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Prediction of Continuous Rainfall-Runoff Scenarios for Snow-Fed Watershed of Himachal Pradesh, India using Geographical Information System (GIS) based on Hydrological Modelling

Kamuju Narasayya

Assistant Research Officer

Central Water and Power Research Station

Pune, Maharashtra

India

ABSTRACT

Rainfall runoff modeling is one of the most complex hydrological modeling due to the involvement of different watershed physical parameters. It is essential for the analysis of watershed hydrological response towards the received precipitation under the influence of watershed variables. As it is a replica of watershed hydrological response, Rainfall-Runoff modeling is essential to evaluate the general characteristics of total surface runoff at catchment's outlet. The main objective of this study was prediction of rainfall runoff using Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) model for Rampur watershed which was covered in Kullu and Shimla districts situated at Upper Sutlej sub-basin of Himachal Pradesh, India. Geo-spatial data of Digital Elevation Model (DEM), LandUse-LandCover (LU-LC) map, Soil map and Hydro-meteorological data of rainfall were collected from different open source web portals to utilise as input parameters for modeling. Soil Conservation Service-Curve Number (SCS-CN) for precipitation loss modeling, Soil Conservation Service–Dimensionless Unit Hydrograph (SCS-UH) for transform modeling, Muskingum method for Runoff routing were used as input parameters of respective components of HEC-HMS model. This article proposes a methodology for generating hourly rainfall data from daily rainfall data using Intensity-Duration-Frequency (IDF) curves in Meteorological model of HMS. The simulation results of runoff with 5 different return period scenarios are follows the return period frequency tendency, such as 1000 year return period runoff peak delivers 4729.5 m^3/s, 500 year return period delivers a peak runoff of 4263.9 m^3/s, 100 year return period gives a peak runoff of 3196.5 m^3/s, 50 year return period runoff deliver 2745.3 m^3/s and 10 year return period deliver 953.7 m^3/s runoff at the outlet of Rampur watershed.

Key Words: Hydro-Meteorological, Hydrograph, Runoff, Soil Conservation Service-Curve Number, Watershed.

1. INTRODUCTION

A basin hydrological response that is obtained from the received precipitation and other basin parameters is commonly called hydrologic modeling. Hydrological models are utilized in various river basins all over the world for the better comprehension of the hydrological procedures and water resources accessibility [1]. It is important to use hydrological model today to assess and predict the water availability of river basins to develop strategies in order to cope with the changing environment. Rainfall runoff modeling is one of the most paramount hydrological modeling that is used to investigate the relationship between the rainfall and direct runoff generated under the influence of different watershed physical parameters [2] and [3]. Stream flow simulation from precipitation events have been advanced over numerous decades [4] in broad areas of water resource fields in terms of structure [5] complexity, data requirements and scale of application from field plot to global, with a similar wide range of purposes from floods to droughts, past to future climate changes, water resources and water quality management. The model helps in forecasting the impact of different watershed management practices upon the hydrologic response corresponding to the expected volume of surface runoff, and aims to aggregate information for better understanding of these practices [6].

At whatever point information isn't accessible, rainfall runoff models are critical indicators that help in understanding the long-term impacts of different land use land cover change and land use management, which are complex and difficult to determine [7]. Regardless of the data scarcity, researchers have conducted rainfall runoff modeling in different river basins all over the world for various objectives. Kishor et al.(2014) [3] have developed rainfall runoff model for Balijore Nala Watershed of Odisha, India in order to assess the interaction of the incoming precipitation and the produced surface runoff. Kimhuy et al. (2016) [8] have developed rainfall runoff modeling in order to investigate stream flow and water resources accessibility in Stung Sangker catchment of Mekong' Tonle Sap Lake basin in Cambodia. Bitew et al. (2019) [9] created a precipitation spill over model for stream simulation in the Lake Tana Basin for case of Gilgel Abay catchment, Upper Blue Nile Basin, Ethiopia. P. Physically based precipitation overflow models that give a sound depiction of hydrological procedures can be utilized to anticipate the outcomes of environmental change and anthropogenic exercises on stream, silt and sediment transport [10]. However, in countries like Ethiopia, adequate data for hydrological modeling are difficult to access or not available. Furthermore, the limited availability of meteorological gauging stations does not spatially balance the available stream flow gauges and financial constraints do not allow data collection at all sites where projects are to be implemented [10]. This enhances the significance of rainfall runoff modeling, so as to investigate the relationship among rainfall, watershed physical parameters and the generated surface runoff within the data scarce areas.

Awash Bello sub-catchment is located along the Awash River in the upper part of Awash River basin. It is one of the flood plains of the basin that faced frequent flood damage due to the over flow of the Awash River, especially during the month of June to September [1]. In order to control flood damage that frequently affects this area, it is imperative to know the flood inundation area. This mainly depends upon the peak flood values obtained at the outlet of the sub-catchment, but direct measuring of this peak flood at outlet point during the specified month is difficult, expensive and time consuming. In order to overcome these problems, it is essential to develop rainfall runoff modeling. Additionally, rainfall runoff modeling helps to identify the correlation between rainfall, watershed physical parameters and runoff volume generated at outlet. In spite of its advantage in representing watershed hydrological response with data scarce areas, rainfall runoff modeling is a complex and time-consuming process to represent in mathematical form in manual computation [11]. As a result of this many users have been challenged in converting rainfall runoff relationship into mathematical equation. However, now a day computer-aided hydrological modeling technology have advanced rapidly and become the solution for such difficulties [12].These hydrological modeling technologies have emerged up with numerous rainfall runoff modeling tools like Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS), Soil and Water Assessment Tool (SWAT) and TOPMODEL. Owing to its simplicity, physically based characteristics, wide applicability and minimum but very important data utilization over the other modeling tools, HEC-HMS was selected for this study.

