# Estimation of Water Balance Components of Chambal River Basin Using a Macroscale Hydrology Model

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***Abstract-*** In the present study, Variable Infiltration Capacity (VIC) a macro-scale hydrological model was used to simulate the hydrology of Chambal river basin of India. This analysis was carried out to generate water balance components including runoff, evapotranspiration and baseflow at 0.25*0.25degree grid for the year 2000 and to estimate daily variation of runoff over entire basin. The effect of change of Land cover, slope and soil type on runoff also investigated in this study. Simulation of VIC model showed the annual runoff generation over the basin is 50%.

***Index Terms***- Chambal river basin, Hydrology modeling, VIC, rainfall, runoff, evapotranspiration

## I. INTRODUCTION

Water is the most precious gift of the nature and it must be conserved and maintained carefully for all living things. Due to scarcity of water and increased rate of population it has become to check optimum use of available water resources, for proper planning and efficient water resources in any region it is necessary to understand the hydrological parameters of the watershed. For reliable prediction of the various hydrologic parameters including rainfall, runoff etc. for remote areas is very tough and time consuming by conventional methods. So it is very important to search suitable methods and techniques for quantifying the hydrological parameters. The fundamental objective of hydrology modeling is to gain an understanding of hydrological system in order to provide reliable information for managing water resources in a sustained manner. Distributed models are based on physical principles governing the movement of water within a catchment area, but they need detailed high-quality data to be used effectively. AVSWAT (ArcView Soil and Water Assessment Tool), MIKE-SHE, Variable infiltration Capacity (VIC) model, HEC-HMS (Hydrologic Engineering Centre-Hydrologic Modelling System) are some of the physically based distributed hydrologic models. In the present study, VIC land surface hydrologic model has been used for modeling the river flow regime. It is a physically based, macroscale hydrological model which represents the partitioning of incoming (solar and long wave) radiation at the land surface into latent and sensible heat, and the partitioning of precipitation (or snowmelt) into direct runoff and infiltration.VIC explicitly represents vegetation, and simultaneously solves the surface energy and water balances. A river routing model when coupled with VIC permits comparisons between the model-derived discharge and observations at gauging stations.

## II. OBJECTIVES

1. Spatio-temporal data collection, database preparation using Remote Sensing / GIS and their integration for model input.
2. To conduct the hydrological modeling using VIC (Variable infiltration capacity) land surface model for Chambal river basin.
3. To generate water balance components at 0.25x0.25 degree grid level on a daily time step.

## III. STUDY AREA

Chambal River Basin is located in eastern Rajasthan, between latitudes 22°27' and 27°20' and longitudes 73°20' and 79°20'.It also covers some part of Madhaypradesh Banas and Mahi Basins lie to its west, and Gambhir and Parbati Basins to its north. Its eastern and southern edges border Madhya Pradesh State. Chambal River Basin extends over parts of Chittorgarh, Bhilwara, Bundi, SawaiMadhopur, Tonk, Jhalawar, Kota, Baran and Dholpur Districts. The total catchment area of the Basin is 31,460 $km^2$ (excluding Banas Basin, which is also a tributary of Chambal). (Fig 1)

The main tributaries of river Chambal are Siwana, Retam, Shipra and Choti Kalisindh in MP, Kalisindh, Parwati, Parwan and Banas in Rajasthan**.** Figure 2 shows the river network of Chambal river basin. The mean annual rainfall over the Chambal Basin was computed as 797 mm, of which about 93% falls during the four Monsoon months (June-September).

