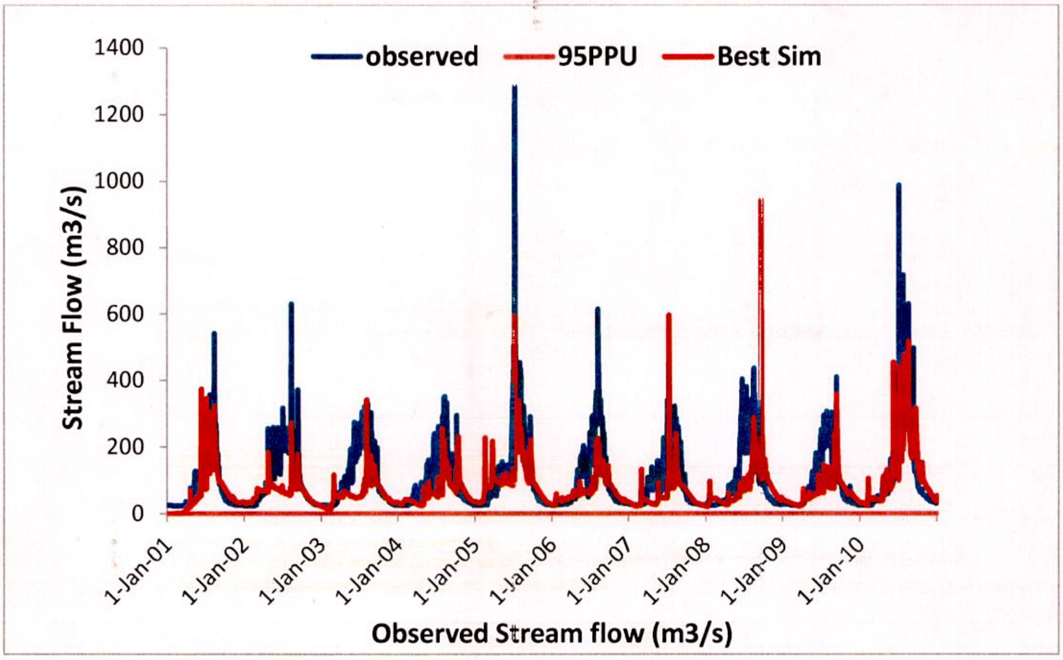


Figure 11: Comparison of daily observed and simulated stream flow hydrograph of Beas basin up to Bhuntar during calibration period (1992-2000)



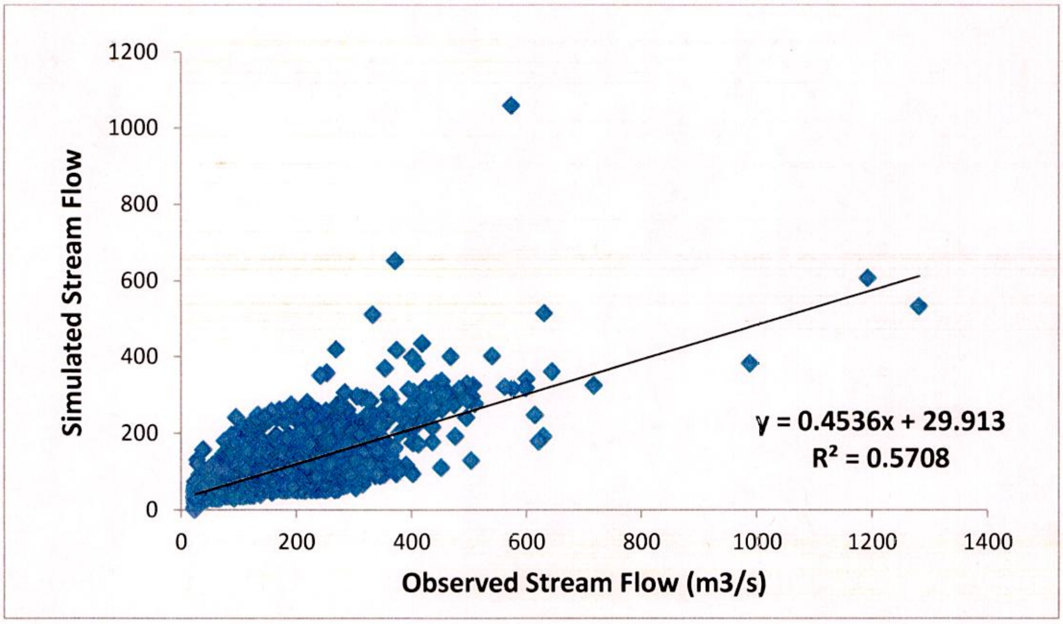
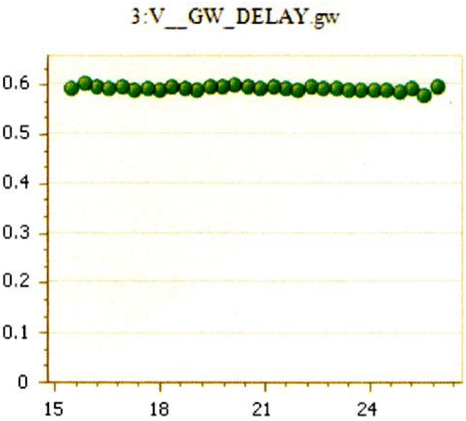


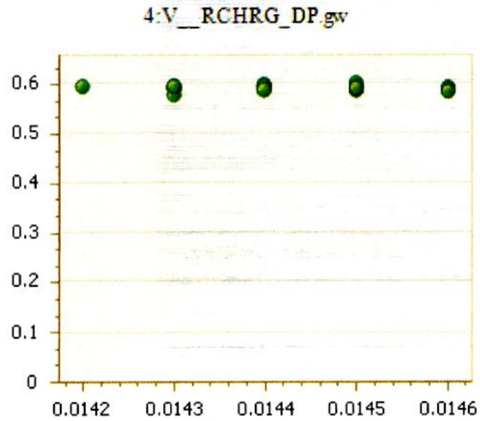
Figure 12: Comparison of daily observed and simulated stream flow hydrograph of Beas basin up to Bhuntar during validation period (2001-2010).

5.3 Dotty plot:

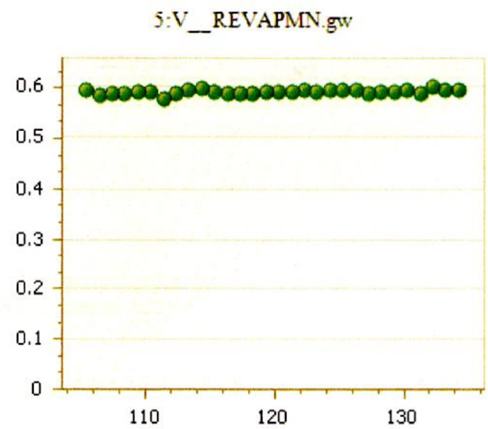
The dotty plots show the distribution of the number of simulations in the sensitivity analysis after comparing parameter values with the objective functions for daily calibrations. The dotty plots for Bhuntar sites are shown in Figure 13. It can be seen in the graph that during the calibration, mostly parameters have shown relatively less uncertainty than obtained values during the validation.



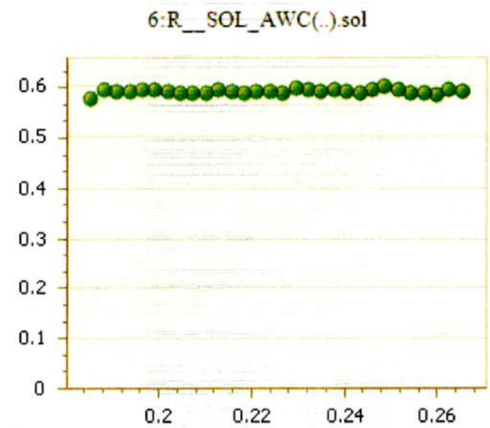
a.



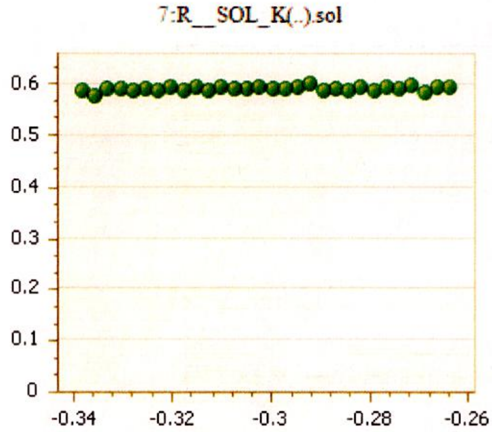
b.



c.



d.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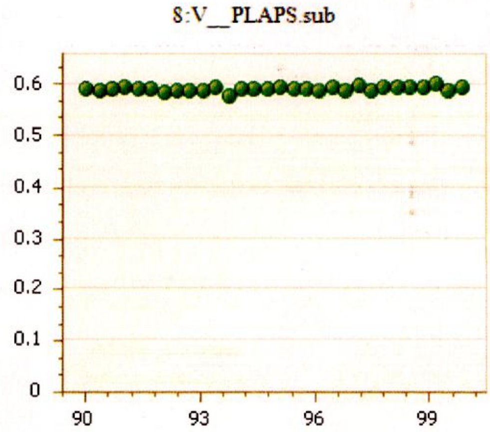
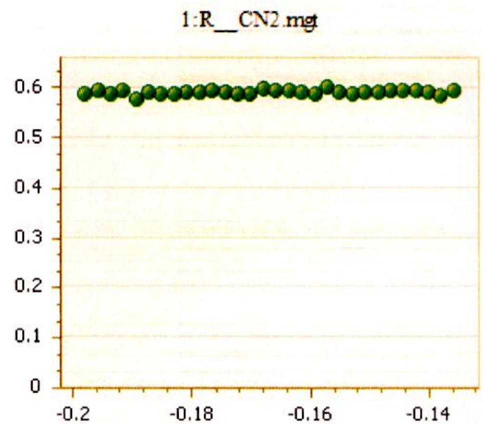
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.34
-0.32
-0.3
-0.28
-0.26

e.


