

Hydrological Modeling with HEC-HMS in Different Channel Sections in Case of Gandaki River Basin

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Abstract

The conceptual and physically based models can be categorized as lumped, semi-distributed and distributed. Lumped model treats the catchment area as one or more homogeneous land segments where the inputs are averaged. Distributed model explicitly represents the spatial variability by dividing the catchment into grids and modeling each grid cell individually. Semi distributed model is a conceptual model that bridge the gap between lumped and distributed models. It utilizes conceptual relationships for hydrological processes that are applied to several relatively homogeneous sub-areas of the catchment area. The main objective of this research paper is to assess the effect of channel geometry of basin at the outlet of basin in semi-distributed rainfall-runoff modeling and to determine performance of the different channel sections that will produce the best results for that basin. From study on the Gandaki river basin, the efficient section for routing depends upon the purposes of the simulating rainfall runoff process. Trapezoidal section is more efficient than other sections for determination of flood forecasting and both trapezoidal and triangular section is efficient for simulating to determine the total annual runoff volume.

Index terms— semi-distributed, geometry, modeling, simulation, Gandaki basin, trapezoidal section, routing.

1 Introduction

Hydrologic models have been developed to simulate the large river basin water supply, flood hydrograph and small urban or natural watershed runoff. The success of development projects (bridge, culverts and sewers) depends on the availability of accurate information describing the volume of runoff that a particular watershed will generate in response to a certain depth of precipitation falling on the basin. The aim of any watershed rainfall-runoff model is to provide a hydrograph showing the variation of volume flow rate of direct runoff over time at a particular point of interest, usually taken as the watershed outlet. Hydrographs produced by models are used directly or in conjunction with other software for the study of water availability, urban drainage, flood forecasting, future urban impact, flood damage reduction, floodplain regulation and systems operation [8] and the performance of hydrographs obtained in different channel section.

The conceptual and physically based models can be categorized as lumped, semi-distributed and distributed. Semi distributed models is a conceptual model that bridge the gap between lumped and distributed models. They utilize conceptual relationships for hydrological processes that are applied to several relatively homogeneous sub-areas of the catchment area [4]. Hydrological simulation could be performed using lumped to physically distributed hydrological models. Since lumped model has no physical meanings and distributed model is difficult and quite sophisticated as it requires large number of parameters, semidistributed model with lesser set of available data is commonly used as it requires less number of parameters. Semi-distributed hydrological models generally have advantage of short calculation time, comparative low calibration needs and high model efficiency.

Spatial discretization either in terms of grid cell size or number of sub divisions of watersheds in hydrological modeling is an essential issue. The optimal spatial scale can be adapted to the modeling objectives for determination of the dominant hydrological processes (Dehotin and Brand, 2008). It has been observed that the sub basin scale have various effects on runoff simulation such as peak time, total runoff, temporal distribution of discharge, flow components and response processes [1]. Therefore, stabilized number of sub basin should be identified for the efficient simulation of hydrological behaviors of catchment using hydrological models. It is more cumbersome job to simulate the river basin considering the different geometries of channel section and various numbers of subdivisions of basin simultaneously and analyzing by semi distributed hydrological model. Definitely it increases the input data preparation effort and the subsequent computational evaluation [6]. The effect of watershed subdivision (or discretization) on the prediction accuracy of hydrological models on 12 watersheds was evaluated by Hromadka et al. (1988). They used a simple model based on the unit hydrograph method. Since most of rainfall runoff models achieve their greatest accuracy for smaller to medium sized watershed. It is beneficial to divide the main watershed into sub-watershed to increase the accuracy of model results.

Furthermore, stream flow may be significantly affected by the difference in soil, vegetation, land use or topography of the watershed and geometry of channel. The flow of water through soil and stream channels of watershed is a distributed process because the flow rate, velocity and depth vary in space throughout the watershed. Estimate of the flow rate or water level at important location in the channel system can be obtained using a distributed flow routing model. This type of model is based on partial differential equations (the Saint Venant equations for one dimensional flow) that allow the flow rate and water level to be computed as functional space and time.

