STUDY THE COMPARATIVE PERFORMANCE OF HEC-HMS AND SWAT MODEL FOR PREDICTION OF SURFACE RUNOFF FROM KAL RIVER OF KONKAN REGION IN MAHARASHTRA

A Thesis submitted to the

DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI - 415 712
Maharashtra State (India)

In the partial fulfillment of the requirements for the degree of

MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)

In
SOIL AND WATER CONSERVATION ENGINEERING

By
Mr. Mohite Nitin Sambhaji
(ENDPM 2016/107)

DEPARTMENT OF SOIL AND WATER CONSERVATION ENGINEERING
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH

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CANDIDATE'S DECLARATION

I hereby declare that this thesis or part there of has not been submitted by me or any other person to any other University or InstituteFor a Degree or Diploma

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This is to certify that the thesis entitled **"Study The Comparative Performance Of HEC-HMS and SWAT Model for Prediction of Surface Runoff From Kal River of Konkan Region In Maharashtra"** submitted to Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist.- Ratnagiri, (Maharashtra State) in the partial fulfilment of the requirements for the award of the degree of **Master of Technology (Agricultural Engineering)** in **Soil and Water Conservation Engineering,** embodies the results of bonafide research work carried out by **Mr. Mohite Nitin Sambhaji (ENDPM 2016/107)** under my guidance and supervision. No part of the thesis has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

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The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

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'Definitely success can be achieved by hard work and sincere efforts. But behind this success there is knowing and unknowing involvement of many innovative minds and creative hands to beautify it. Emotions cannot be adequately expressed in words because then emotions are transferred into mere formalities. Nevertheless, formalities have to be completed. My acknowledgement are many more than what I am expressing here.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations	Meanings
%	Percent
<	Less than
>	Greater than
^{0}C	Degree Celsius
abs.	Absolute
ASTER	Advanced Spaceborne Thermal Emission and Reflection
CAET	College of Agricultural Engineering and Technology
Cm	Centimeter
COE	Coefficient of Efficiency
DEM	Digital Elevation Model
dS/m	deciSiemens per metre
E	East
Equ.	Equation
et.al	And others
Fig.	Figure
GIS	Geographical Information System
Ha	Hectares
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HSCG	Hydrological Soil Cover Group
HRU	Hydrologic Response Unit
i.e	That is
i/p	Input
IRS	Indian Remote sensing
Km	Kilo meter

Km^2	Kilo meter square
LISS	Linear Imaging Self Scanning Sensor
LU/LC	Land use –Land cover
m/s	Meter/second
m^3	Meter cube
Max.	Maximum
Min.	Minimum
Mm	Millimeter
mm/hr	Millimeter per hour
MRSAC	Maharashtra Remote Sensing Application Centre
N	North
NSE	Nash Sutcliffe Efficiency
No.	Number
PBIAS	Percent Bias
resp.	Respectively
RS	Remote Sensing
R^2	Coefficient of Determination
RSR	Ratio of Root Mean Square error and Standard Deviation
SOI	Survey of India
Sq.	Square
SRTM	Shuttle Radar Topography Mission
SWAT	Soil and Water Assessment Tool
USDA	United States Department of Agriculture

ABSTRACT

"STUDY THE COMPARATIVE PERFORMANCE OF HEC-HMS AND SWAT MODEL FOR PREDICTION OF SURFACE RUNOFF FROM KAL RIVER OF KONKAN REGION IN MAHARASHTRA"

By

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The socio-economic and political development of a nation is vastly dependent on the availability and distribution of freshwater provided by the river. The estimation of runoff volume of a catchment is an important aspect in engineering planning, environmental impact assessment, flood forecasting and water balance calculations. Proper estimation of runoff magnitude is required for efficient design, planning and management of river basin projects that deal with conservation & utilization of water for various purposes. Therefore numerous models have been developed by different researchers to simulate Rainfall Runoff process.

HEC-HMS and SWAT model has been applied for the Kal river catchment in this study. To study the comparative performance of HEC-HMS and SWAT model for prediction of surface runoff from Kal river of konkan region in Maharashtra.

It is observed that, the statistical indices performed to compute the surface runoff by HEC HMS indicates that R^2 is 0.95 for simulation period and R^2 for calibration period is 0.94 whereas for all study period 1991 to 2003 is 0.94. Like that, Nash-Sutcliffe efficiency (NSE), Percent Bias (PBIAS) and Root mean Square error and standard deviation ratio (RSR) were estimated to check the performance of the model during

simulation and calibration period. It is observed from that the NSE values for simulation is 0.90 and during calibration period is 0.92 whereas for whole study period is 0.91. The PBIAS value observed during simulation is -14.45 per cent and for calibration period 8.63 per cent whereas for whole study period is -3.79 per cent. The RSR for simulation period is 0.34 and calibration period is 0.29 whereas for study period is 0.32. It indicates from all indices that, the model predict surface runoff during simulation and calibration period satisfactorily.

In other hand, the statistical indices performed to compute the surface runoff by SWAT indicates that R^2 is 0.94 for simulation period and R^2 for calibration period is 0.93 whereas for all study period i.e 1994 to 2003 is 0.93. The NSE value for simulation is 0.89 and during calibration period is 0.91 whereas for whole study period is 0.90. The PBIAS value observed during simulation is -14.55 per cent and for calibration period 7.80 per cent whereas for whole study period is -4.23. The RSR for simulation period is 0.36 and calibration period is 0.31 whereas for study period is 0.34. It indicates from all indices that, the model predict surface runoff during simulation and calibration period satisfactorily.

The statistical indices (R^2, NSE, PBIAS, and RSR) R^2 values for HEC HMS and SAWT model in predicting the surface runoff during simulation and calibration period is more than 0.9 and approaches to the 0.95. This indicated the both model were very good in simulating the surface runoff compared to the observed runoff. The other indices such as PBIAS, values are very realist and approaches toward the real estimating the surface runoff by both HEC-HMS and SWAT model as their values are ranging between -14.14 to 8.6. Also the values of the NSE and RSR estimated are in the permission limits as per suggested.

As per above discussion, it is felt that, both model performance for predicting the surface runoff is very good for Kal river of Konkan region. The model parameters adopted and calibrated for Kal river may be suitable for predicting the surface runoff by HEC-HMS and SWAT model. The results for predicting the surface runoff by HEC-HMS and SWAT found to similar due the basic approached in both model same and SCS-CN methods is adopted for simulating the surface runoff.

I. INTRODUCTION

The innumerable services rendered by the surface water resources have been benefitting the people and the economy of the nations for many centuries. Rivers have been supporting several beneficial uses such as flora and fauna, domestic, agricultural and industrial purposes. The socio-economic and political development of a nation is vastly dependent on the availability and distribution of freshwater provided by the river. Drainage basin of a river is the area which contributes runoff to the main stream and its tributaries. The watershed and drainage basin are synonymous terms indicating to an area surrounded by a ridge line that is drained through a single outlet. Surface runoff is the flow of water that comes from excess water from rain, meltwater, or other sources that flow over the Earth's surface. It is a major component in regional and global hydrological cycle. It has direct impacts on human lives since it is a key water resource for agriculture, industry, urban water use, and so forth. Estimation of runoff is important as runoff values based on direct measurements are much less available as compared to rainfall. Rainfall and runoff are the important components contributing significantly to the hydrological cycle. In surface hydrology, rainfall-runoff processes play a vital role. The rainfall-runoff relationship is one of the most important phenomena in hydrologic design of hydrological structures and drainage systems. The estimation of runoff volume of a catchment is an important aspect in engineering planning, environmental impact assessment, flood forecasting and water balance calculations (Balvanshi and Tiwari, 2014).

The determaination of the runoff volume of watershed is crucial in managing natural disaster, design and construction of water conservation structures. For sustainable enlargement and better management of water resources, a complete understanding of hydrologic response of a particular watershed must be known. This leads to a trustworthy representation of the rainfall-runoff relation at various spatial and temporal scales (Duhan and Kumar, 2017).

Proper estimation of runoff magnitude is required for efficient design, planning and management of river basin projects that deal with conservation & utilization of water for various purposes. To determine accurate quantity of surface runoff in any river basin, understanding of the complex relationship between rainfall and runoff processes of particular basin is necessary. Rainfall-runoff models play an important role in water resource management planning. Therefore, different types of models with various degrees of complexity have been developed for this purpose (Solaimani, 2009).

Hydrological model is a simplified representation of natural system and are simplified systems to quantify the processes of the hydrological cycle in an entire river basin or parts of it. Rainfall-Runoff models can be classified according to their degree of representation of the physical processes and to the spatial and temporal description. Although a variety of Rainfall-Runoff models are available, selection of suitable model for a given watershed is essential to ensure efficient planning and management of watershed. Numerous models have been developed by different researchers to simulate Rainfall Runoff process.

Now-a-days, hydrologic response of catchment systems are changing due to rapid increase in urbanization and industrial growth including deforestation, land cover and land use pattern changes. Along with climate change, soil heterogeneity has also put great emphasis on the flow of many rivers all around the world. Therefore to evaluate the impact of these changes, Hydrological models have been developed across the world to study the hydrologic behaviour of a catchment system. (Duhan and Kumar, 2017).

Application of models in hydrological studies has become an indispensable tool for understanding of the natural processes occurring at the watershed scale. Plenty of computer-based hydrologic models have been developed and available for applications in hydrologic modeling and water resources studies. A model can be evaluated by comparing the model results or capabilities to other models or some other expected/specific response. In the past, many different attempts have been initiated to evaluate the hydrological models amongst themselves and with lumped models. (Dhami and Pandey, 2013).