8:V__PLAPS.sub
0.6
0.5
0.4
0.3
0.2
0.1
0
90
93
96
99

f.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0.2
0.1
0
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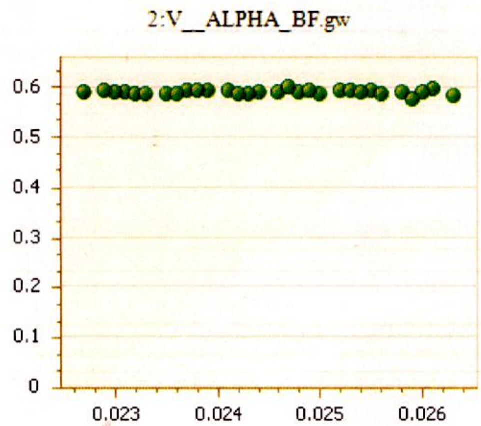
-0.16
-0.14

g.


2:V__ALPHA_BF.gw
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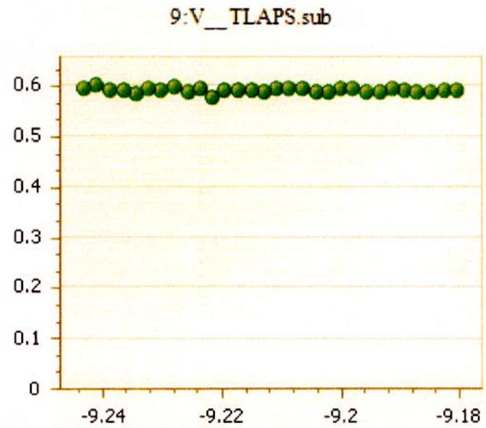
0.5
0.4
0.3
0.2
0.1
0
0.023
0.024
0.025
0.026

h.


9:V__TLAPS.sub
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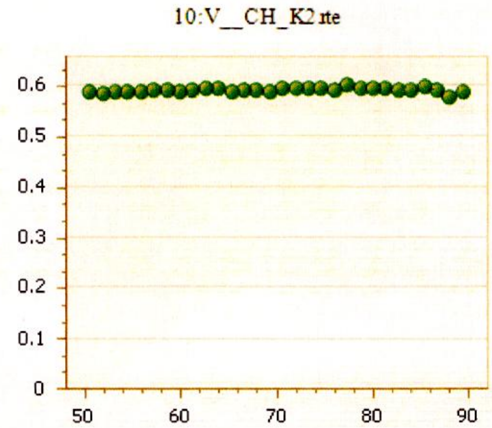
0.5
0.4
0.3
0.2
0.1
0
-9.24
-9.22
-9.2
-9.18

i.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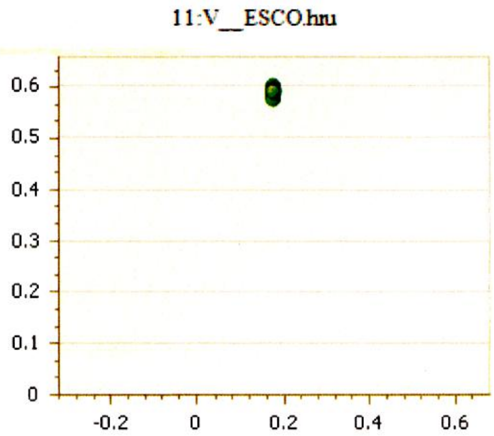
0.4
0.3
0.2
0.1
0
50
60
70
80
90

j.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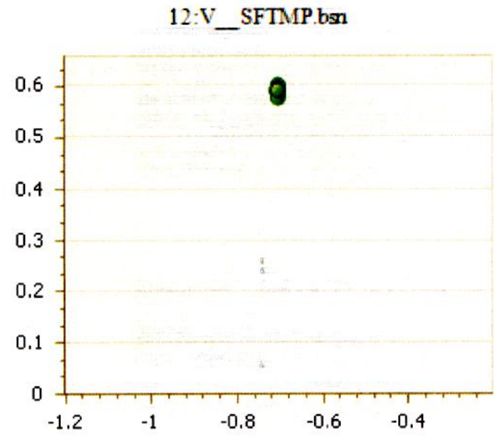
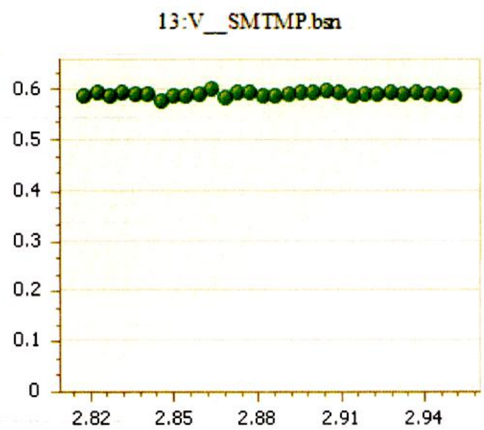
0.5
0.4
0.3
0.2
0.1
0
-0.2
0
0.2
0.4
0.6

k.


12:V__SFTMP.bsn
0.6
0.5
0.4
0.3
0.2
0.1
0
-1.2
-1
-0.8
-0.6
-0.4

l.


13:V__SMTMP.bsn
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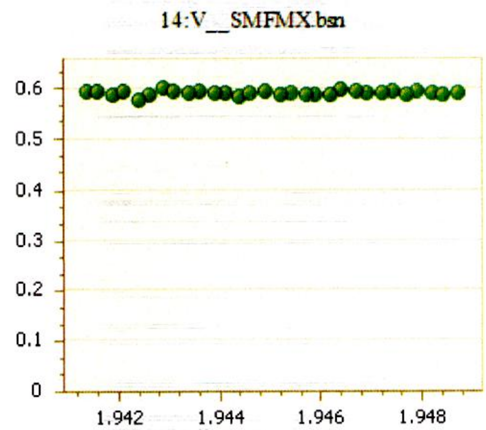
0.5
0.4
0.3
0.2
0.1
0
2.82
2.85
2.88
2.91
2.94

m.


14:V__SMFMX.bsn
0.6
0.5
0.4
0.3
0.2
0.1
0
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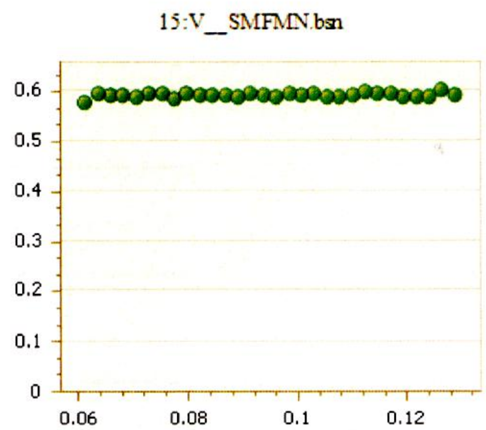
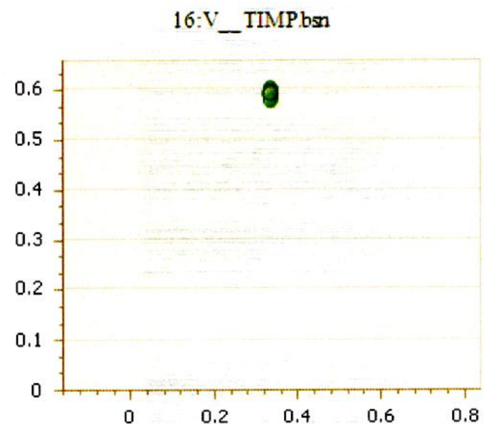
1.944
1.946
1.948

n.


15:V__SMFMN.bsn
0.6
0.5
0.4
0.3
0.2
0.1
0
0.06
0.08
0.1
0.12

o.


16:V__TIMP.bsn
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0.4
0.3
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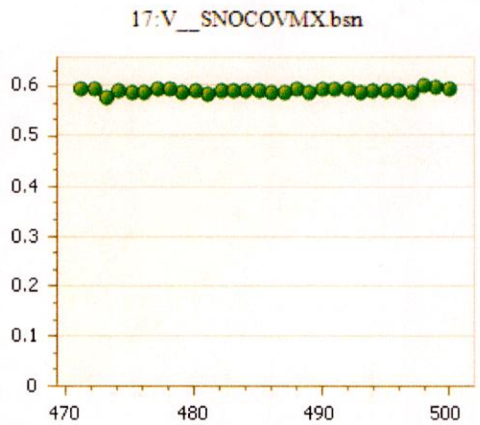
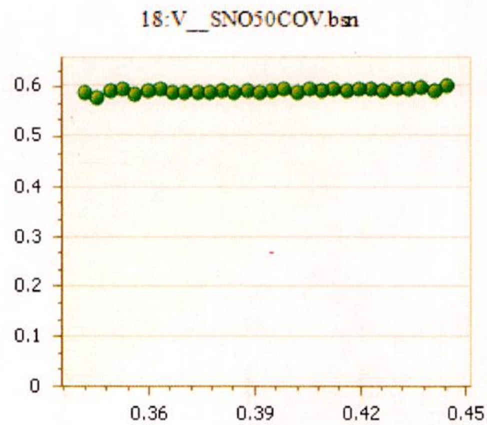
0.1
0
0
0.2
0.4
0.6
0.8

p.



q.



r.

Figure 13: Dotty plots for Bhuntar basin during calibration.

The Dotty plots parameters have been optimized and identified through the sensitivity analysis. Calibrated sensitivity parameter values shows that the CN is the most sensitive parameter for changes in the discharge process. A part from that, Other parameters (Next to CN) are related to groundwater among which ALFA_BF parameter is an index value which describe the underground flow response to changes inflow. In the present study, snowmelt related parameters were found to be less sensitive compared to catchment related parameters. PLAPS and TLAPS are more sensitive than the others sensitive parameter. Five objective functions viz. *P*-factor (ranges between 0% and 100%), *R*-factor (ranges between 0 and infinity), coefficient of determination $R^2 = 0.6013$, NSE = 0.60 and $bR^2 = 0.352$ (coefficient of determination multiplied by the coefficient of regression line) were selected to analyse efficacy of the model for simulated stream flow.The time series of the observed and simulated daily stream flows for the calibration period of Bhuntar site in Figure 12a. Uncertainty results of SUFI-2 are shown as the shaded region (95PPU) which contains all uncertainties from the different sources.As can be seen from the figure that the overall shape of the hydrographs is matching well. Some of the observed values have high peaks which define the simulated results are satisfactory but some are under simulated. There are some peaks in the simulated hydrograph which are not seen in the observed hydrograph, these could be due to some error in the model parameter. The shaded region in the plots (95PPU band) shows uncertainty in the model. In this case it brackets a large amount of the simulated data. The time series of the observed and simulated daily hydrographs for the calibration period (1992-2000) is shown in Figure 11. It is seen from the graph that the simulated hydrograph correlates very well with observed hydrograph. Scatter plot between observed simulated discharges for the calibration data indicates that the points are evenly distributed around **the 1:1 line** but some points in the high flow range are far away from the line. Further, for the calibration period, the scatter plot Figure 11. Also shows that most points are close to **the 1:1** line but some points are away.

