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MODELLING APPROACH OF WATER BALANCE STUDIES DURING THE HEAVY RAINSTORM USING SWAT: A CASE STUDY IN THE BEAS RIVER BASIN

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Abstract- Rainfall is the main source of fresh water, which is predominantly controlled by the summer monsoon in India. Extreme Rainfall leads to flooding in the Himalayan sub-basins causing loss of life and property. Present study uses the Hydrological Model, SWAT that requires the GIS interface to analyze the hydro-meteorological data and to carry out water balance studies in the Beas Sub-basin. The study emphasizes the rainstorm analysis which is the key feature of the analysis. Water balance components during a heavy rainstorm are examined for the Beas sub-basin of the Indus river basin in the northern parts of India. Results indicate that maximum water yield corresponding during rainstorm period because of reduction in the evapotranspiration. No change in the pre monsoon rainfall is noticed while decreasing trend is seen for monsoon rainfall and annual rainfall and also in 1-day extreme rainfall series of the basin. Rainstorm of 24th September 1988 was found to be severe most in the basin during 1951 - 2009 data period so it is further considered for flood risk analysis in Beas basin using SWAT hydrological model. Its areal spread and central rainfall value was highest compared to remaining storms analyzed in the present study. Such analysis is useful for proper planning, management, and design of different types of water resources projects in this river basin. Such studies are also useful for agricultural planning and also for proper management of water allocation within these river basins.

Keywords - GIS, Remote Sensing, SWAT, Rainstorm, Water Balance Components, Flood Risk Analysis. *(Key Words)*

I. Introduction

It is well known that, water availability in India is driven by the monsoon. The whole year's rainfall is concentrated in just a few months. For its optimum utilization around the year requires proper water management. Due to large spatial and temporal variability in rainfall occurrence, some river basins in peninsular India fall in the category of water stress and water scarcity while river basins having an origin in the Himalayas are affected by floods resulting into loss of Life and damage to properties. This problem has become more serious due increasing population and human settlements encroaching to the natural floodplains of the mountain streams. Climate change and deterioration in water quality are other issues to be considered for water management. Extreme Rainfall leads to flooding in the Himalayan sub-basins causing loss of life and property. As the study involves the selection of heavy rainstorms in the Indus basin. Naturally, it is logical to examine the flood risk during the heavy rainstorm occurred in the Indus basin. A case study has been undertaken here to use the Hydrological Model namely Soil and Water Assessment Tool (SWAT) to examine the water balance components during the heavy rainstorm of September 1988 in the Beas sub-basin. Time required for running the SWAT model on large basin is huge and therefore as a case study in the present analysis only Beas sub-basin is considered to run the SWAT Model.

The main objective of the study is to examine the water balance components during heavy rainstorm duration using hydrological model SWAT (Soil and Water Assessment Tool) to delineated stream, tributaries, basin and sub-basins, soil and land use classification. To use the latest technique of GIS to analyze the widespread heavy rain spells. Remote sensing datasets on global land/soil freely available in GIS format on different websites are downloaded and used to run the hydrological model. To examine rainfall climatology, extreme rainfall, and their temporal changes and lastly to study water balance components such as Rainfall, Water yield, ET, PET, and etc.

II. Study Area

The Beas River which is a tributary of the Indus river basin of the northern India. It is the second easternmost of the rivers of the Punjab. The river rises at an elevation of 3,960 m in the Rohtang Pass in the Himalayas in central Himachal Pradesh. Subsequently, it flows south through the Kulu valley, receiving tributaries from the flanking mountains, and then enters the Punjab plains to meet the Sutlej at Harike. The total length of the Beas River is 460 km. and catchment area of the Indian Territory is 20,303 km2. Figure 1 shows the location of the study area on the map of India. Beas basin along with different streams generated by Digital elevation map is also shown in the Figure.