In recent years, the Hydrologic Engineering Centre (HEC) of US Army Corps of Engineering (USACE) has developed Geographical Information System (GIS) based HMS models for specific tasks such as processing terrain for drainage path, generating Grid-based rainfall, etc. It is new generation software being developed for precipitation-runoff simulation that will supersede the Hydrologic Engineering Center's HEC-l program.

The Hydrologic Modeling System (HEC-HMS) is designed to simulate the complete hydrologic processes of dendritic watershed systems. The software includes many traditional hydrologic analysis procedures such as event infiltration, unit hydrographs, and hydrologic routing. HEC-HMS also includes procedures necessary for continuous simulation including evapo-transpiration, snowmelt, and soil moisture accounting. Advanced capabilities are also provided for gridded runoff simulation using the linear quasi-distributed runoff transform (ModClark). Supplemental analysis tools are provided for model optimization, forecasting streamflow, depth-area reduction, assessing model uncertainty, erosion and sediment transport, and water quality. The software features a completely integrated work environment including a database, data entry utilities, computation engine, and results reporting tools. A graphical user interface allows the user seamless movement between the different parts of the software. In such a way HEC-HMS is developed to use readily available digital geospatial information to construct hydrologic model extension more appropriately than using manual methods.

SWAT (Soil & Water Assessment Tool) is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds. SWAT is a public domain software enabled model actively supported by the USDA Agricultural Research Service at the Blackland Research & Extension Center in Temple, Texas, USA. It is a hydrology model with the following components: weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading, and water transfer. SWAT can be considered a watershed hydrological transport model. This model is used worldwide and is continuously under development.

The physics-based, distributed hydrologic models are widely applied for managing the flood events and water resource in the world. Soil and Water Assessment Tool (SWAT) is a distributed parameter continuous time model developed by the United States Department of Agriculture, Agricultural Research Service (USDA-ARS) (Singh *et al*. 2013). SWAT is a continuous-time, process based, physics-based, long-term, and distributed hydrological model and has been applied worldwide as an excellent assessment model for hydrological modelling and water resource management (Singh *et al*. 2013).

The present study was carried out for Kal River. The Kal river is tributary of Savitri basin and is the west flowing river in Maharashtra. This is a major tributary of the river Savitri. The expected outcome of project will be simulate runoff from catchment will helpful for future prediction of runoff and planning of water resources in catchment and decide management strategies. The main objective of this study to predict the surface runoff of Kal river using both HEC-HMS and SWAT model and study the comparative performance on simulation of surface runoff from Kal river catchment. With this background study entitled “Study the comparative performance of HEC-HMS and SWAT model for prediction of surface runoff from Kal river of Konkan region in Maharashtra” is undertaken with following objectives,

1. To predict surface runoff by using HEC-HMS model.
2. To predict surface runoff by using SWAT model.
3. To compare performance of HEC-HMS and SWAT model.

II. REVIEW OF LITRATURE

2.1 Application of HEC-HMS for estimation of Runoff Modelling

Coskun and Musaoglu (2006) studied the rainfall- runoff modelling of the van lake catchment by using remote sensing and GIS integration. The aim of this study was to determine runoff depth of the Van Lake basin by using remote sensing and geographic information system (GIS) integration. While determining the results they used various data sets such as Landsat satellite image 1:25000 standard topographic map, and soil map data. Standard 1:25000 topographic maps were used to derive digital elevation model. Digital Elevation Model was used to determine basin model through Hec-GeoHMS. Soil Conservation Curve Number method was used to determine curve numbers and runoff depth distribution of the basin area. The study showed that remote sensing and GIS technology are suitable for analysis of the runoff depth distribution of the basin area. The proposed method can be applied to predict for ungaged watersheds, flood, and other water resource applications.

Bakir and Xingnan (2008) studied that GIS-Based Hydrological Modelling: a comparative study of HEC-HMS and the xinanjiang model. In this research, attempt was made to critically look at the application of HEC-GeoHMS which is an extension of ArcView in HEC-HMS. The main role of HEC-GeoHMS is to formulate a watershed data structure under the platform of GIS that can be imported directly to HEC-HMS. With the topographic information supplied by HEC-GeoHMS, HEC-HMS works more readily and exactly.

Jeongwoo (2010) studied the stream flow analysis using ArcGIS and HEC-GeoHMS.This study focuses on the stream flow estimation and comparison of peak discharge and discharge volume as results of different transform methods in HMS. This study chose San Antonio basin as study area and gathered the various raster and feature class data. SCS transform and Clark transform method were adopted for calculating runoff in HMS. SCS loss and Muskingum method were chosen for loss method and routing method, respectively, in HMS. As input data for the rainfall-runoff model, this study selected the total 18 number of gage station. To reflect spatial rainfall characteristics of precipitation data of specific hydrologic events periods Thiessen weight method was used. Finally, results of runoff from different transform methods were estimated and compared.

Majidi and Shahedi (2012) studied the simulation of rainfall-runoff process sing Green-Ampt method and HEC-HMS model (Case Study: Abnama Watershed, Iran) in this study, Simulation of rainfall-runoff processes in Abnama watershed is main objective of this research. For this reason HEC-HMS model and Green-Ampt method were applied Rainfall-runoff simulation was con-ducted with five events, and initial results for the first four events show differences between simulated and observed discharges. Therefore the model calibration conducted to optimize the parameters. The model validation with optimized lag time values showed 9.1% difference between observed and simulated discharges. This difference is in range of 20% acceptable error. The comparison of observed and simulated hydrographs and their correlation (R^2=0.86) showed capability of the model to be used in hydro-logic simulation in Abnama watershed. Finally concluded that model can be used with reasonable approximation in hydrologic simulation in Abnama watershed.

Choudhari *et al.,* (2014) studied the simulation of rainfall-runoff process using HEC-HMS model for Balijore Nala watershed, Odisha, India. In this paper HEC-HMS model is used to simulate rainfall-runoff process in Balijore Nala watershed of Odisha, India. To compute runoff volume, peak runoff rate, base flow and flow routing methods SCS curve number, SCS unit hydrograph, Exponential recession and Muskingum routing methods are chosen, respectively. Rainfall-runoff simulation is conducted using 24 random rainstorm events covering four year (2010 - 2013) data. Out of these, 12 events are selected for model calibration and the remaining 12 for model validation. For calibration of model the statistical tests of error functions like mean absolute relative error (MARE) and root mean square error (RMSE) between the observed and simulated data are conducted. The results indicate values of MARE of 0.20 and 0.25 for runoff depth and peak discharge, respectively. Similarly the values of RMSE between the observed and simulated data are obtained as 2.30 mm and 0.28 m^3/s for runoff depth and peak discharge, respectively. However after parameter optimization the above mentioned error functions reduce to 0.10, 0.12, 0.75 mm and 0.09 m^3/sec in sequence. The calibrated model with optimized parameter is used for model validation. The model validation was found to be satisfactory with low values of statistical error functions.

Kaffas and Hrissanthou (2014) studied the application of a continuous rainfall-runoff model to the basin of Kosynthos River using the hydrologic software HEC-HMS. In this study, they presented the application of a continuous rainfall-runoff model to the basin of Kosynthos River (district of Xanthi, Thrace, northeastern Greece), as well as the comparison of the computational runoff results with field discharge measurements were presented. For the comparison between computed and measured discharge values, the root mean square error (RMSE), relative error, Nash-Sutcliffe efficiency coefficient and correlation coefficient R were used which gives RMSE value 0.68, relative error varies between 90.7% and 166.79%, Nash-Sutcliff efficiency coefficient 0.84 and correlation coefficient R 0.927. So it was concluded that there is a very good approximation between the computed and measured discharge values and that the deviation between these values is not considerable. So the results of the comparison between computed and measured discharge values are very satisfactory.

Reza (2014) studied the simulation of runoff using modified SCS-CN method using GIS system, case study: Klang watershed in Malaysia. This study aims to specify the results of SCS-CN loss model to estimate runoff in Klang watershed on long time daily rainfall data. The daily time-series of the 23 rainfall gauges were entered into the meteorological model to develop hydrograph at the sub-basins. Initially, the watershed was divided into homogeneous sub-basins using HEC-Geo-HMS to get the sub-basin geometric data and then, the hydrological modelling was developed in HEC-HMS for the watershed using all the parameters obtained from the previous step. Modified SCS-CN loss method was performed by changing in amount of initial abstraction ratio into 0.05 in the watershed to estimate the accuracy of calibration and validation results of hydrology model. The results revealed that initial abstraction (λ = 0.05) and $CN_{0.05}$ of daily rainfall by percent error in peak have given no significant difference results rather than initial abstraction with 0.2 value and $CN_{0.2}$, because using $CN_{0.05}$ for loss model, the simulated flows are underestimated to observed discharges equal to 23.6 and 13.49% for calibration and validation periods, respectively.