The hydrographs of the observed and simulated daily flows for the validation period are shown in Figure 12. In this case also, the overall shape of the simulated hydrograph is matched well with the observed hydrograph. Some of the observed high peaks have been simulated well but some are poorly matched. The time series of the observed and simulated hydrographs on the daily basis for the validation period is shown in Figure 12. The simulation was carried out for ten year 2001-2010. Simulated hydrograph correlates significantly well with observed hydrograph. Scatter plot between observed and simulated discharges for the validation shown in figure 12. Indicates that even distribution of the points around the **1:1** line with some points lying far away from the line. Even though several points in the higher flow range are away from the **45^o line**, the scatter is somewhat lesser than in the case of Bhuntar. Further, for the validation period, the scatter plot (Figure 12) also shows the points of the simulated flows are close to the **45^oline**.It is difficult to desegregation of the error into source components, in case the model is nonlinear and different sources of error may interact to produce the measured deviation.

As can be seen from Table 4. About 27% data were bracketed by 95PPUin daily stream flow calibration for Bhuntar, respectively. While in daily stream flow validation about 11% data were bracketed by 95PPU, for Bhuntar and Thalout respectively. Both the catchments show an acceptable simulation uncertainty range (R factor<1) which brackets the observations most of the time (P factor>50%). Even though some simulations are less accurate during low-flow periods, the shape of the hydrograph is very well approximated for Bhuntar basins, and the 90% uncertainty bounds are generally narrow. The Statistical performance indicates for calibration and validation for the Beas River basin up to Bhuntar shown in Table 1. The

Coefficient of determination R^2 comes out to be 0.60.While during validation these values were 0.57 and 0.48 shown as a satisfactory results for the study area.

5.4 Estimation of water balance for the Bhuntar catchment

The mean annual water balance of the sub basin simulated by SWAT for the duration 1990-2010.The observed average annual discharge is 129.31 cumec and simulated discharge comes out to be 122.55 cumec for Bhuntar site. The water balance components for calibration as well as validation period for the Bhuntar basins are given in Table .... The main water balance components include: the total amount of precipitation falling on the sub-basin, actual evapo-transpiration from the basin, snowmelt runoff, and the net amount of water that leaves from the basin and contributes to stream flow (water yield). Here, water yield includes surface runoff contribution, lateral flow contribution to stream flow (water flowing laterally within the soil profile that enters the main channel) and ground water contribution to stream flow (water from shallow aquifer that returns to river reach). The results indicate that the direct surface runoff contribution is small in the water yield and the main contribution to water yield is through lateral flow and ground water flow. The ET for Bhuntar comes out to be 12-13 % for precipitation. As catchment up to Bhuntar site covers more snow area, ET found to be less. The snowmelt contribution at Bhuntar is found to be comparatively more. The snowmelt runoff contribution at Bhuntar site comes out to be about 60% during calibration and validation of stream flow.

The study area as a whole, receives 1012.1 mm precipitation out of which 474.8mm is lost due to evapo-transpiration (ET). Another, 16.81 total surface runoff and 357.54 mm lateral flows comes out by the simulation. Some amount of precipitation falling on the ground is stored deep inside the ground through infiltration and percolation. The estimated mean annual water yield of the basin is 515.84mm. This is the amount of available water which can be utilized for drinking as well as irrigation purposes. The water budget component and their contribution are shown below:

Table 5: Annual water balance catchment for Bhuntar basin

Annual basin	Calibration (parameters)	Validation (parameters)
PCP	1012.1 MM	1014.0 MM
SNOW FALL	135.61 MM	71.88 MM
SNOW MELT	79.43 MM	37.61 MM
SUBLIMATION	43.28 MM	29.36 MM
SURFACE RUNOFF Q	16.81 MM	49.52 MM
LATERAL SOIL Q	357.54 MM	132.20 MM
GROUNDWATER (SHAL AQ) Q	141.50MM	75.06 MM
DEEP AQ RECHARGE	2.09 MM	0.81 MM
TOTAL AQ RECHARGE	515.84 MM	76.25 MM
TOTAL WATER YLD	515.84 MM	256.73 MM
PERCOLATION OUT OF SOIL	144.35MM	76.31 MM
ET	474.8MM	1184.7 MM
PET	1160.1MM	1893.3MM

5.5 Climate scenario

In the high mountains areas of the world, the role of snow and ice as an important source of freshwater has been highlighted by several earlier studies (Kaser et al., 2010). The glaciers are the most sensitive records of climate changes and active geomorphic agents in shaping the landforms of glaciated regions. There are serious concerns about the potential impacts of reduction of snow and glacier under warming climate on the social and economic development (Barry et al., 2006) with its hydro ecological consequences to surrounding communities (Kehrwald et al., 2008). The climate change has influence on the functionality of dams and reservoir characteristics (Soundharajan et al., 2013).

The potential effect of climate change in daily time series stream flow at Bhuntar basin was evaluated using two climate scenarios, i.e. IPSLSD in year 2011 to 2060 and EC_earth in year 2011 to 2040 (GCM) data. GCM data was available at the downscale. Temperature and precipitation data has been prepare for SWAT format and edit weather parameter to investigate climate change scenario. The entire database were re-edited or re-loaded in the model to estimate the scenario of climate change and re run SWAT for the year 2011-2020, 2021-2040, and 2041-2060. Likewise, same step were followed for the EC_earth data. SWAT has been run successfully and results were generated for the climate trends. The simulated outcomes of stream flow have been converted from daily to monthly basis for the basin. The simulated stream flow for the different time frame past, present and future were compared with the observed data and it was noticed that the simulated stream flow increase with the time. The findings of the model for the current study were satisfactory.

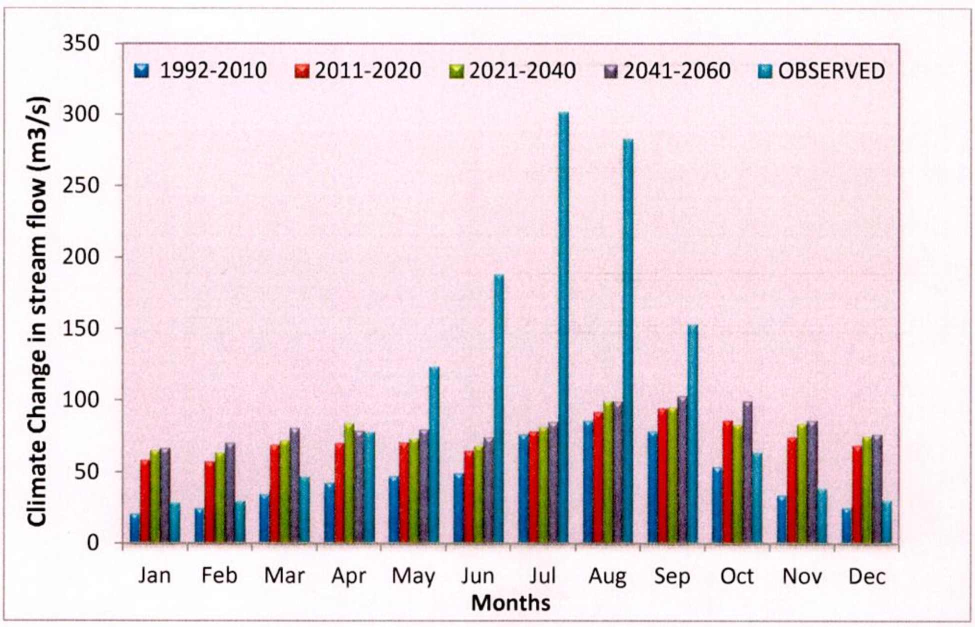


Figure 14: Climate change scenario for periods (1992-2060) with respect to observed stream flow simulation through IPSLSD/GCM

