HYDROLOGIC MODELING OF SELECTED CATCHMENT USING SOIL CONSERVATION SERVICES AND GREEN AMPT LOSS METHODS: A CASE STUDY OF MUZAFFARABAD, DISTRICT PAKISTAN

By

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CERTIFICATE

Certified that the contents and form of thesis entitled "Hydrologic modeling in selected catchments of Muzaffarabad, Pakistan using two loss methods SCS-CN and Green and Ampt loss methods" submitted by Miss. Rabia Yousaf (2012-NUST-MS PhD-GIS-12) have been found satisfactory for the requirement of the MS degree.

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RABIA YOUSAF

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ABSTRACT

This study focuses on flood event based hydrological modeling using HEC-HMS and geographic information system (GIS) on sub-catchments of Neelum and Jhelum rivers of Muzaffarabad, District Pakistan. The sub-catchments of Neelum and Jhelum, in Muzaffarabad, are the domain of the study because it is a region subject to frequent occurrences of severe flash flooding. Modeling was done on extremely high rainfall event of July 2002 for calibration and on July-August 2010 event for validation purpose. Soil conservation services (SCS) and Green Ampt loss methods were used to simulate the loss component of the model. Parameters were estimated for SCS-CN and Green Ampt loss methods using HEC-Geo HMS model. Digital elevation model (DEM) was the main input for basin processing of the catchments. Land Cover maps obtained from images of Landsat 4-5 and soil maps were merged together to obtain curve number (CN) of each sub basins while parameters for Green and Ampt i.e loss method were obtained from Green and Ampt lookup table. Lag time, basin lag, curve number and initial abstraction parameters were calculated using the above methods. Correlation analysis between observed and simulated hydrograph showed that SCS Curve Number had significant correlation (r = 0.7) while Green Ampt which had low correlation (r = 0.58) on sub basin 1. Results found Nash value of 0.98 using SCS curve number and 0.97 using Green and Ampt loss method in calibrated events for Neelum River sub catchment. Parameters estimated through GIS and HEC-Geo HMS tools enhanced model capabilities to simulate stream discharge that was in close agreement with observed stream flow. Peak discharge rates by incorporating land use, soil type and hydrological conditions show efficient loss methods for flood forecasting and managements strategies.

Chapter 1

INTRODUCTION

Floods are ranked as highest among the natural disaster due to the high rate loss of life and property (Horritt & Bates, 2002; Knebl, Yang, Hutchison, & Maidment, 2005; Majidi & Vagharfard, 2013). Many of the destructions in history were caused by floods. Approximately 178 million people of the world were killed due to floods at the end of 20th century. Comparing flood disasters among continents of the world, Asia is considered as the most flood prone continent as it faces several types of floods (Guha-Sapir, Vos, Below, & Ponserre, 2011). Asia contains approximately one-fifth of the earth's land area and one fifth of the world's population lives here (Kabir Uddin 2013; Uddin, Gurung, Giriraj, & Shrestha, 2013). Due to changing climatic conditions natural disasters continues to increase around the world and Asia being experiencing multiple types of disaster every year that not only cause severe destruction of property, livestock, infrastructure and lives. Nearly half of the total population is affected by flood during past 30 years.

Generally floods are caused by heavy rainfall concentrated on the catchments and its effects sometimes increased by augmentation of snow. Floods happen in varying locations and at varying magnitudes giving markedly different effects on the environment. Riverine floods that are due to the inundation river water in case of heavy discharge due to extreme. rainfall events. These are normally happens in low lying areas with even topography. Anthropogenic activities and urbanization impact around the flood plains and downstream of the rivers cause increase in flood volume because of reduction of infiltration to groundwater (Lan, 2012; Shuster, Bonta, Thurston, Warnemuende, & Smith, 2005). In Pakistan, floods are being considered as major natural disasters. Along the Indus River and its tributaries there was a history of floods associated with it and the floods of 1928, 1929, 1955, 1957, 1959, 1973, 1976, 1988, 1992, 1995, 1996 and 1997 causes severe destruction to land and property of people their infrastructures and as well as many of them lost their lives. Major types of floods that hit the northern and southern Pakistan were mostly flash flood and riverine floods. Flash floods that were mainly due to heavy spell of rain and storm and the amount of storm water that accumulated in the watersheds cause rise of water level in the course of river and main streams with speed and force. The time and amount of runoff due to flash floods are often unpredictable. Therefore mitigation and management strategies associated with flash floods are often not very effective because they are difficult to monitor (Borga, Gaume, Creutin, & Marchi, 2008; Creutin & Borga, 2003). The territory of district Muzaffarabad is vulnerable to many such natural hazards including earthquake, landslides and massive flash floods.

1.1 Flash Floods in Muzaffarabad

In Pakistan flash floods are associated with mountainous and semi mountainous regions. Due to the current changing weather pattern, flash floods occur in some recent years. Flash floods in such areas have more hazardous effects because of little early warning and cause severe damage to property and lives of people. The continuing impact of Flash floods due to changing climatic conditions brings attention to the development of early warning system in terms of flash flood hazard mapping in terms of magnitude and intensity of floods. Makri Nullah of Muzaffarabad is the source of communication at local level. In recent years similar events take place in Nakdar ,Shuntar, and Shoai Nallas. Mal Nallah in Bagh city cause damage to the city due to the heavy rainfall in the Nullah. To smaller extents some southern Districts of Kotli and Bhimber are also vulnerable to flooding.

1.2 Rainfall and Runoff Modeling

The term 'Runoff' refers to the portion of rainfall that makes its way to stream channels, lakes, or oceans as surface runoff (also called direct surface runoff) and/or subsurface runoff, which comes in the form of interflow, through flow, return flow and base flow from groundwater storage (Karki, 2007). One of the most important parts of the hydrological cycle is rainfall and runoff modeling. This has always been an important issue to hydrologist for its accurate measurement. By the end of the 19thCentury many hydrological models have been developed to measure the rainfall and runoff relation depending upon the type of watersheds whereas many of them describe the physical process affecting the system. Physical model usually are distributed models that take into account many parameters to perform simulations of the given scenario (Ray Singh, 2012). Many loss methods are there to model the loss component of hydrological cycle among them Soil Conservation Services (SCS), Horton's Infiltration method and Green Ampt infiltration methods are being used. Horton's methods is simple but it require parameters that needs to be physically measured from field observations for infiltration rates and its parameters cannot be determined from Soil type and Land use (Gabellani, Silvestro, Rudari, & Boni, 2008). In this study SCS Curve Number and Green and Ampt loss methods are used to model runoff in catchments of Neelum and Jhelum River.

1.3 Hydrological Modeling

Hydrologic models take into account the physical characteristics of the watershed by considering different parameters. Over the past many different hydrologic models have been used to measure the quantity of floods, to measure the peak flood events, for flow forecasting and reservoir operations in spillway design studies and for many other purposes. Usually storm water hydrographs measures the peak runoff rates verses time that is used for flood control in hydrologic engineering (Al-Hasan & Mattar, 2014). These models express the mathematical components of the part of hydrological cycle in a physical way. GIS helps in the integration creating and manipulating the spatial component of the system while hydrological model estimates the surface, sub surface and overland flow component of the hydrological cycle.

1.4 Lumped and Distributed Hydrological model

Many types of hydrological models are there on the basis of their applicability, incorporation of parameters and hydrological process they are modeling. Among these distributive and lumped hydrological models are there that are classified on the basis of integration of watershed components as single or multiple identity. Distributive models incorporate spatially varying land characteristics and precipitation data and divide the watersheds into simpler components. Distributive models takes into account the small variations in the watershed by dividing the watershed into subunits and then measure the combined response of watersheds.

Lumped hydrologic models assume the watershed as a single entity. The discharge at the watershed outlet is described based on a overall response of the watershed as a single unit. There are numerous lumped hydrologic models. These models are usually based on the concept of the unit hydrograph, UH**.** Lumped models do not takes into account the surface runoff after infiltration into the soil through a permeable rock or surface and therefore it underestimates runoff component of the model. Some of the hydrologic models take into account each component of the system including the Catchments, Sub Basins and Aquifers as single unit these are called lumped hydrological models. Some of the examples of lumped hydrological models are SSARR (USCE, 1975), HBV (Bergström and Forsman, 1973) and Stanford model (Linsley, 1976). The main disadvantage of the lumped models is that it does not takes into account the spatial variability of various land uses and spatial diversity of physical hydrological process (Dutta, Herath, & Musiake, 2000).

1.4 Role of Remote Sensing and GIS In Hydrological Modeling

Geographical information system in integration with hydrological model proved a very powerful tool in estimating stream flows (Györi & Haidu, 2011). Many advances and development in the models have been occurred due to incorporation of GIS that assist in the representation of the spatial component of the globe while hydrologic model aids in the estimation of surface runoff, infiltration and sub surface flow. GIS and hydrologic model benefits from each other's by measuring spatial component like terrain modeling, basin processing and temporal variations like rainfall, infiltration and evapo-transpiration measurement respectively. GIS can also assist in the handling of various data format that would be difficult without it to engineers for modeling of water resource (Bakir & Zhang, 2008).

For hydrological and watersheds modeling remote sensing proves to be low cost input data for estimating many watersheds parameter (Bhaskar & Suribabu, 2014). Various temporal data sets, with multi resolution, and multi spectral characteristics can be collected using satellites images. These datasets are not only available rather converted into valuable land use information for monitoring and evaluation of change in urban land use (WENG, 2001).

1.5 Rationale

Muzaffarabad district is situated at the confluence point of the two rivers Neelum and Jhelum at Domel. This area always gets more importance because of its hilly terrain and many disasters are associated with it including floods, landslides and earthquakes. Muzaffarabad is situated at the Northern part of our country. It receives the highest rate of rainfall throughout the year and throughout this region. There is a history of floods in Neelum and Jhelum Rivers in the form of flash floods and riverine floods as well.

Current study focus on the extreme rainfall events and associated flash floods. Some major storm events during monsoon periods cause flooding and rise in the water level of the rivers. The methodology used combines hydrological modeling with GIS and remote sensing which can help in better and more accurate comparison of observed discharge and simulated discharge. Two different hydrological models were used for evaluating the simulated discharge results.

1.6 Objectives

The main objective of the study was to calibrate & validate HEC-GeoHMS model for peak hydrograph event of 2002 and 2010 flood events using SCS-CN loss method with Green Ampt methods.

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Chapter 2

MATERIAL AND METHODS

2.1 Study Area

The study area Domel, Muzaffarabad (73˚ 24’ 6” to 73 ˚ 46” E and 43˚ 42’ to 34˚ 35’ 25” N) situated at the confluence of the Jhelum & Neelum Rivers was selected (Fig 1). Its elevation is 724 meter from mean sea level. Muzaffarabad terrain is mainly hilly and mountainous. The climate varies considerably in the north and in the south. The southern part of the district experience warm summer and cold winter whereas in the north summer is cool and winter extremely cold. June, July and August are the hot months. Average annual precipitation of the district is 1511 millimeters (Nawaz & Shafique, 2003). The months of November to March are the coldest (minimum temperature ranges between 3.2ºC to 9.6ºC) while May to June are hottest (maximum temperature ranges between 28ºC to 37.6ºC). The mean annual rainfall in Muzaffarabad is around 127 mm and 30-60 % of the precipitation received in the form of snowfall during December to February. Mainly floods are due to the heavy rainfall that occurs during summer monsoon (July to September). Cloud burst can cause rainfall up to 100 mm during a single event that damage is equivalent to flash floods or landslides. As this area is under the influence of changing climatic patterns, so more intense rainfall can be likely to happen.