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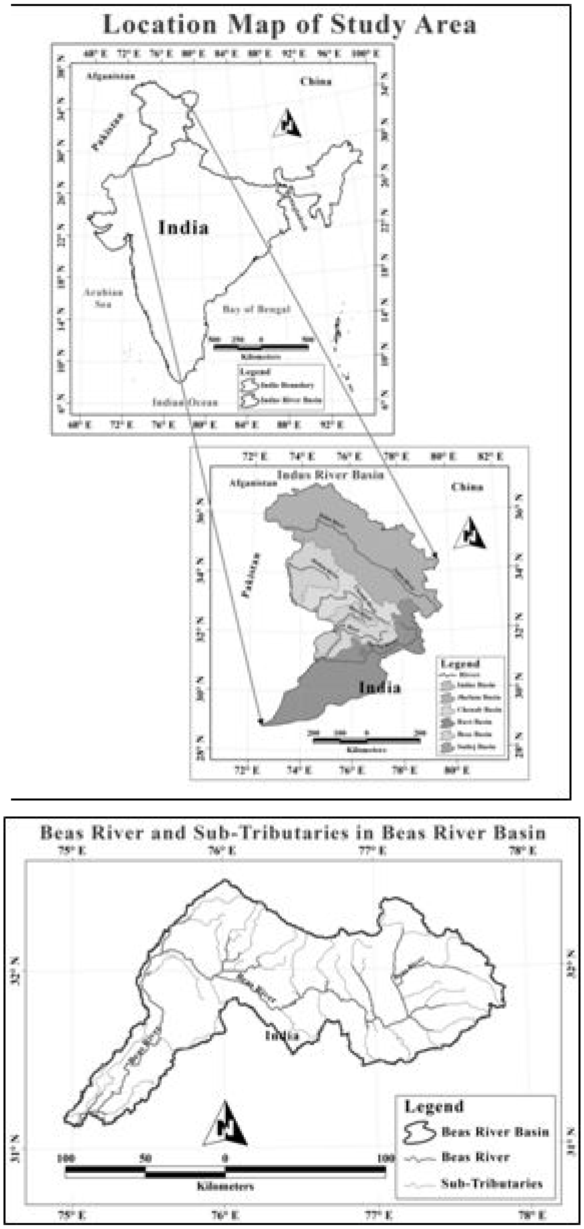

Figure 1. Location Map of the study area - Beas basin

III. Study Objectives

Main Objective of the study is to examine the water balance components during heavy rainstorm duration using hydrological model SWAT (Soil and Water Assessment Tool) to delineated stream, tributaries, basin and sub-basins, soil and land use classification.

To use the latest technique of GIS to analyze the widespread heavy rain spells. Remote sensing datasets on global land/soil freely available in GIS format on different websites are downloaded and used to run the hydrological model.

To examine rainfall climatology, extreme rainfall, and their temporal changes and lastly to study water balance components such as Rainfall, Water yield, ET, PET, and etc.

IV. Data Used and Methodology

Different data sets as mentioned here and Meteorological data sets also available from India Meteorological Department (IMD, Pune) are used in the study. Details about the SWAT model which is used here are given in this study. Remote sensing datasets on global land/soil freely available in GIS format on different websites are downloaded and used to run the hydrological model - SWAT. ArcGIS 10.1 version which is used for Geographical Information System (GIS) and Remote Sensing data analysis. The present study attempts to examine the water balance components during the heavy rainstorm.

Data Sets Required for Running the SWAT-Hydrological Model:

C. Digital Elevation Model Data:

The ASTER Global Digital Elevation Model (ASTER GDEM) is a joint product developed and made available to the public by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). It is generated from data collected from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), a spaceborne earth observing optical instrument. DEM data has been downloaded from the website: *http://gdem.ersdac.jspacesystems.or.jp/*

B. Land Use / Land Cover Data sets:

Land use land cover data and soil data are obtained from which is freely downloadable datasets. Land use/ Land cover should be classified according to USGS (U.S. Geological Survey) database.