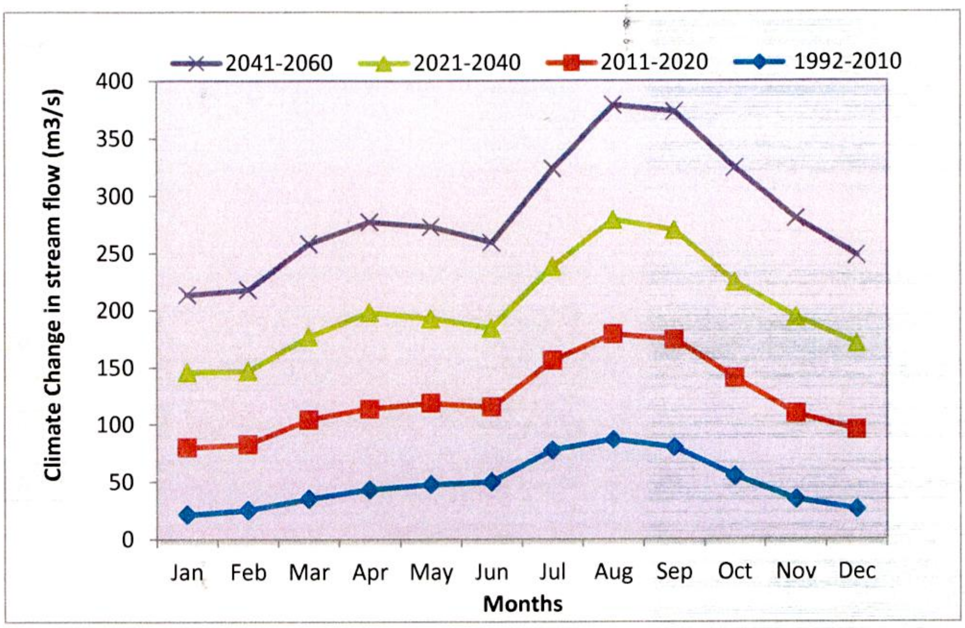


Figure 15: Climate change scenario with respect to stream flow simulation

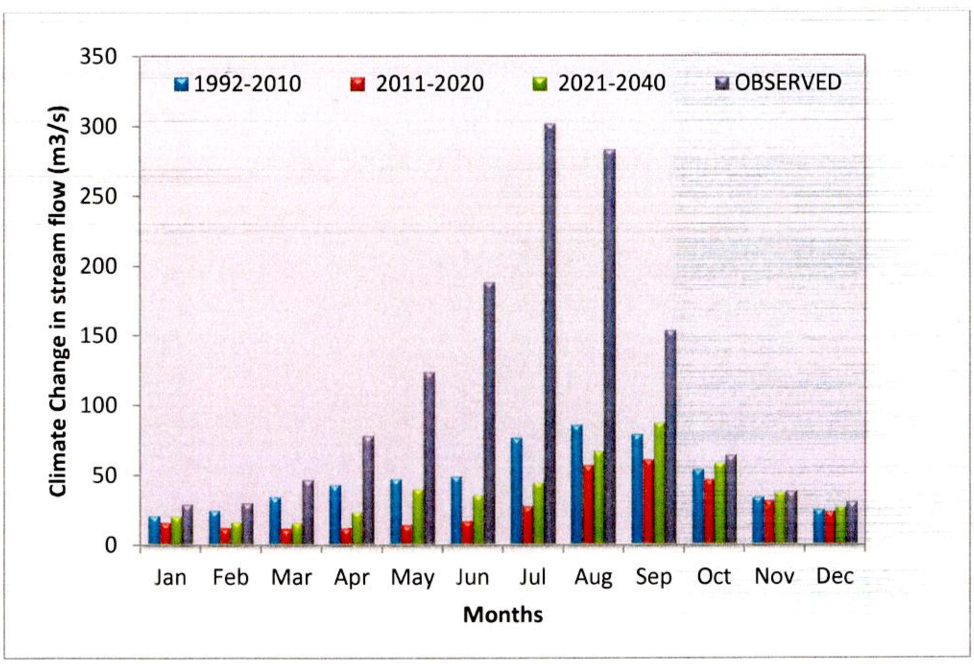


Figure 16: Climate change scenario for periods (1992-2040) with respect to observed stream flow simulation in Earthed/GCM

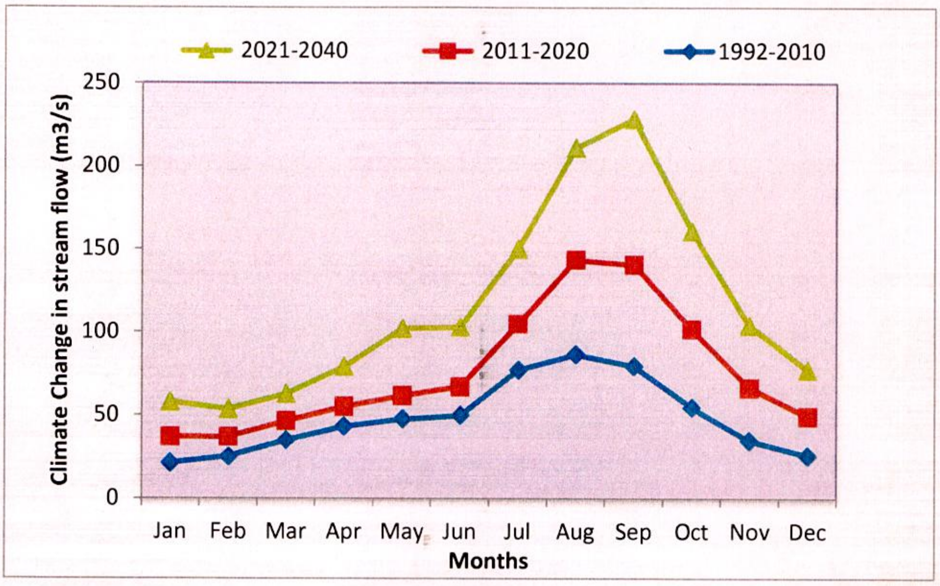


Figure 17: Climate change scenario with respect to stream flow simulation

Future climate scenarios used here which suggests increase in the future temperature and precipitation. The simulated climate scenario shows that future snowmelt and snowpack is expected to substantially decrease. It is very likely that due to increased temperature, more precipitation will fall as rain. The changes in temperature and precipitation pattern also affect the timing of snowpack development and occurrence of snowmelt; Potential impacts of these changes include an increased stream discharge in winter and early spring (Zion et al., 2011).

CHAPTER 6

CONCLUSIONS

Modeling of the hydrologic behavior of snow and rain fed Himalayan river basins is important since a large population depends on water from these rivers which also have huge hydropower potential. But limited studies have been taken towards a better understanding and quantification of hydrologic behavior of Himalayan Rivers. This study has attempted to simulate the response of the Bhuntar basin.

Modeling results show an acceptable simulation uncertainty range (R factor<1) for both the catchments which bracketed the observations most of the time (P factor>50%). The uncertainty during calibration was smaller than that during validation. The values of R^2 for calibration (1992-2000) and validation (2001-2010) are good and 0.60 and 0.57 respectively. The model performance was found to be quite good for Bhuntar sites given the availability of meteorological data. Overall, the hydrograph shape could be reproduced satisfactorily although all the peaks could not be reproduced very well. After a number of model runs, it was realized that no further significant improvement in modeling can be achieved without strengthening the database. Thus, the SWAT model can be considered to be a good tool to model the hydrograph and carry out water balance for a Himalayan basin.

Under higher air temperature in present and future climate change scenario, SWAT indicate more precipitation falling as rain and reduced snow pack leading to change in stream flow pattern particularly during winter and early spring. Future climate scenarios used here suggested increases in future temperature and precipitation. The simulation got using these climate scenarios showed that future snowmelt and snowpack is expected to substantially decrease.

For improved modeling of the Himalayan basins, efforts should be made to install more meteorological stations, particularly at higher altitudes. A better database of snowfall is also important. Further, the density of river gauging station also needs to be increased and multi-hourly river flow data would help in better Modelling and improved short term management of water resources. Further, climate change will have a profound impact on Himalayan Rivers including increased instances of

Water-triggered disasters. Improved measurements and modeling coupled with early flood warning systems will go a long way in developing strategies for optimal water management in these basins.

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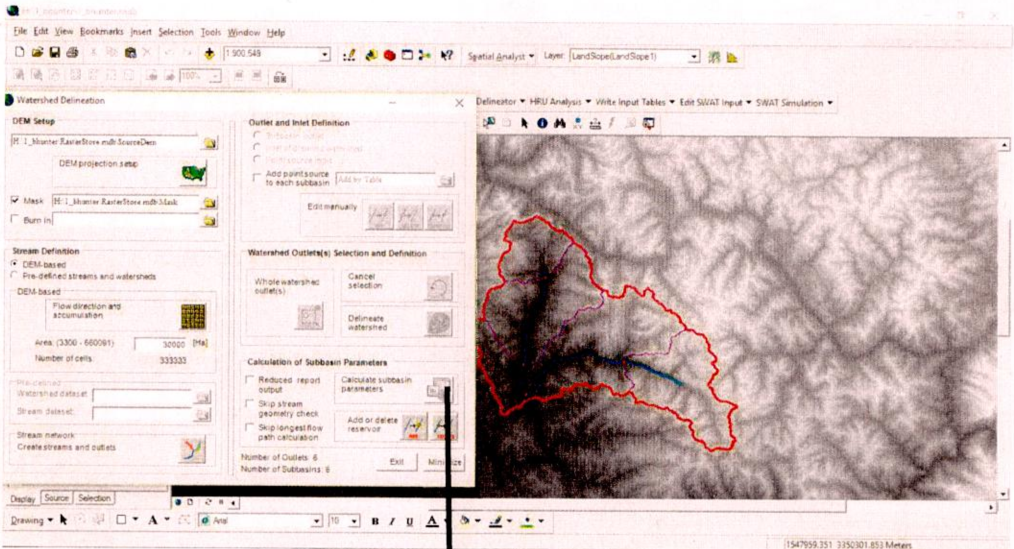
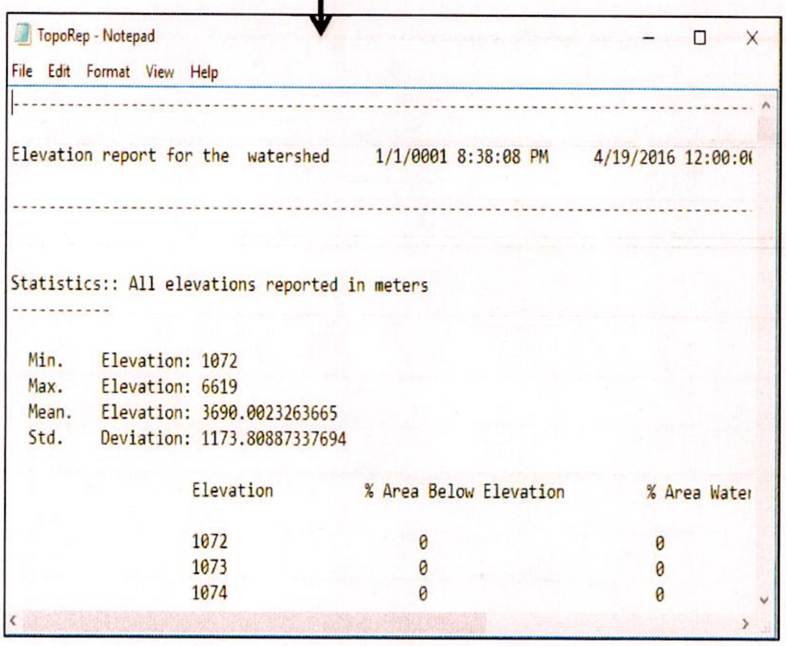
Annexure (s)



1. Watershed delineated in Bhuntar Basin through SWAT

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Elevation report for the  watershed     1/1/0001 8:38:08 PM     4/19/2016 12:00:0