There are two major rivers flowing through the region i.e. Neelam and Jehlum Rivers. Neelum River arises from Krishnar lake that originates from

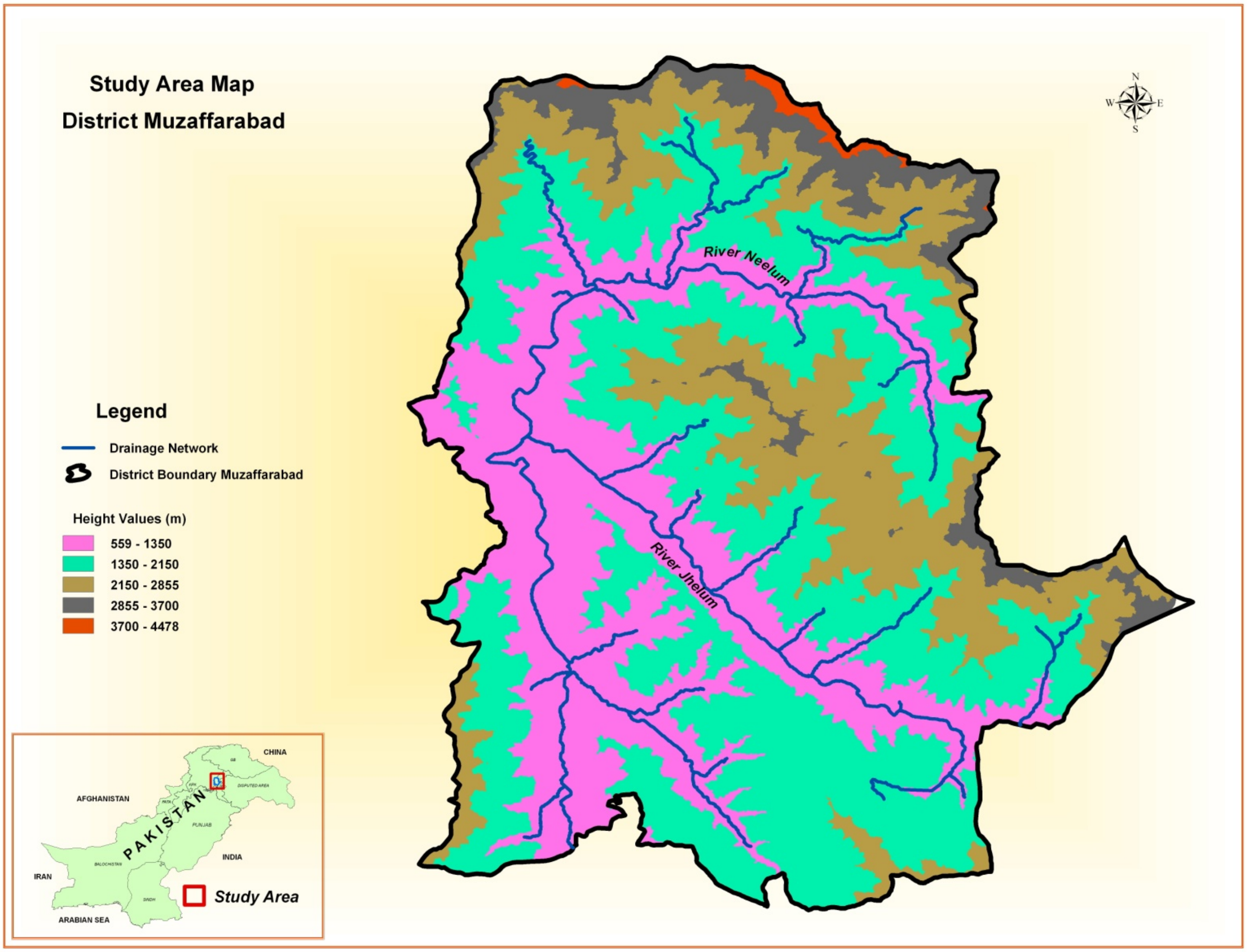

Figure 1**.** Study area Muzaffarabad and main tributaries of the Neelum and Jhelum Rivers.

occupied Jammu and Kashmir. Many Glacial tributaries feed the water of Neelum River along its way (Nawaz & Shafique, 2003). There are 6 stream-gauging and one climatological station in and around study area site which are being used for Mangla reservoir operation and flood management purposes. The Jhelum River originate from south eastern Kashmir India where it starts flowing from the foothills of the Pir Panjal of Verinang Spring before entering Pakistan.

Total catchment area of Jhelum River up to Mangla Dam is about 33,333 km^2 while the mean elevation of the catchment area is about 1,540 masl. The characteristic of the valley within the study area is like a V-shaped valley with steep slopes on both banks mostly covered with bushes having few trees. The main stream of Jhelum River from Chakoti to Muzaffarabad flows with average river gradient of 0.59 % over a length of about 60 km and in the next 110 km length i.e. from Muzaffarabad to Karot Bridge/ Mangla Reservoir, the Jhelum River flows with an average gradient of 0.27%.

Jhelum River catchment is mainly fed by snowfall, small glaciers and intensive rainfall over the year. Snowmelt is dominant in early spring and rainfall feeds the catchment during monsoon months. Although low flows are fraction of summer flow and snow covers the major part of catchment, there is some water flowing in all major tributaries of Jhelum River system. There exist four gauging stations in upper Jhelum catchment; located at Chinari/ Hattian Bala.

(since 1970), at Domel (since 1970), at Kohala/ Chatter Klas (since 1965) and at Azad Pattan (since 1978).For reservoir operation and design and many flood management purposes WAPDA has installed 22 stream gauging and meteorological station at catchment of Mangla. Chief Engineer (H&WM) and (SWHP) Surface water hydrology project section of WAPDA is maintaining these stations. From these the 5 rain gauges (Mangla, Domel, Kallar Syedian, Kotli, and Palandari) and 6 river gauge stations (Muzaffarabad, Domel, Talhata, Chattar Klass, and Azad Pattan, Kotli) are in used in flood warning and control operations.

2.2 Datasets

This study is carried out by using remotely sensed data as well as field survey data and vector data generated using HEC-Geo HMS as GIS layers. Landsat 4-5 images of 2002 used for calibration purpose and 2010 image is used for validation purpose for monsoon period. For GIS layers soil map, land use map obtained from classification of satellite landsat 4-5 images for the period of 2002 and 2010, Digital Elevation Model (DEM) for terrain and basin processing that are needed for generation of catchment characteristics and parameters TRMM rainfall data and discharge data were used as hydrometeorologic component of model.

2.3 Satellite Images

Estimation of runoff using the SCS CN loss method uses a combination of Land use and soil type. For this purpose Landsat images were used as it was freely available at desired temporal resolution. Preparations of land Cover maps were most important in the calculation of CN lag of the basin using HEC-Geo HMS tools. These images were obtained from the USGS website. After downloading the image of the desired area and spatial resolution classification was performed in land cover map preparation (Fig 2).To calibrate and validate the model 2002 and

2010 data sets were used, respectively. These images were 100 percent cloud free and geometrically and radiometricaly were corrected. The study area falls in the 150 Path and 36 Row of the Landsat. For image stacking thermal band was not used as it was of low resolution therefore 1 to 5 and 7 bands were used for stacking. In the current study ASTER DEM (Advance Space Borne Thermal Emission and Reflectance Radiometer) was used for terrain processing of the basin (Fig 3).

Due to the limited number of rain gauges in selected watershed satellite base TRMM data were downloaded from the website of TRMM. Daily 32 Bit product was used for this purpose. Resolution of the data is 0.25° x 0.25° grid that is on the latitude of 50° N-S. Multiple points were created on the watershed for the desired spatial location. The data were obtained in the raster format and values were extracted using the extract by a multi value tool by the Arc Map 10.1. After that the values were converted into excel format for direct use by the model HEC-HMS. Data were downloaded for 2002 and 2010 storm events.

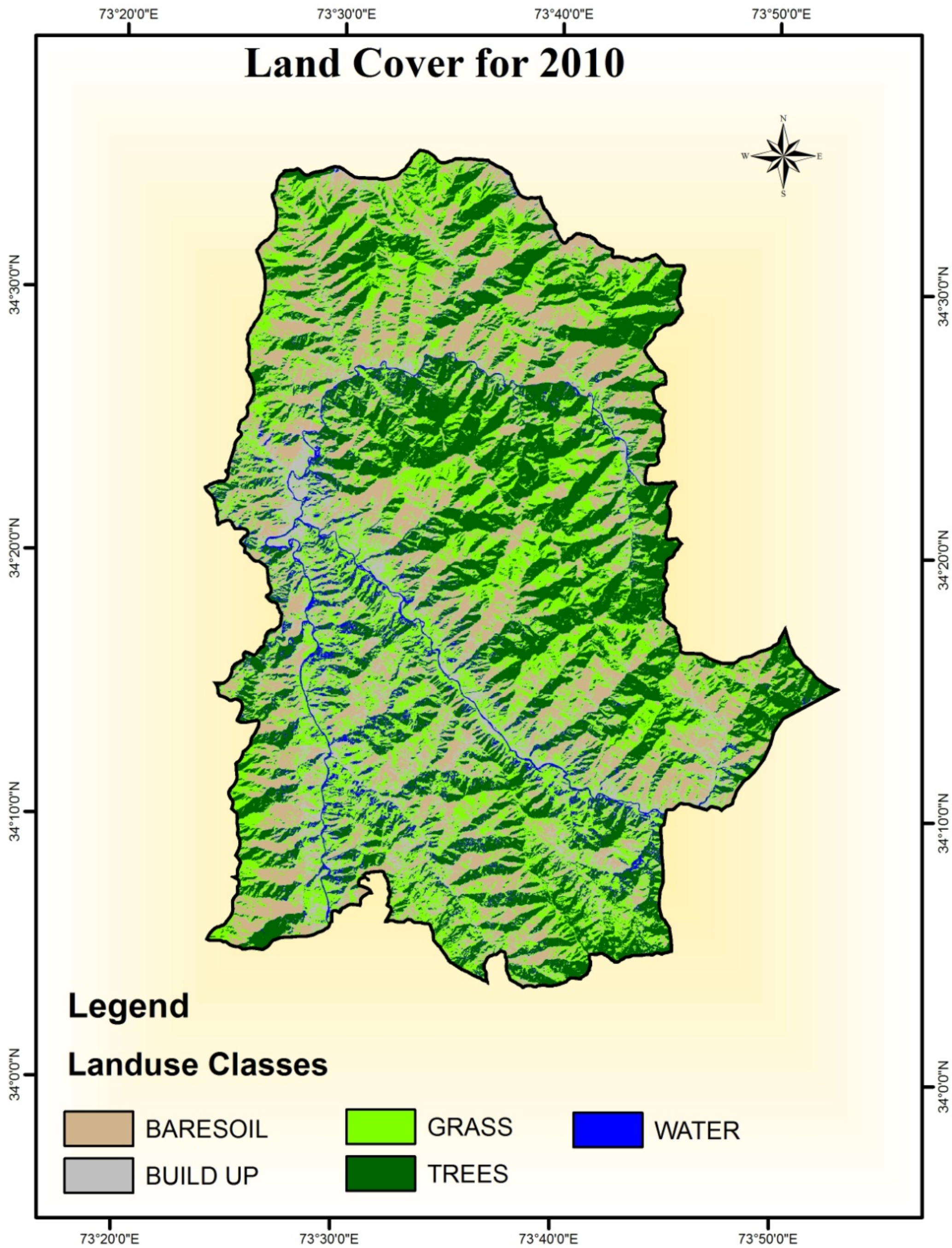

Figure 2. Land Cover map of the region generated by supervised classification of the Landsat image for year 2010 which will further used in creation of CN Grid.