Hydrological model of HEC-HMS has developed based on simulation of rainfall-runoff in watersheds that can model rainfall runoff relationship using a graphical interface [11]. It is a semi-distributed, physical based model developed with various methods for precipitation loss modeling, excess precipitation transformation to direct runoff, base flow and flood routing [4]. Currently, many researchers have applied HEC-HMS for rainfall runoff modeling all over the world and have obtained satisfactory results. Abdessamed et al.(2018)[13] developed a rainfall runoff model in a semi-arid region of Ain Sefra watershed in Algeria through employing a HEC-HMS model. They used frequency storm, Soil Conservation Service Curve Number (SCS-CN) and Soil Conservation Service-Unit Hydrograph (SCS-UH) methods for meteorological modeling, excess precipitation modeling and excess precipitation transformation to direct runoff and obtained nearly the same computed and observed flow. Mokhtari et al. (2016)[14] performed hydrologic modeling of rainfall runoff by means of HEC-HMS model on a watershed of the wadi CheliffGhrib in Algeria, and based on their end results, they suggested that HEC-HMS is applicable and the result was accepted for that particular area. Shahedi and Majidi (2012) [15] utilized HEC-HMS hydrological model to simulate rainfall runoff in the watershed of Abnama situated in south Iran. They used Green-Ampt, SCS unit hydrograph and Muskingum routing techniques to calculate infiltration loss, rainfall surplus conversion to runoff and flow routing, and lastly found that the model had a decent correlation with the observed flow and was acceptable. Bitew et al. (2019) [9] have applied HEC-HMS for stream flow simulation in Lake Tana Basin Upper Blue Nile Ethiopia. They used SCS-CN, SCS-UH and Muskingum method for precipitation loss, direct runoff and flood routing respectively. Based on the model result they suggested that HEC-HMS is valid and applicable in the Ethiopian context and it can be used for runoff modeling.

2. MATERIALS AND METHODOLOGY

The materials used in this study are Geo-spatial data and hydro-meteorological data. Geo-spatial data in the form of DEM, LU-LC and soil map. The other non-spatial data of hydro meteorological data in the form of daily rainfall within the watershed available from 2 stations as shown in Fig.2. The detailed description of each data are explained in the following paragraphs.

2.1 Study Area- Rampur Bushahr

Rampur Bushahr is a town and a municipal council is about 130 km in Shimla district in the Indian state of Himachal Pradesh, which was situated at 1,005 meters on the left bank of the Sutlej, Bushahar's served as winter capital well connected with NH-5 which passes through Theog, Narkanda and Kumarsain. One of the important note is that, throughout this article the study area mentioned as 'Rampur watershed'. Rampur is located at 31.45°N 77.63°E, and watershed have an area of 820 km^2 and covered in

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Shimla and Kullu districts. This watershed has an average elevation of 1021 metres. Sutlej is the main river flows through watershed. The main tributaries of 'Beha Khad', 'Dhurmu Gad', 'Chainre Kad'on right bank of river and 'Khaneti Khad' tributary on the left bank of the river joined Sutlej river. It is a very beautiful place situated at the bank of the Sutlej River. It borders on the north with Spiti, on the west with Kumarsain and Anni, on the east with Kinnaur and on the south with Rohru. The city is also the home to Asia's largest underground Hydro Power Project-The Nathpa Jhakri Hydro Power Station built by Satluj Jal Vidyut Nigam Ltd at Jhakri. The location map of study area of Rampur watershed as shown in Fig.1