Depending upon the drainage pattern, geometry of the channel and existence of dams, reservoirs, bridge etc. within the basin is to be routed during its journey to the watershed outlet to compute out flow hydrograph on the outlet reach. Stream flow may be significantly affected by the geometry of the channel of the stream. In this paper, Channel flow is simulated using a channel geometry relationship reflective of the natural channel shape. Alternative channels (Trapezoidal, rectangular and triangular) will be used to determine the output hydrograph of the given watershed at the end (outlet) of the basin. The simulated hydrographs will be compared with the observed hydrograph of the given basin at the outlet at different channel geometries (Rectangular, Trapezoidal and Triangular) on the routing process also finding the channel cross section of the stream give the best results.

II.

3 Scope of the Study

The scope of this research paper, as per the objectives, contains application of the semi-distributed model to simulate the channel geometries on watershed. The study deals with pre processing and spatial analysis of the Digital elevation model (DEM) for the automated delineation of sub basins and river. GIS extension tools will be used for the extraction of physical characteristics of sub basin and rivers.

Required other model parameters such as daily precipitation, evapotranspiration are collected from department of hydrology and metrology of Nepal and analyze by Thiessen polygon method. Hydraulic conductivity, suction head, initial moisture deficit and roughness coefficient are extracted on the basis of soil and land use map of the study area and these models parameters are used in HEC-HMS model simulation.

Hydraulic parameters are routed by using kinematic wave method for overland and Muskingum cunge method for channel routing. Simulated flow is compared with the observed flow at the outlet of the basin and analyzes the performance of the result to achieve the objective of the study [14].

III.

5 Principle and Tools a) Infiltration process

Infiltration is the vertical entry of the water into the soil surface and its subsequent vertical motion through the soil profile. It is the most important loss process. The major factors that influence the infiltration rates are soil texture, vegetation cover, the soil surface condition, land use, soil porosity, soil hydraulic conductivity and soil moisture content. Some of the popular infiltration models are the model developed by Green and Ampt (1911), Horton (1933, 1939), and Philip (1957).

Green and Ampt (1911) developed an infiltration loss model based on the physical theory in which the wetting front moves vertically downward. The wetting front is a sharp boundary dividing the soil with saturated moisture content from the underlying soil with lesser moisture content. The water moves vertically downwards from saturated soil to unsaturated soil. Horton (1933, 1939) developed an empirical equation for infiltration capacity based on the infiltration rate [15] begins at some rate f_0 and then decreases exponentially until it reaches a constant saturated infiltration rate f_c . Philip (1957) solved Richard's equation and proposed an equation to estimate the infiltration capacity.

6 b) Parameters for the Green & Ampt equation

Required parameters for the Green and Ampt model to estimate the excess runoff are the hydraulic conductivity of the soil at saturation, volumetric moisture deficit at the beginning of rainfall, and wetting front capillary action. Source: [1] c) Routing Routing is simply a method of translating the hydrograph in time and accounting for the hydrographs change in shape as it moves through the stream system. Hydrologic routing accounts for changes in the time distribution of volume and employs a relatively straightforward computation procedure. There are many methods available within the semi-distributed mode (HEC-HMS) as Clark unit hydrograph, Kinematic wave, Mod Clark, SCS unit hydrograph, Snyder hydrograph and User specified unit hydrograph. Among them kinematic Wave method is selected for both overland flow model and stream channel routing to accomplish the objectives of study.

For hydrograph routing, Kinematic Wave method is selected. Channel properties are extracted with the help of Geographical Information System (GIS) tool with the extension HEC Geo-RAS. Manning's roughness coefficient (n) is taken from the soil map.