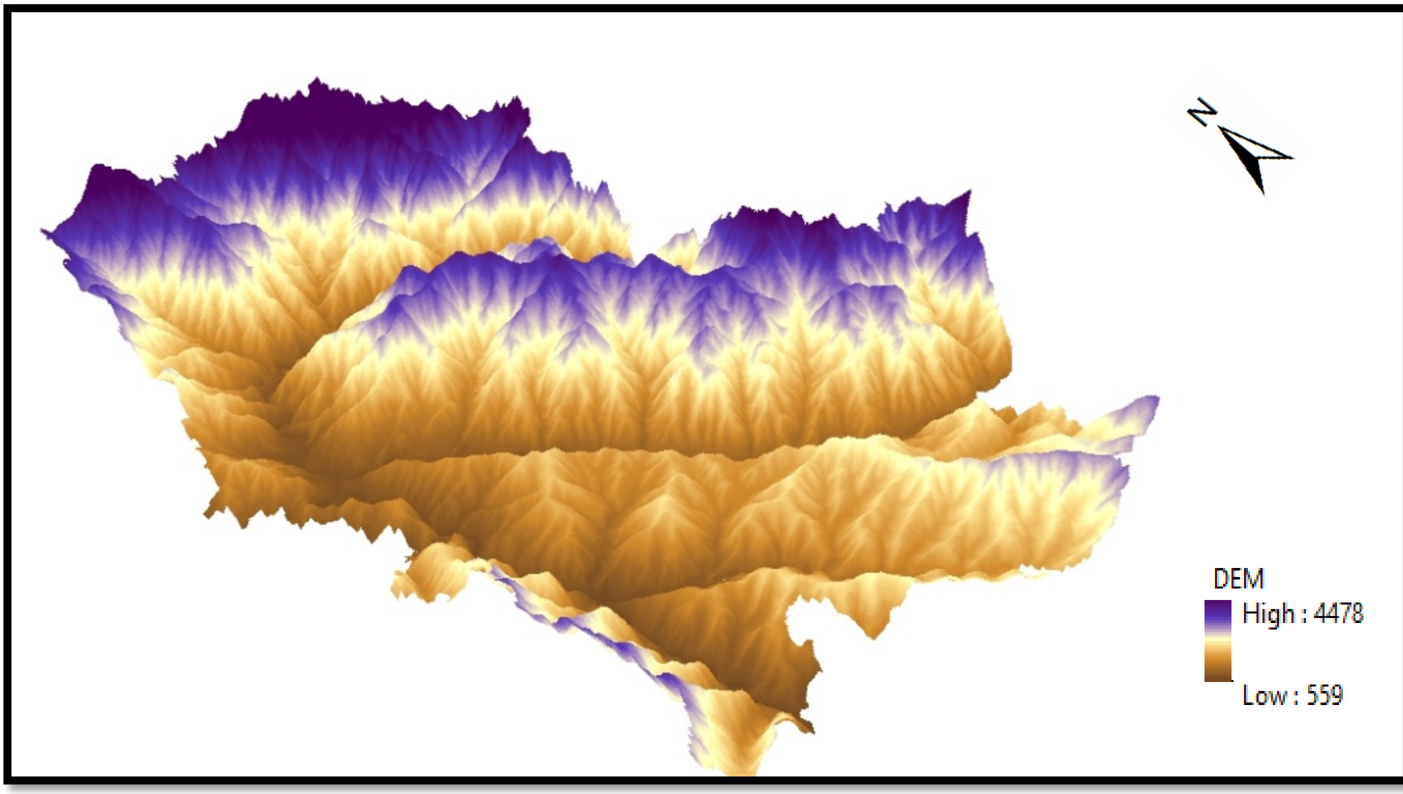

Figure 3. ASTER GDEM (30 Meter) of Muzaffarabad in 3D view showing its highest and lowest elevation.

2.4 Hydro-Meteorological Data

Jhelum River catchment is mainly fed by snow fall, small glaciers and intensive rainfall over the year. Snow melt is dominant in early spring and rainfall feeds the catchment during monsoon months. Although low flows are fraction of summer flow and snow covers the major part of catchment, there is some water flowing in all major tributaries of Jhelum River system.

Discharge data on a daily basis were gathered from SWHP (Surface Water Hydrology Project) Department of WAPDA of 2002 and 2010 monsoon events. There are seven stream gauges installed in Muzzaffarabad district. Out of which four were chosen for the analysis of stream flow. Two gauging stations at Nosheri and Neelum at Muzaffarabad were chosen for the upper catchment of Neelum River. While two gauging stations of Hattian Bala and Domel were chosen for catchment 2 at Jhelum River (Fig 4). 2002 discharge data of June events were used for calibration whereas 2010 discharge data of 2010 July and August events were used for validation.

2.5 Soil Data

Another main component in the determination of the CN Curve Number for runoff generations is the soil of the area. Soil characteristics were highly varying in the study area due to the mountainous topography and slope. Hydrological conditions with varying slope are the main factors of variations. There were two types of soil found in the study area Loam and Clayey Loam as shown in Fig 5.

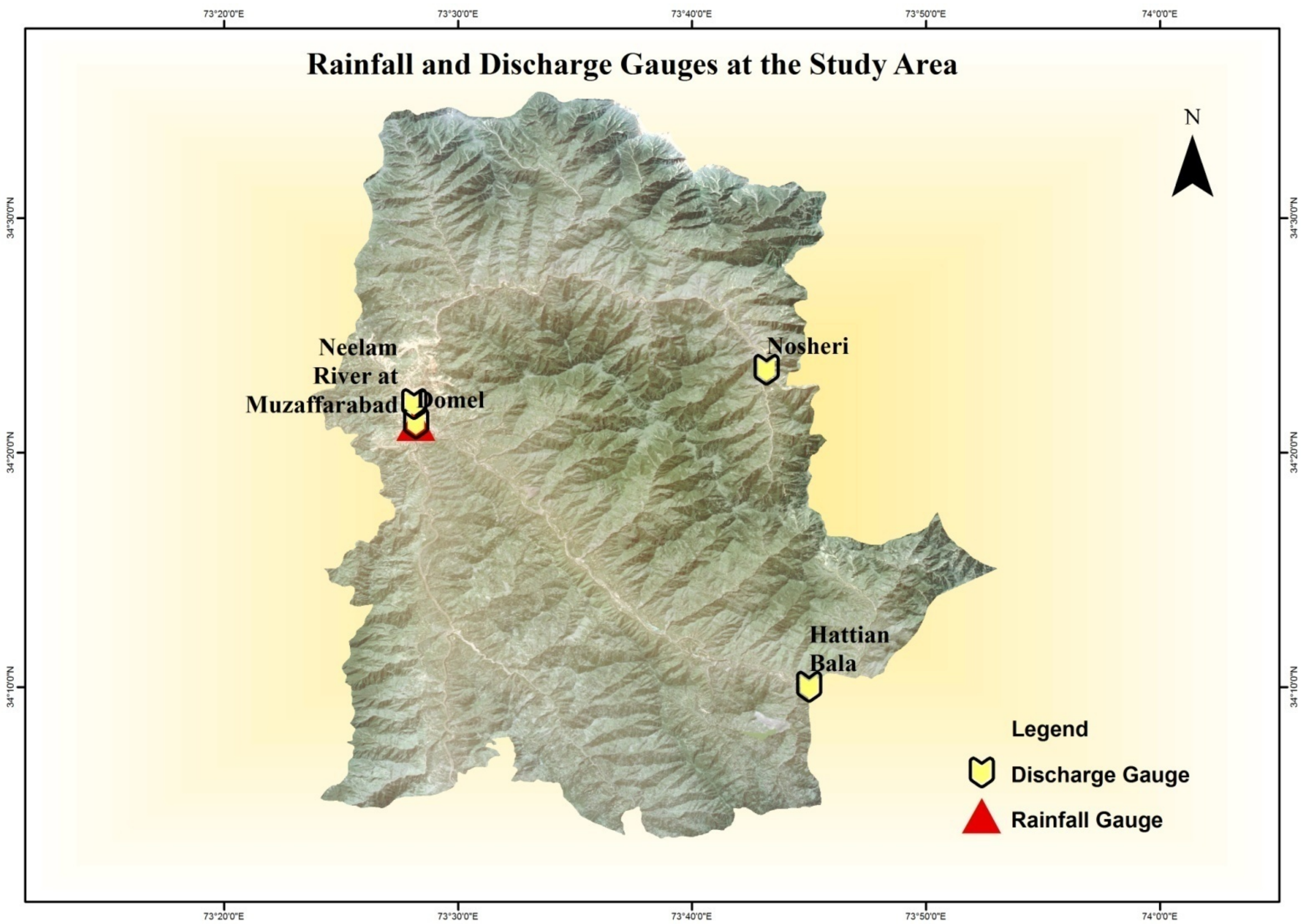

Figure 4.Location map of rainfall as well as stream gauges at Muzaffarabad.

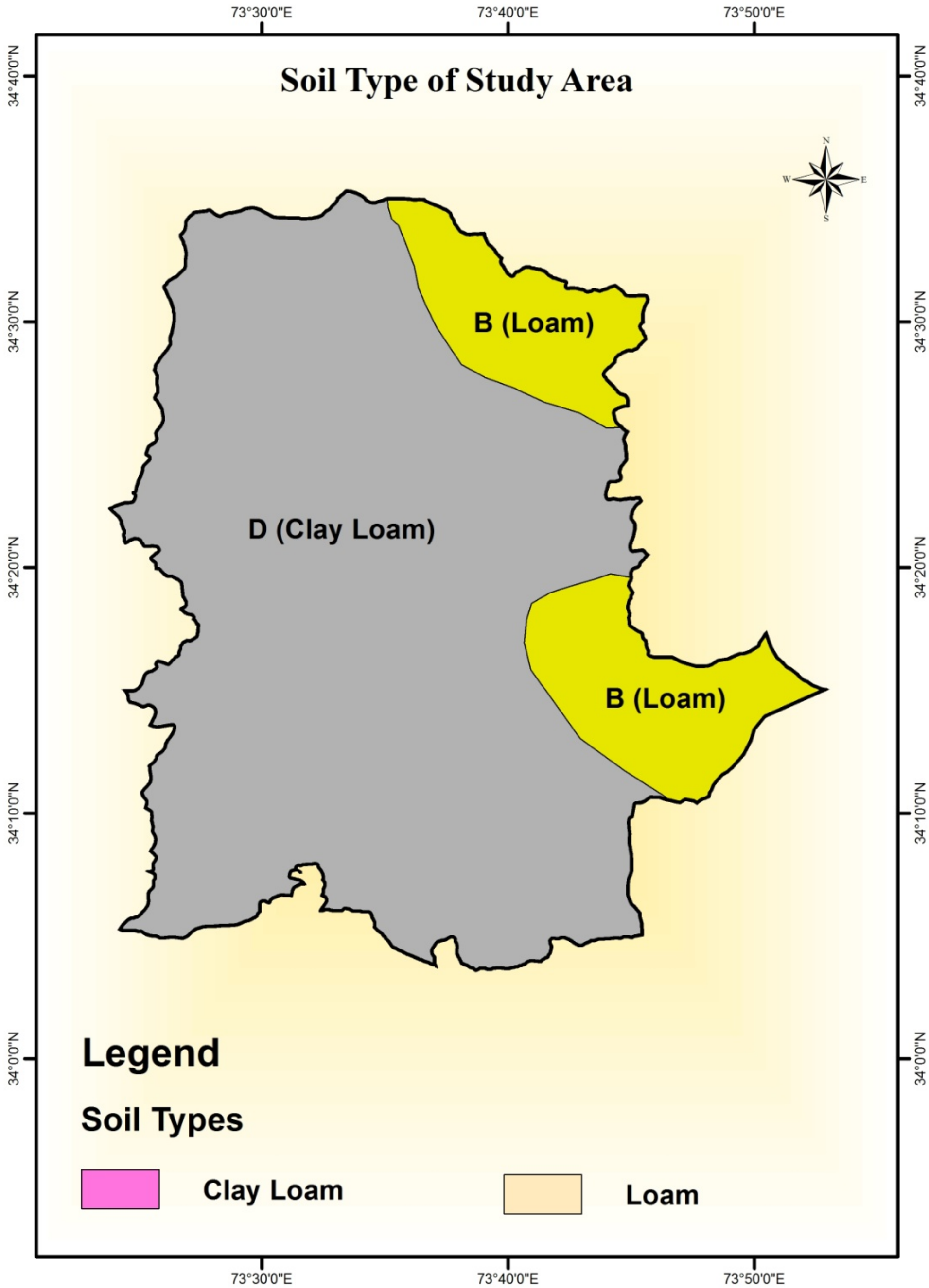

Figure 5. Major Soil type of the Study area mainly Clay Loam and Loam.

2.6 Hydrological Soil Groups HSG:

There is Hydrological Soil Group that is associated with each type of soil and it shows its infiltration capacity and rate of water transmission through the soil. For assigning HSG to the soil the surface of the soil is considered as bare .The values of HSG are used by combing land use or land cover values for estimation for CN for the specific area in a watershed. (AMMAR, 2014). All soil types are classified into four HSG groups (A,B,C,D) with respect to their infiltration rates considering the bare soil surface after prolong period of wetting (Assefa M. Melesse a, 2002). Figure 6 shows the corresponding hydrological soil groups as well respective infiltration rates of soil (Table 2.1).