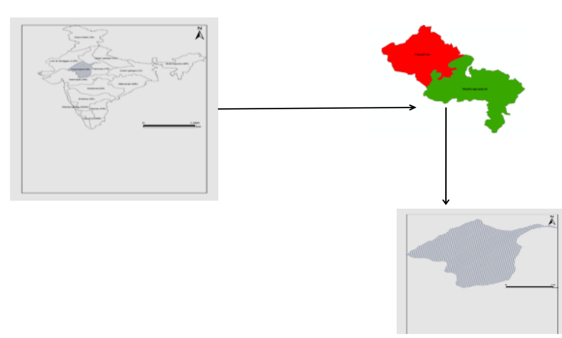

Figure 1: Study Area

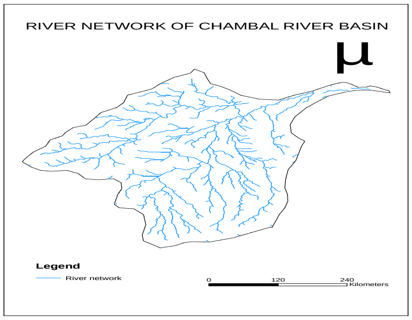


**Figure 2: River Network in Chambal basin**

## IV. MATERIALS AND METHODOLOGY

**Data and software**

The satellite data used are Landsat ETM+data from USGS classified with same classed as used in GLC 2000 vegetation classification data , MODIS (MODIS 15 A 02) data for LAI and (MCD43B3) ALBEDO. Not only satellite data Soil data from STATGO, FAO and NBSSLUP, Digital Elevation Model (GTOPO30) of approximately 1 kilometer resolution and maximun, minimum temperature and rainfall data from Indian Meteorological Department were required to run the model. The software used were ERDAS (Earth resources Data analysis System) imagine 9.2 versions and ARCGIS 9.3 for generating grid mesh, preparing land use/land cover map and soil maps as well as while extracting mean LAI and ALBEDO values and Mean elevation values. ENVI 4.0 software was used during the study, to prepare all the rainfall, maximum and minimum temperature maps. The operating system used was windows and cygwin.

## V. METHODOLOGY

Grid mesh was created over the area corresponding to latitude and longitude with spatial resolution of 25 km * 25km in ARCGIS. Grid mesh is consisting with 19 rows and 23 columns. . Starting from the upper left corner the values were assigned going right and downward for each grid cell. Total number of grid was 436. Figure 3 shows the basin grid. Four major input files are necessary to run the VIC model. They are Vegetation parameter file, Vegetation Library file, Soil parameter file and Forcing file. All the files are represented according to ASCII format. Vegetation characteristics related to each grid cell are reflected by vegetation parameter file and vegetation library file. The vegetation parameter file describes the vegetative composition of each grid cell, and uses the same grid cell numbering as the soil file (latitudes and longitudes are not included in the file). This file cross-indexes each vegetation class (from any land-cover classification scheme) to the classes listed in the vegetation library. To prepare this file, land use map was overlaid on the grid map and the no. of vegetation classes as well as fraction of grid covered by those classes was extracted. A small code in C language was used to read this information from crossed map and arrange it in the format specified by the model. For the selected land cover classification of the study area, a vegetation library file was set up. This describes the static (varying by month, but the same values year-to-year) parameters associated with each land cover class. The variables used in vegetation parameter file and vegetation library file are Gridcel, Vegetation_type_no, Veg_class, CV, root depth, root fraction, Gridcel, Overstory, Rarc, Rmin, LAI, ALBEDO, roughness