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Statistics:: All elevations reported in meters
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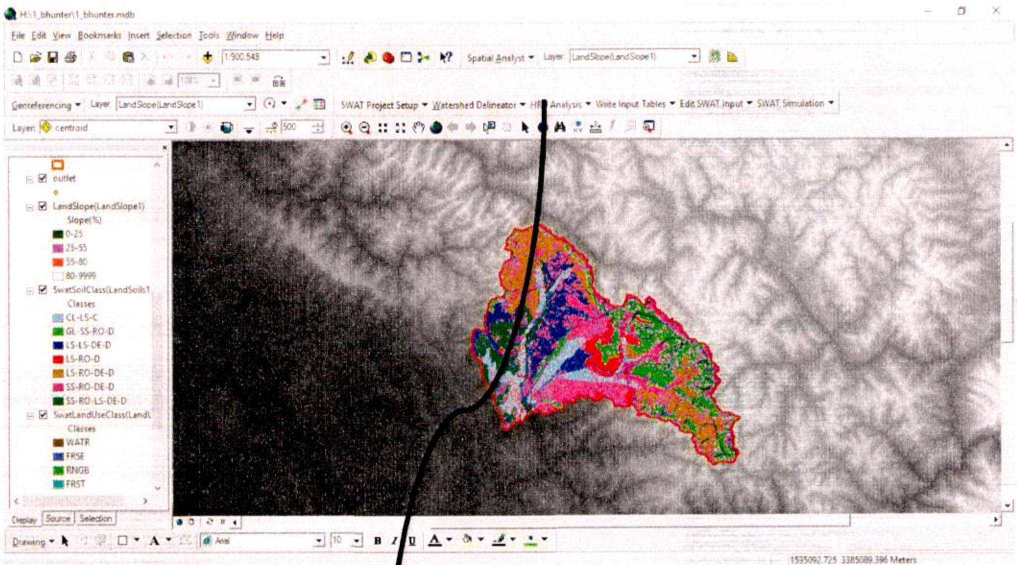
  Min.    Elevation: 1072
  Max.    Elevation: 6619
  Mean.   Elevation: 3690.0023263665
  Std.    Deviation: 1173.80887337694