2.6.1 Soil Group A:

These groups of soil are associated with low runoff and high infiltration rates. They are composed of well drained texture, deep sand and gravels and have a high rate of water transmission of greater than 0.30 inc/hr.

2.6.2 Soil Group B:

When thoroughly wetted these soils exhibit a moderate rate of infiltration. These are less than gravel and less aggregated than sand. The whole system of group of soil behaves less infiltration than group A soils. Chiefly composed of Silty Loam and Loam. Their rate of water transmission is (0.15 – 0.30 inc/hr).

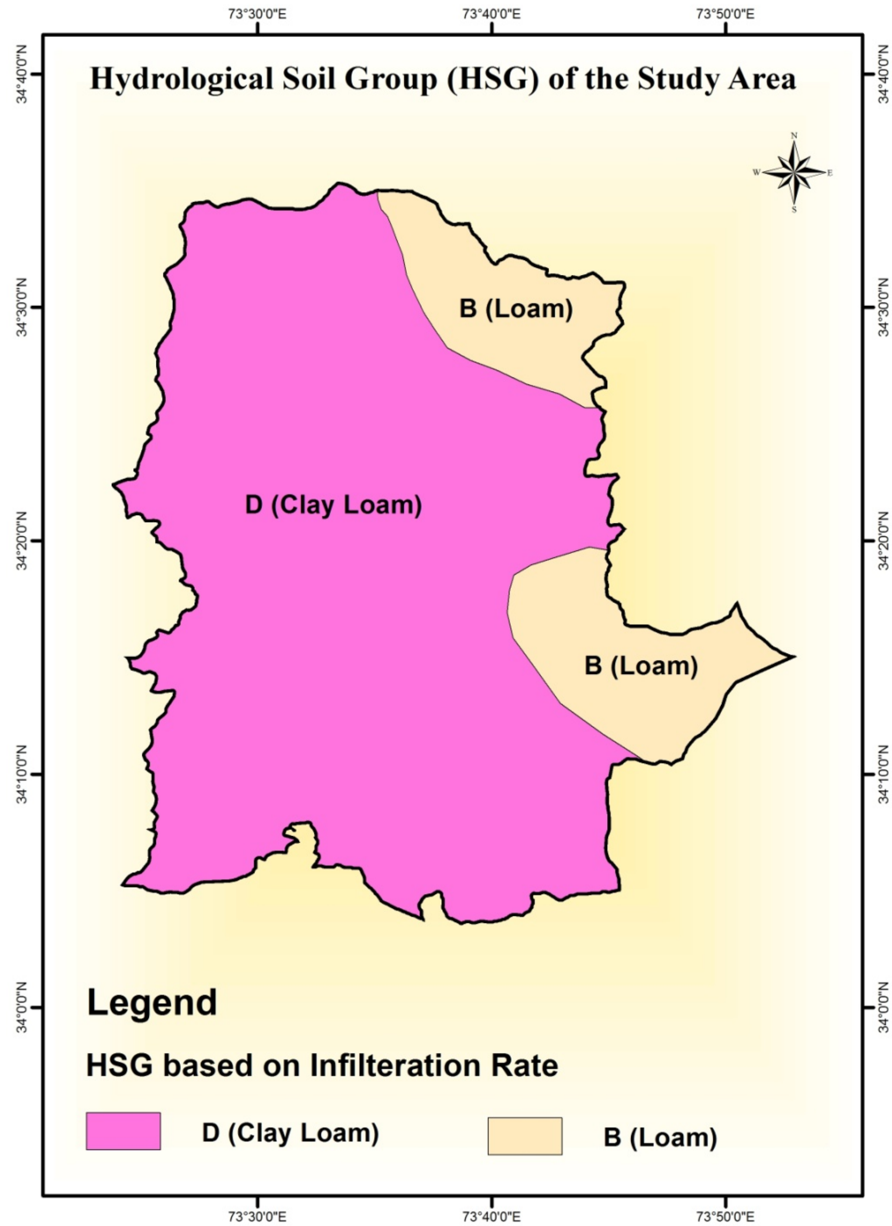

Figure 6.After converting the corresponding values of soil types into hydrological soil groups B and D were obtained.

Table 2.1. Following table shows dominant soil types and corresponding hydrological soil groups with their infiltration rates.

Soil Type	Clay Loam	Loam
HSG	D	B
Percentage Area	72%	28%
Infiltration Rates	(0-0.05)in/hr	(0.15-0.30) in/hr

2.6.3 Soil Group C:

These groups of soil have little infiltration rates than group B soils. These soils are with fine texture, usually shallow composed of Clay and their colloids and have low rate of transmission of water that is (0.05 – 0.15 in/hr).

2.6.4 Soil Group D:

These soil have low infiltration rates and therefore responsible for high runoff when wetted thoroughly. These soils have high swelling potential. They are mainly composed of Clay pans and due to which soil permanent remain wet when there is high water table. These are shallow soil with impervious material. Their rate of water transmission is (0-0.05 inc/hr).

2.7 Antecedent soil moisture conditions

Antecedent soil moisture is the moisture conditions of the soil prior to that rainfall event and CN values are based on this. It is an indication of the soil wetness and capacity of the soil storage before that specific rainfall. Normally the period of five days taken into consideration to determine the moisture of the soil. There are 3 types of moisture conditions AMC I, AMC II and AMC III that can calculated using the following formula given below.

$$\mathrm{RCN(I)} = \frac{4.2\mathrm{RCN(II)}}{10 - 0.058\mathrm{RCN(II)}} \qquad (1)$$

$$\mathrm{RCN(III)} = \frac{23\mathrm{RCN(II)}}{10 + 0.13\mathrm{RCN(II)}} \qquad (2)$$

The range of each AMC condition based on the cumulative rainfall given in the Table 2.2.

Table 2.2. Following table shows three AMC conditions of the soil before dormant and rainfall season .

AMC	Cumulative 5-days Antecedent Rainfall (mm)	
	Dormant season	Rainfall season
1	<12.7	<35.6
2	12.7-27.9	35.6-53.3
3	>27.9	>53.3

2.8 Methodology Flow Chart

The analytical framework presents the overall methodology followed during the research work (Fig 7). It includes the data collection, data pre-processing, and model processing through calibration and validations and finally the analysis of the obtained results.

2.9 Data Processing

Before populating data into the model there data preprocessing was done. These involve the extraction of DEM of desired spatial extent. Projecting it to the coordinates of the study area. Extraction of rainfall data from TRMM converting it to nc.tiff format. Data of various soil types and assigning hydrological and ground conditions to the Curve Number. Setting the location of the project in HEC-Geo HMS and associated parameters.

2.10 Landsat image Processing

Muzaffarabad has a mountainous terrain due to which there are some confusing pixels of water features and soil due to the reflectance of soil in shallow water. In small streams of the watershed the water gives the less reflectance than soil therefore these features were also classified as bare soil. This problem was with all the temporal images. Unsupervised classification does not give best results due to these confusing pixels. For this purpose supervised classification using the minimum distance method was used for assigning respective classes to the pixels. Because this classification method pixel are classified into class who’s known or estimated distribution most closely

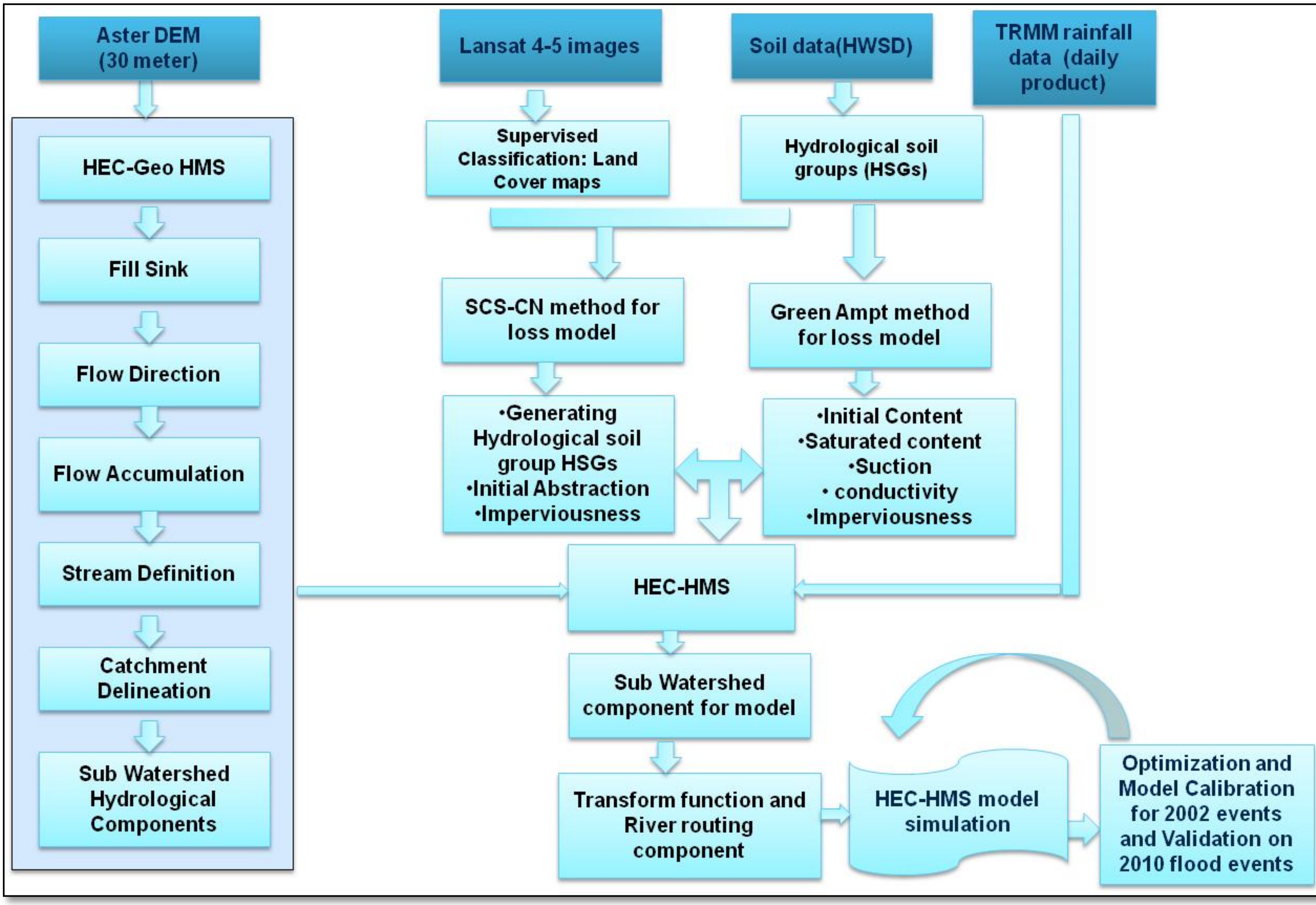

Figure 7. Methodology flow chart showing the systematic procedure in HEC-GeoHMS for terrain processing using ArcHydro tools, basin processing and river processing and model simulation in HEC-HMS using all the required layers exported from HEC-GeoHMS and hydro meteorological data in table.

resemble estimated distribution of pixels to be classified. ERDAS Imagine 12 was used for classification purpose, while Arc Map helps in the extraction and merging of different classes as needed. Total five classes were used for classification i.e Water, Bare soil, Trees, Grass and Built up (Fig 2).

125 training samples were digitized for the images of 2002 and 2010. To enhance the accuracy of classification high resolution Google earth images was used with historic images to match with the images of 2002 and 2010. For validation purpose random points were generated on the Arc Map and imported to Google earth for reference and classification accuracy were performed using these data by creating an error matrix. This proves helpful as some areas of the basin are not accessible due to the steep terrain. All the accuracy measures i.e user accuracy, producer accuracy and overall accuracy were performed for accuracy assessment.

2.11 Runoff estimation using SCS curve number

Curve Number is the parameter in hydrologic modeling that depicts the total runoff potential of the watershed area. It is a combination of Land use , Soil moisture conditions and Soil type of the basin (Sumarauw & Ohgushi, 2012).