length, displacement height, overstory, architectural resistance, minimum stomatal resistance. For this purpose Landsat ETM+ data was supervisly classified with same classed as used in GLC 2000 vegetation classification data to obtain land/use land cover map of the study area which have lkm*lkm spatial resolution as seen in Figure 4 using ERDAS imagine Software. Different vegetation types in land use map were used to include the all parameters accordingly by giving identification number for each. For derivation of LAI, MODIS LAI and albedo maps the monthly values were reprojected from sinusoidal WGS to Albers equal area projection system All the images were subset using boundary map in ARCGIS and all the images were multiply by 0.1 to get actual value and then mean LAI values for every month were obtained using Band math function. Other variables like roughness length, displacement height, overstory, architectural resistance, minimum stomatal resistance were derived from LDAS 8$^{th}$ database (http://ldas.gsfc.nasa.gov/LDAS 8th/MAPPED.VEG/ web. veg.monthly.table.html) and MM5 terrain dataset. Figure 8 and 9 represents the LAI and ALBEDO map prepared for May 2000.For derivation of soil parameter file Soil texture map (Fig 5) was rasterized and overlaid with the grid map to extract dominant soil type in each grid. Mean elevation values for each grid were derived from Digital elevation model and slope map shown in Fig 6. And Fig 7.Annual precipitation was obtained from the gridded rainfall map was provided from IMD (Fig 10). All other parameters except c, elevation, depth, off_gmt, rough, and annual prec are a function of soil texture and were derived using soil hydraulic properties index defined in VIC model documentation. Forcing data files play big role in the model to produce all the out puts in both water balance and full energy balance. This is done in the global control file using the FORCE_TYPE parameter. The VIC model is written entirely in the C programming language, and can be compiled using a gcc compiler on UNIX, Linux and DOS operating systems. The code was compiled using the make file included in the archive, by typing 'make'. The compiled code creates an executable entitled VicNl'. To begin running the model, VicNl -g (global control file name)' was written at the command prompt. Global control parameters were modified according to the input characteristics and to activate the ware balance. In addition to that input and output path were specified. VIC use infiltration formula used in Xinanjang model which assumes precipitation in excess of the available infiltration capacity forms surface runoff. Penman-monteith formula is used to calculate the evapotranspiration .Base flow was derived as the function of soil moisture in the lowest soil layer using Arno non linear formula.