C. Soil Data Sets:

The information on soil types was obtained from FAO (Food and Agriculture Organization) in the form of digital Soil Map. The information is available at the official FAO website hosted at:

http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116

Methodology Used to Carry Out Analysis:

A. Digitization:

Digitization is the process of converting analog information into a digital representation. In regards to spatial information, one application of this is the process of creating a vector digital database by creating point, line and polygon objects. A shapefile of Beas basin is created by digitization map of India and measured the area using the geometric calculator.

B. Soil and Water Assessment Tool (SWAT):

SWAT is a hydrologic/water quality model developed by United States Department of Agriculture-Agricultural Research Service (USDA-ARS), a successor of EPIC and SWRRB. It is a continuous time model that operates on a daily time step. The SWAT model (Arnold et al., 1998) is a physically based model and requires data such as weather variables, soil properties, topography, vegetation and land management practices occurring in the catchment. Some of the advantages of the model include modelling of untagged catchments, prediction of relative impacts of scenarios (alternative input data) such as changes in management practices, climate, and vegetation on water quality, quantity or other variables. SWAT also has a weather simulation model that generates daily data for rainfall, solar radiation, relative humidity, wind speed and temperature from the average monthly variables of these data. This provides a useful tool to fill in missing daily data in the observed records.

C. Delineation of Streams, Sub-Basins using DEM:

Digital Elevation Models (DEM) is increasingly used for visual and mathematical analysis of topography, landscapes, and landforms, as well as modeling of surface processes.

ASTER DEM is useful for an interpretation of the macro and meso relief, and provides the opportunity for mapping especially at medium scales (1:100,000 and 1:50,000). The original 30 m. resolution DEM was generated by using tie points and was finally re-sampled to 15 m. to exploit full ortho-image resolution.

The topography of the land surface is one of the most fundamental geophysical measurements of the Earth, and it is a dominant controlling factor in virtually all physical processes that occur on the land surface. The topography of the land surface also significantly controls processes within the overlying atmosphere, and it reflects the processes within the underlying lithosphere. Consequently, topographic information is important across the full spectrum of earth sciences and the availability of an up-to-date, high resolution (1-arc-sec or less) global DEM has been a priority of earth scientists for a long time. The ASTER GDEM, with 30 m grid postings and produced from a consistent primary data source, meets the requirements for global topographic information. The same has been used in the present study. The data set is displayed on the Beas sub-basin of the Indus River and is shown in the next section.

V. Results and Discussions

A. DEM based Analysis of Basin Generation using SWAT:

Soil and Water Assessment Tool (SWAT) is used to delineate stream flows, sub-basins using the Digital elevation model data. SWAT is a distributed model where each watershed is first divided into sub-basins and then into hydrologic response units (HRUs) based on the land use and soil distributions. To run the SWAT following data sets are used:

a. DEM (Digital Elevation Model)

b. Land Use and Land Cover Data

c. Soil Data

d. Meteorological parameters such as Rainfall, Temperature on a daily timescale.