Curve number method was first developed by the Agriculture Department of the United State of (NRCS) Natural Resource Conservation Services. This method is applicable on small to medium size catchments for measuring direct runoff in un gauged basins (L. SILVEIRA, 2000). Part of the Loss model is calculated by SCS curve number method. By measuring loss parameters with help of this method transform method also used these parameters for further calculation of storm hydrograph (Asadi & Boustani).

(Chow, 1976) uses method developed by the Soil Conservation Service (SCS) for measuring effective precipitation from storm event of a rainfall. For a single storm event the depth of direct runoff is always less than to the depth of total precipitation.

For calculating Initial Abstraction following equation is used

$$I = 0.2S \qquad (3)$$

Following equation used by NRCS to model rainfall and runoff process in a watershed. Direct runoff is estimated by converting excess precipitation to stream flow. For calculation of storage CN is used in following way (Melesse & Shih, 2002).

$$S = \frac{25400}{CN} - 254 \qquad (4)$$

By substituting equation 2 into equation 1 equation 4 is obtained

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad (5)$$

2.12 Curve Number Grid Generation

Method behind calculating curve number was described in chapter two but raster maps are prepared in Arc Map using create CN grid tool. Values of CN on the basis of Hydrological Soil groups and different ground condition like poor, good and fairly good were taken from the TR55 reference manual.

Inputs were land use and hydrological soil groups that were combined together with the help of union tool into Soil and Land use polygons. Slope raster were also generated using HEC-Geo HMS tools and combining above all layers CN raster were prepared for the watershed (Fig 8). Average values of CN were prepared for all Sub-Basins in HEC-Geo HMS by suing Basin lag parameter.

2.13 Green and Ampt Loss method

To calculate the loss rate and discharge after infiltration there are many methods that consider some empirical values determined from each watershed or has to be calculated using the physical parameters. This is a conceptual model that calculates the rate of rainfall losses after infiltration in permeable soils. Green and Ampt method is acceptable methods as it represent the simplified form of loss model in terms of infiltration in the field (Kabiri, 2014). This model only requires the parameters that can be determined from the soil textures (Rawls, Brakensiek, & Miller, 1983).

Water after infiltration moves down to the soil vertically in form of wetting front. It assumes the fact that before the rainfall, soil has some amount of moisture it which is θ_i When water infiltrates in such soil a line sharp edge.

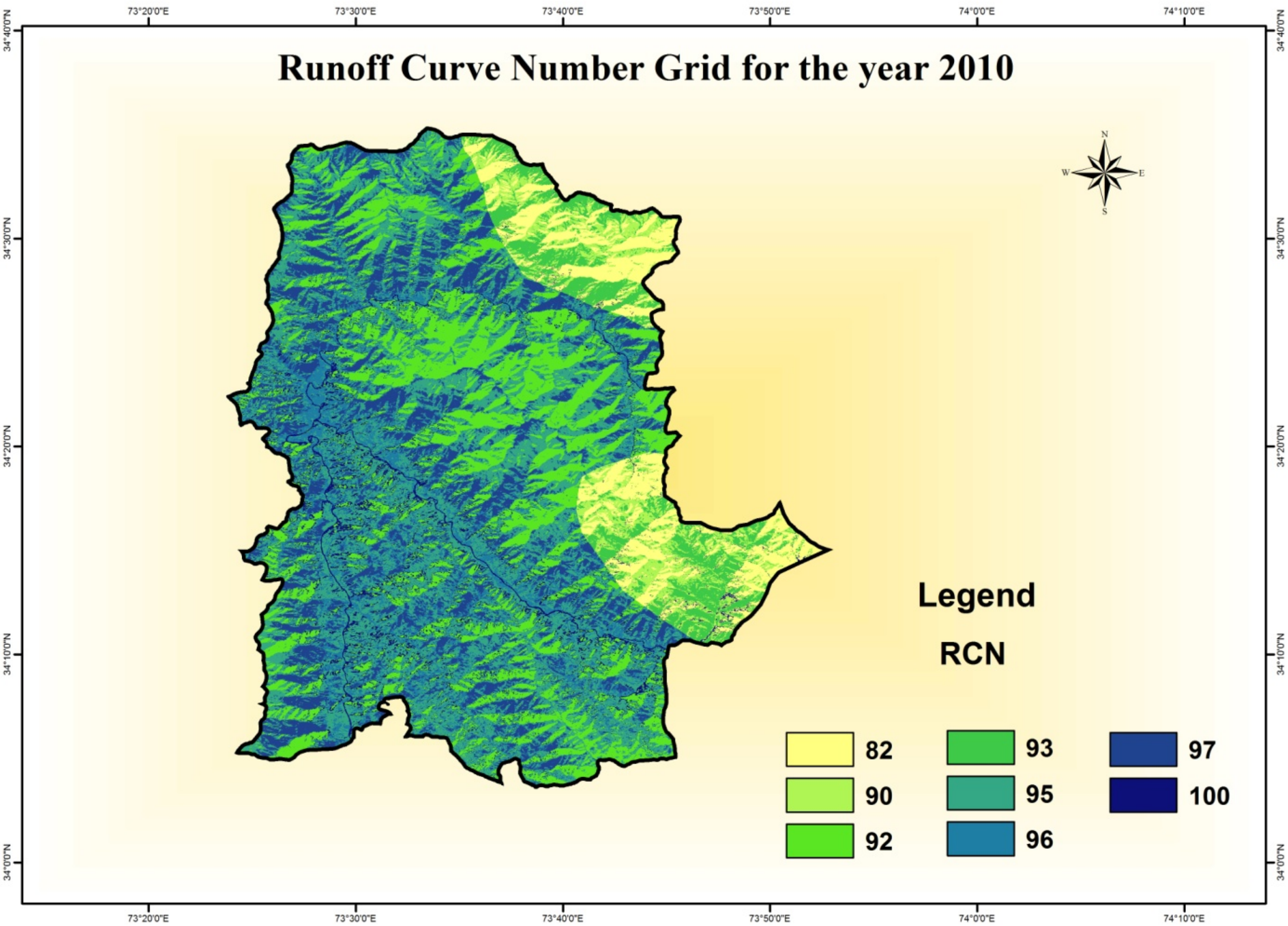

Figure 8. Curve number grid (2010) generated after merge of landuse and soil characteristics that depicts the runoff value of a watershed.

develops between dry soil that has moisture content θi) – and moist soil that has moisture content (Fig 9). This is equal to the porosity of the soil, which is η. The amount of water that got added to the soil is equal to the following equation.

$$F(t) = L(\eta - \theta_i) \qquad (6)$$

Where L is the depth of wetting front

Look up tables developed by Green Ampt (Scharffenberg & Fleming, 2010) that use the soil texture and give the values of other parameters from it. Infiltration parameters of Green ampt methods, including Initial Content, Saturated content, Suctions, Conductivity, Imperviousness percentage are calculated manually using Excel formula are as shown in the table 2.2. Then the values for each sub Basin, according to the soil type were populated in HEC-Geo HMS.

$$F = \frac{K_s S_w(\theta_s - \theta_i)}{I - K_s} \qquad (7)$$

Where θ_i and θ_s are the initial content and saturated content of the soil S_w is the negative pressure due to soil water suction I is rainfall intensity ($\frac{in}{hr}$), and K_s is the saturated hydraulic conductivity.

2.14 Muskingum routing method

The Muskingum method describes the hydraulics of the river and streams in the watershed. This method describes the routing of river on the basis of continuity equation. K and X parameters are used to calculate the routing. K is

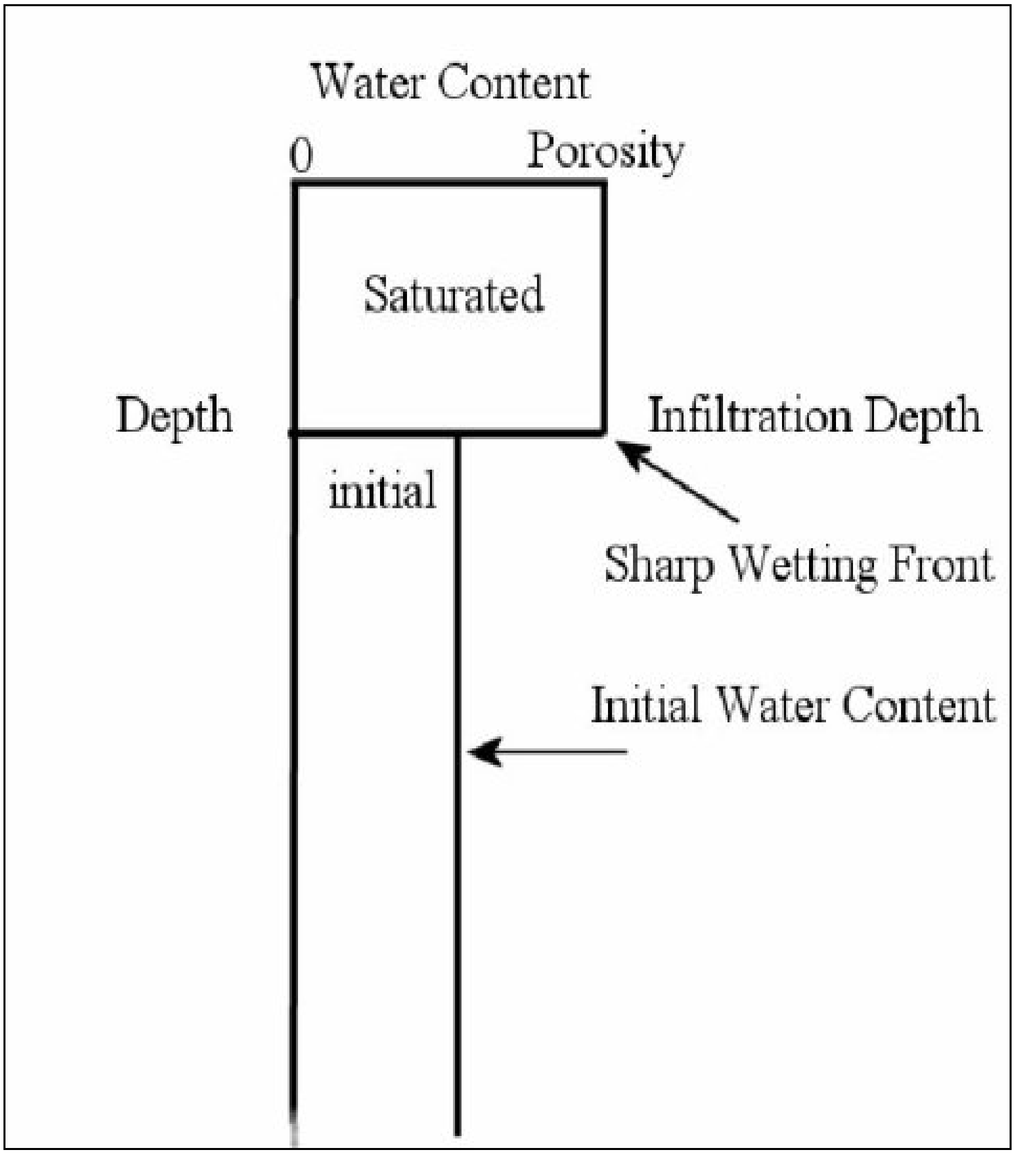

Figure 9. Basic Assumption behind Green and Ampt loss method infiltration depths are measured in mm.

Table 2.3 Estimate of each parameter in Green Ampt method using the texture table of each soil type.

Soil Type	Porosity	Suction head	Hydraulic conductivity	Initial Moisture Deficit
	H	(mm)	(mm/h)	
Sand	0.437	49.5	117.8	0.346
Loamy sand	0.437	61.3	29.9	0.312
Sandy loam	0.453	110.1	10.9	0.246
Loam	0.463	88.9	3.4	0.193
Silt loam	0.501	166.8	6.5	0.171
Sandy clay Loam	0.398	218.5	1.5	0.143
Clay Loam	0.464	208.8	1	0.146
Silty clay Loam	0.471	273	1	0.105
Sandy clay	0.43	239	0.6	0.091
Silty clay	0.479	292.2	0.5	0.092
Clay	0.475	316.3	0.3	0.079

the hydraulic constant while X measure the rate of inflow and outflow influx through the channel.