Sampath *et al.,* (2015) carried out study of continuous rainfall-runoff modelling in part of the Deduru Oya basin with intra-basin diversions and storage irrigation systems using the Hydrologic Engineering Center – Hydrologic Modeling System (HEC–HMS) version 3.0.1 to estimate runoff in the Deduru Oya river. Long term daily rainfall data at several rain gauging stations, evaporation, land use and soil data in the river basin, daily river runoff at a stream gauging station, intra-basin diversions from the river into a storage reservoir, irrigation releases from the reservoir and drainage flow returned to the river from irrigation systems were used to set up the HEC-HMS model. The results depict the capability of HEC–HMS to reproduce stream flows in the basin to a high accuracy with averaged computed Nash Sutcliffe efficiencies of 0.80. The study demonstrates potential HEC–HMS application in flow estimation from tropical catchments with intra-basin diversions and irrigation storages. The model developed is a tool for water management in the Deduru Oya river basin.

Rathod *et al.,* (2015) carried out study to estimate runoff for different rainfall events in three sub basins of Tapi River (India). Lumped continuous hydrological model is developed for the study area using HEC-HMS 3.5. In this study to account for loss, Green-Ampt method is being used. For better runoff estimation SCS unit hydrograph and Snyder Unit hydrograph methods are compared and best suitable method for the study area is chosen for the final simulation. Objective of this study is to fit the peak flow discharges and maximizing the Nash-Sutcliffe coefficient. Final results show that Nash-Sutcliffe coefficient values come out to be more than 0.8 for all three sub basins. Correlation coefficient between observed and simulated discharge is more than 0.9 for all three sub basins. Finally study concludes that HEC-HMS model can be used with reasonable approximations on Tapi River.

Ravi Babu *et al.,* (2015) applied the Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS) model to a small watershed situated in Chotanagpur plateau region of India for simulation of peak runoff rates. Initial and constant loss method and Snyder unit hydrograph were chosen for computing the precipitation losses and transforming the estimated runoff into direct surface runoff, respectively. Seven sets of observed hyetographs and corresponding flood hydrographs were used for calibration of model parameters *viz.,* initial loss, constant loss rate, Snyder peaking coefficient and standard time lag. The model output was validated with other set of flood hydrographs (five in number) of the same watershed. A simple linear relationship between predicted and observed peak flow rates was also developed. The HEC-HMS simulated depths of runoff and peak runoff rates matched reasonably well with the observed data. The average value of absolute relative error in estimated peak, a measure of goodness of fit between the peak runoff rates of predicted and observed hydrographs was found to be 6.94 %. It was concluded from the study that the HEC-HMS model with the calibrated parameters can be safely used for the determination of the depth of runoff and peak runoff rates from ungauged watersheds with similar hydrological conditions.

Bathis and Ahmed (2016) studied the rainfall-runoff modelling of Doddahalla watershed an application of HEC-HMS and SCN-CN in ungauged agricultural watershed. The Doddahalla watershed is part of Krishna basin in southern India. In this study Cartosat-1 CartoDEM (30 m) was used to delineate the subwatershed and generate the stream network by Geospatial Hydrologic Modeling Extension (HEC-GeoHMS), along with ArcHydro extension in ArcGIS 9.3. HEC-GeoHMS was also used to delineate the physical properties and create the input file in the form of sub-catchment boundaries, a meteorological model, for use in HEC-HMS. SCS curve number loss method is used to estimate the excess rainfall and surface runoff in Doddahalla watershed. The research concludes that the model stimulated result can be useful for the water and land resource planning and management practice in the Doddahalla watershed. The HEC-HMS model can be best utilized in ungauged watershed where the monitored data are limited, and runoff estimation is mandatory to sustain the water resources.

Derdour *et al.,* (2017) studied the hydrological modelling in semi-arid region using HEC-HMS model. In this study, the frequency storm was used for the meteorological model, the SCS curve number is selected to calculate the loss rate and SCS unit hydrograph method had been applied to simulate the runoff rate. After calibration and validation, the simulated peak discharges were found very closed with observed values. The Nash-Sutcliffe efficiency coefficient was 0.95 which indicated that the hydrological modelling results are satisfactory and accepted for simulation of rainfall-runoff. The peak discharges obtained for the 10, 50, 100 and 1000 years storms were 425.8m^3/s, 750.5m^3/s, 904.3m^3/s and 1328.3m^3/s respectively.

2.2 Application of SWAT for estimation of Runoff Modelling:

Jain *et al.* (2010) studied simulation of runoff and sediment yield for a Himalayan watershed using SWAT Model. The Soil and Water Assessment Tool (SWAT) having an interface with ArcView GIS software (AVSWAT2000/X) was selected for the estimation of runoff. The model was calibrated for the years 1993 and 1994 and validated with the observed runoff and sediment yield for the years 1995, 1996 and 1997. The performance of the model was evaluated using statistical and graphical methods to assess the capability of the model in simulating the run-off and sediment yield from the study area. The coefficient of determination (R^2) for the daily and monthly runoff was obtained as 0.53 and 0.90 respectively for the calibration period and 0.33 and 0.62 respectively for the validation period.

Reshma *et al.,* (2012) studied the simulation of sub-daily runoff for an indian watershed using swat model. In This study ArcSWAT model is used in simulation of sub-daily runoff of Harsul watershed located in Nashik district, Maharashtra, India. Hourly rainfall data, Land Use (LU)/Land Cover (LC), Soil data and Digital Elevation Model (DEM) data of the watershed has been used to simulate the runoff of the watershed. The model has been applied for the three month's rainfall data. From the simulations, it is observed that, the model is able to simulate the volume of runoff and time to peak runoff. But large variations are observed in peak runoff. This may be because of inexactness in the values of parameters. It is also observed that sensitivity analysis has to be carried out to improve the simulation results.

Narasayya *et al.,* (2013) studied the prediction of storm-runoff using physically based hydrological model for burhanpur watershed, India. The model consists of a Rainfall–Runoff model (ArcSWAT) that converts precipitation excess to overland flow and channel runoff. Whatever the mechanism placed in estimation of runoff, water balance is the primary force governing the equations. Soil Conservation Services-Curve Number (SCS-CN) method is the governing equation for estimation of infiltration characteristics of the catchment, based on land use and soil properties. The watershed parameters are developed using spatial and non-spatial data as input for the model to predict a good simulation of Rainfall-Runoff for 21 sub-basins. The simulation gives a moderate results of an average of 75% is predicted when compared to observed runoff at outlet point of Burhanpur watershed.

Shivhare *et al.,* (2014) studied simulation of surface runoff for upper Tapi sub-catchment area (Burhanpur watershed) using SWAT. In the study, Tapi subcatchment area (Burhanpur watershed) located in inter-state basin of Madhya Pradesh and Maharashtra, India, is selected for the estimation of surface runoff using SWAT model.

The SWAT works in conjunction with ArcGIS 9.3. Various parameters Digital Elevation Model (DEM), slope derived from DEM, Landuse/Landcover (LULC) and NBSSLUP soil data and temporal data for temperature and precipitation was used as input for the model to predict runoff at the catchment outlet. The model was run from the year 1992 to 1997. The performance of the model in terms of simulated runoff was evaluated using statistical method and compared simulated monthly flow with the observed monthly flow values from 1992 to 1996 to a significant extent. The coefficient of determination (R2) for the monthly runoff values for 1992 to 1996 was observed to be 0.82, 0.68, 0.92, 0.69.

Swami *et al.,* (2015) studied the simulation of runoff and sediment yield for a kaneri watershed using swat model. The Soil and Water Assessment Tool (SWAT) having an interface with Arc-View GIS software (ArcGIS 10.1 with Arc SWAT 2012 extension) was selected for the estimation of runoff and sediment yield from Kaneri watershed, located in Western Maharashtra region. The coefficient of determination (R^2) for the monthly and yearly runoff was obtained as 0.849 and 0.951 respectively for the calibration period 1979 to 2000 and 0.801 and 0.950 respectively for the validation period 2001-2013. The R^2 value in estimating the monthly and yearly sediment yield during calibration period was computed as 0.722 and 0.788 respectively. The R^2 for monthly and yearly sediment yield values for validation period was observed to be 0.565 and 0.684 respectively.

Sai Srinivas *et al., (*2016) studied simulation of runoff for an experimental watershed using SWAT. In this study, Soil Water Assessment Tool (ArcSWAT) an extension tool has been used to simulate runoff process in Walnut Gulch watershed located in Arizona, USA over sub hourly base. For computing infiltration, excess rainfall conversion to runoff and flow routing, methods like Green and Ampt method are adopted and the sensitive parameters that influence the model are identified. The model has been calibrated and validated for the five rainfall events. From the results obtained, we can assume that the ArcSWAT model has performed satisfactorily for the runoff simulations for differed rainfall events**.**

Mahzari *et al., (*2016) studied using swat model to determine runoff, sediment yield and nitrate loss in Gorganrood watershed, Iran. The adequacy of the SWAT model in the estimation of runoff, sediment yield and nitrate loss in the Gorganrood watershed was tested, using the existing spatial database as the primary data. The model was then executed for a 31-years' time period. In combination with the SWAT model, the Sequential Uncertainty Fitting Program (SWAT-CUP and SUFI-2) was added used to calibrate and validate a hydrologic model of the watershed. The obtained values at 14 stations were between 0.48 to 0.83 for NS and 0.58 to 0.90 for R^2, respectively. The results showed that nitrate loss was higher in cultivated lands, and in the loess deposits. The maximum amounts of runoff and sediment yield were largely produced in steep areas of the watershed, where dry farming was practiced. In general, the results showed that SWAT could be a proper tool for simulating runoff, sediment yield and nitrate loss into the river.