7 d) Tools for model i. Arc view GIS

GIS is a powerful tool for simulation and modeling of water resources engineering. Arc view GIS developed by ESRI that is equipped with excellent graphical user interface that enables visualization, exploring and the analysis of spatial data [2]. It has capability of displaying, viewing, editing vector dataset also the facility to display tables, charts, layouts associated with the shape files. The processing, modeling, visualization and interpretation of grid based raster data can be performed using the spatial analyst extension [2].

ii. HEC-GeoHMS HEC-GeoHMS uses DEMs to determine watershed boundaries and flow path by analyzing the direction of steepest descent at each grid cell also watersheds are automatically defined by HEC-GeoHMS based on the user defined threshold for watershed size and at stream confluences. The user can manually add a watershed by defining an outlet on the stream network [3], and user can merge connected watershed. It creates the basic input for the HEC-HMS.

8 iii. HEC-GEORAS

For implementing the kinematic model in HEC-HMS the description of channel shape (triangular, rectangular or trapezoidal), principle dimension of channel cross section and channel side slope. HEC-GeoRAS is an ArcView GIS extension specifically designed to process geospatial data for use with the Hydrologic Engineering Center's River Analysis System (HEC-RAS). To create the import file, an existing Digital Terrain Model (DTM) of the river system in the TIN (Triangulated Irregular Network) format is required.

IV. V.

9 Study Area

10 Methodology

The objective of the study is to assess the effect of channel geometries in semi-distributed rainfall-runoff modeling with the help of input data including precipitation, discharge, DEM (digital elevation model), soil, land use and meteorological data. Kinematic wave method is used both catchment and channel routing. To fulfill this objective, the HEC-HMS Model is used. Finally, the output is compared with the observed discharge at selected gauging of the basin. The conceptual framework for overall methodology is followed by GIS based processing and Rainfall runoff modeling.

11 a) GIS Based Processing

Topographical data, soil data and meteorological data are common inputs for GIS based processing. The type of data used in this study and their sources are shown in table 5.1.

12 b) Topographical Data (DEM) and its processing

Before performing any spatial analysis of a river basin we should first prepare a three dimensional replica of the catchment. Digital elevation model (DEM) is one of such 3D model, which is prepared by generating a surface passing through the nodes of a triangular irregular network (TIN). DEM is a sampled array of elevations for a number of ground positions at regularly spaced intervals. DEM describes the elevation of any point in the study area in digital format and contains the information on drainage, crest and breaks of slopes. DEM is the primary spatial data source based on which GEOHMS extract catchments boundary, topographic variables such as basin geometry, stream networks, slope, aspect, flow direction, etc. The work was made simpler by the availability of 100m resolutions DEM of whole Nepal in free downloadable web site. The DEM for Gandaki basin was clipped out. Stream and watershed delineation has been conducted using HEC-GeoHMS Extension. This extension uses 8-Direction pour point Model to determine flow path.

13 c) Hydro-Meteorological Data

Hydro-Meteorological, vegetation and soil data of Gandaki watershed was collected from Department of Hydrology and Meteorology. Meteorological data used in this study includes precipitation, maximum and minimum temperature, maximum and minimum relative humidity data of daily duration.

14 Model Execution a) Digital Elevation Model (DEM)

The DEM is the important input to describe the topography of the watershed on the basis of semi distributed model. The DEM used in this study is of 100 meters resolution i.e. 100*100 m grid size. Stream map and stream network are also derived by imposing digitized stream network on the DEM.

15 Fig. 6.1 : DEM of Gandaki Basin b) Spatial Analysis (terrain processing)

Terrain processing is used to generate hydrologic parameters from a digital elevation model. Hydrologic derivatives include fill sink, flow direction, flow accumulation, watershed sub delineation and stream segmentation [9]. ii. Reach parameters extracted from HEC-GeoRAS Besides the movement of excess precipitation over the land surface, flow within a river channel and flood banks are required to predict the rate at which water will flow through a given point in the stream in the hydrologic stream routing. While there are many methods of predicting stream routing in HEC-HMS, the model in this study is the kinematic wave method.