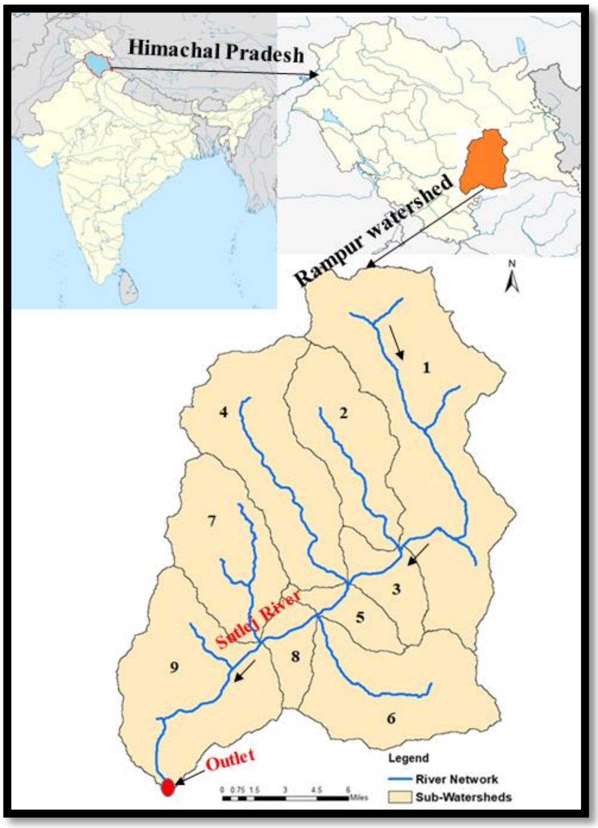

Figure 1: Location map of Rampur watershed

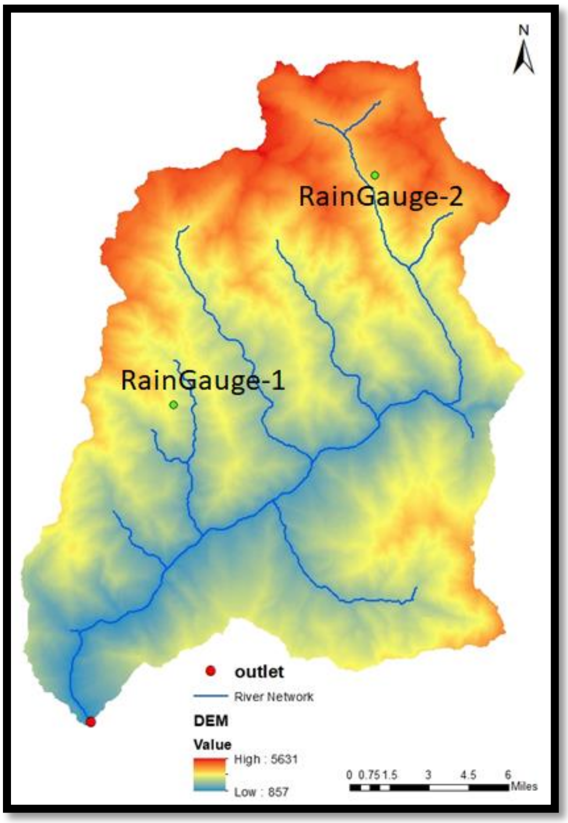

Figure 2: DEM with Rain-gauge locations

2.2 Geo Spatial & Non–geo Spatial Data

The open source geo-spatial and non-geo spatial data were collected from different web portals. The details of each data are described as follows under sub-headings.

2.2.1 Digital Elevation Model (DEM)

DEM represents the bare-Earth surface, removing all natural and built features. DEM's are important inputs for representation of topography for the accurate modelling of floodplain hydrodynamics. Floodplains have a key role as natural retarding pools which attenuate flood waves and suppress flood peaks. The limited availability of high- accuracy DEMs dictate that dated open-access global DEMs are still used extensively in Rainfall-Runoff models, particularly in data-sparse areas. Nevertheless, high-accuracy DEMs have been found to give better runoff estimation, and this can be considered a 'must-have' for any hydrological modeling.

For instance, high resolution DEM (i.e.12.5mX12.5m) was downloaded from ALASKA Satellite Facility website and analyzed in ArcGIS for the extraction of watershed hydrological elements and physical parameters. This digital elevation model shows elevation ranges from low elevation to high elevation, e.g. the interval of 857m-5631m above mean sea level as shown in Fig.2.

2.2.2 LandUse-LandCover Map (LU-LC)

With the advancements in Remote Sensing, monitoring networks, and Geographic Information Systems (GIS), the availability of geo spatial data is rapidly increasing. These geo spatial data include not only maps and locations of LU-LC, but also multiple attributes of the data from the census. Improvements in the use and accessibility of multi-temporal, satellite–derived environmental data or other thematic raster data have contributed to the growing use in hydrological modeling. Remote Sensing

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technology provides synoptic information on vegetation growth conditions over a large geographic area in real time. The LU-LC map (Fig.3) acquired from NRSC-Hyderabad of Bhuvan-ISRO web portal. This thematic map layer utilized for computation of Curve Number (CN) values of 9 sub-watersheds (Fig.1) of Rampur watershed. The highest percentage of 45.61% was forest area and lowest percentage of agricultural land 0.72% covered in the Rampur watershed.

2.2.3 Soil Map

Soil information is critical in watershed-scale hydrological modelling and soil is adominant factor in controlling hydrological flowpaths through partitioning precipitation into different components of the water balance. This is due to the ability of soil to store and transmit water. Soil information is therefore an important input for physically based hydrological models. But soil information is often not readily available in appropriate format for modellers to use in various physically based hydrological modeling. The advances in digital soil mapping have paved the way for providing detailed soil information in an adequate scale and format for hydrological modeling studies. For this study a digital soil map acquired from FAO web portal and made several spatial analysis to fit into the model as shown in Fig.4.