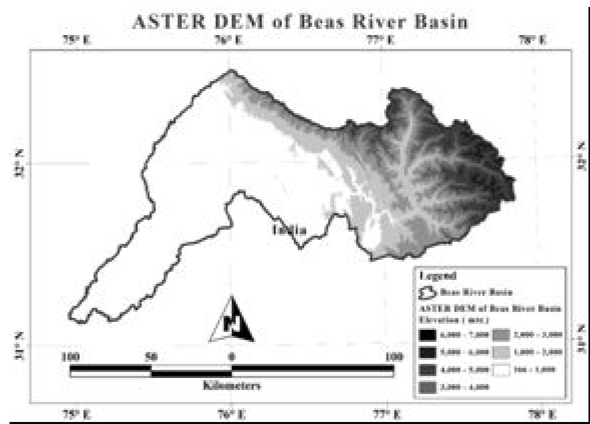

Figure 2. ASTER DEM of Beas basin

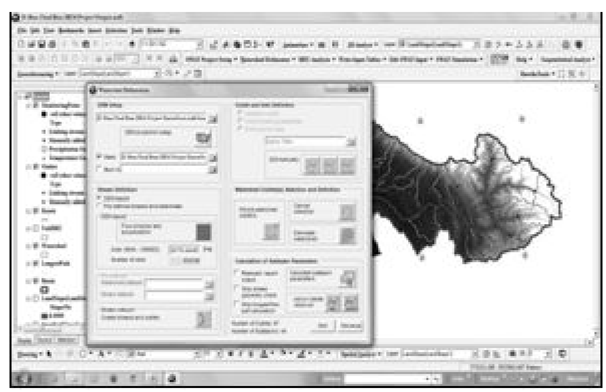

figure 3. Snapshot of watershed area delineation work of Beas basin using SWAT

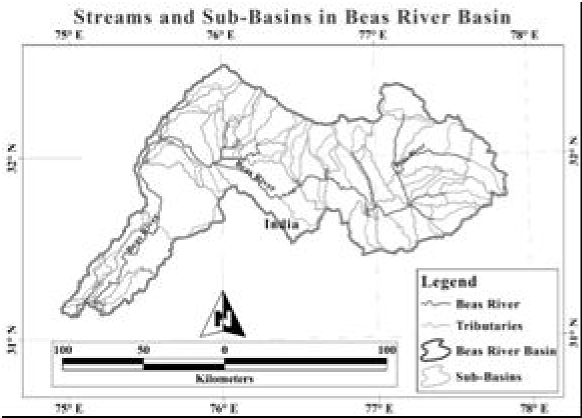

Figure 4. Streams and Sub-Basin delineation of Beas basin using SWAT

The delineation of sub-watersheds and streams based on an automatic procedure using Digital Elevation Model data is shown in FIGURE 4. The watershed delineation carries out advanced GIS functions to aid the user in segmenting into several "hydrologically" connected sub-watersheds for use in watershed modelling with SWAT. The Watershed Delineation tool uses and expands ArcGIS and spatial analyst extension functions to perform watershed delineation. The delineation process requires a Digital Elevation Model in ESRI grid format. Once the delineation is finished, a detailed report (topographic Report) is added to the current project and several layers will be added to the current map, such as Basin, Watershed, Reach, Outlet, and Monitoring point.

B. Land Use and Land Cover (LULC):

Land use and Land cover data has been retrieved from the various websites as mentioned in data used section of first Chapter. FIGURE 5. Shows the snapshot of the SWAT model where land use and land cover, soil data enter into the model.

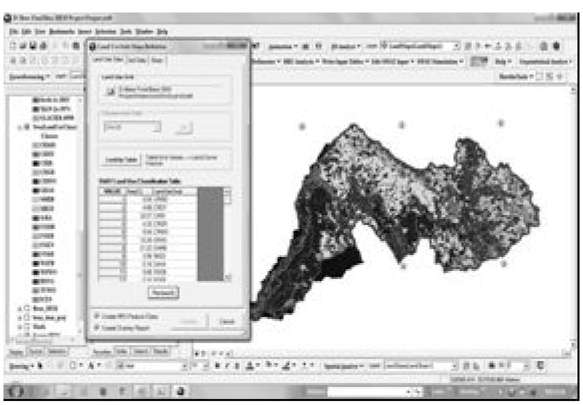

Figure 5. Snapshot of land use and land cover data delineation work on Beas basin.