                    Elevation         % Area Below Elevation        % Area Wate

                    1072                  0                          0
                    1073                  0                          0
                    1074                  0                          0
```

2.Topographic report of Sub basin watershed



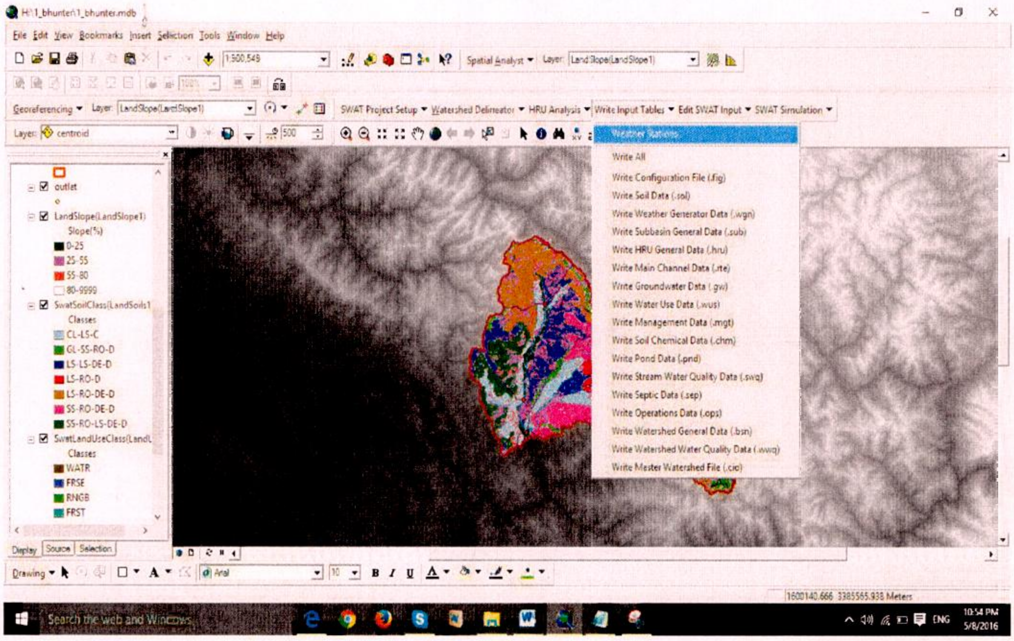
3.HRU,s of Sub basin watershed

MULTIPLE HRUs LandUse/Soil/Slope OPTION THRESHOLDS : 10 / 10 / 15 [%]
Number of HRUs: 100
Number of Subbasins: 6

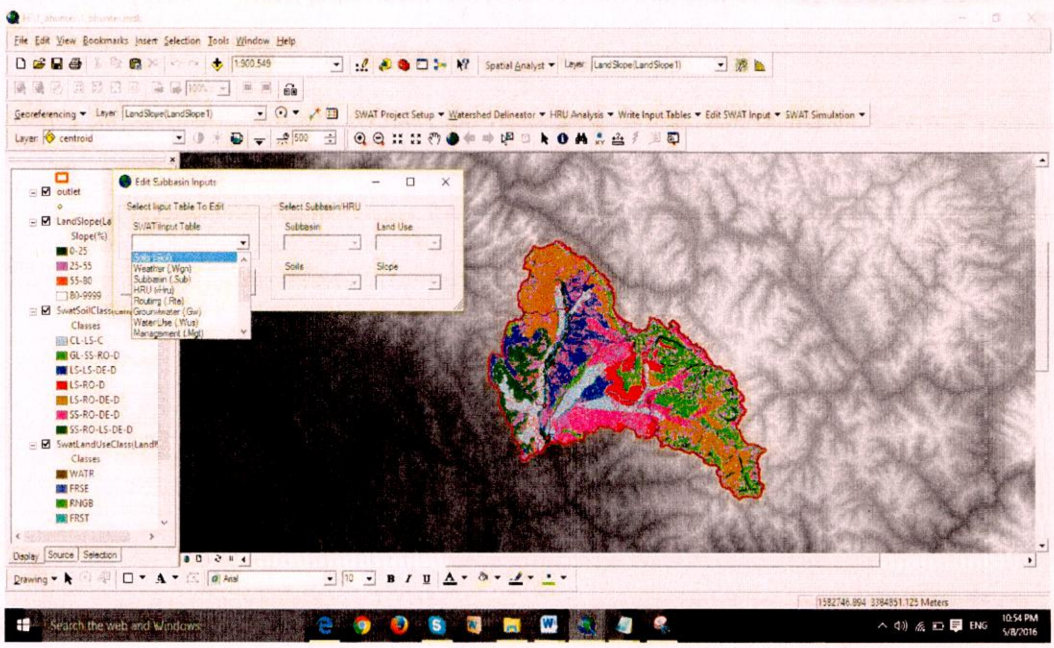
		Area [ha]	Area[acres]	
Watershed		312977.3400	773382.6560	

		Area [ha]	Area[acres]	%Wat.Area
LANDUSE:				
	Forest-Evergreen --> FRSE	113242.7858	279828.5860	36.18
	Range-Brush --> RNGB	4163.4636	10288.1266	1.33
	SNOW --> SNOW	191389.6051	472933.2838	61.15
	Forest-Mixed --> FRST	4181.4854	10332.6596	1.34
SOILS:				
	CL-LS-C	37401.3757	92420.6693	11.95
	LS-LS-DE-D	39142.8048	96723.8278	12.51
	LS-RO-DE-D	66189.9340	163558.6364	21.15
	GL-SS-RO-D	82062.5352	202780.6276	26.22
	SS-RO-LS-DE-D	26088.9470	64467.0926	8.34
	SS-RO-DE-D	44409.4772	109738.0387	14.19
	LS-RO-D	17682.2661	43693.7636	5.65
SLOPE:				
	80-9999	67558.8754	166941.3590	21.59