Kangsabanik and Murmu (2017) studied the rainfall-runoff modelling of Ajay river catchment using SWAT model. In this study the catchment area had been delineated using the DEM (Digital Elevation Model) and then divided into 19 sub-basins. IRS-P6 LISS-III images were used for preparation of land use map and the soil map is extracted from HWSD (Harmonized World Soil Database) raster world soil map. The sub-basins were further divided into 223 HRUs which stands for Hydrological Response Unit. Then by using 30 years of daily rainfall data and daily maximum and minimum temperature data SWAT simulation is done for daily, monthly and yearly basis to find out runoff for corresponding rainfall. The result showed that, the coefficient of correlation (r) for rainfall in a period and the corresponding runoff is found to be 0.9419.

Emam *et al., (*2017) studied the hydrological modelling and runoff mitigation in an ungauged basin of central Vietnam using swat model. In this study, a multi-approach technique was used to calibrate the hydrological model. The model was calibrated in three time scales: daily, monthly and yearly by river discharge, actual evapotranspiration (ETa) and crop yield, respectively. The model was calibrated with Nash-Sutcliffe and R^2 coefficients greater than 0.7, in daily and monthly scales, respectively. The outcomes showed that the highest mean monthly surface runoff, 323 to 369 mm, between September and November, resulted in extreme soil erosion and sedimentation. The monthly average of actual evapotranspiration was the highest in May and lowest in December. Furthermore, installing "Best Management Practices" (BMPs) reduced surface runoff in agricultural lands.

Worku *et al.,* (2017) carried out study on modelling runoff–sediment response to land use/land cover changes using integrated GIS and SWAT model in the Beressa watershed. In this study input data like LU/LC, weather and soil data features are used to undertake watershed simulation. The model had been calibrated and validated in SWAT-CUP. The data from 1980 to 1999 were used for calibration, while the data from 2000 to 2014 were used for validation. LU/LC analysis showed that agricultural and settlement areas had increased between 1984 and 2015, while barren, grazing land and forest area had decreased. However, the share of forest cover increased in between 1999 and 2015. SWAT model successfully simulated and calibrated runoff and sediment yield. During calibration periods (1980–1999), the values of R^2, NSE, RSR and PBIAS were obtained as 0.72, 0.67, 0.52 and 3.9%, respectively, whereas during the validation periods (2000–2014) the values were 0.68, 0.64, 0.56 and 7.6%, respectively. Runoff and sediment yield has significantly increased. Thus, it was concluded that the change in LU/LC significantly influenced the runoff and sediment yield.

Byakod *et al.,* (2017) studied the application of SWAT model for generating surface runoff and estimation of water availability for Balehonnuru catchment area for Badhra river basin. In this study, the soil and water assessment tool (SWAT) used for simulation of rainfall runoff and estimation of water availability in Balehonnuru catchment of area 800sqkm. Various parameters such as digital elevation models (DEM), land use land cover, soil data and temporal data for temperature and precipitation data were used as input for the model to predict the runoff at catchment outlet. The performance of model is evaluated using statistical methods. The R^2 and NSE values for period used for calibration were 0.878 and 0.78 and for the validation period were 0.869 and 0.75 respectively.

2.3 Comparative study of SWAT and HEC-HMS

Jordi Pascual-Ferrer *et al.,* (2013) carried out study of the Ethiopian Central Rift Valley basin hydrologic modelling using HEC-HMS and ArcSWAT. An Integrated Water Resources Management (IWRM) shall be applied to achieve a sustainable development, to increase population incomes without affecting lives of those who are highly dependent on the environment. First step should be to understand water dynamics at basin level, starting by modeling the basin water resources. For model implementation, a large number of data and parameters are required, but those are not always available, especially in some developing countries where different sources may have different data, there is lack of information on data collection, etc. The Ethiopian Central Rift Valley (CRV) is an endorheic basin covering an area of approximately 10,000 km^2. For the period 1996-2005, the average annual volume of rainfall accounted for 9.1 Mm^3, and evapotranspiration for 8 Mm^3 (Jansen *et al.,* 2007). In order to reduce uncertainty of numerical simulation, two semi-distributed open software hydrologic models were implemented: HEC-HMS and ArcSWAT. According to this, ArcSWAT would be the best option for IWRM (Integrated Water Resources Management) implementation in the basin. However, considering data uncertainty and model complexity a previous hydrologic assessment of the basin based in HEC-HMS simulation is advisable. As a first approach HEC-HMS was implemented for basin modeling in order to get physical parameters of interest, results from HEC-HMS calibration were used to setup the accuracy of the ArcSWAT numerical modelling.

Dao Nguyen Khoi (2015) studied the comparison of the HEC-HMS and SWAT hydrological models in simulating the stream flow in the Srepok River Catchment. In this study, the stream flow was simulated using HEC-HMS and SWAT hydrological models. Calibration and validation of the two models were conducted by using the observed stream flow at the Ban Don station in the period 1981-2009. The results of calibration and validation suggest that both models could simulate fairly well the stream flow for the study area. The HEC-HMS gave the model performance with the NSE > 0.62 and R^2 > 0.65; and the SWAT model provided the model performance with the NSE > 0.72 and R^2 > 0.80 for the calibration and validation periods. In general, the simulated stream flow given by the SWAT model is more satisfactory than that provided by the HEC-HMS model.

III. MATERIALS AND METHODS

This chapter deals with the study area and its location, meteorological, hydrological and remote sensing data acquisition as well as procedures used for data processing is presented, software's and systems used for research work. Procedures used for generation of different thematic layers for simulation of both HEC-HMS and SWAT model using GIS are discussed. Detailed procedures for preparation of land use/land cover maps using satellite data are described. Methodologies for generation of input parameters for both HEC-HMS and SWAT model are described. Statistical parameters such as R^2, NSE, PBIAS, RMSE and RSR are described for evaluation of result of prediction of surface runoff from both HEC-HMS and SWAT models.

3.1 Study Area:

The study area selected was Kal river of Konkan region in Maharashtra. The Kal river is tributary of Savitri river and is the west flowing river in Maharashtra. This is a major tributary of the river Savitri. The Kal basin lies between North latitudes of $17^0$51' to $18^0$20' and East longitudes of $73^0$22' to $73^0$41' (Gharde *et.al*,2015). It originates from Sahyadri hill ranges in the Raigad district of Maharashtra. The total length of this West Flowing River from its origin to its confluence with the Savitri River is 36 km. The Kal river comprises catchments area 340 Sq. Km and hydrologic and meteorological station located at Birwadi.

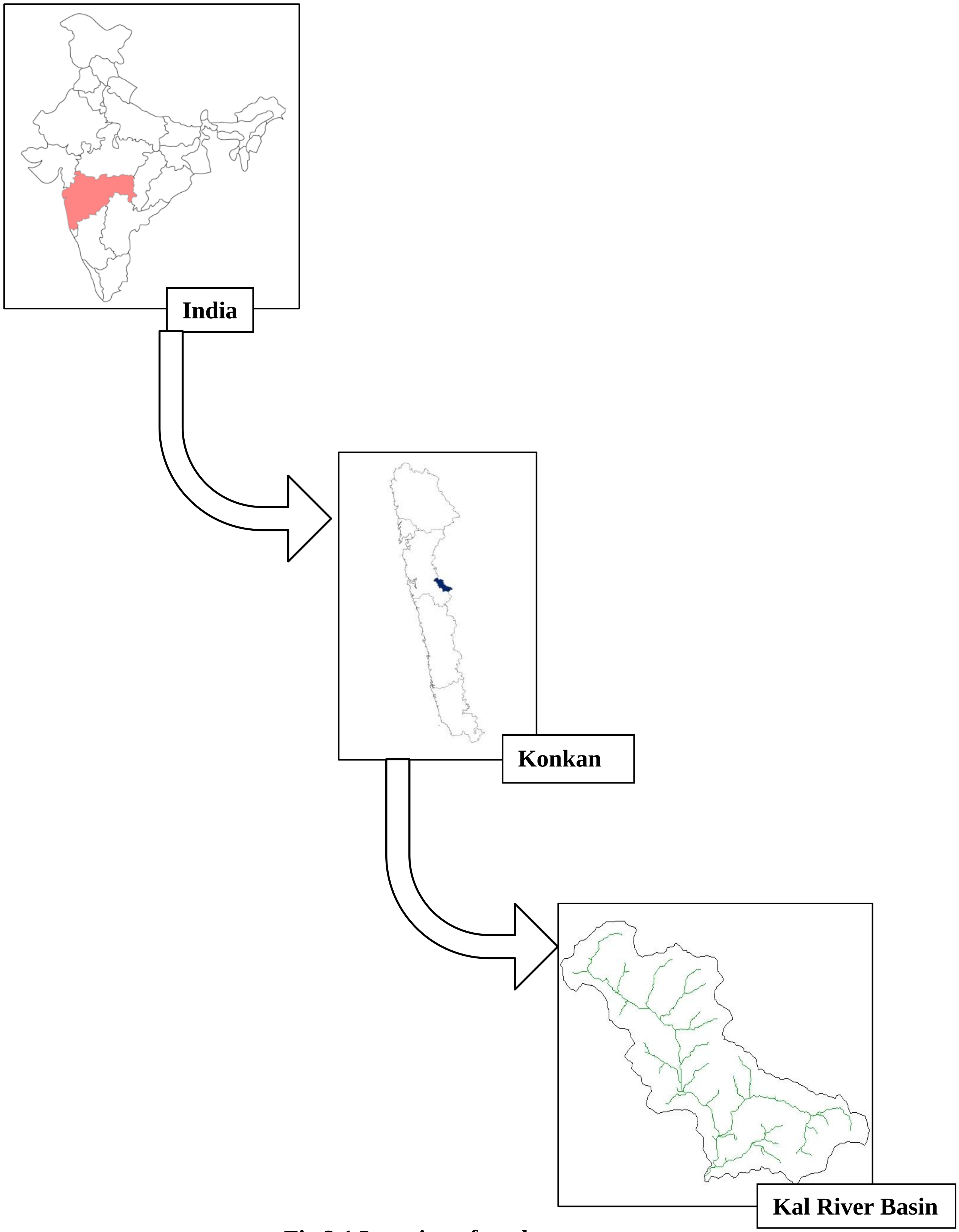


Fig 3.1 Location of study area

3.2 Data required and collected:

The following section presents the data used to run HEC-HMS and SWAT model for the Kal river catchment.