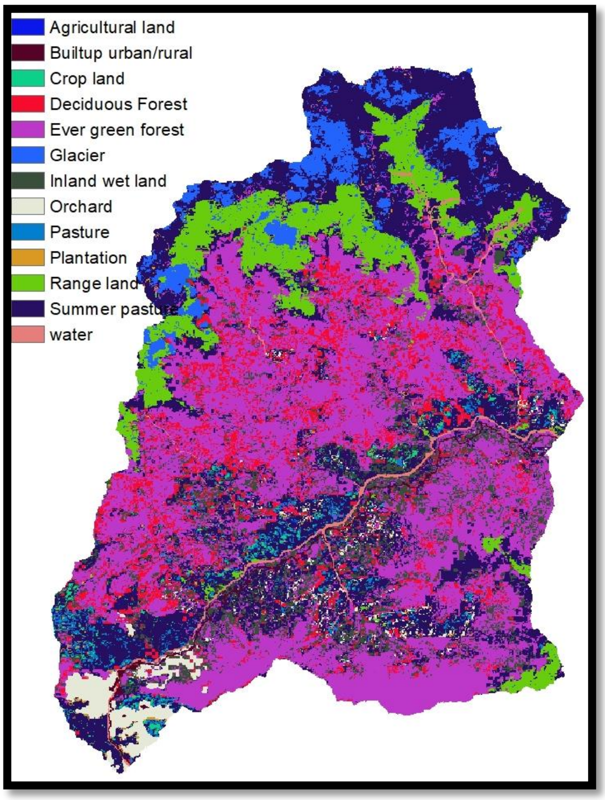

Figure 3: Lu-Lc map of Rampur watershed

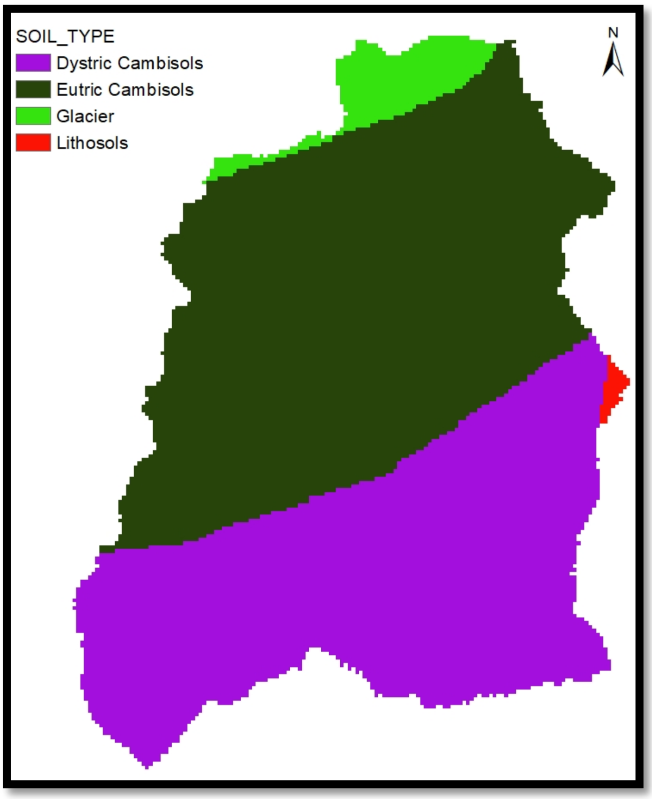

Figure 4: Soil map of Rampur watershed

The other important Geo-spatial data of soil map along with LU-LC map is utilized to derive CN of the Rampur watershed for each sub-watershed. The soil type of Eutric Cambisols contains dominated percentage of 52.68% and Lithosols having a least 0.36 percentage of area covered in the Rampur watershed. The details of area and corresponding percentage covered of each type of LU-LC and soil classes covered are illustrated in Table-1

2.2.4 Rainfall

Daily rainfall data of about 36 years from 1985-2020 at two places located within Rampur watershed was collected from NASA-POWER web portal as shown in Fig.2. The daily temporal data of hydro-meteorological data used to derive IDF curve for converting daily rainfall data into hourly data. After collection of this Geo-spatial data and meteorological data, several computations have been made to derive hydrological variables to incorporate as input parameters in HMS model. The methodology applied to perform model run successful as shown in flow diagram Fig.5

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TABLE 1: DETAILS OF LU-LC MAP AND SOIL MAP

Lu/Lc Type	Area, km^2	Percent, %
Agricultural land	0.42	0.05
Built-up urban/rural	4.4	0.54
Crop land	5.49	0.67
Deciduous forest	76.29	9.31
Evergreen forest	297.53	36.3
Glacier	35.84	4.37
Inland wetland	71.86	8.77
Orchard	20.00	2.44
Pasture	12.43	1.52
Plantation	3.68	0.45
Rangeland	74.85	9.13
Summer pasture	208.77	25.47
Water	7.98	0.97

Soil Type	Area, km^2	Percent, %
Eutric Cambisols	432.10	52.68
Dystric Cambisols	352.17	42.94
Lithosols	2.97	0.36
Glacier	32.94	4.02