	55-80	87386.3677	215936.0840	27.92
	25-55	124879.7265	308584.0482	39.90
	0-25	33152.3704	81921.1648	10.59

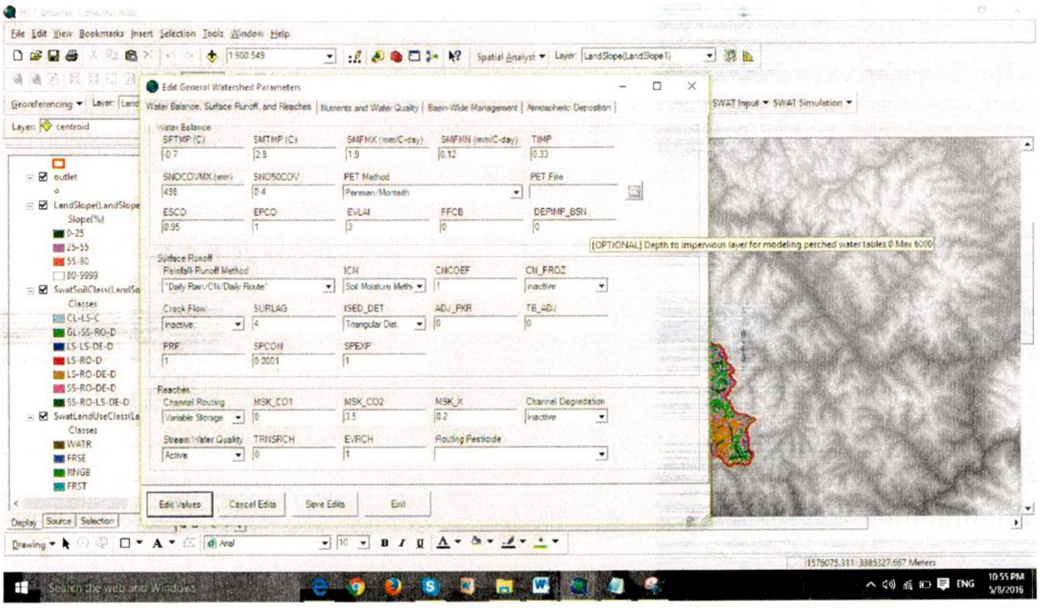
4. Topographic report of Sub basin watershed



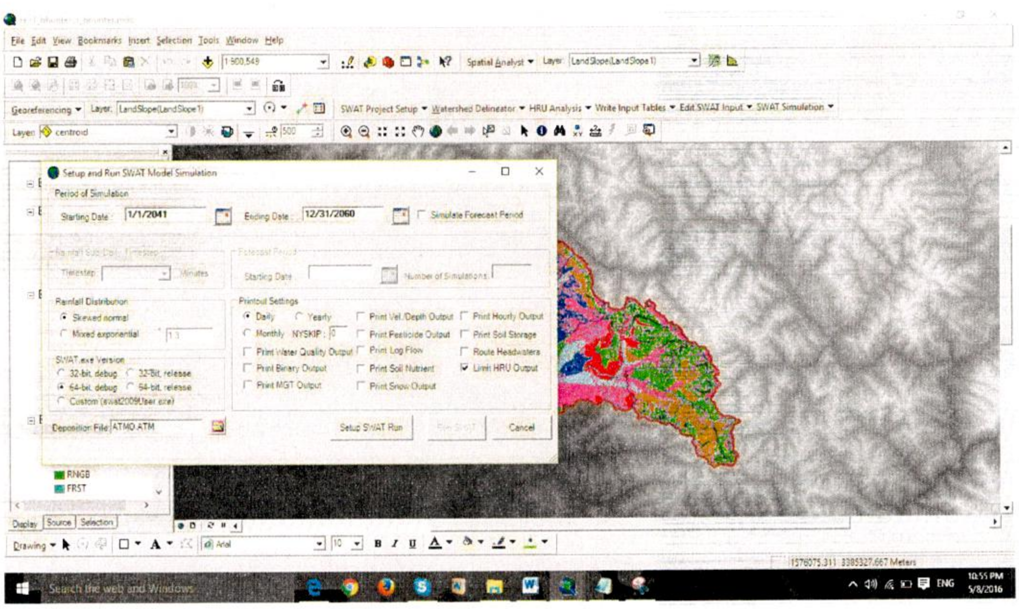
5. Import Weather generator files and run



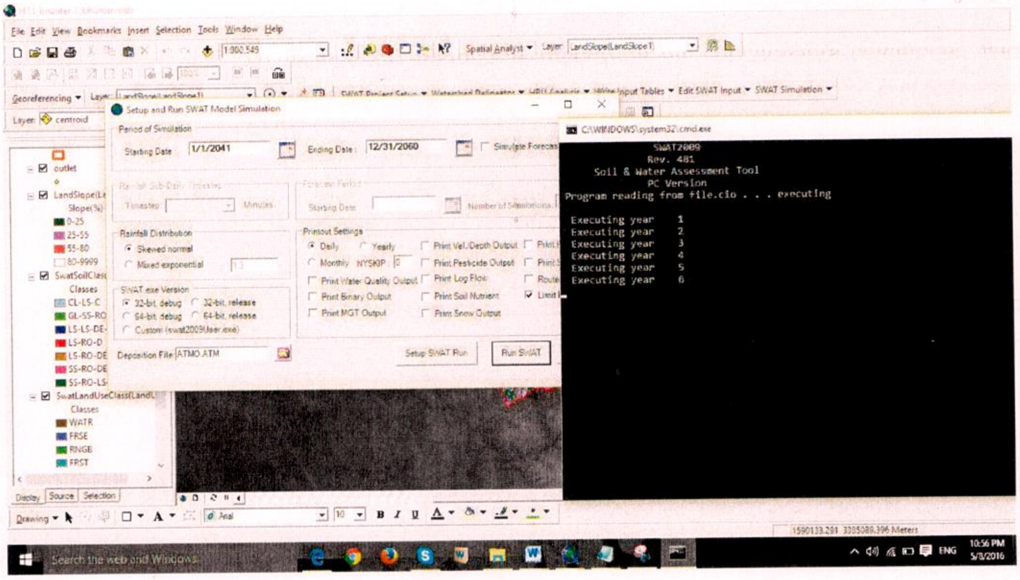
6. Import and Edit soil, LULC data



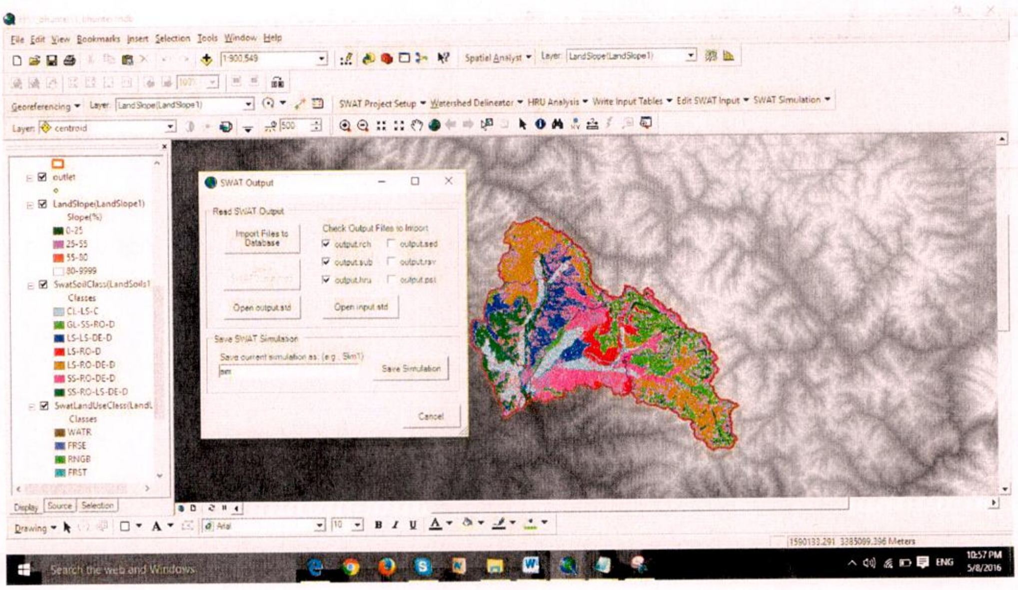
7. Edit snow parameter for each basin



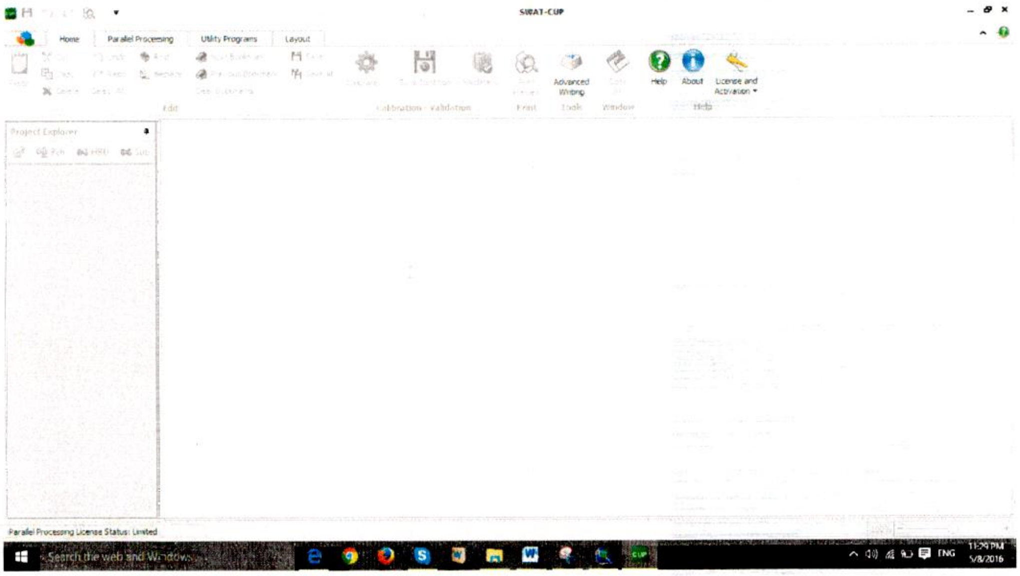
8. Ready to set up SWAT Run



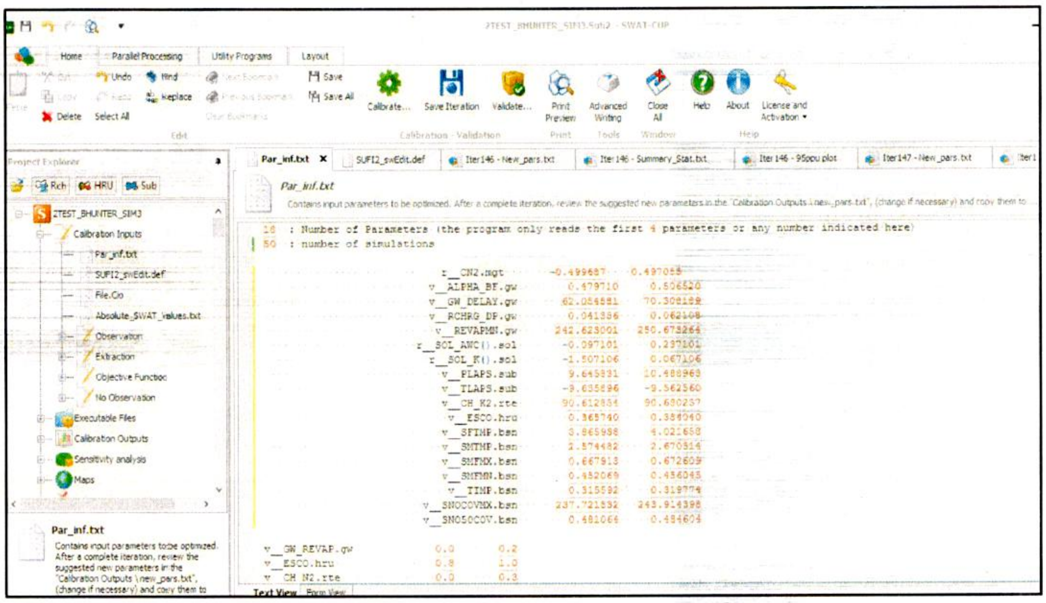
9. Run SWAT model



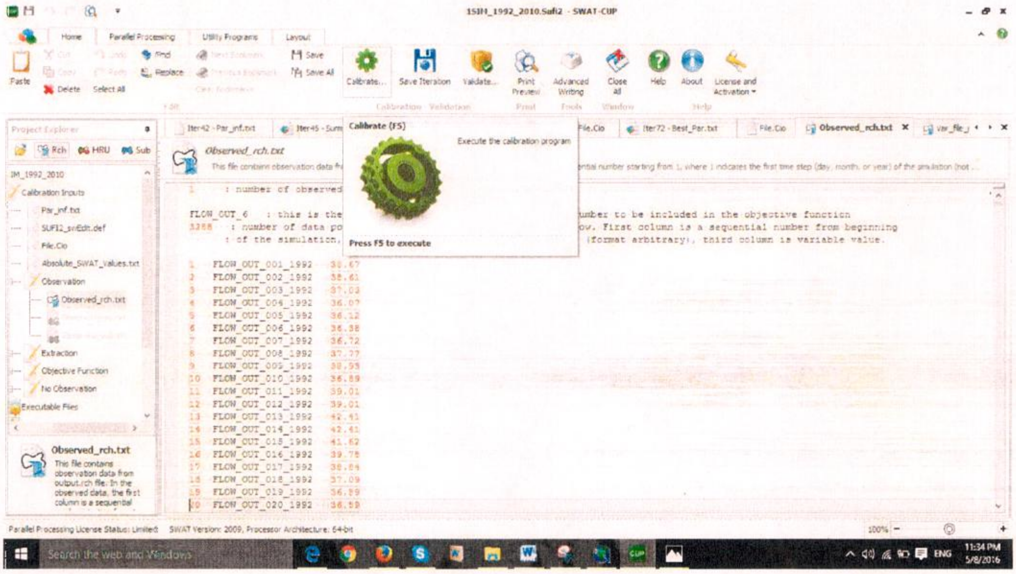
10. Save SWAT output rch, sub and hru.



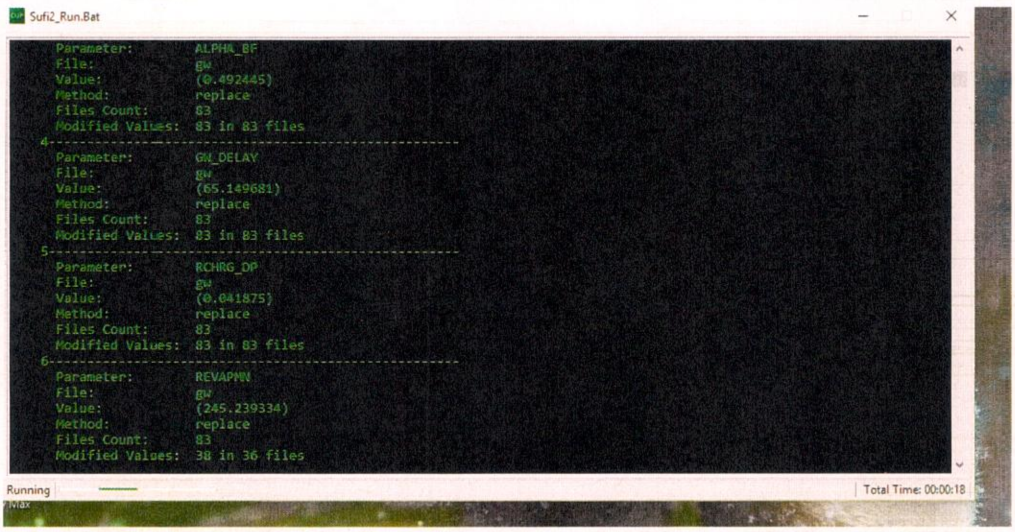
11. SWAT-CUP model.



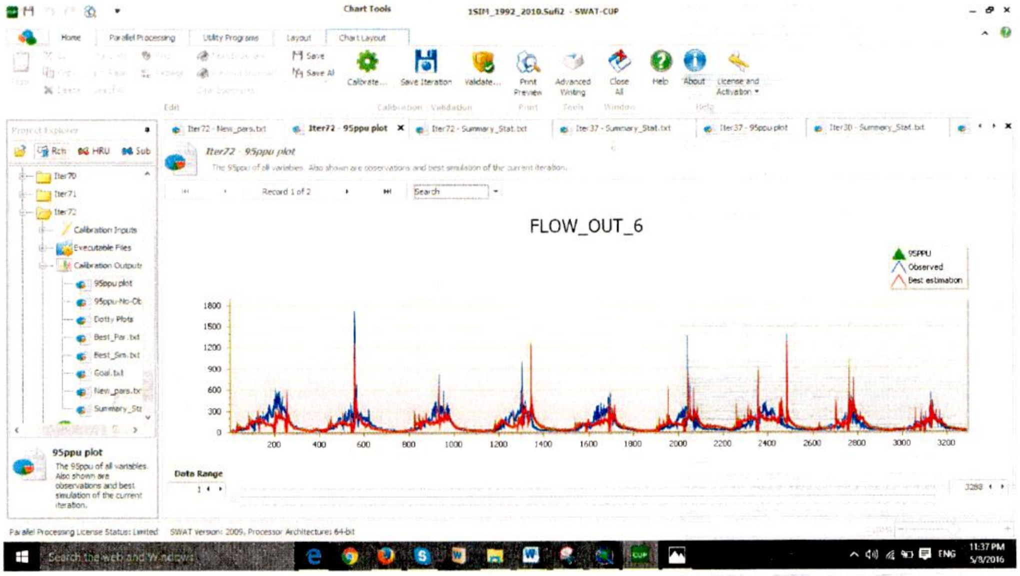
12. Edit parameters in SWAT-CUP.



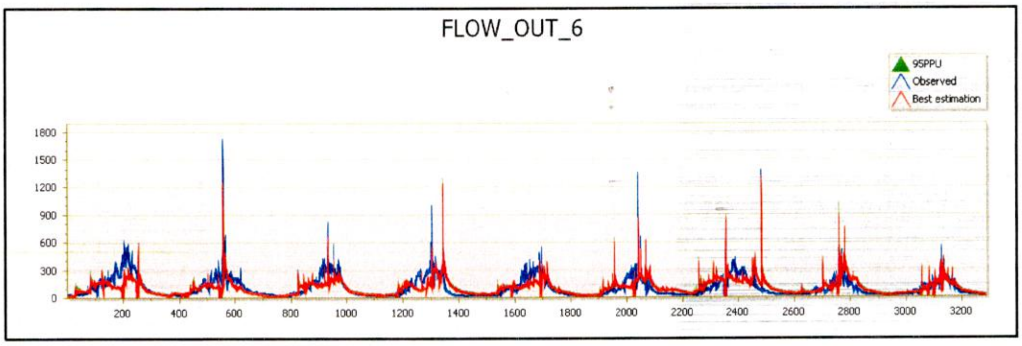
13. Calibration process.

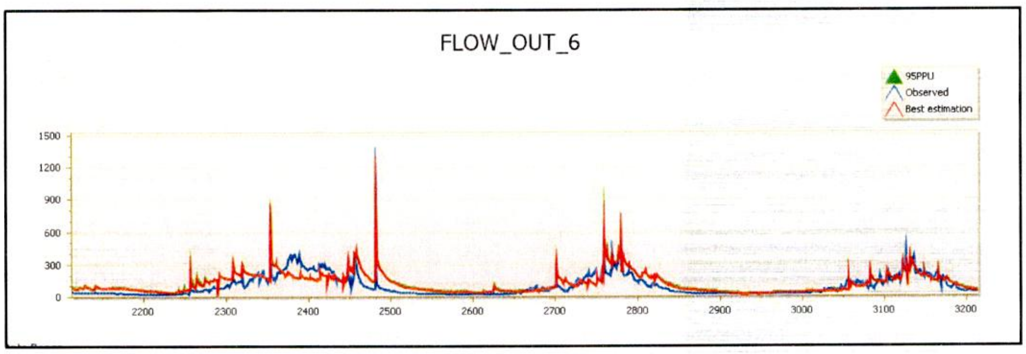


14. Run SWAT-CUP

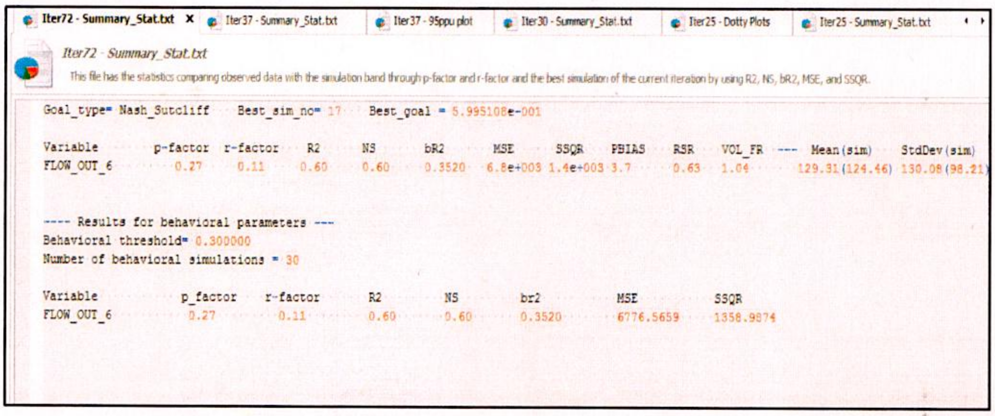


15. Calibration result

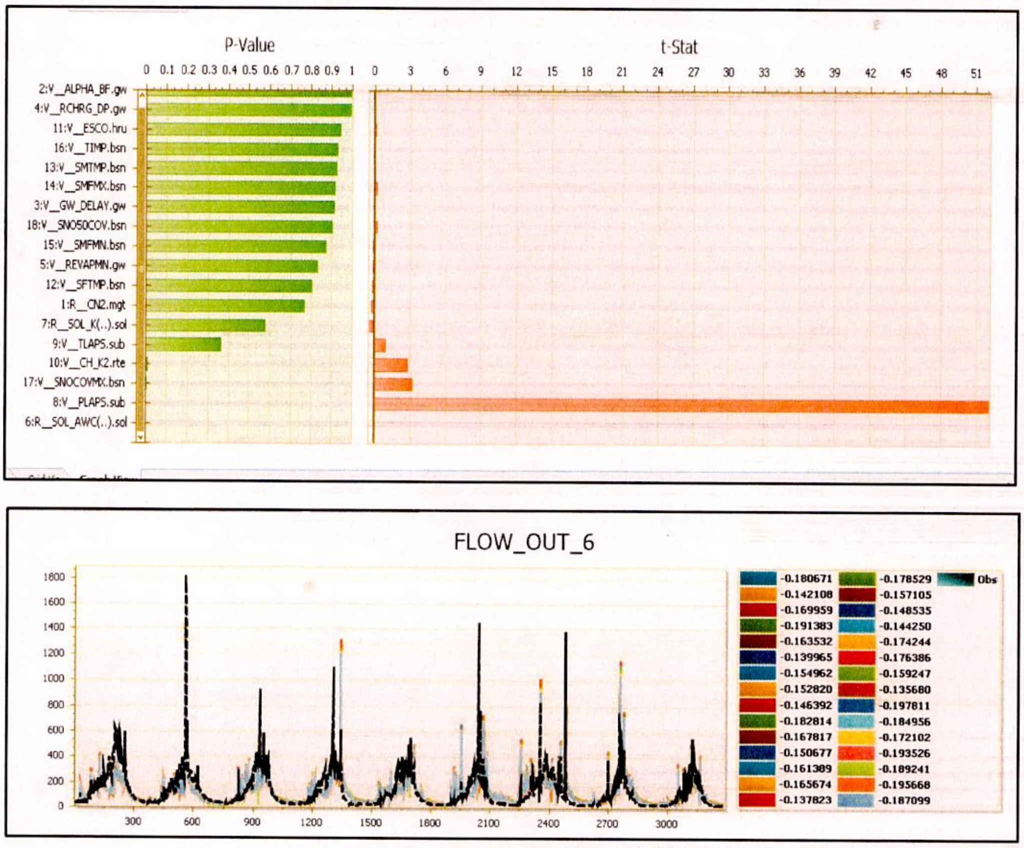




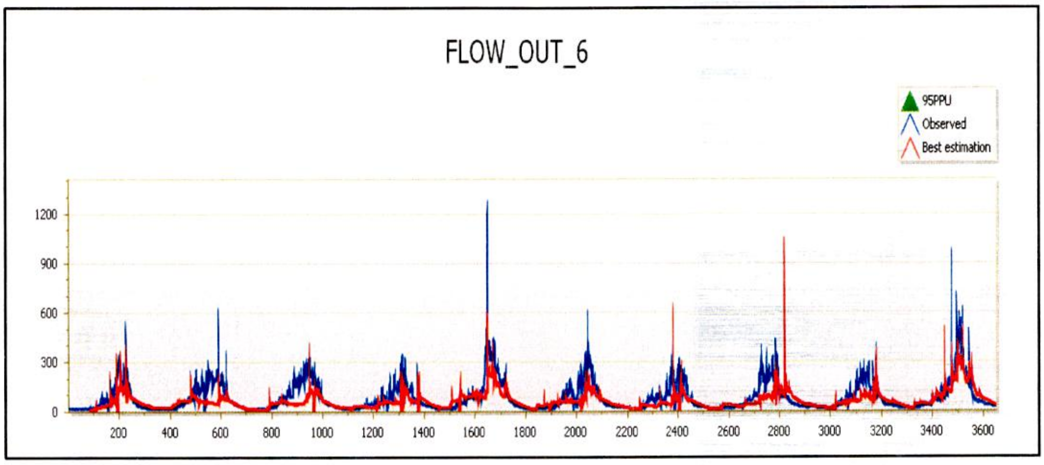
16. Stream flow simulation for Bhuntar basin (calibration process)

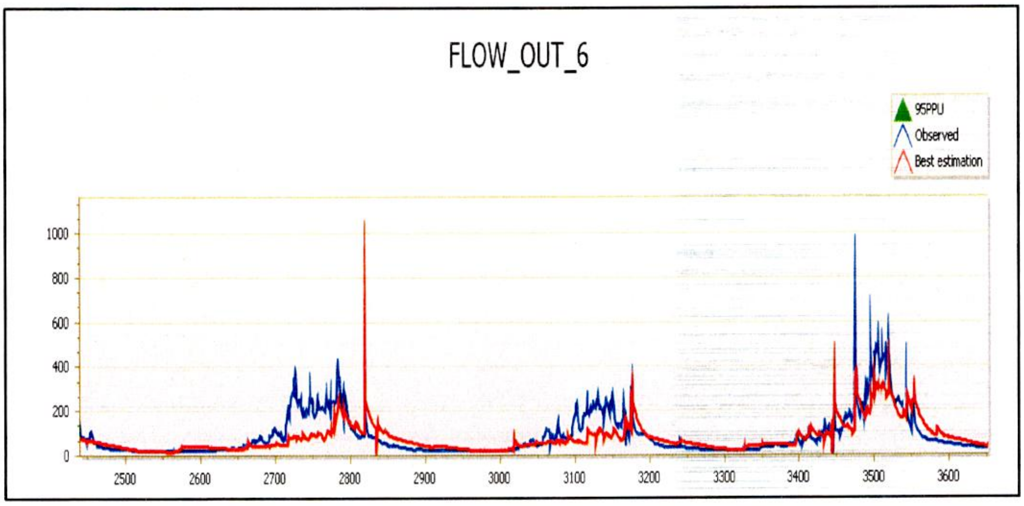