1. Daily hydro-meteorological data i.e. daily rainfall (mm), minimum and maximum daily temperature (^{o}c), relative humidity, wind speed and discharge (m^3/sec) etc. data were collected from Hydrologic project, Water Resource Department, Nashik for period of 1991-2011 of Birwadi station.
2. The soil map with different soil properties such as texture, hydraulic conductivity, bulk density, organic carbon, percentage of sand, silt, clay etc. of Kal river basin were collected from NBSS&LUP Nagpur.
3. Digital Elevation Model (DEM) of the study area was prepared using AsterDEM data (https://earthexplorer.usgs.gov/).
4. Landsat-8 Satellite images used for preparation of land use land cover map for HEC-HMS and SWAT model were downloaded from (https://earthexplorer.usgs.gov/).

3.3 Software and System required

Arcs-GIS 10.3, HEC-GeoHMS 10.2, HEC-HMS 4.2.1, ArcSWAT 2012.10.3.19 and MS-Office suit were used for data creation, data analysis and output generation. Arc-GIS is advanced tool used for mapping, geographic analysis, spatial analysis, hydrology, overlay analysis, data editing etc. HEC-GeoHMS is a GIS extension that provides the user with a set of procedures, tools, and utilities for the preparation of GIS data for import into HEC-HMS and generation of GIS data from HMS output. ArcSWAT is an ArcGIS-ArcView extension and graphical user input interface for SWAT. MS-Office was used for documentation and analysis purpose.

3.4 Watershed delineation

Watershed delineation plays an important role in watershed management. Watershed delineation was performed in ArcGIS 10.3. AsterDEM data was used for watershed delineation. The shape file generated through watershed delineation of the study area is used for clip satellite images for further processing. Flowchart for the watershed delineation is presented in Fig 3.2.

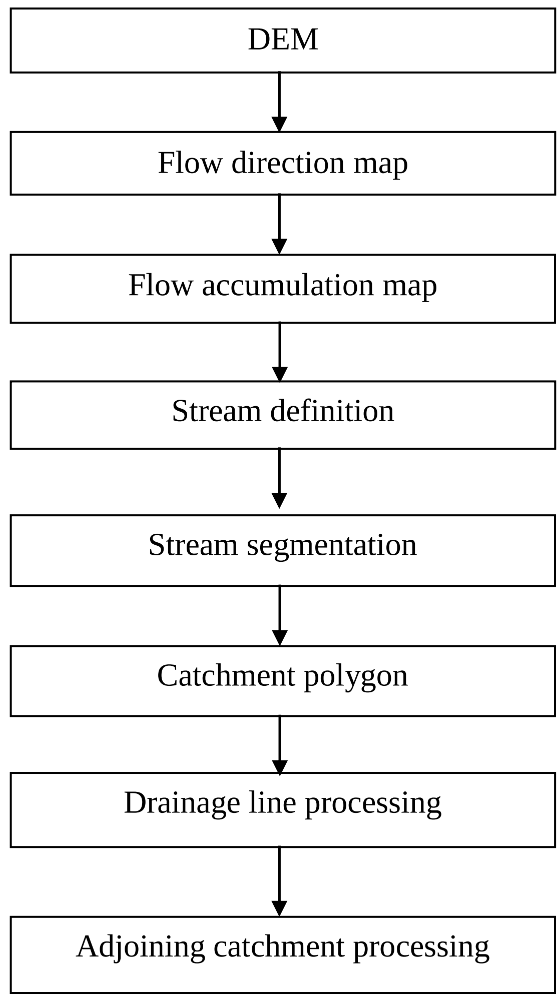


Fig 3.2 Flowchart for the watershed delineation

3.5 Preparation of land use/ Land cover map for both HEC-HMS and SWAT model

Land use land cover plays a major role in the study of watershed as it provides the present status of land utilization and its pattern. Land is scarce resource due to immense agricultural and demographic pressure. Land use is refers to man's activities and the various uses which are carried on land where Land cover is refers to natural vegetation, water bodies, rock/soil, artificial cover and others resulting due to land transformations. The study of land use/land cover is very important for utilization and proper planning of natural resources and their management. Thematic mapping of the different land use/ land cover classes were achieved through supervised classification in ArcGis 10.3. The raster file of classification generated in ArcGis10.3 was used as input for the both the HEC-HMS and SWAT model. Supervised classification is an interactive approach in which the operator classifies an area or group of pixels that belong to one or more categories of specific land use/land cover (LU/LC). Flowchart for the generation of LU/LC map is presented in Fig 3.3

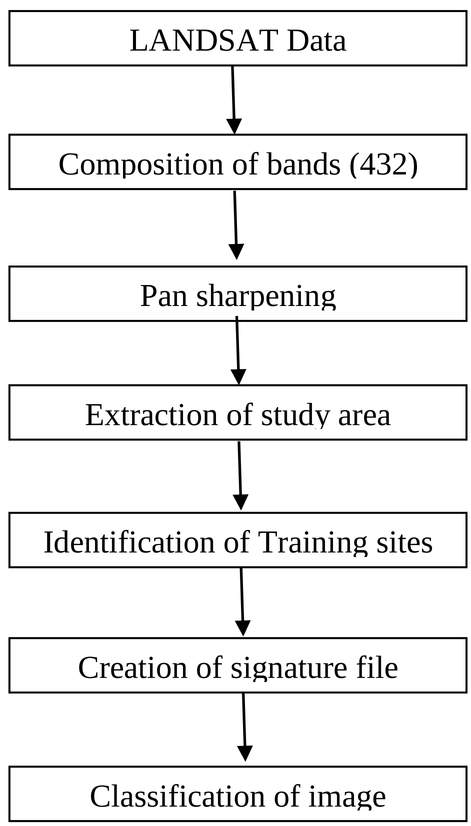


Fig 3.3 Flowchart for the preparation of LU/LC map

The land use and land cover characteristics of the study area was described using land use/land cover (LU/LC) maps. Both the models required land use/land cover map as input parameter. The LU/LC in the Kal river basin area was classified into five classes: (i) Water bodies (ii) Barren (iii) Forest (iv) Agriculture and (v) Settlement. The land use and land cover classes of kal river basin are shown in table 3.1 and land use and land cover map shown in fig 3.4.

Table 3.1 Area coverage under different land coverage

Sr. No.	**Land Use/Land Cover**	**Area (Sq. km)**
1.	Water bodies	2.652
2.	Barren	82.552
3.	Forest	136.238
4.	Agriculture	116.076
5.	Settlement	2.414
	Total	**340**