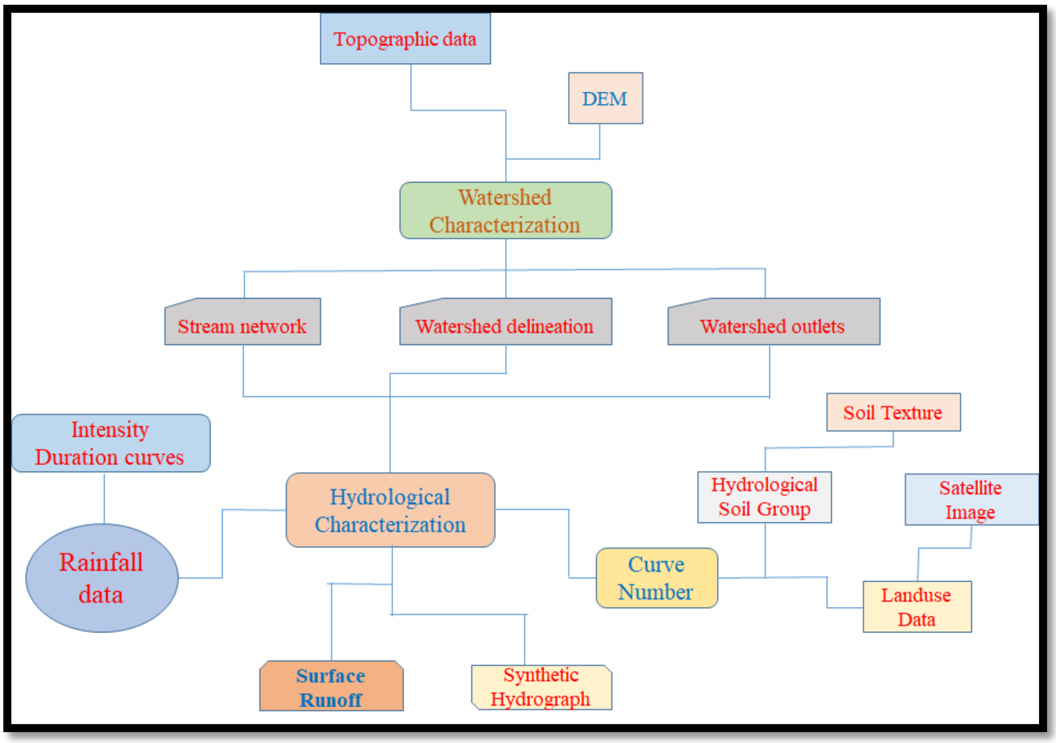

Figure 5: Flow diagram of methodology

3. HYDROLOGIC MODELING SYSTEM (HMS)

Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) is a deterministic semi-distributed model evolved by the United States Army Corps, used for Rainfall-Runoff modeling in the scale of watersheds. This model disposes of a broad range of parameters allowing the transfer of the precipitation to direct runoff and then to flow discharge, the outputs in the flood and dams management and also could be used for the prediction of the impact of climate change. The HEC-HMS model has four major components to build a structure of the basin model for the description of watershed elements. The HEC-HMS schematic diagram with elements of the watershed derived as shown in Fig.6.

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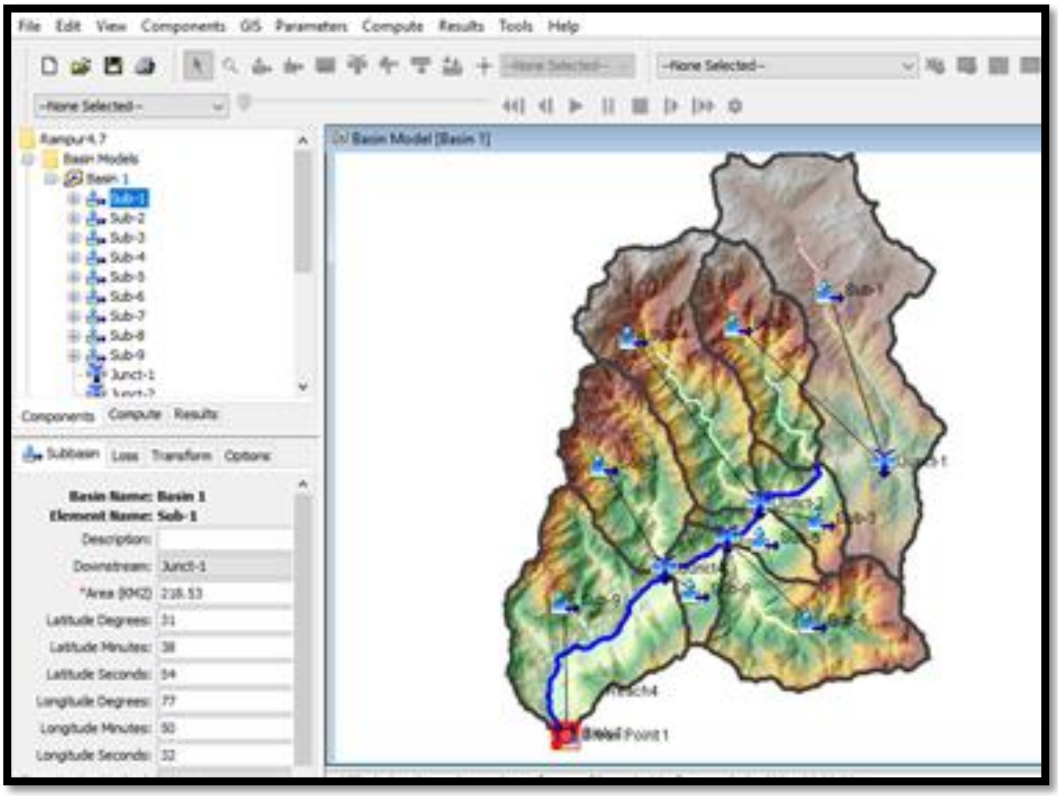

Figure 6: Schematic representation of HEC-HMS model

To simulate the transfer Rainfall-Runoff under HEC-HMS, the SCS-CN method is used for the estimation of the losses, the SCS Unit hydrograph is used as a transfer function. The designed hyetographs derived from I-D-F curve method was introduced in the meteorological component of the model. The routing phase controls the amount of water that goes from the main channel to the outlet, using Muskingum routing method. The hydrologic parameters for each sub-watershed were entered using HEC-HMS sub-basin editor.

A precipitation model is the next component of the HEC-HMS model. The intensity of rainfall was obtained from the Intensity-Duration-Frequency (IDF) curve from two rainfall station for five selected return periods of 10 year, 50 year 100 year, 500 year and 1000 years. For each time duration, the corresponding precipitation depth was computed as the product of intensity and duration. The precipitation data were entered for all the 5 return periods as mentioned above. Finally, a simulation time window sets the time span and time interval of a simulation run. This can be done using the control specifications manager. A simulation run calculates the precipitation-runoff response in the basin model given input from the meteorological model. All three components are required for complete simulation run of the model to compute rainfall runoff at outlet of Rampur watershed.