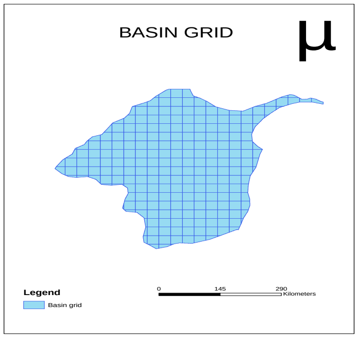


**Figure 3: Chambal grid map**

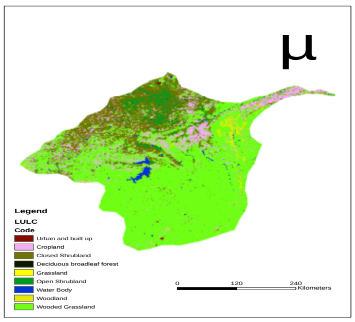


**Figure 4: Lulc map over the area**

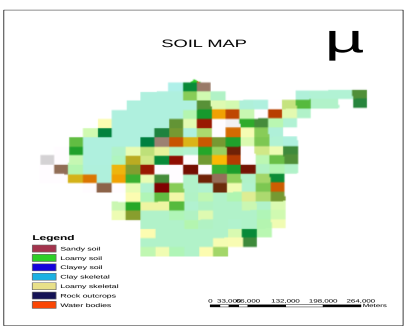


**Figure 5: Soil map of Chambal river basin**

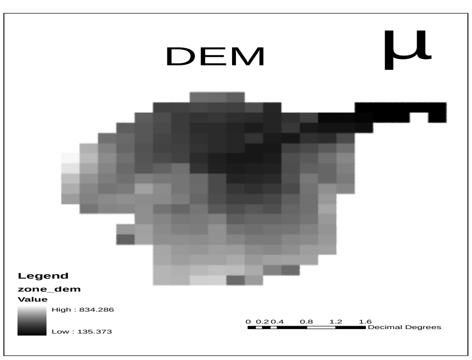


**Figure 6: Digital Elevation model**

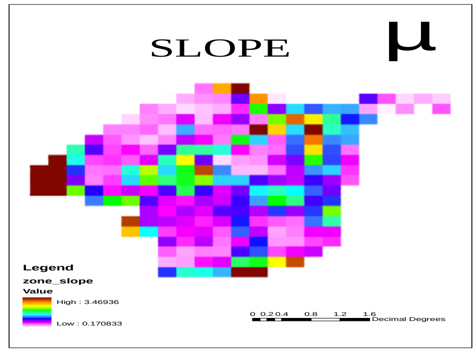


**Figure 7: Slope map**

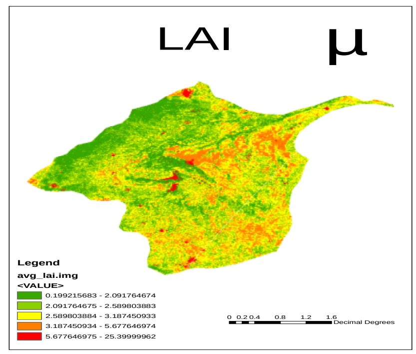


**Figure 8: LAI map of Chambal river basin**

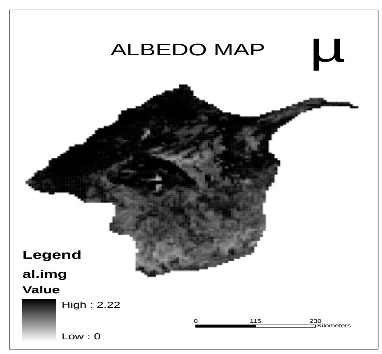


**Figure 9: Albedo map of Chambal river basin**

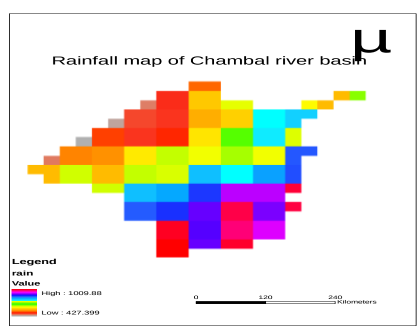


**Fig 10: Gridded Rainfall map of Chambal river basin**

ISSN 2250-3153

## VI. RESULTS AND DISCUSSION

The results obtained through the simulation are represented under this chapter. Although VIC model produce number of hydrological parameters the present analysis mainly focuses on the major components which are Runoff, Evapotranspiration, and Base flow.

**Major Hydrological component**

Figure 11 shows the spatial distribution of annual rainfall calculated from January 2000 to December 2000 over the grid mesh of Chambal basin. It ranges from 465mm to 1024 mm. Also maximum rainfall is received in July and lowest in December. It is observed that in monsoon, this area received high rainfall and winter received less.Rainfall, Land use/land cover, Elevation, Slope, Soil types are main limiting factors for the runoff generation. Simulated annual runoff varies from 0 mm to 516.8 mm and is presented in Figure 12. Highest Runoff has produced in July and lowest in December. According to the simulated results it has shown that average annual runoff generation over the basin is 50 % corresponding to the rainfall. Figure 14 shows the annual division of precipitation into the different components of the water balance which averaged for the whole basin. Figure 13 shows the daily variation of rainfall and runoff for the whole basin.