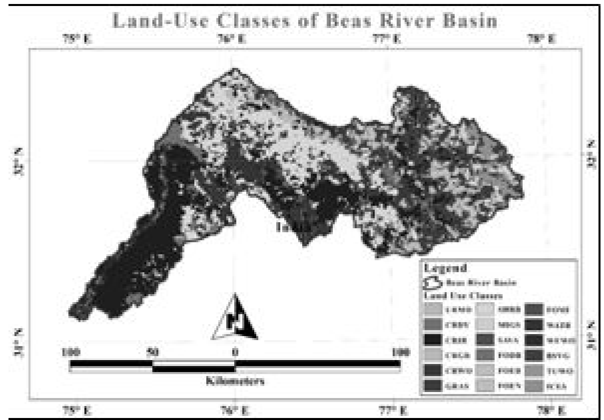

Figure 6. Land Use and Land Cover Classification of Beas Basin

Classified land cover data produced using remote sensing technique, by the University of Maryland Global Land cover Facility (18 categories) with a resolution of 1 km grid cell size has been used (Hansen et al., 1999). In order to prepare the data on Land use land cover (LULC), for SWAT, land use should be classified according to USGS (U.S. Geological Survey) database. Hence, from the GIS data, a translation from Thai Nguyen land uses code to USGS. The translation process is elaborated in the above figure. In order to classify land use, USGS code is used in this study. Further details can be found in USGS land use codes for remote sensing data (Anderson, 1976). FIGURE 6. and TABLE I. gives land use and land cover data generated using SWAT Model. The map in the figure shows the dominance of native agriculture land near vicinity of water bodies. Rang-grasses are observed over a highly elevated area of the terrain. The eastern boundary of the basin covers much of the forest area.

TABLE I. USDA - USGS Classes of Land Use/Land Cover

Sr. No.	Colour Code	LULC Code	LULC Class Name
1		URMD	Residential - Medium Density
2		CRDY	Dryland Cropland And Pasture
3		CRIR	Irrigated Cropland And Pasture
4		CRGR	Cropland/Grassland Mosaic
5		CRWO	Cropland / Woodland Mosaic

Sr. No.	Colour Code	LULC Code	LULC Class Name
6		GRAS	Grassland
7		SHRB	Shrubland
8		MIGS	Mixed Grassland / Shrubland
9		SAVA	Savanna
10		FODB	Deciduous Broadleaf Forest
11		FOEB	Evergreen Broadleaf Forest
12		FOEN	Evergreen Needleleaf Forest
13		FOMI	Mixed Forest
14		WATB	Water Bodies
15		WEWO	Wooded Wetland
16		BSVG	Baren or Sparsly Vegetated
17		TUWO	Wooded Tundra
18		ICES	Snow or Ice

C. Soil Classification on the Beas Basin:

The Food and Agriculture Organization of the United Nations (FAO) developed a supra-national classification of soil, also called World Soil Classification, which offers useful generalizations about soil pedogenesis in relation to the interactions with the main soil-forming factors. It was first published in form of the UNESCO Soil Map of the World (1974) (scale 1: 5 M.). Many of the names offered in that classification are known in many countries and do have similar meanings. The information on soil types was obtained from FAO (Food and agriculture organization) in the form of digital Soil Map. FIGURE 8. shows the soil classification as displayed on the Beas Basin. The information is available at the official FAO website hosted at: *http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116.*

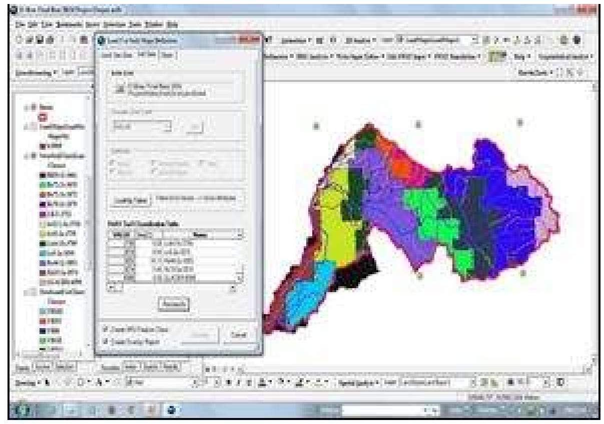

Figure 7. Snapshot of soil data classification work on Beas basin.