16 Result and Recommendation

The main objective of this paper was to find out the channel section of the study area which gives the best result. To achieve the main objective, the temporal variation of the flow by using different channel sections was analyzed and examined the result of different channel geometries at the outlet of the watershed at Narayanghat by considering the model's response of three-year separate precipitation. The simulated annual stream flow volume that occurred at the outlet of the basin in response to the channel geometries during calibration and validation period are presented in table 7.1 and fig. 7.13. The volume deviation using trapezoidal and triangular section obtained almost similar but in rectangular channel the volume deviation is higher than other section ii. Annual mean flow using different channel section

The simulated annual mean stream flow that occurred at the outlet of the basin in response to the channel geometries during calibration and validation period are presented in table ??2 and fig. 7.14. The annual mean flow using trapezoidal and triangular section obtained almost similar but in rectangular channel the annual mean flow is higher than other section. iii. Peak flow using different channel section The simulated peak stream flow that occurred at the outlet of the basin in response to the channel geometries during calibration and validation period are presented in table 7.3 and fig. 7.15. The peak flow using trapezoidal near to the observed flow but for triangular and rectangular section, the peak flow is higher than the observed peak. The time of peak using trapezoidal channel exactly same to the observed time of peak in calibration and validation period, but time of peak using triangular and rectangular section is same in calibration period and slightly different in validation period. Fig. 7.16 : Efficiency using different channel section It is clear from simulated hydrographs that different channel section show different degree of agreement between modeled and observed discharge. Explanations for the results obtained can be pointed out in the following bullets.

- ? The precipitation, the infiltration parameters and channel routing method and parameters cause the difference in Peak flow, peak timing, and total volume, annual mean flow of observed and simulated hydrographs.

- ? Basins with a greater diversity of basin characteristics, including topography, soils and land use will produce poorer results than homogenous basins.

- ? Stream flow is affected by selection of channel geometry.

- ? Errors in peak flow due to inaccurate precipitation, inaccurate sub basin runoff parameters, incorrect timing of tributaries or the wrong amount of attenuation in channel routing.

17 VIII. Conclusion and Recommendation

The main objective of this research was to identify the efficient channel section in the computerbased rainfall runoff processes for Gandaki river basin. The GIS based semi-distributed model named HEC-HMS was used for this study. The response of channel geometry in simulating rainfall runoff was analyzed for the basin using DEM, Evapotranspiration soil type, and land use data. The GIS based extension tool HEC-GEOHMS and HEC-GEORAS were mainly used for preparation of inputs for HEC-HMS.

The model was calibrated for two years flow data and verification of the calibrated parameters for one year's flow data. For this study, especially trapezoidal, rectangular and triangular channel section were taken to account for the simulation. The result shows that using trapezoidal channel section is more efficient than triangular and rectangular section on the basis of Nash efficiency and degree of determination (R-squared value). The peak flow and time to peak at the outlet using trapezoidal channel section is nearly matched to the observed peak flow and time to peak for calibration and verification period than other sections. However the average annual flow and

total annual volume at the outlet is nearly same using trapezoidal and triangular sections and slightly deviated from observed mean flow and annual volume respectively.

From the above result of this study which is the efficient section for routing that depends upon the purposes of the simulating rainfall runoff process. Trapezoidal section is more efficient than other for determination of flood forecasting and both trapezoidal or/and triangular section is efficient for simulating to determine the total annual runoff volume.

? Following are the specific conclusion from the analysis.

? The model provide the best result using trapezoidal channel section as a function of peak flow and time to peak.

? Hydrologic modal parameters can be derived from historic stream flow, precipitation and GIS database.

? The reasonable result were obtained using different channel sections for semi distributed model with efficiency ranging from 88.51% to 90.47% for calibration period and 87.12% to 88.76% for verification period respectively. The Nash -Sutcliffe (1970), efficiency of stream flow that occurred at the outlet of the basin in response to the channel geometries during calibration and validation period are presented in fig. 7.16.The efficiency of flow using trapezoidal channel is higher than the triangular rectangular section.

? Based on the result of this study, the trapezoidal channel section is most suitable for flood forecasting with continuous simulation.

18 a) Recommendations

From the study result, suitable channel section can be used for similar channel routing model. To develop capability of the model, following significant concepts are needed for further similar studies.