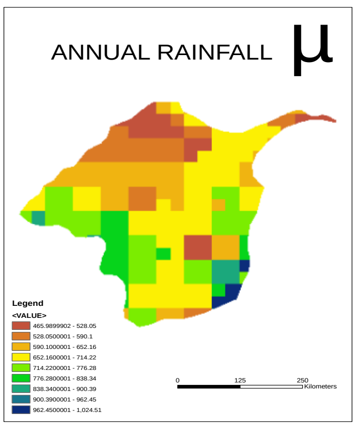


**Fig 11: Annual rainfall distribution over basin**

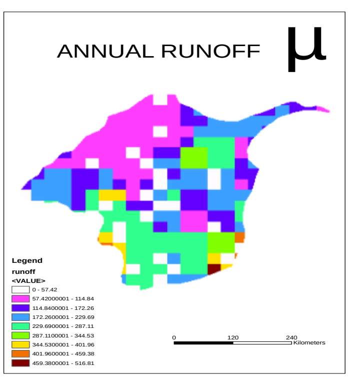


**Fig 12: Annual runoff distribution over basin**

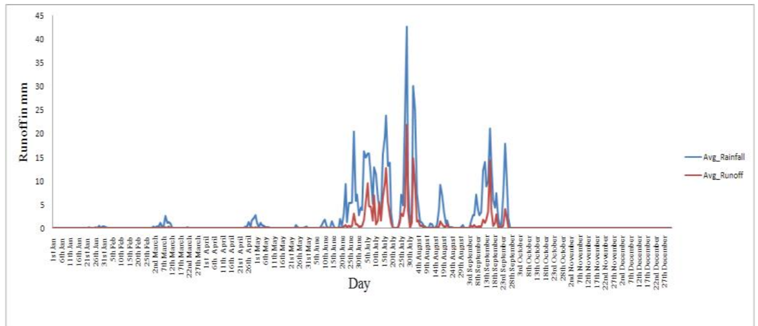


**Fig 13: Daily variation of Rainfall and Runoff over basin**

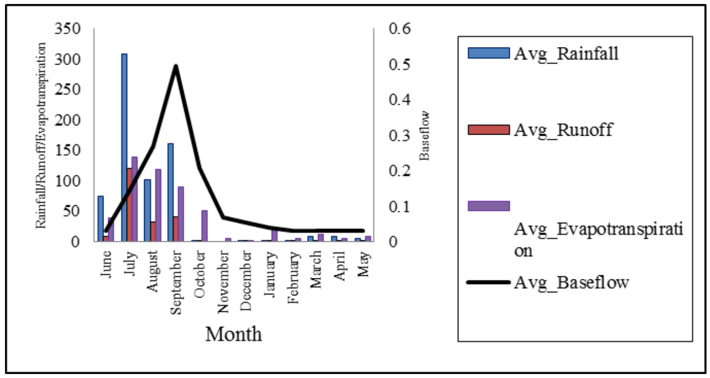


**Fig 14: Annual average distribution of different hydrological components**

Base flow has produced according to the precipitation intensity and durations. The areas which receives lower precipitation has produced negligible amount of base flow. It is observed that annual base flow over the area range from 0 mm to 184 mm according to the precipitation received. In VIC model Base flow is generated from the bottom layer. Hence bottom layer characteristics have influenced on base flow. However variation of Base flow ratio correspondent to rainfall is very smooth over the area as seen in Figure 16.The annual Evapotranspiration over the area simulated by VIC model ranges from 0 mm to 663 mm as seen in Figure15. However with respect to temperature changes in different months evapotranspiration has changed. Evapotranspiration has become lowest in December with respect to minimum temperature. Although South east part received higher rainfall, evapotraspiration has shown lower value than northern part of the basin. In addition to that it has shown evapotranspiration is higher in forest area with compare to the little or no vegetation area.

**Effect of Land use/ Land cover, slope and soil type on runoff**

It is observed that runoff has changed over the area according to the land use and land cover. Chambal basin mainly consists with mixture of vegetation types. Figure 17 shows runoff changes with correspondent to different land use/land covers. According to it open shrub land has produced lower runoff and cropland has produced higher runoff. Usually high slope tends to more runoff generation, retarding infiltration where as low slope area creates low runoff giving time for the infiltration. It has clearly shown in Figure 18 which represents the fraction of runoff generation.