3.1 Data preparation and processing

The primary vital geo-spatial data required to describe the physical parameters of watershed was Digital Elevation Model (DEM). Hydrologic elements are added and connected to one another to obtain a model of the real-world flow of water in a natural watershed. The basin model manager can be used to add a new basin model to the project. Hydrologic elements can be added to the basin map after it is created. Most hydrologic elements require parameter data so that the program can model the hydrologic processes represented by the element. The meteorologic model calculates the precipitation input required by a sub-basin element. The meteorologic model can utilize both point and gridded precipitation and has the capability to model frozen and liquid precipitation along with evapo-transpiration. In this study point rainfall data used for time series data model. The event rainfall data collected daily and it is converted into hourly interval using IDF curve method. The author of this research article felt that it is necessary to give some of the research article references to emphasize the importance of I-D-F curve method. The research review about I-D-F method described in the next paragraph.

3.2 I-D-F method – Research Review

The Intensity–Duration–Frequency (IDF) curves describe rainfall intensity as a function of duration for a given return period [16], [17]. Chow, 1964 underlines the relation between the Intensity, Duration, and Frequency of rainfall. The intensity is the

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magnitude of rain amount per unit time generally measured in mm/h, in other terms, it is the ratio between the precipitation expressed in millimetre and the duration in an hour. The frequency is the inverse of the return period, which is the time length of re-occurrence of a specific amount of rainfall (2,5, 10, 25,50,100,200 years…), for a continuous period of time these curves give the probability for which the intensity exceeds the threshold intensity [18]. IDF curves are obtained by applying the frequency analysis on a rainfall series, then fitting a probability distribution method such Asthe Montana [19] commonly used in real study cases. The times equation evolved by the Spanish Water Authority, and the method of maximum likelihood [20]. The above-mentioned method, could be used to develop the design hyetograph and estimate the peak flow of a hydrologic series, they are widely used for flood control, dam and bridges construction and management [21] by means of hydrological and hydraulic modeling.

The IDF curve method has gained a large prominence through different study all over the world (e. g. Jakob et al., 2007; Xu and Tung, 2009; Lee et al., 2010; Haddad et al., 2011; Dourte et al., 2013; Du et al., 2014), they were applied on Yangambi station in Congo, using precipitation series in conjunction with Montana method, the results uncovered advantages and the inconvenient of the classical Montana formula, which did not lead to a satisfying result regarding the probabilistic and physical-based approach [22]. Further a study carried out in the south of Quebec, compared two different estimators of IDF curves, using the partial duration series (SDP) and the series of annual maxima (SMA), Another study was performed in Brazil, aims to analyse the temporal distribution for intense rainfall and develop an IDF equation [23]. Munshi Md. Rasel and Sayed Mukit Hossain (2015) evolve IDF empirical equation for Bangladesh, using a data for 41 years, in order to measure the rain intensity for any duration or return period, then predict future climate fluctuations, the authors used Gumbel method for data distribution, the results figure out that the probability of occurrence of high-intensity rain for a specific duration is inferior to the occurrence of lower intensities [24], the aforementioned method was also accomplished is Surat city of India with a view to use it in the design of urban drainage patterns, drainage water sink, and hydraulic constructions [25]. In Saudi Arabia Al-Anazil and El-Sebaie (2013) applied IDF relationships for Abha, by using Gumbel, Log normal and Log Pearson Type III distributions for six different frequency period. Al-Shaikh (1985) carry out distribution with the maximum likelihood method in four regions in Saudi Arabia and generate the IDF curves.

4. HEC-HMS APPLICATION

The construction steps of the hydrologic model for this study case is treatment of the DEM in order to delineate the watershed, define the flow direction and accumulation, and also calculate the physical characteristics of the model, such as area, slope concentration-time, and curve number. The generated parameters are introduced in the HEC HMS model, where the hydroclimatic data is added and treated. The final steps concern the production of the direct runoff and the transfer to the flow discharge by means of the functions the model disposes of.

The analyzed Hydro-meteorological data and the generated curve number were used in US Army Corps of Engineers Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) in order to simulate rainfall runoff modeling. A HEC-HMS consists of different methods for precipitation loss modeling, direct runoff modeling, base flow modeling and flood routing. For this study, Soil Conservation Services-Curve Number (SCS-CN) method for precipitation loss modeling, Soil Conservation Services–Unit Hydrograph (SCS-UH) method direct runoff modeling, and Muskingum method for routing were preferred and applied for successful simulation of the model.

4.1 Precipitation loss

Precipitation loss is due different factors such surface depression, interception, evaporation, infiltration, etc. The Soil Conservation Service Curve Number was used in order to estimate excess precipitation, calculated through equation (1-3).

$$S = \frac{25400}{CN} - 254 \qquad \text{Eqn. (1)}$$

Where, S -Potential maximum retention and CN-Curve Number,

$$I_a = 0.2\,S \qquad \text{Eqn. (2)}$$

I_a – initial abstraction and it represents precipitation loss before the commencement of surface runoff.