17. Summary report of stream flow in Bhuntar area (calibration)

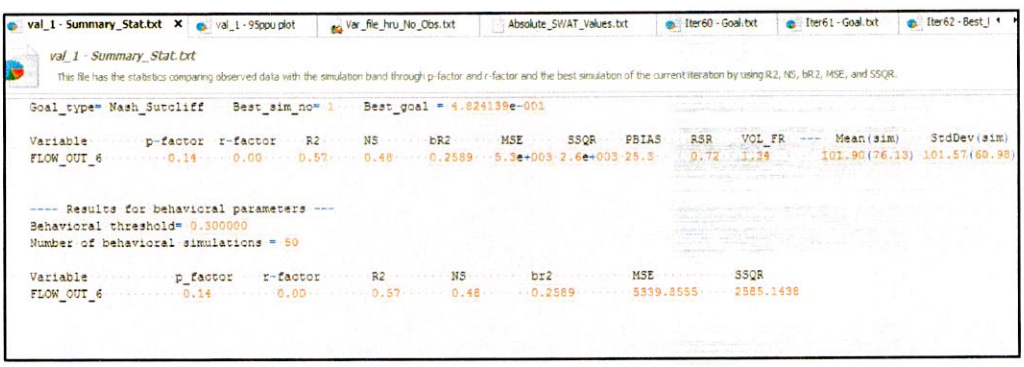


18. Sensitive analysis (calibration process)





19. Stream flow simulation for Bhuntar basin (Validation process)



val_1 - Summary_Stat.txt | val_1 - 95ppu plot | Var_file_hru_No_Obs.txt | Absolute_SWAT_Values.txt | Iter60 - Goal.txt | Iter61 - Goal.txt | Iter62 - Best_I

val_1 - Summary_Stat.txt

This file has the statistics comparing observed data with the simulation band through p-factor and r-factor and the best simulation of the current iteration by using R2, NS, bR2, MSE, and SSQR.

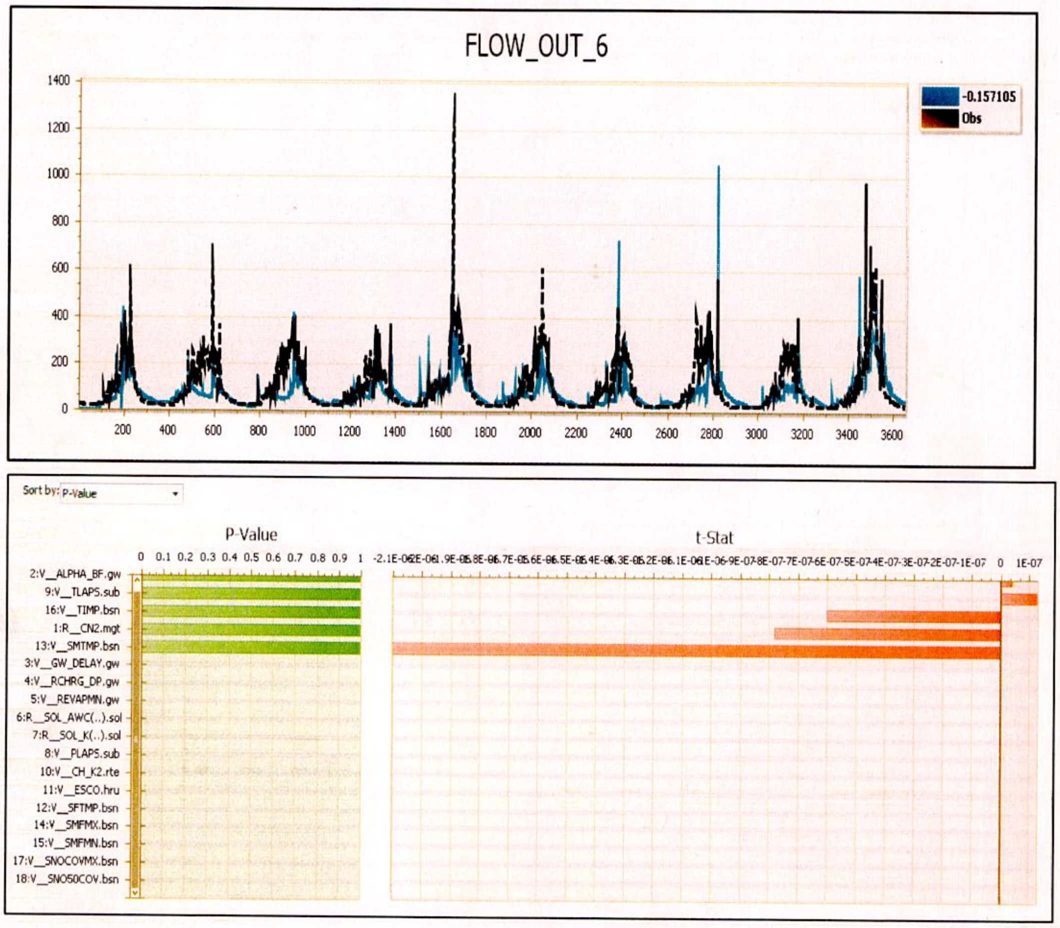
Goal_type= Nash_Sutcliff Best_sim_no= 1 Best_goal = 4.824139e-001

Variable	p-factor	r-factor	R2	NS	bR2	MSE	SSQR	PBIAS	RSR	VOL_FR	---	Mean(sim)	StdDev(sim)
FLOW_OUT_6	0.14	0.00	0.57	0.48	0.2589	5.3e+003	2.6e+003	25.3	0.72	1.34		101.90(76.13)	101.57(60.98)

---- Results for behavioral parameters ---
Behavioral threshold= 0.300000
Number of behavioral simulations = 50

Variable	p_factor	r-factor	R2	NS	br2	MSE	SSQR
FLOW_OUT_6	0.14	0.00	0.57	0.48	0.2589	5339.8555	2585.1438

20. Summary report of stream flow in Bhuntar area (validation)



21. Sensitive analysis (validation process)