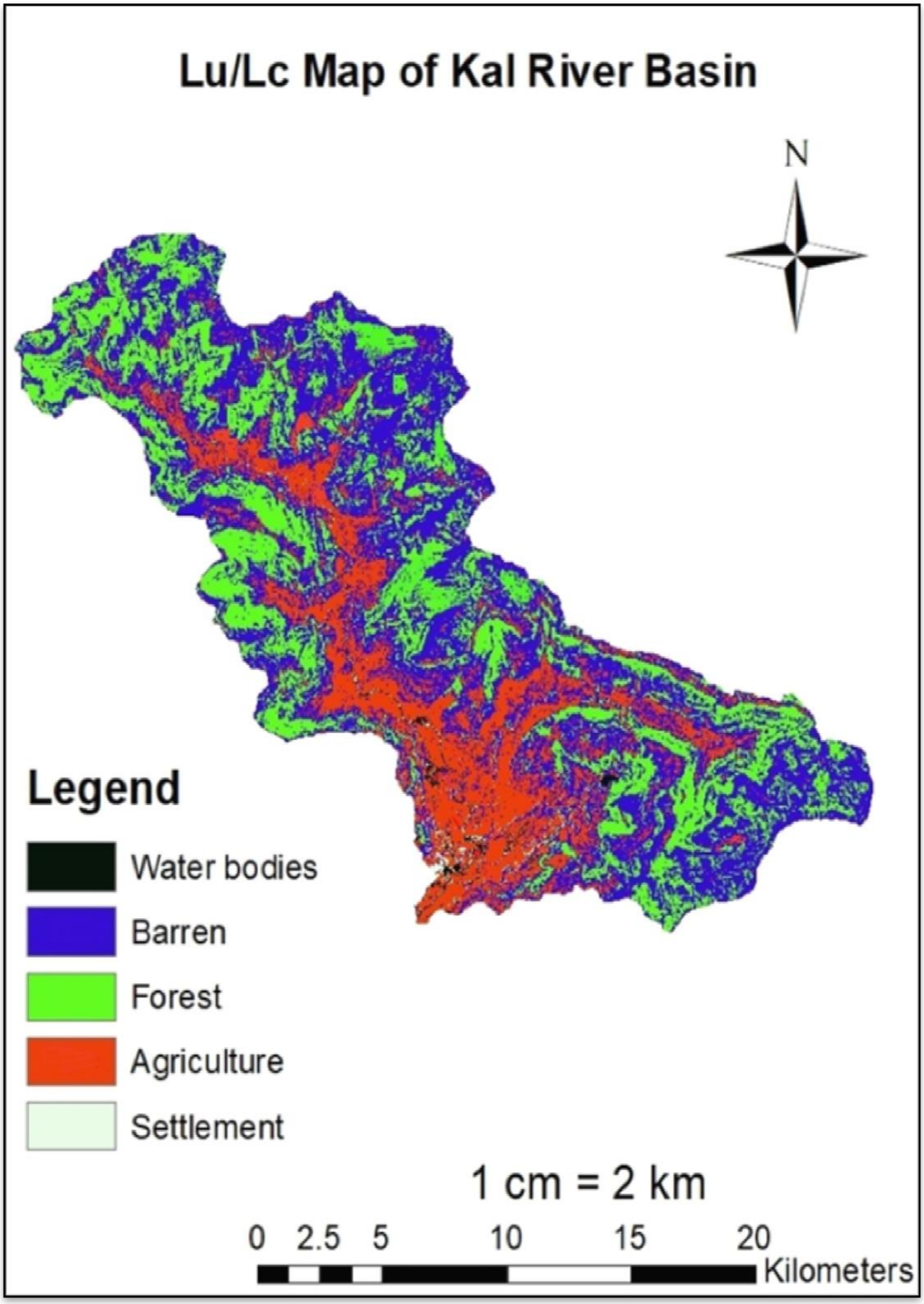


Fig 3.4 Land use/Land cover map of Kal river basin

3.6 Soil map

The soil map is required for the both the HEC-HMS and SWAT model. HEC-HMS requires soil hydrology groups for generation of curve no. grid as input parameter whereas soils data used by SWAT can be divided into two groups, physical characteristics and chemical characteristics. The hydrological soil group and soil characteristics are assigned for the particular Soil ID. Soil map of Kal river basin is shown in fig 3.5.

The soils data used by SWAT can be divided into two groups, physical characteristics and chemical characteristics. The physical properties of the soil govern the movement of water and air through the profile and have a major impact on the cycling of water within the HRU. While the physical properties are required, information on chemical properties is optional. The soil input file defines the physical properties for all layers in the soil. Following is a brief description of the variables in the soil input file for SWAT model.

(a) SNAM (Soil name)

-The soil name is printed in HRU summary tables.

(b) HYDGRP (Soil hydrologic group A, B, C, or D)

-The U.S. Natural Resource Conservation Service (NRCS) classifies soils into four hydrologic groups based on infiltration characteristics of the soils. NRCS Soil Survey Staff (1996) defines a hydrologic group as a group of soils having similar runoff potential under similar storm and cover conditions.

(c) SOL_ZMX (Maximum rooting depth of soil profile, mm)

-If no depth is specified, the model assumes the roots can develop throughout the entire depth of the soil profile.

(d) ANION_EXCL (Fraction of porosity (void space) from which anions are excluded)

-Most soil minerals are negatively charged at normal pH and the net interaction with anions such as nitrate is repulsion from particle surfaces. This repulsion is termed negative adsorption or anion exclusion.

(e) SOL_CRK (Potential or maximum crack volume of the soil profile expressed as a fraction of the total soil volume)

-To accurately predict surface runoff and infiltration in areas dominated by vertisols, the temporal change in soil volume must be quantified.

(f) TEXTURE (Texture of soil layer)

-This data is not processed by the model and the line may be left blank.

(g) SOL_Z (Depth from soil surface to bottom of layer in mm)

(h) SOL_BD (Moist bulk density, Mg/m^3 or g/cm^3)

-The soil bulk density expresses the ratio of the mass of solid particles to total volume of the soil. In moist bulk density determinations, the mass of the soil is the oven dry weight and the total volume of the soil is determined when the soil is at or near field capacity. Bulk density values should fall between 1.1 and 1.9 Mg/m^3.

(i) SOL_AWC (Available water capacity of the soil layer, mm H_2O/mm soil)

-The plant available water, also referred to as the available water capacity, is calculated by subtracting the fraction of water present at permanent wilting point from that present at field capacity, $AWC = FC - WP$ where *AWC* is the plant available water content, *FC* is the water content at field capacity, and *WP* is the water content at permanent wilting point.

(j) SOL_K (Saturated hydraulic conductivity, mm/hr)

-The saturated hydraulic conductivity, K_{sat}, relates soil water flow rate (flux density) to the hydraulic gradient and is a measure of the ease of water movement through the soil. K_{sat} is the reciprocal of the resistance of the soil matrix to water flow.

(k) SOL_CBN (Organic carbon content, % soil weight)

(l) SOL_CLAY (Clay content, % soil weight)

-The percentage of soil particles which have equivalent diameter is less than 0.002 mm.

(m)SOL_SILT (Silt content % soil weight)

-The percentage of soil particles which have an equivalent diameter between 0.05 and 0.002 mm.

(n) SOL_SAND (Sand content, % soil weight)

-The percentage of soil particles which have a diameter between 2.0 and 0.05 mm.

(o) SOL_ROCK (Rock fragment content, % total weight)

-The percent of the sample which has a particle diameter of less than 2 mm.

(p) SOL_ALB (Moist soil albedo)

-The ratio of the amount of solar radiation reflected by a body to the amount incident upon it, expressed as a fraction. The value for albedo should be reported when the soil is at or near field capacity.

(q) USLE_K (USLE equation soil erodibility (K) factor)

-The USLE equations K factor soil.

(r) SOL_EC (Electrical conductivity, dS/m)

(s) SOL_CAL (Soil CaCo3 (%), (0 – 50%)

(t) SOL_PH (Soil Ph (3-10)