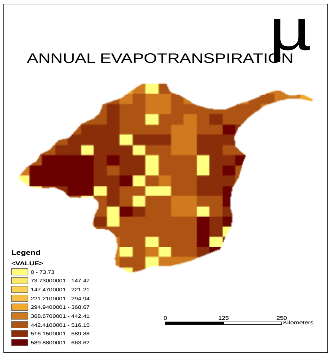


**Fig 15: Annual evapotranspiration distribution over the basin**

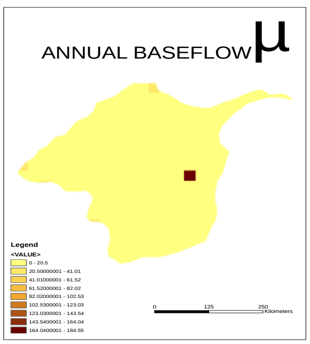


**Fig 16: Annual Baseflow distribution over the basin**

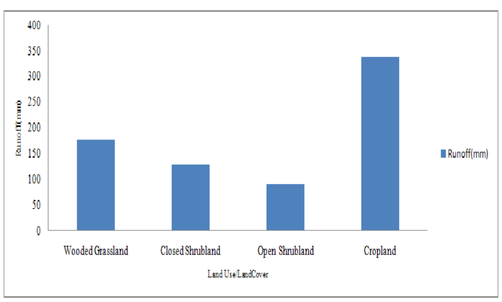


**Fig 17: Runoff changes according to Land cover**

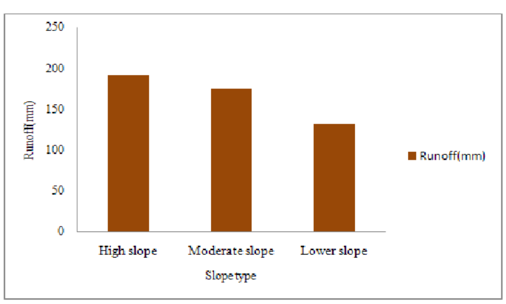


**Fig 18: Runoff changes according to slope**

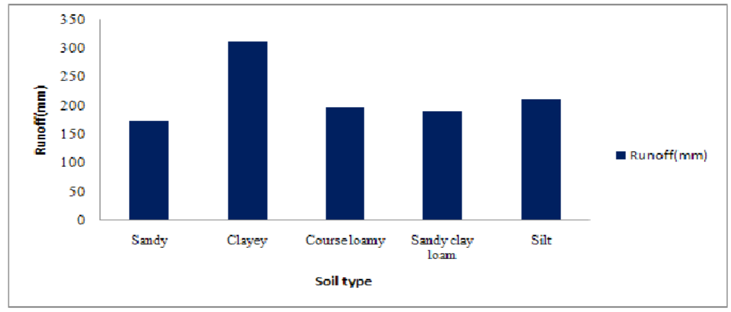


**Fig 19: Runoff changes according to Soil**

Figure 19 illustrate annual runoff variations according to the soil characteristics. It has shown that sandy soil formed low runoff due to high infiltration capacity where as clay soil has produced comparatively high runoff.

## VII. CONCLUSION

The grid based most recent version of VIC Model was implemented at 25km*25km grid resolution for the Chambal river basin with aid of Remote Sensing and GIS data. The different hydrological parameters are simulated according to the input data and those have shown acceptable degree of accuracy over the area. The advantage of the model is, it can utilized most of the Remote Sensing and GIS data which can easily derived from web-based spatio-temporal data especially for the areas which has very limited amount of data. Although model has formulated considering macro scale catchment areas it can successfully apply for the small watersheds to extract number of hydrological parameters. Also with this model it is possible to find the hydrological parameter changes over the catchment areas due to different alterations which help in decision making process. Some knowledge about programming is necessary to run the models which can be consider as a disadvantage of the model.VIC Model computed grid-wise water balance components simulated the seasonal and annual hydrological processes in Chambal River basin for the year 2000. Grid-wise daily water balance simulations provided the estimates of evapotranspiration, runoff and base flow at daily time step. The annual runoff generation over the basin is 50%. Land use/ land cover, soil and slop characteristics influences the hydrological processes in considerable manner. Higher runoff produce correspondent to less vegetative area where as low runoff produced in densely vegetated areas. Higher slopes contribute high runoff where as plain area produces low runoff. Also runoff changes in considerable manner with respect to soil type and soil characteristics over the area. The Sandy soil produces less runoff and Clay soil produces high runoff.

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