The value of X ranges from 0 to 0.5. Number of reaches associated with it should also be defined in the model.

$$K = \frac{l}{V} \tag{8}$$

Where: l is length of reach (m) and V is mean velocity (m/s)

$$X = \frac{l_2^1}{np_3^2} \tag{9}$$

Where: I is river slope, n is Manning's roughness coefficient and P is wetted perimeter (m)

2.15 HEC-Geo HMS

HEC-Geo HMS is a geospatial hydrology tool. It operates in GIS environment, as an extension of ArcGIS. For the current study, the versions that were used are HEC-GeoHMS 4.0 and ArcGIS 10.1. The HEC-GeoHMS is used for the creation of background map files, basin models files, metrological model files that can be later imported in HEC-HMS to develop a hydrologic model (Papathanasiou et al., 2013).

2.15.1 Components of HEC-Geo HMS:

HEC-Geo HMS produce a number of files such as back ground shape file, basin model, meteorological al model and project file that can be directly used by HEC-HMS for further analysis.

This extension is used to calculate all the necessary parameters that will be further used by the model. By using terrain processing tools of model all the raster and vector layers were generated these includes Fill sinks, Flow direction, Flow accumulation, Stream definition, Stream link, Link, Grid, catchments and watershed slope. Basin processing part of model calculates the longest flow path of sub basins their centroids and then centroidal flow path. CN grid was converted into vector layer to obtain values for basin curve number and basin slope (table 2.3).

2.15.2 Parameters calculated through Green and Ampt method

Loss rate were calculated using another method called Green and Ampt method by which parameters based on soil texture were calculated and using this method discharge rate was also calculated. Porosity, Suction head, Hydraulic Conductivity and Initial Moisture values were populated in the HEC-HMS model as shown in Table 2.4 for each sub Basin, equation 6 was used by model to calculate discharge after infiltration.

Table 2.4. Table showing all the sub-basins generated by HEC-GeoHMS and its associated parameters of basin lag, basin curve number, and basin slope.

Sub Basins	Area km^2	Basin Slope	Basin CN	Basin Lag
120	69.6	67.6	93.2	0.5
130	91.4	64.1	94.9	0.7
140	31.0	77.9	89.7	0.5
150	78.9	74.1	88.1	0.9
160	12.6	64.5	95.4	0.3
170	40.1	62.3	94.9	0.5
180	43.4	62.6	94.7	0.5
220	32.8	66.1	93.4	0.4

Table 2.5. Parameters calculated using Green and Ampt method for each sub basin based on soil texture.

Soil Type	SubBasins	Initial content	Saturated Content	Suction (mm)	Conductivity (mm/hr)	Impervious (%)
Clay Loam	W120	0.2163	0.464	2.808	1.0	3
Clay Loam	W130	0.2163	0.464	2.808	1.0	3
Loam	W140	0.3038	0.463	88.9	3.4	9
Loam	W150	0.3038	0.463	88.9	3.4	2
Clay Loam	W160	0.2163	0.464	2.808	1.0	6
Clay Loam	W170	0.2163	0.464	2.808	1.0	6
Clay Loam	W180	0.2163	0.464	2.808	1.0	7
Clay Loam	W190	0.2163	0.464	2.808	1.0	5

2.16 HEC-HMS Model Setup

HEC-HMS model after importing the project file from HEC-GeoHMS creates a separate model for each component for simulation. These are three models that should define in HEC-HMS i.e Basin model, meteorological model consists of hydrological data, such as rainfall data, snow, evapo-transpiration and stream data third is control specification that This includes the start and end time of the model simulation and also defines the model to simulate on hourly, 6 hourly, daily or on monthly basis.

2.17 Components of HEC-HMS:

2.17.1 Basin Model

The main Component of the project is Basin model. This convert all the atmospheric processes taking part in runoff generation into the runoff volume at the outlet of the watershed .Different hydrologic elements work separately in a watershed. They are connected through a dendritic stream network to form an overall system of the watershed. Basin model is added by a background map file which helps in the placement of each element with respect to its geographic location.

B. Meteorological Model

The principle purpose of the model is to prepare principal boundary conditions for sub basins. Before defining a new meteorological model basin model should be created first. Single basin models can be used with different meteorological models depending upon the temporal variety. Although simulations done by Meteorological model will compared with the respective sub basins of the basin model using the unique name of the Basin model. Different basin model with the same names of sub basins will assisnged similar boundary conditions for the Meteorological model.

C. Control Specifications

The final component of the model that is regarding to give a time span to the simulation. For an event the start and end time is give in control specification. After that model is run Control Specifications define the model start and stop time and the time step interval. Timing of the simulations is specified by the Control Specifications, including the start and end time and time interval for simulations (Xingnan, 2008).

Chapter 3

RESULTS AND DISCUSSION

3.1 Peak runoff hydrograph

Peak flood estimation was done on the watersheds of Muzaffarabad that comprises of Neelum and Jhelum Rivers. Two loss methods were used in comparison for selection of better model to calculate runoff. Calibration was done using stream flow data of 19th June to 30th June, 2002 comprising of flood events and validation was performed on the peak flood events of 22nd July to 7th August. Both the methods i.e. SCS curve number and Green and Ampt loss method were used for calibration and validation of the model on both catchments.

3.2 Adjusted parameters for SCS loss method

Initial Abstraction, Curve number based on AMC i.e initial moisture conditions, Time lag and K and X parameter for river routing were used for model calibration using SCS loss method. AMC conditions that are moisture conditions of the soil prior to rainfall are used for 2002 events and values for curve number was obtained using AMC II conditions. For validation keeping the above parameters same AMC III conditions were used as cumulative rainfall before that particular storm was greater than 53 mm. So, high curve number values were obtained for 2010 storm events. Lag time which is time difference between peak precipitation and peak runoff is between 27 to 47 minutes in Neelum sub catchments are therefore responsible for peak floods in less time interval.

3.3 Adjusted Parameters for Green and Ampt loss method

Green and Ampt method considers the properties of soil texture. The parameters that were used for calibration are initial abstraction that measures the soil infiltration rate after the specific rainfall events and it was found 0.21 for clay loam and 0.303 for loamy soil. Therefore low infiltration rates of clay loam soil are responsible for high rate of runoff. Saturated content, Suction and Hydraulic conductivity was found 0.464, 2.808 and 1 for clay loam and 0.463, 88.9 and 3.4 for loamy Soil respectively (table 2.5).

3.4 Model Calibration

The calibration results using hydrologic modeling shows a correlation coefficient of 0.7 ($p \leq 0.05$) (Fig 10) using SCS curve number method and 0.58 ($p \leq 0.05$) using Green and Ampt loss method (Fig 11) on Neelum catchment. Calibrated results on Jhelum catchment shows a correlation coefficient of 0.7 ($p \leq 0.05$) using SCS (Fig 12) and 0.624 ($p \leq 0.05$) was obtained using Green and Ampt loss method (Fig 13 and table 3.1).

Calibrated results were found satisfactory using both methods. As model assumes watershed in distributive environment by incorporating sub watersheds components. Calibrated parameters of lag time , longest flow path and basin centroids calculates the variations in elevations and prepare a model that can be used further for analysis as well as for flood forecasting by incorporating only rainfall data.

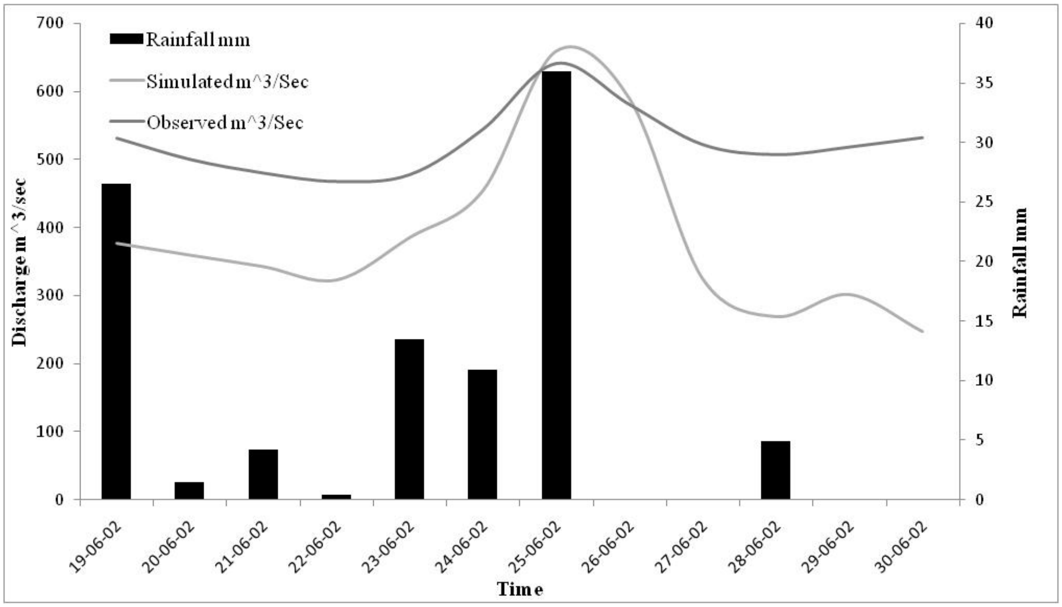

Figure 10. Results of the calibrated events from 19 to 30 June 2002 using SCS Curve number loss method between simulated and observed hydrograph at Neelum catchment.

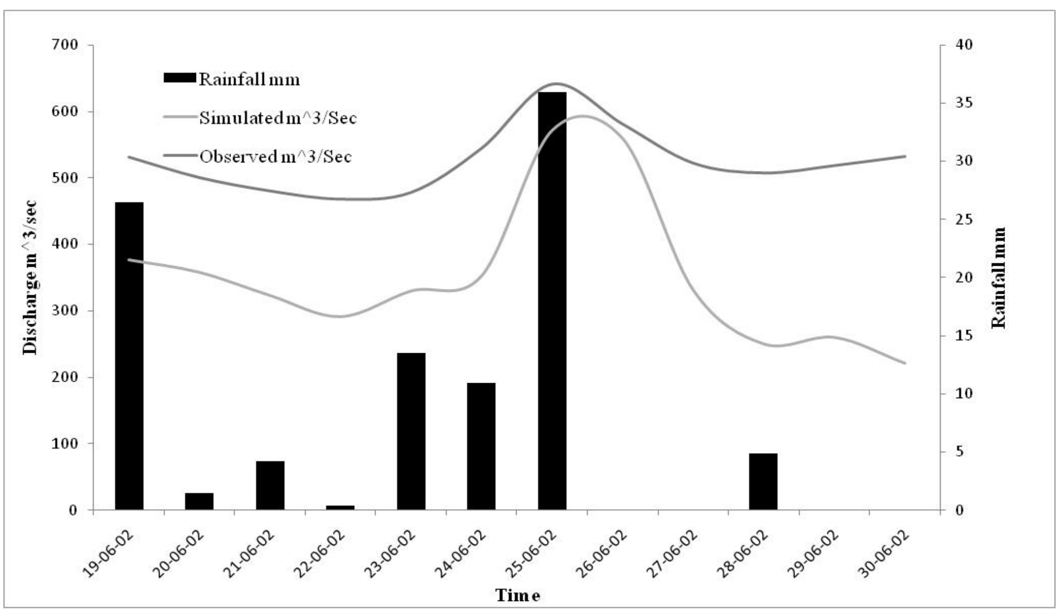

Figure 11. Results of the calibrated events from 19 to 30 June 2002 using Green and Ampt loss method between simulated and observed hydrograph at Neelum catchment.