Finally, the cumulative excess precipitation was calculated using equation (3).

$$P_e = \frac{(P - I_a)^2}{(P - I_a - S)} \qquad \text{Eqn. (3)}$$

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Where, Pe-effective precipitation and P-cumulative precipitation

4.2 Direct Runoff

SCS-UH was employed in order to convert excess precipitation to direct runoff. The SCS-UH here requires only basin lag time in minutes and was exported for every sub-watershed. A typical dimensionless unit hydrograph developed by the US Soil Conservation Services (SCS) consists of 37.5% of the total runoff volume before the peak discharge and remaining volume after the peak discharge occurs. The UH can be solved using simplified form of 'triangular' unit hydrograph. The Dimensionless UH is very useful for constructing a synthetic unit hydrograph for a wide variety of watersheds.

4.3 Flood Routing

HEC-HMS model contains different methods of flood routing that require various parameters. Among the different methods provided in the HEC-HMS for flood routing, the Muskingum method was selected. It was computed through equations (4-6). The calibrated and validated flood wave travel time (K= 0 -100) and weighted discharge coefficient (X= 0 - 0.5) was used in equation (6) for flood routing and equation (4) used for calculating the initial value of K.

$$K = \frac{v}{l} \quad \text{eqn. (4)}$$

Where K – flood wave travel time in hour, v – permissible velocity in m/s, l – reach length in m.

$$\frac{ds}{dt} = I - Q \quad \text{eqn. (5)}$$

Where, $\frac{ds}{dt}$ - rate of change of storage per unit time, I – inflow, Q – outflow

$$S = k[xI + (1 - x)Q] \quad \text{eqn. (6)}$$

Where, S – Storage, x-weighted coefficient of discharge, k-flood wave travel time

The Remote Sensing technology furnish information in the form of DEM, LU-LC maps and Geographic Information Systems (GIS) based hydrologic model HEC-HMS were used to simulate rainfall excess (runoff) using the Soil Conservation Service Curve Number method, this excess rainfall is transformed into Direct Runoff Hydrograph (DRH) using SCS-Dimensionless Unit Hydrograph and routing is performed using Muskingum method to derive runoff hydrographs at the outlet of Rampur watershed.

From the results of the hydrographs, the runoff volume, peak discharge and percent loss were determined. For the design storms with 10 years return period, the total precipitation was 153.46 mm, the total loss was 49.14 mm, and the total rainfall excess (runoff) was 104.32 mm. While for the design storms with 50 years return period, the total precipitation was 141.74 mm, the total loss was 48.12 mm and the total rainfall excess (runoff) was 93.59 mm. For the design storms with 100 years return period, the total precipitation was 114.46 mm, the total loss was 50.68 mm, and the total rainfall excess (runoff) was 63.78 mm. While for the design storms with 500 years return period, the total precipitation was 92.01 mm, the total loss was 46.95 mm and the total rainfall excess (runoff) was 45.06 mm. For the design storms with 1000 years return period, the total precipitation was 74.66 mm, the total loss was 43.23 mm, and the total rainfall excess (runoff) was 31.43 mm.

The results of all 5 return periods obtained from the HMS model were drawn in the form of graph as shown in Fig.7. The graph reveals that the precipitation shown as in decrease trend from lower return of 10 year to higher return period of 1000 years. Similarly the runoff also in decreasing trend from lower return period of 10 years to higher return period of 1000 years. The losses computed also decrease in trend as follows the precipitation and runoff trends. Interestingly, lower losses were obtained and consequently runoff values gained higher values following the trend of precipitation as shown in Fig.7.

4.4 Runoff- Scenarios

The HEC-HMS model run in 5 scenarios for different return periods of 10 year, 50 year, 100 year, 500 and 1000 year with 36 years of daily precipitation converted into hourly rainfall using I-D-F curve method. The runoff occurred in each sub-watersheds are given in the table-2. The subsequent runoff received from different sub-watersheds in each reach of the watershed also summarized in the table-3.

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Figure 7: Precipitation-Loss-Runoff for 5 return periods

TABLE 2: RAINFALL-RUNOFF RESPONSE OVER ALL SUB-WATERSHEDS

Sub-watershed no.	Area Sub-watershed km²	Runoff in m³/s				
		10 year	50 year	100 year	500 year	1000 year
w-1	218	329	491	723	1270	1392
w-2	80	175	260	374	448	498
w-3	32	55	87	142	184	208
w-4	122	243	358	512	699	772
w-5	23	110	159	223	205	230
w-6	102	320	464	671	772	860
w-7	83	403	567	760	966	1059
w-8	24	120	175	240	189	215
w-9	128	391	561	800	772	864

Rampur watershed divided into 9 sub-watersheds. The highest runoff occurred for the higher return period of 1000 year for all sub-watersheds as shown in Fig.8. As shown in fig1, the sub-watershed no.1 having larger area, correspondingly the higher runoff of 1392.8 m^3/s occurred in 1000 year return period. The lower area of sub-watershed was no.5, and the lowest runoff not occurred in the corresponding sub-watershed. However, the lowest runoff occurred in 10 year return period of sub-watershed no.3.

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TABLE 3: RAINFALL-RUNOFF RESPONSE OVER REACHES

Reach No.	Runoff in m^3/s				
	10 year	50 year	100 year	500 year	1000 year
R-1	466.8	659.3	971.6	1639.2	1804.6
R-2	680.6	960.3	1415.5	2310.9	2550.3
R-3	1010.4	1320.5	1929.8	3062	3386.3
R-4	1247.1	1584.3	2283.6	3527.8	3901.7

The runoff received from sub-watershed no.1 flow through reach-1 and the runoff collected from nearby sub-watershed flows through reach-2. Likewise runoff received from reach-3 join with reach 4 and finally entered into sink/outlet of Rampur watershed. The fact reveals from table-4, that the runoff 466.8 m^3/s received by reach-1 and the runoff from reach-2, reach-3 collected and at the end of reach-4. The runoff received at the end of reach-4 of Rampur watershed outlet was 3901.7 m^3/s. This result fallows the trend of increasing runoff according to increase of return period increases runoff.