Digital elevation model plays vital role to enhance the capability of model. It is recommended to use high resolution digital spatial database for real replication of topography for the better performance of the model.

Channel cross sections are derived using HEC-GeoRAS extension of GIS. It should be checked by field surveys to get better result.

It is recommended to consider contribution of snow for better result.

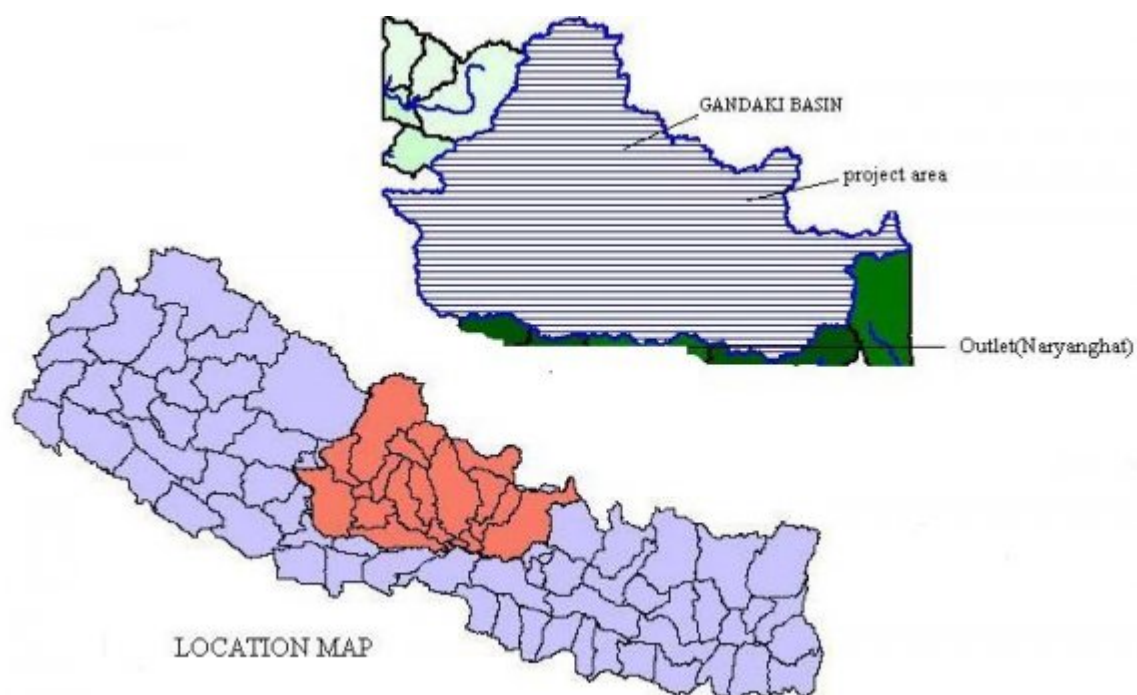
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Figure 1:

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accumulation

Figure 2: Flow accumulation :