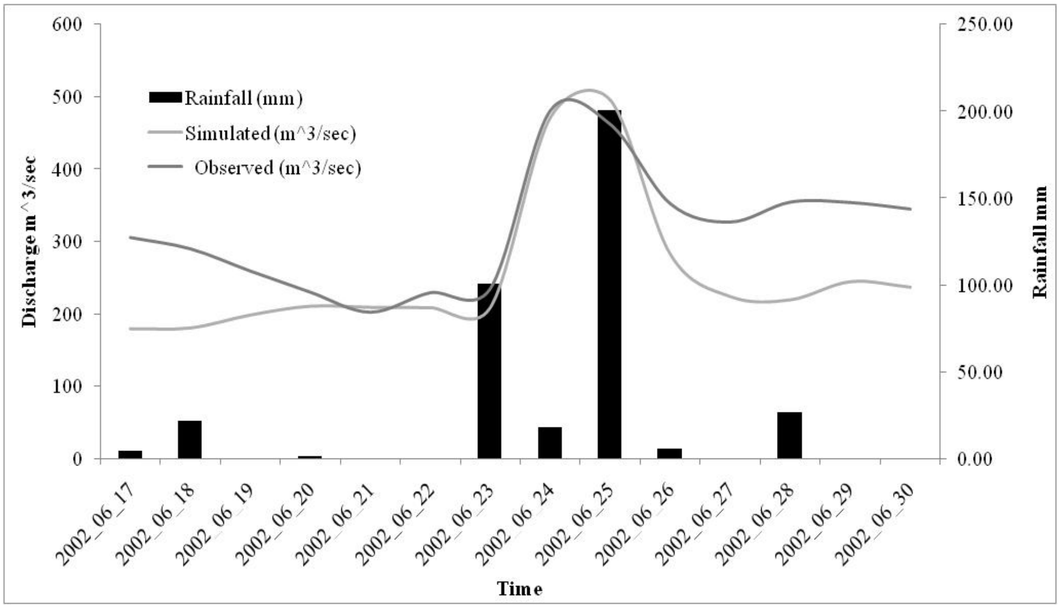

Figure 12. Results of the calibrated model events from 17 to 30 June 2002 using SCS Curve number loss method between simulated and observed hydrograph at Jhelum catchment.

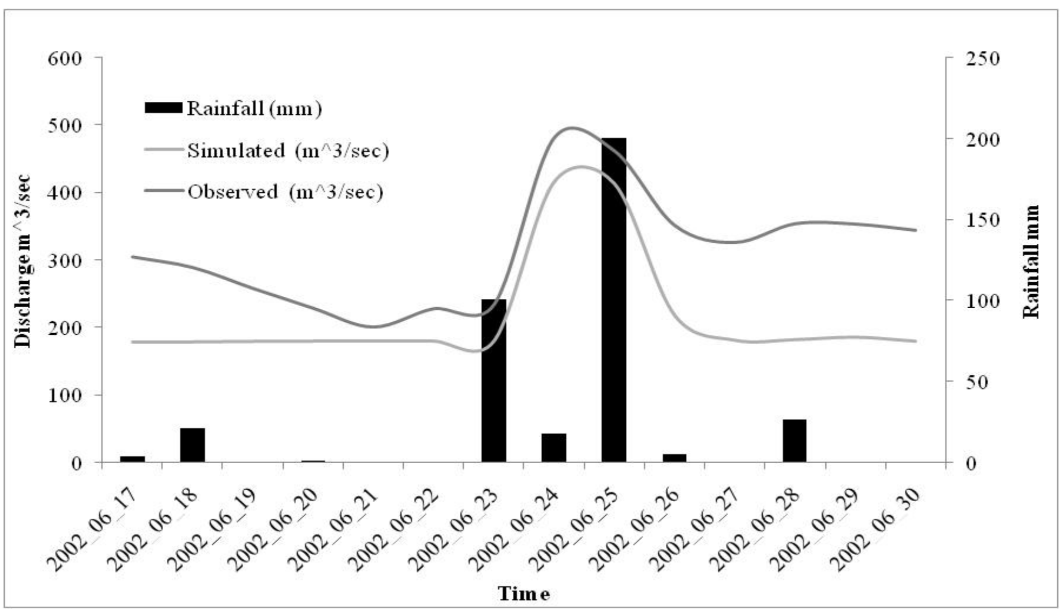

Figure 13. Results of the calibrated events from 17 to 30 June 2002 using Green and Ampt loss method between Simulated and observed hydrograph at Jhelum catchment.

3.5 Model Validation

Model validation is an important part of assessing the performance of a hydrological model. Parameters that were calibrated are used in validation without changing the value of any parameter. The validation results show a correlation coefficient of 0.824 ($p \leq 0.05$) using SCS loss method (Fig 14) and 0.842 ($p \leq 0.05$) using Green and Ampt loss method (Fig 15) at Neelum catchment. While at Jhelum catchment correlation coefficient of 0.904 ($p \leq 0.05$) was obtained using SCS loss method (Fig 16) and 0.894 ($p \leq 0.05$) was obtained using Green and Ampt loss method (Fig 17 and table 3.2). Both these methods shows good correlation with observed discharge but SCS Curve number methods gives better results than Green and Ampt loss method. Better performance of SCS curve number method reveals that it incorporates more parameters i.e landuse and initial moisture conditions of the soil than Green and ampt method therefore correlation between simulated results using SCS loss method and observed stream flow was greater.

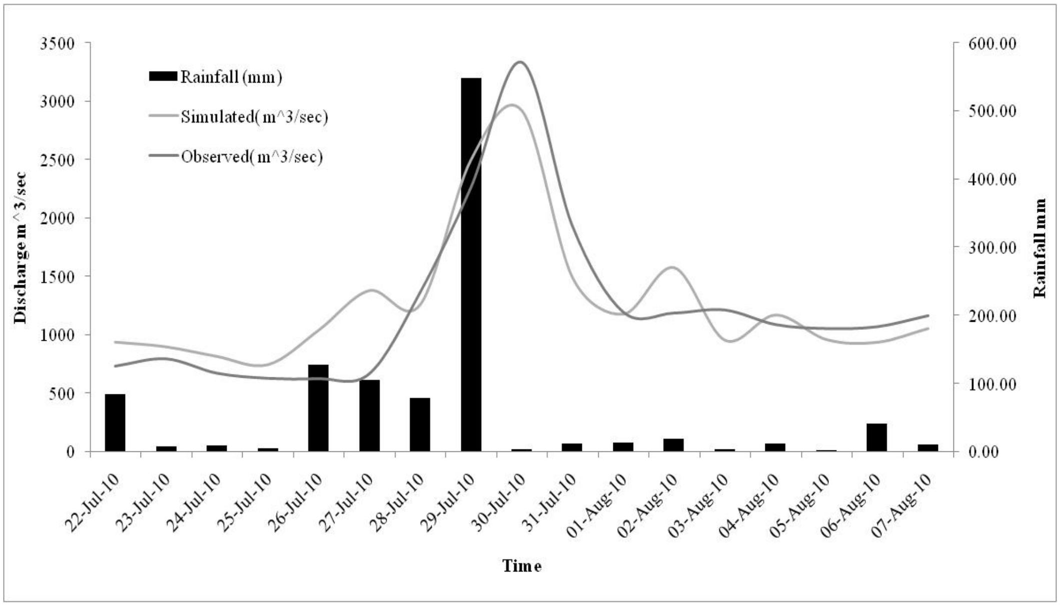

Figure 14. Results of the validated model events from 22 July to 7th August using SCS Curve number loss method between simulated and observed hydrograph at Neelum catchment.

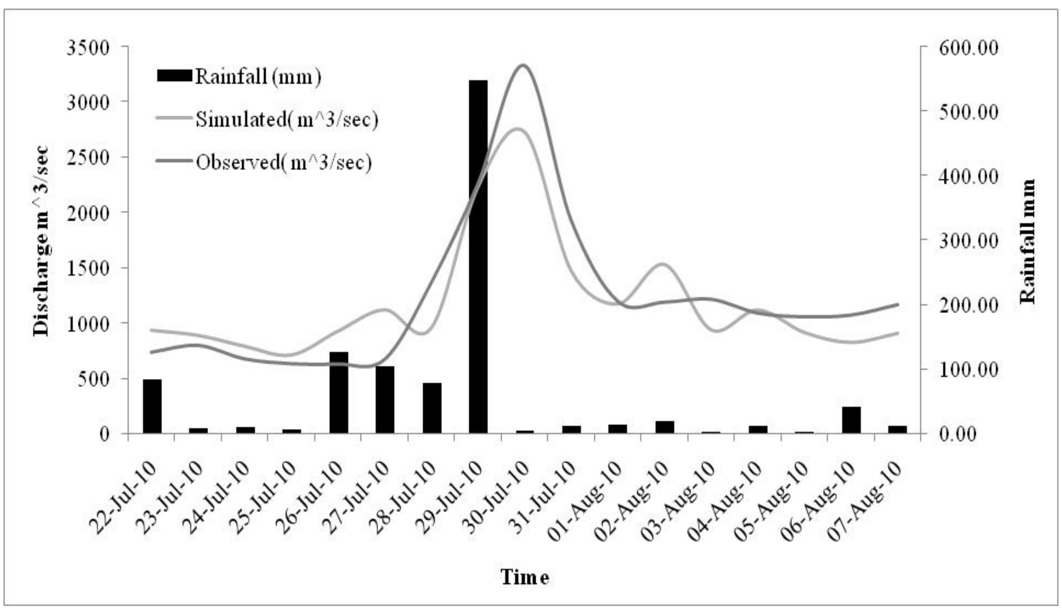

Figure 15. Results of the validated model events from 22 July to 7th August using Green and Ampt loss method between simulated and observed hydrograph at Neelum catchment.

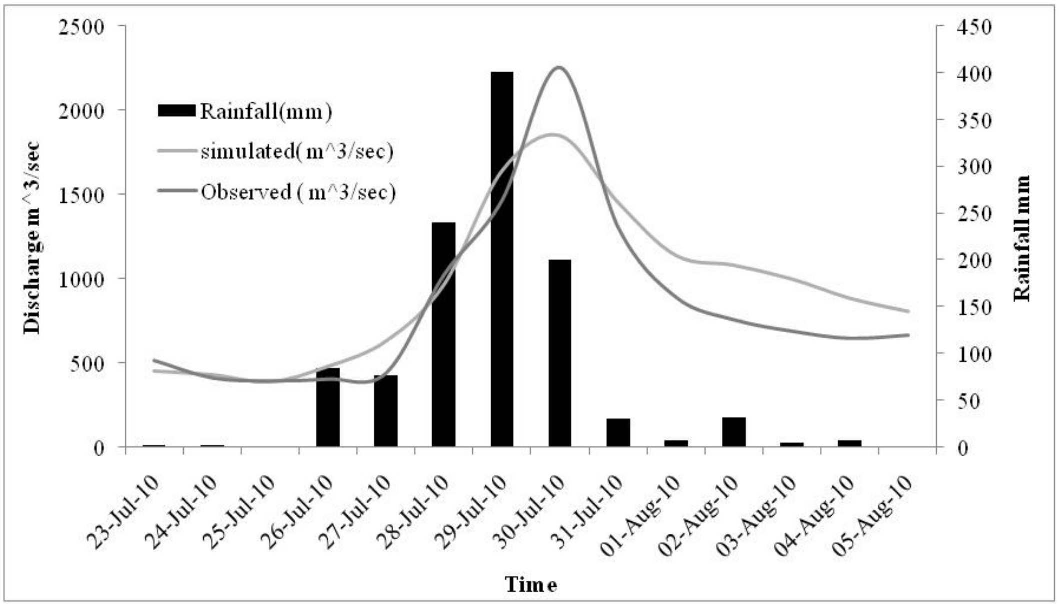

Figure 16. Results of the validated model events from 23rd to 5th August using SCS Curve number loss method between simulated and observed hydrograph at Jhelum catchment.