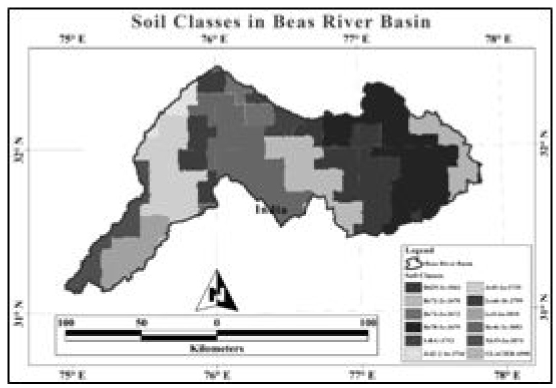

Figure 8. Soil classification map of the Beas basin

TABLE II. USDA – USGS Textural Classes of Soils

Sr. No.	Colour Code	Soil Code	Soil Description /Texture Name
1		Bd29-3c-3661	(CL=Clay Loam) Loamy soils (Moderately fine texture)
2		Be72-2c-3670	(L=Loam) Loamy soils (Medium texture)
3		Be72-3c-3672	(C=Clay) Clayey soils (Fine texture)
4		Be78-2c-3679	(L=Loam) Loamy soils (Medium texture)

Sr. No.	Colour Code	Soil Code	Soil Description /Texture Name
5		I-B-U-3712	(L=Loam) Loamy soils (Medium texture)
6		Jc42-2-3a-3736	(CL=Clay Loam) Loamy soils (Moderately fine texture)
7		Jc45-2a-3739	(L=Loam) Loamy soils (Medium texture)
8		Lo44-1b-3799	(SL=Sandy Loam) Loamy soils (Moderately coarse texture)
9		Lo5-2a-3810	(L=Loam) Loamy soils (Medium texture)
10		Re46-2c-3853	(L=Loam) Loamy soils (Medium texture)
11		Xk19-2a-3874	(L=Loam) Loamy soils (Medium texture)
12		GLACIER-6998	SL = Glacier

After careful examination of the available soil data shows that the soil of the Beas sub-basin is broadly divided into five categories namely:-

i. Loamy Soils (Medium texture) (L=Loam)

ii. Clayey Soils (Fine texture) (C=Clay)

iii. Loamy Soils (Moderately fine texture) (CL=Clay Loam)

iv. SL= Glacier

v. Loamy Soils (Moderately coarse texture) (SL=Sandy Loam)

The soil map of the Beas basin is shown in above Fig. 6 to 8. It can be seen from the soil map that most part of the basin has Loamy type of soil. The Southern part of the basin near the confluence with river Sutlej shows a Loamy type of soil while very small part in the western area of the basin shows sandy soil.

D. Water Yield Analysis on Weather Data:

Daily gridded rainfall and temperature data sets (IMD, Pune) as mentioned in previous section, are used here to run the SWAT model. Model has been run continuously for 1-day time step for 37 years data period 1969-2005 and components of water balance covering the rainstorm period i.e. 21st to 30th September 1988 has been picked up from the final output.

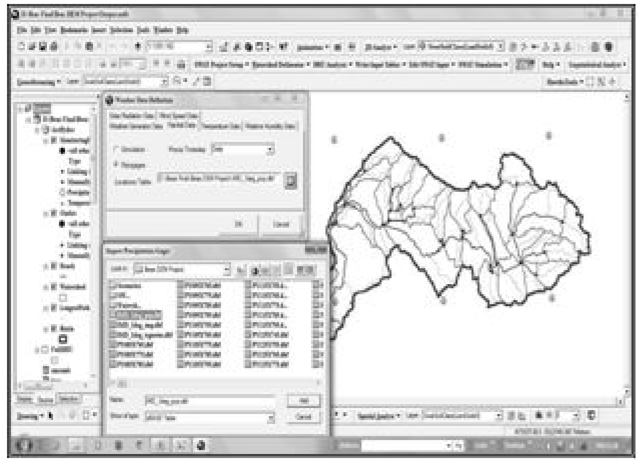

Figure 9. Snapshot of Weather, Rainfall and Temperature Data Delineation Work on Beas Basin

Table –III Water Balance Components Covering Rainstorm Period

S. No.	DATE	PREC. (mm)	WATER YIELD (mm)	ET (mm)
1	21/09/1988	5.62	1.28	1.67
2	22/09/1988	6.56	0.72	1.58
3	23/09/1988	58.08	25.44	1.4
4	24/09/1988	**156.97**	**103.97**	2.1
5	25/09/1988	67.19	51.89	1.93
6	26/09/1988	101.85	71.7	1.1
7	27/09/1988	60.67	51.64	1.38
8	28/09/1988	0	8.31	**2.94**
9	29/09/1988	0	4.18	2.56
10	30/09/1988	0	2.56	2.16