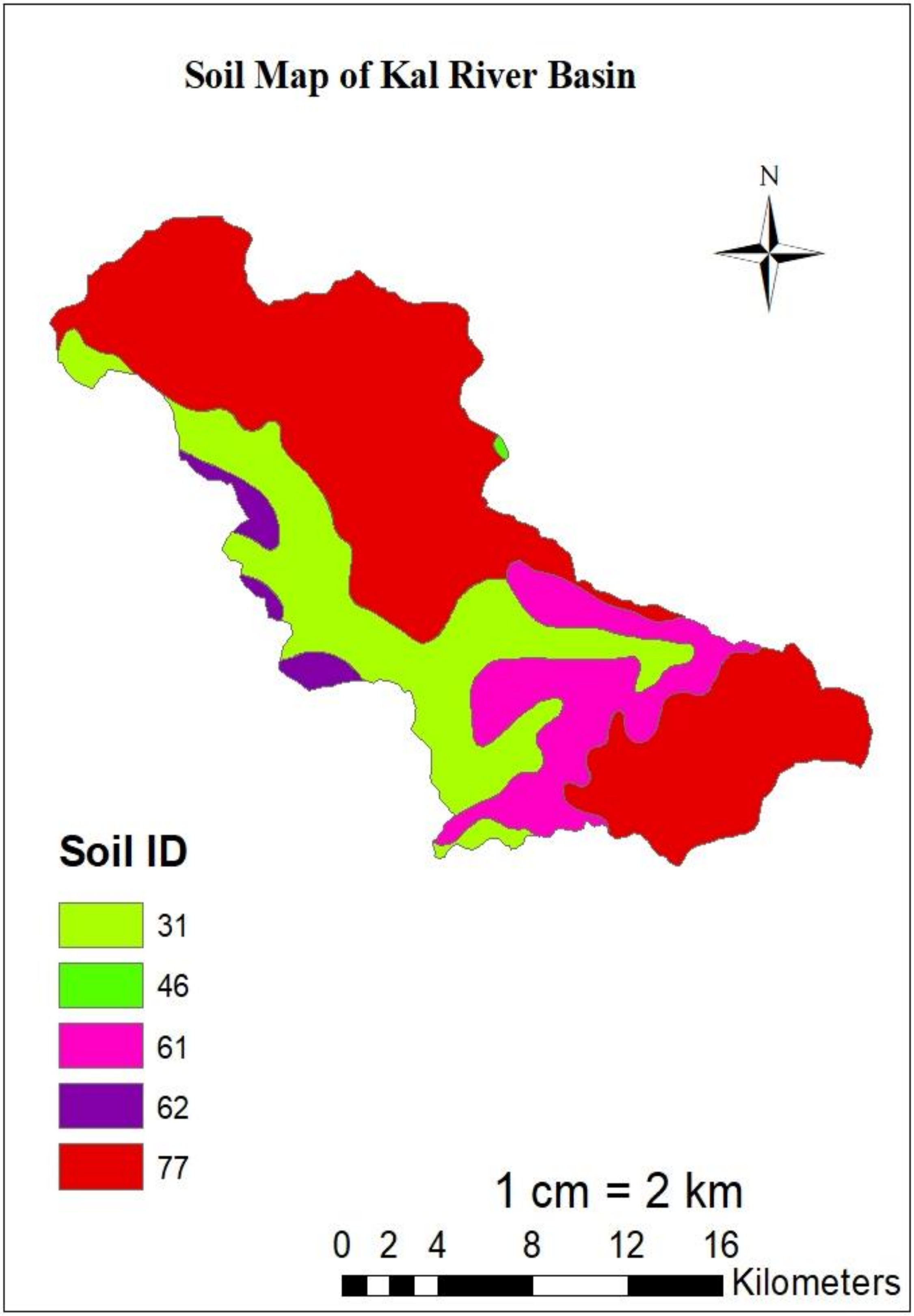


Fig 3.5 Soil Map of Kal river basin

3.7 HEC-HMS Model

The Hydrologic Modelling System (HEC-HMS), developed by US Army Corps of Engineers Hydrologic Engineering Center, is designed for both continuous and event-based hydrologic modeling. It provides different options to the users for modelling various components of hydrologic cycle. Initially it was developed to simulate the precipitation-runoff processes of dendritic watershed systems but later it was improved to solve widest possible range of problems including large river basin water supply, flood hydrographs, and small urban or natural watershed runoff (USACE, 2010). For watershed modelling, the HEC-HMS model contains four components: (I) Basin model, (II) Meteorological model, (III) Control specification, and (IV) Input data. All the watershed physical descriptions are accomplished through the basin component which contains elements of the basin. Meteorological model contains the rainfall, evapotranspiration and snowmelt data. All the meteorological data analysis, for example, precipitation required by a sub-basin element is performed using this meteorological model component. Control specification contains start/stop timing and calculation intervals for the run. (Singh and Pandey, 2013)

3.7.1 HEC-GeoHMS Model

The Geospatial Hydrologic Modelling Extension (HEC-GeoHMS) has been developed in year 2000 by Hydrologic Engineering Centre (HEC), California, USA, as a geospatial hydrology toolkit for engineers and hydrologists with limited GIS experience. HEC-GeoHMS uses ArcView and the Spatial Analyst extension to visualize spatial information, document watershed characteristics, perform spatial analysis, and delineate sub basins, streams and develop a number of hydrologic modelling inputs for the HEC-HMS. The following steps describe the major steps in starting a HEC-HMS project and taking it through the HEC-GeoHMS process.

3.7.1.1 Terrain Preprocessing

Using the terrain data as input, terrain pre-processing is a series of steps to derive the drainage network. The steps consist Fill sinks, Flow direction, Flow accumulation, Stream definition, Stream segmentation, Catchment grid delineation, Catchment polygon processing, Drainage line processing, Adjoint catchment processing, Drainage point processing etc.

(a) Fill DEM: The Fill DEM is created by filling the depressions or pits by increasing the elevation of the pit cells to the level of the surrounding terrain. The pits are often considered as errors in the DEM due to re-sampling and interpolating the grid. (Fig. 3.6)

(b) Flow Direction: Flow direction map generated using Hydro DEM as input data, which defines the direction of the steepest descent for each terrain cell. (Fig. 3.7)

(c) Flow Accumulation: Flow accumulation map determines the number of upstream cells draining to a given cell, using flow direction data as input. (Fig. 3.8)

(d) Stream Definition: This step classifies all cells with a flow accumulation greater than the user-defined threshold as cells belonging to the stream network. (Fig. 3.9)

(e) Stream Segmentation: Flow direction and stream grids are used to divide the stream grid into segments. Streams segments, or links, are the sections of a stream that connect two successive junctions, a junction and an outlet, or a junction and the drainage divide.

(f) Catchment Grid Delineation: The watershed is delineated in sub-basins for every stream segment using flow direction and stream link grids. (Fig. 3.10)

(g) Catchment Polygon Processing: A vector layer (polygon sub-basin layer) of sub-basin is created using the catchment grid. (Fig. 3.11)

(h) Drainage Line Processing: A vector stream layer is generated using stream link and flow direction grid.

(i) Adjoint Catchment Processing: This step aggregates the upstream subbasins at every stream confluence. This is a required step and is performed to improve computational performance for interactively delineating subbasins and to enhance data extraction when defining a HEC-GeoHMS project.

(j) Drainage Point Processing: This function allows generating the drainage points associated to the catchments.

(k) Slope: This function allows generating a slope grid in percent or degree for a given DEM. (Fig. 3.12)

Terrain preprocessing maps of Kal river Basin are shown below from fig 3.3 to 3.9