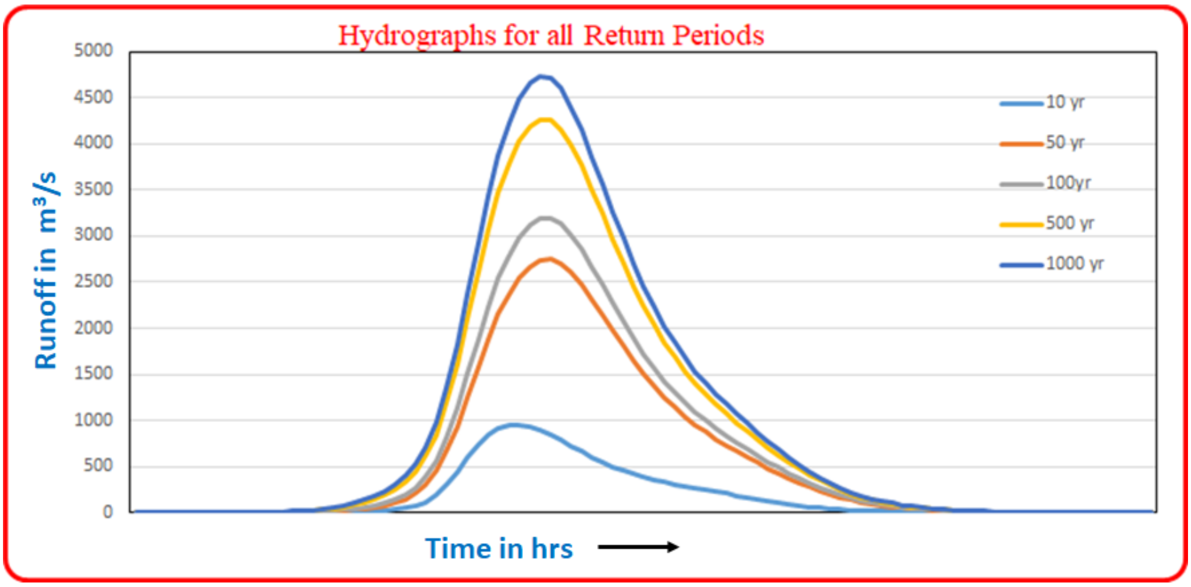

Figure 8: Runoff scenarios of all 5 return periods

The principle objective of this study is compute runoff at the outlet of Rampur watershed in 5-scenarios for 5-return periods from 10 year to 1000 year. The results obtained from HEC-HMS were drawn in graphical form as shown in Fig.8. The peak runoff following an increase in trend from lower frequency return period of 10 years to higher frequency of return period of 1000 years. The fig.8 reveals that the runoff peak difference between 10 year return period to 50 year return period is 1791.6 m^3/s, whereas between 50 year to 100 year return period is less by 451.2 m^3/s and peak runoff difference between 500 year to 1000 year return period is smaller by 465.6 m^3/s.

5. CONCLUSION

The principle tenet of this research article is to generate Rainfall-Runoff scenarios for different frequency return periods. To achieve this, Remote Sensing acquired information in the form of DEM, LU-LC and soil map in addition to rainfall were selected. For application of this selected data a GIS based hydrological model-HEC-HMS has been used for rainfall runoff modeling of Rampur watershed situated at Upper Sutlej sub-basin, Himachal Pradesh, India. Watershed physical parameters such as Curve Number, Basin lag time, initial abstraction, maximum potential retention, flood wave traveling time (K), and weighted coefficient of discharge (X) have been derived to utilize in model as input data in addition to precipitation data. Curve Number grid created using ArcGIS from LU-LC and Soil maps to derive Curve Numbers (CNs) for each sub-watershed using HEC-GeoHMS. The basin lag time and time of concentration of the watershed also computed from the physical parameters obtained from HEC-HMS model. Among the watershed physical parameters used for rainfall runoff modeling of this study, flood wave travel time (K) and

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weighted coefficient of discharge (X) have been more sensitive. Though it was a snow-fed watershed, not computed considering loss method like snowmelt from parameter tool, because the Rampur watershed having 4.37 % of glacier covered which is less percentage comparatively with whole watershed. The other main objective of this study is to utilise IDF curve method to derive different frequency of 5 return periods to utilize in meteorological model to perform rainfall runoff for Rampur watershed. The runoff scenarios of 5 different return periods, peak flow occurred in ascending order of return periods. The high runoff occurred 4729.5 m^3/s for 1000 year return period, and lowest peak runoff occurred 953.7 m^3/s of 10 year return period. This ascending tendency of peak runoff, satisfy the peak flood of return periods such as high return period deliver high runoff as well as low return period derive low peak runoff. With these results one can conclude that, HEC-HMS can be applicable in order to develop rainfall runoff modeling for the specified sub-catchment and computed flow can be represented the direct observed flow with further sub-catchment investigation and modification. The research could be extended by using various loss methods, transform methods and routing methods to verify the validation of the watershed runoff using HEC-HMS model. This approach can deal with instantaneous water management issues by tackling flood risks and providing an appropriate range of data for the Dam safety measures and reservoir management.

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