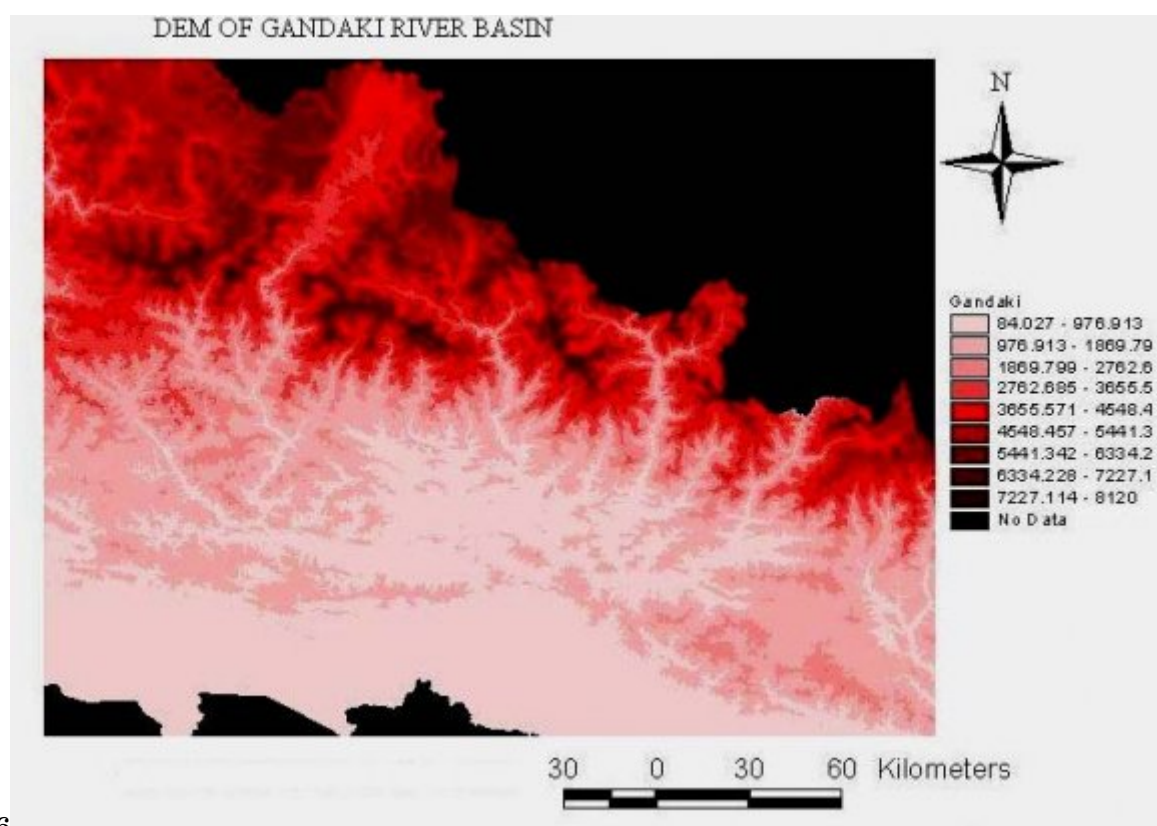


Figure 3: Fig. 6 .

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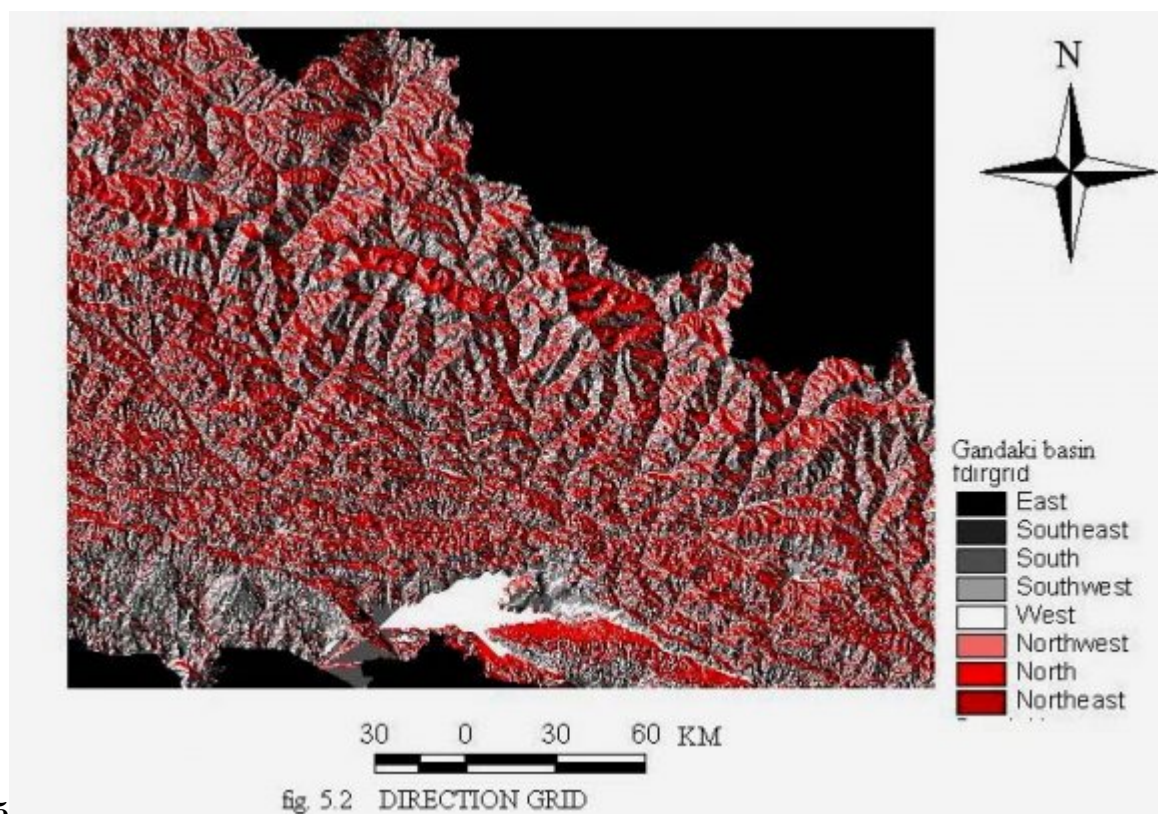