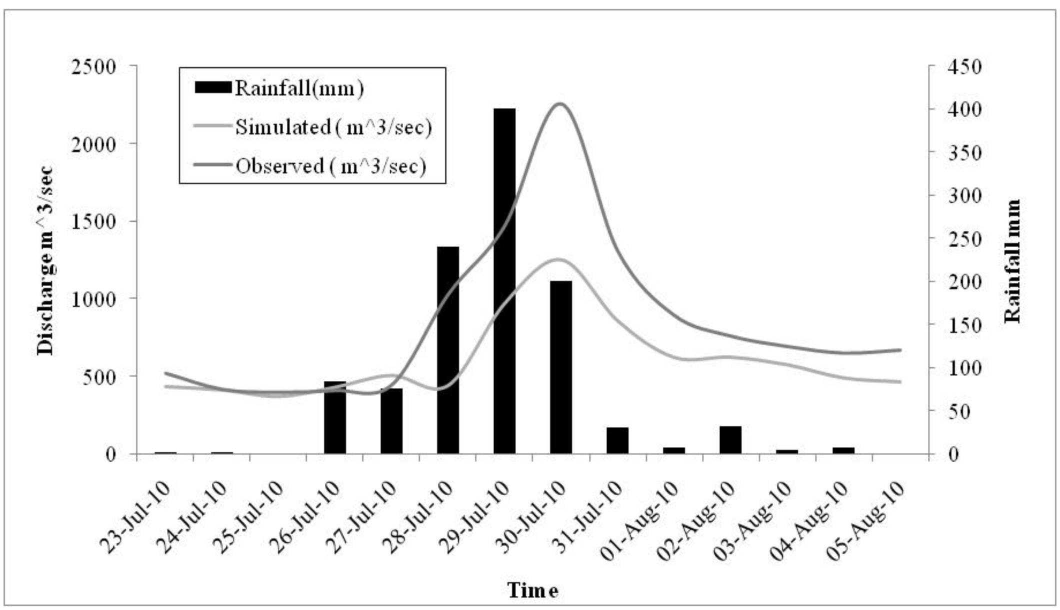

Figure 17. Results of the validated model events from 23rd to 5th August using Green and Ampt loss method between simulated and observed hydrograph at Jhelum catchment.

Table 3.1. Correlation coefficient and Nash coefficient values using both basins and methods for calibrated events.

Year	2002			
Basin	Neelum River		Jhelum River	
Loss method	SCS-CN	Green Ampt	SCS-CN	Green Ampt
Correlation Coefficient	0.7	0.58	0.7	0.642
NSCE	0.98	0.77	0.99	0.96

Table 3.2. Correlation coefficient and Nash coefficient values using both basins and methods for validated events.

Year	2010			
Basin	Neelum River		Jhelum River	
Loss method	SCS-CN	Green Ampt	SCS-CN	Green Ampt
Correlation Coefficient	0.824	0.842	0.904	0.894
NSCE	0.8	0.99	0.93	0.76

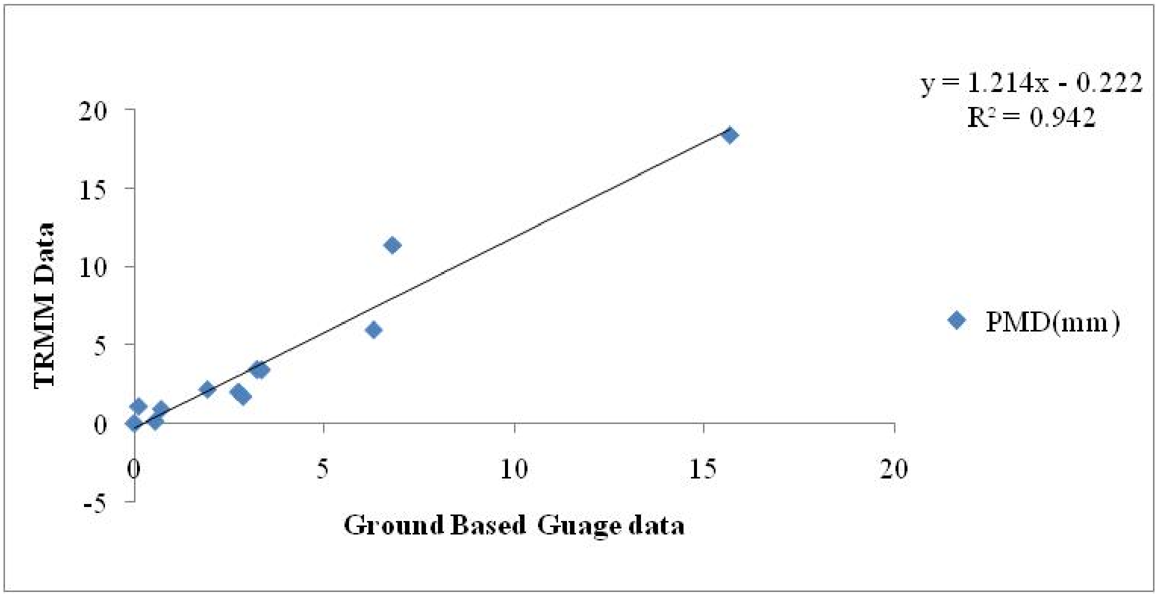

Figure 18.Correlation between gauge rainfall and TRMM satellite data on monthly basis of 2010 year.

3.6 Discharge computation using SCS and Green Ampt method

As SCS method incorporates the landuse, soil and moisture conditions of the soil at Neelum basin during calibration events i.e from 19th to 30th of June 2002 model shows peak at maximum rainfall day that is 25th June is comparable with observed discharge. While Green Ampt method being use only soil texture characteristics have discharge greater difference with observed streamflow. Main advantage of these calibrated parameters is that by using real time rainfall data on hourly or daily basis model can forecast streamflow which can be helpful in flood managements in these basins.

Validated model results at Neelum and Jhelum catchments show a good correlation of R^2 and Nash with observed discharge. Calibrated parameters of lag time, longest flow path and time of concentration were kept same for validation and give best results using both methods. While SCS curve number method shows more correlation due to the incorporation of landuse and moisture conditions of the soil at both catchments. At 30th July 2010 discharge of 2920 m^3/sec and 2731 m^3/sec was simulated using SCS loss method and Green Ampt method respectively at Neelum sub catchments. While at Jhelum sub catchments simulated discharge was 1848 m^3/sec and 1248 m^3/sec respectively using SCS and Green Ampt loss methods.

Table 3.3 Error matrix for accuracy assessment of supervised classification image

	Classified Image							
		Water	Grass	Trees	BareSoil	Settlements	Row total	Producer accuracy
Reference Image	Water	**6**	0	0	4	0	10	60
	Grass	0	**25**	3	0	1	29	86
	Trees	0	3	**14**	0	0	17	82
	BareSoil	0	0	0	**7**	0	7	100
	Settlements	0	0	0	4	**3**	7	43
	Column Total	6	28	17	15	4	70	
	User Accuracy	100	89	18	0	25		

Chapter 4

CONCLUSION AND RECOMMENDATIONS

4 .1 Conclusions

Incorporation of Geographic information System with lumped hydrologic models proves to be very efficient in determining basin characteristics and parameters. SCS Curve number method gives results in real time with the use of land use and soil moisture conditions.

- Runoff generated in Neelum river catchment and Jhelum river catchments is comparable with the simulated results using SCS and Green and Ampt loss methods.
- Model has also the capability to simulate the results on hourly, daily and monthly basis.
- Main advantage of using this methodology is that it provides runoff using those parameters that do not require field measurements and this method gives best results where no monitoring activity exist to measure discharge of river or streams.
- Model efficiency and suitability of methods attempted for simulation were tested by different statistics and correlation between simulated and observed was satisfactory.
- Results indicate that semi-distributed environments give better results than lumped hydrological model.
- Analysis of runoff using Green Ampt method on the other hand gives low correlation results than SCS Curve number method. It is due to the

fact that Green Ampt loss method uses only parameter of soil for infiltration modeling.

4 .2 Recommendations

Based on the results obtained as stated, it is thus suggested that with improvement in data conditions like high spatial resolution of satellite images and monitoring gauges in watersheds results can be improved.

Following are some recommendation that can be used to enhance model efficiency.

- Rain gauges installation should in catchment boundary for accurate measurement of runoff generated due to rainfall.

- High-resolution satellite data enhance the accurate estimation of land cover and by classifying more number of land use classes CN values can be accurately estimated for runoff simulation.

- Digital Elevation model less than 30 meter provide more variation in terrain hence basin and river processing part of model can be precisely measured

- Automatic rain gauges collecting data on hourly basis should be installed on such catchments that are associated with flash floods hazards. So that using short time interval forecasting can be done for management purpose.

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APPENDICES

Appendix 1. Calibrated results showing simulated discharge with both methods at Neelum sub basins and observed discharge.

Date	Rainfall mm	Simulated m^3/Sec	Simulated m^3/Sec	Observed m^3/Sec
		Using SCS-CN method	Using Green and Ampt method	
19-06-02	26.48	376.7	376.7	531
20-06-02	1.44	359.4	357.9	500
21-06-02	4.18	342.6	323	479.9
22-06-02	0.41	322.9	291	467.5
23-06-02	13.47	385.3	329.7	477.6
24-06-02	10.9	454.3	352.6	544.3
25-06-02	35.9	659.2	571.9	640.9
26-06-02	0	589.4	559.4	580.6
27-06-02	0	324.5	331.1	521.8
28-06-02	4.88	269.1	249.9	507
29-06-02	0.05	301.6	259.8	518.1
30-06-02	0.04	247.2	220.8	531.9

Appendix 2. Calibrated results showing simulated discharge with both methods at Jhelum sub basins and observed discharge.

Dates	Rainfall (mm)	Simulated (m^3/sec)	Simulated (m^3/sec)	Observed (m^3/sec)
		using SCS-CN method	Using Green Ampt method	
17-06-02	4.35	179.4	179.4	304.8
18-06-02	21.73	180.5	179.5	289.1
19-06-02	0.06	198.4	180.3	258.3
20-06-02	1.42	210.6	180.7	229
21-06-02	0.00	209	180.7	201.3
22-06-02	0.05	208.6	180.7	228.4
23-06-02	100.70	208.8	180.7	234.1
24-06-02	17.91	471.3	416.3	480.6
25-06-02	200.68	495.4	413.9	461.5
26-06-02	5.60	282.3	219	351.5
27-06-02	0.00	223.9	182	326.2
28-06-02	26.58	219.4	182.9	353.8
29-06-02	0.00	244.5	186.5	353.3
30-06-02	0.34	236.9	180.6	344.2

Appendix 3. Validated results showing simulated discharge with both methods at Neelum sub basins and observed discharge.

Date	Rainfall (mm)	Simulated(m^3/sec)	Simulated (m^3/sec)	Observed (m^3/sec)
		Using SCS-CN method	Using Green Ampt method	
22-Jul-10	84.19	934.7	934.7	732
23-Jul-10	7.65	894.3	888.5	794.2
24-Jul-10	8.75	812.4	790.8	671.6
25-Jul-10	4.66	740.6	711	628
26-Jul-10	126.71	1035	926.2	624.6
27-Jul-10	104.49	1376.2	1120.1	666.7
28-Jul-10	77.46	1254.4	954.8	1361
29-Jul-10	548.36	2494.5	2231.3	2258
30-Jul-10	3.43	2920.6	2731	3330
31-Jul-10	11.56	1489	1473	1928
01-Aug-10	13.23	1173.9	1172.8	1194
02-Aug-10	18.47	1572.9	1530.2	1186
03-Aug-10	2.75	951	938.9	1212
04-Aug-10	10.81	1166.8	1118.4	1087
05-Aug-10	1.94	956.4	914.7	1053
06-Aug-10	40.22	932.9	825.1	1069
07-Aug-10	10.44	1051	907	1163

Appendix 4. Validated results showing simulated discharge with both methods at Jhelum sub basins and observed discharge.

Dates	Rainfall(mm)	Simulated(m^3/sec)	Simulated (m^3/sec)	Observed (m^3/sec)
		Using SCS-CN method	Using Green Amp method	
23-Jul-10	1.52	450	432.9	517.6
24-Jul-10	1.64	428.4	411.7	414.1
25-Jul-10	0.82	385.8	370.2	395.4
26-Jul-10	84.76	478.1	429.4	406.5
27-Jul-10	76.31	627.9	505.4	442.5
28-Jul-10	240	965.1	440.7	1027
29-Jul-10	400.87	1640.7	968.2	1469
30-Jul-10	200.43	1848.2	1248.8	2257
31-Jul-10	30.41	1451.1	856	1308
01-Aug-10	7.47	1136.1	621.2	892.2
02-Aug-10	31.68	1078.3	622.3	758.4
03-Aug-10	4.93	996.3	574	691.1
04-Aug-10	7.89	881.7	489.1	648.3
05-Aug-10	0.97	804.1	463.7	667.4