Model output during the rainstorm period of 1988 September is extracted and analyzed. Water yield is generated as the output for the duration 21st Sept. to 30th Sept 1988. TABLE III. Presents some water balance components obtained by running SWAT model. From the table, it is seen that maximum rainfall on 24th September caused maximum Water yield on the same day. Because of the cloudiness, evaporation decrease on 23rd of September

1988. Following FIGURE 10. shows the graph generated using GIS for three water balance components namely rainfall, water yield, and evapotranspiration during the period 21st to 30th September 1988.

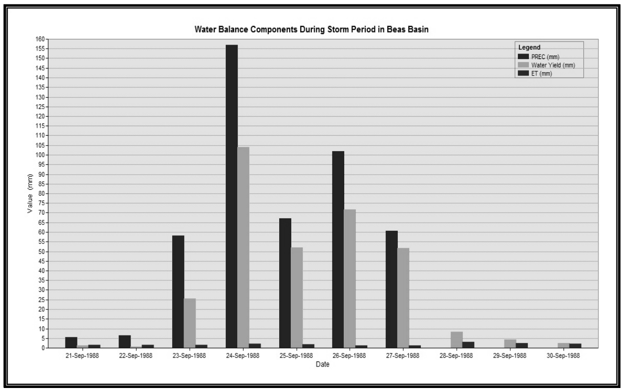

Figure 10. Plot of water balance component during rainstorm period in Beas basin (21st to 30th sept. 1988)

The graph indicates in 24th Sept. 1988 higher precipitation (156.97 mm.) and water yield (103.97 mm.) in the Indus basin. Evapotranspiration was very small during the period of Rainstorm causing maximum water yield.

V. Conclusions

In the context of global warming scenario, understanding of the regional climatic changes over India is therefore directly linked to the understanding of the rainfall patterns in the region, its inter-annual and intra-seasonal variations. There are regions which receive abundant precipitation and have lakes and rivers; there are also regions practically devoid of water. Floods and droughts occur frequently over extensive areas due to high variability of rainfall.

Analysis was carried out using the latest technique of GIS to examine the hydro meteorological data. Remote sensing datasets on global land/soil freely available in GIS format on different websites are downloaded and used to run the hydrological model. Hydrological Model namely, Soil Water Assessment Tool (SWAT) which requires the ArcGIS interface is used to study the water balance components. The present study examines the hydro-climatic features of the major river basin like Indus, in India, which are very useful for hydrological and agricultural planning and also for proper management of water allocation within these river basins. The study emphasizes the rainstorm analysis (observed and future projections) which is the key feature of the analysis. Another key feature of the study is to display and analyze the meteorological parameters to study the teleconnections with extreme rainfall over the basin.

In this study, water balance components during heavy rainstorm duration of 1988 rainstorm were examined for the Beas sub-basin using hydrological model SWAT. Stream, tributaries, and sub-basins were delineated using SWAT. Spatial patterns of Soil type and land use/Land cover classification are displayed on the basin map. Soil Water Assessment Tool (SWAT) hydrological model is run using Land/Soil data, DEM, and meteorological parameter data. Output for the particular days of a heavy rainstorm (21 to 30 Sept 1988) was analyzed. No change in the pre-monsoon rainfall is noticed while decreasing trend is seen for monsoon rainfall and annual rainfall and also in 1-day extreme rainfall series of the basin. A rainstorm of 24th September 1988 was found to be severe most in the basin during 1951 - 2009 data period so it is further considered for flood risk analysis in Beas basin using SWAT hydrological model. Its areal spread and central rainfall value were highest compared to remaining storms analyzed in the present study. Results indicated maximum water yield corresponding to the rainstorm period. Very Low values of ET are seen during the rainstorm period.

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