Figure 4: Fig. 6 . 5 :

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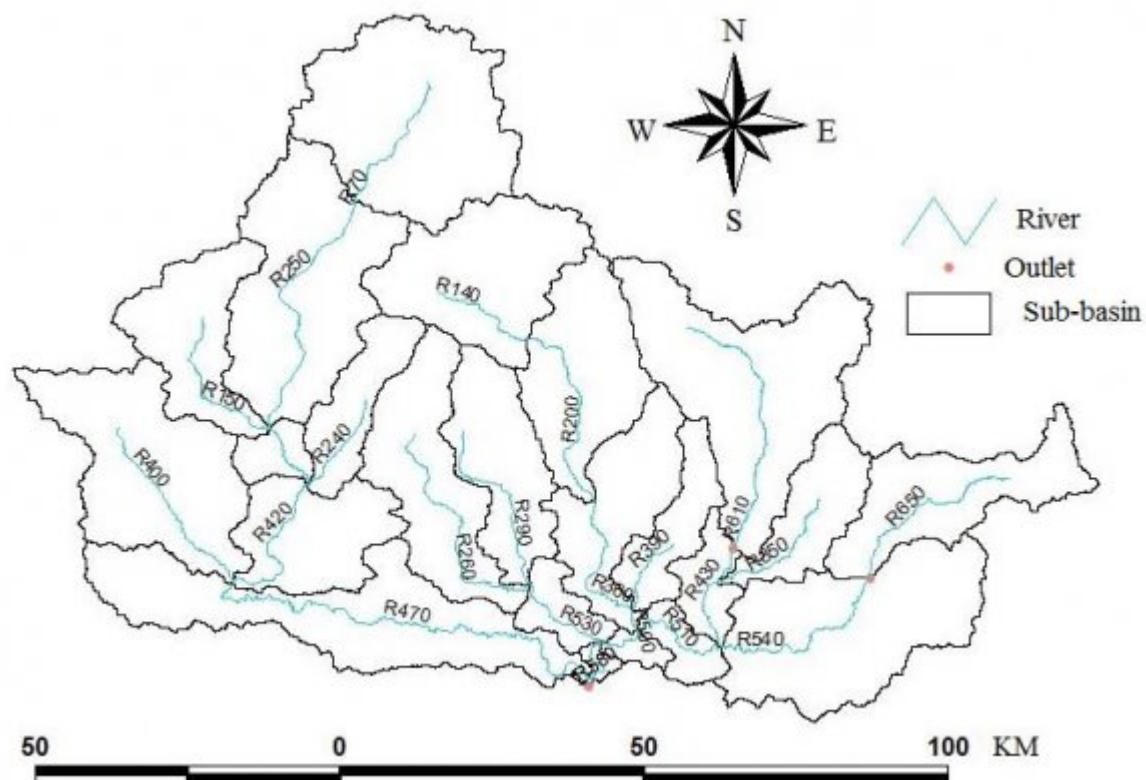


Figure 5: HydrologicalFig. 7 . 1 :Fig. 7 .Fig. 7 . 6 :Fig. 7 . 7 :

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Soil class	Porosity (?)	Effective ?(c)	porosity	Wetting front suction head ?(cm)	soil	Hydraulic conduc- tivity K(cm/h)
Sand	(0.374-0.5) 0.437	(0.345-0.480) 0.417		(0.97-25.36) 4.95		11.78
Loamy sand	0.437 (0.363-0.506)	0.401 (0.329-0.473)		6.13 (1.35-27.94)		2.99
Sandy loam	0.453 (0.351-0.555)	0.412 (0.283-0.541)		11.01 (2.67-45.47)		1.09
Loam	0.463 (0.375-0.551)	0.434 (0.334-0.534)		8.89 (1.33-59.38)		0.34
Silt loam	0.501 (0.42-0.582)	0.486 (0.394-0.578)		16.68 (2.92-95.39)		0.65

Figure 6: Table 3 . 1 :

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Data Type	Resolution	Source
DEM	100m Horizontal, 1m Vertical	STRM, U.S.A.
Soil and Landuse	250 m	DoS, Nepal
Rainfall-runoff	Average daily	DHM, Nepal
Temperature and Humidity	Average daily	DHM, Nepal

Figure 7: Table 5 . 1 :

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S.No	Reach Name	Reach Length (M)	Energy Slope (m/m)	Cross section shape		Rectangular Botom width (M)	Triar Slope
				Trapezoidal	Bottom width (M) Slope(H:V)		
1	R70	45102	0.0128	40	37.5	71.667	65.33
2	R140	32586	0.0285	90.000	48.333	140.000	100.0
3	R250	77369	0.0262	61.667	43.333	85	71.66
4	R150	49206	0.0261	11.250	8.578	27.500	10.96
5	R270	23204	0.0055	20.000	18.540	43.750	26.25
6	R240	32251.9	0.0255	15.000	36.019	62.500	35.32
7	R200	64020	0.0316	56.667	143.333	170.000	186.6
8	R220	11691	0.0053	12.500	8.333	21.667	19.00
9	R350	43863.2	0.0182	24.000	28.000	45.000	65.56
10	R290	58737.8	0.0138	32.500	17.500	47.500	40.00
11	R400	61316.6	0.0102	20.000	27.833	41.667	45.83
12	R420	27829.1	0.0065	16.750	7.375	34.500	14.91
13	R260	78026.7	0.0104	31.250	59.375	100.000	87.50
14	R360	7718.4	0.0031	66.667	94.333	105.000	121.1

Figure 8: Table 6 . 3 :

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Channel section	2004		2005		2006	
	Observed	simulated	Observed	simulated	Observed	simulated
	volume	volume	volume	volume	volume	volume
	(10 7 m 3)	(10 7 m 3)	(10 7 m 3)	(10 7 m 3)	(10 7 m 3)	(10 7 m 3)
Trapezoidal	4591.8	4264.458	4066.3	4060.03	3840.46	3909.9
Triangular		4276.44		4063.27		3916.41
Rectangular		4191.34		3998.9		3854.42

Figure 9: Table 7 . 1 :

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Channel section	2004		2005		2006	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
	Peak flow (m ³ /s)	Peak flow (m ³ /s)	Peak flow (m ³ /s)	Peak flow (m ³ /s)	Peak flow (m ³ /s)	Peak flow (m ³ /s)
Trapezoidal		7531.3		8302.1		5277.8
Triangular	7020	7445.1	7590	8850.5	5480	5184.2
Rectangular		7621.7		9131.5		5093.3

Figure 10: Table 7 . 2 :

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