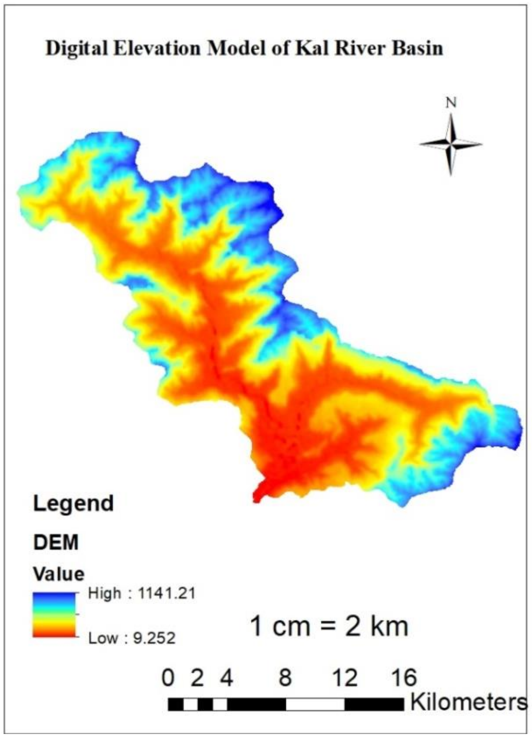


Fig 3.6 Digital Elevation Model of Kal river basin

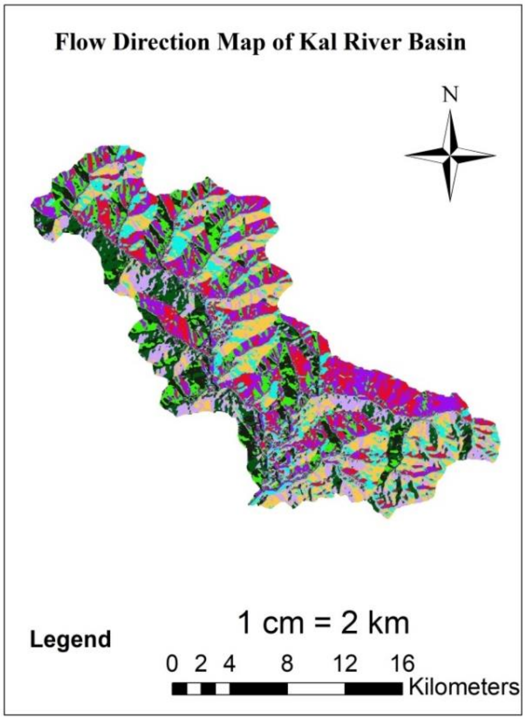


Fig 3.7 Flow direction map of Kal river basin

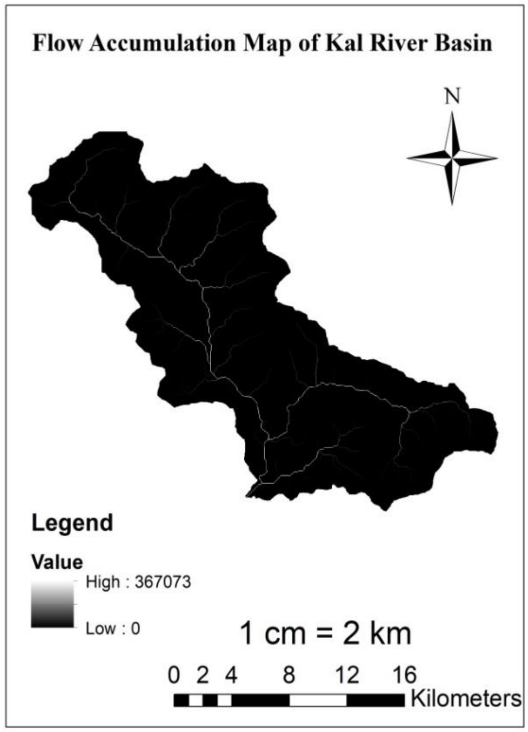


Fig 3.8 Flow accumulation map of Kal river basin

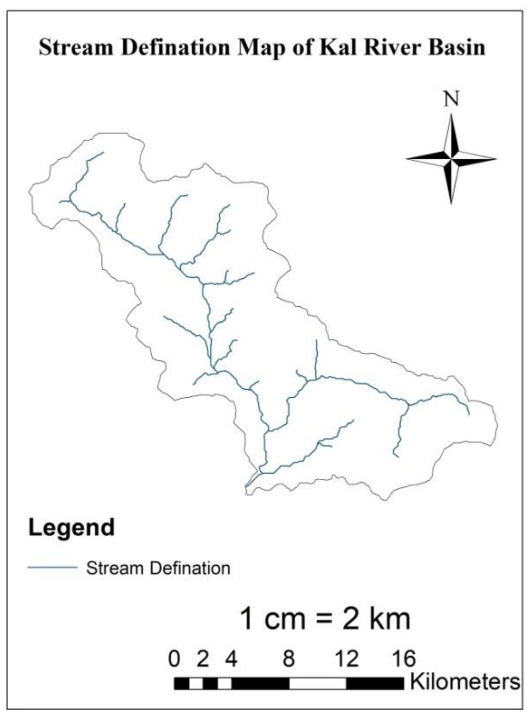


Fig 3.9 Stream defination map of Kal river basin

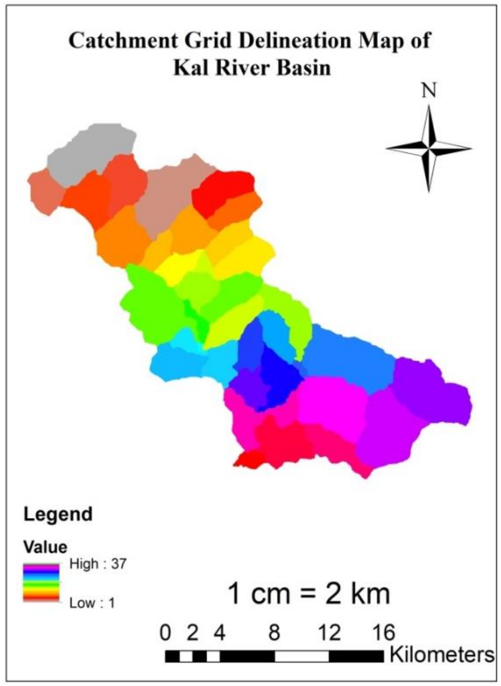


Fig 3.10 Catchment grid delineation map of Kal river basin

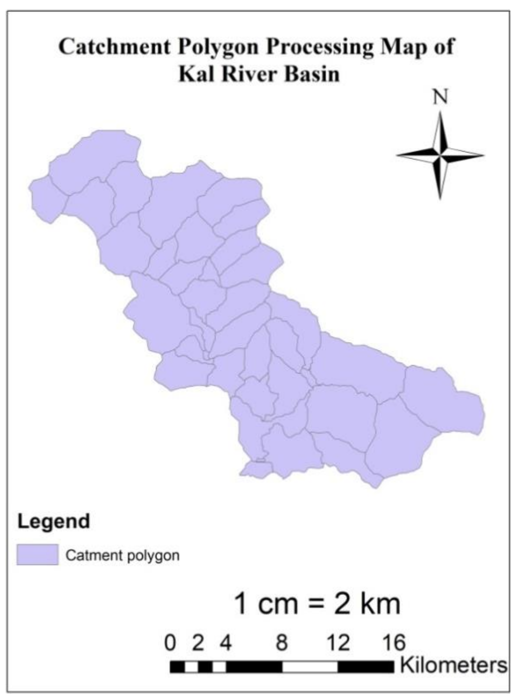


Fig 3.11 Catchment polygon processing map of Kal river basin

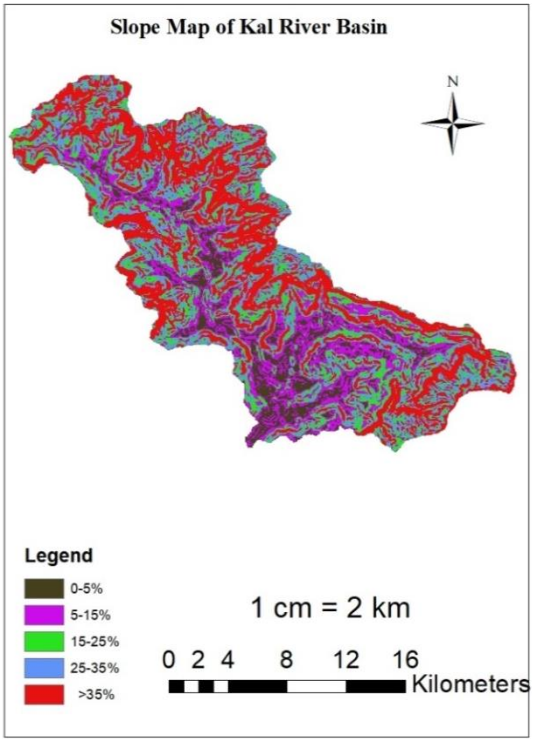


Fig 3.12 Slope map of Kal river basin

3.7.1.2 Project Setup

Next step is the definition of a project point. This point is situated at the downstream end of the Kal River Basin. After defining the downstream outlet, a tool named Generate Project is applied, and the area upstream the outlet is defined. Necessary data for the drainage area are extracted from the Terrain Pre-processing and a Project for the study area is created. After the terrain preprocessing is completed and a new project has been created.

3.7.1.3 Basin Processing

After the terrain preprocessing is completed and a new project has been created, the basin processing menu can be used to revise the sub-basin delineations. Basin processing includes Basin Merge, Basin Subdivision, Subbasin Divide by Maximum Area, River Merge, River Profile, Split Basins at Confluences, Batch Subbasin Delineation, etc.

3.7.1.4 Stream and Subbasin Characteristics

When the delineation has been finalized, physical characteristics for a stream line such as length, upstream and downstream elevations, and slope were extracted from the terrain data and similarly, physical characteristics for a sub-basin, such as longest flow length, centroidal flow lengths, and slopes were extracted from the terrain data.

(i) River Length: River length was computed using river layer for selected or all routing reaches in the river layer.

(ii) River Slope: Upstream and downstream elevation and slope of a river was computed using RawDEM and River layer as input data.

(iii) Basin Slope: Average basin slope in the watershed was computed using sub-basin and slope grid. Basin slope was used for the computation of the CN Lag time parameter.

(iv) Longest Flow Path: A number of physical characteristics such as the longest flow length, upstream/downstream elevation and slope between endpoints were computed using RawDEM, flow direction grid and sub-basin.

(v) Basin Centroid: Basin centroid was identified for each sub-basin. There are three algorithm Center of gravity method, longest flow path method and 50% area method.

(vi) Basin Centroid Elevation: Elevation for each centroid point was calculated using RawDEM.

(vii) Centroidal Flow Path: Centroidal flow path was calculated using sub-basin, centroid and longest flow path. It is measured from the projected point on the longest flow path to the sub-basin outlet.

3.7.1.5 Hydrologic Parameters

After the physical characterises of streams and sub-basins, hydrologic parameters were defined such as HMS process, river auto name, basin auto name, time of concentration, CN Lag method, etc.

3.7.1.6 Develop HEC-HMS Model Files:

HEC-GeoHMS produces a number of files which can be used directly by HEC-HMS. These files include background shape files, the basin model file, the meteorological model file and a project file.

(i) Map to HMS Units: Physical characteristics of RawDEM, Sub-basin, Longest flow path, centroidal longest flow path, river and centroid are converted to English or International System (SI) units.

(ii) HMS Data Check: The program keeps track of the relationship between the stream segments, subbasins, and outlet points. These checks are necessary because the relationships between hydrologic elements may have been broken by unintentional use of subdivide and merge tools.

(iii) HEC-HMS Basin Schematic: The HMS basin schematic is the GIS representation of the HEC-HMS model. This tool builds a simple hydrologic network of model elements and shows their connectivity.

(iv) HMS Legend: Point and line features in the HMS Node and HMS Link layers are represented in HEC-HMS element icons.

(v) Add Coordinates: Geographic coordinates are attached to features in the HMS Node and HMS Link layers using Raw DEM. The coordinates are added to attribute tables.

(vi) Prepare Data for Model Export: Basin model file is exported with hydrologic elements, their connectivity, and related parameters using sub-basin and river layers.

(vii) Background Map File: Background map layers capture the geographic information of the sub-basin boundaries and stream reaches in ASCII text file or shape file format.

(viii) Basin File: The basin model captures the hydrologic elements, their connectivity, and related geographic information in ASCII text file that can be loaded into an HEC-HMS project.

(ix) Meteorological Model: The Precipitation Model is a set of information required to define historical precipitation used in conjunction with a basin model.

(x) Create HEC-HMS Project: The Create HEC-HMS Project tool creates a subdirectory and copies all HEC-HMS project files that were created by HEC-GeoHMS to subdirectory. This includes the basin, meteorological, gage, grid cell, and background map files. It also creates the .HMS file that contains the HEC-HMS project information

3.7.2 HEC-HMS Model Set-up

The HEC-HMS model provides a variety of options for simulating precipitation-runoff processes. The hydrologic elements are arranged in a dendritic network, and computations are performed in an upstream-to-downstream sequence. Computations are performed in SI units.

3.7.2.1 SCS Curve Number (CN) Method

It is simple, predictable and stable method used for estimating precipitation excess as a function of cumulative precipitation, soil cover, land use, and antecedent moisture. This method is based on the potential maximum retention (S) of the watershed, which is determined by wetness of the watershed i.e. the Antecedent Moisture Condition and physical characteristics of the watershed.

The Soil Conservation Service (Soil Conservation Service 1964; 1972) for conditions prevailing in the United States originally developed the curve number method. Since then, it has been adapted to conditions in other parts of the world. Runoff depth was computed using following equation;

$$Q = \frac{(P - 0.3S)^2}{P + 0.7S}$$

.... .3.1

Where,

Q = Runoff, mm

P = Rainfall, mm

S = Potential maximum retention (ability of a watershed to abstract and retain storm precipitation).

The maximum potential retention (S) and watershed characteristics are related through an intermediate parameter, called curve number (CN). It is an index that represents the combination of hydrological soil group, land treatment classes, and antecedent moisture conditions and is expressed as:

$$S = \frac{25400}{CN} - 254$$ ………….......3.2

CN has a range of $100 \geq CN \geq 0$.

CN = 100 represents a condition of zero potential retention and CN = 0 represents an infinitely abstracting catchment with $S = \infty$.

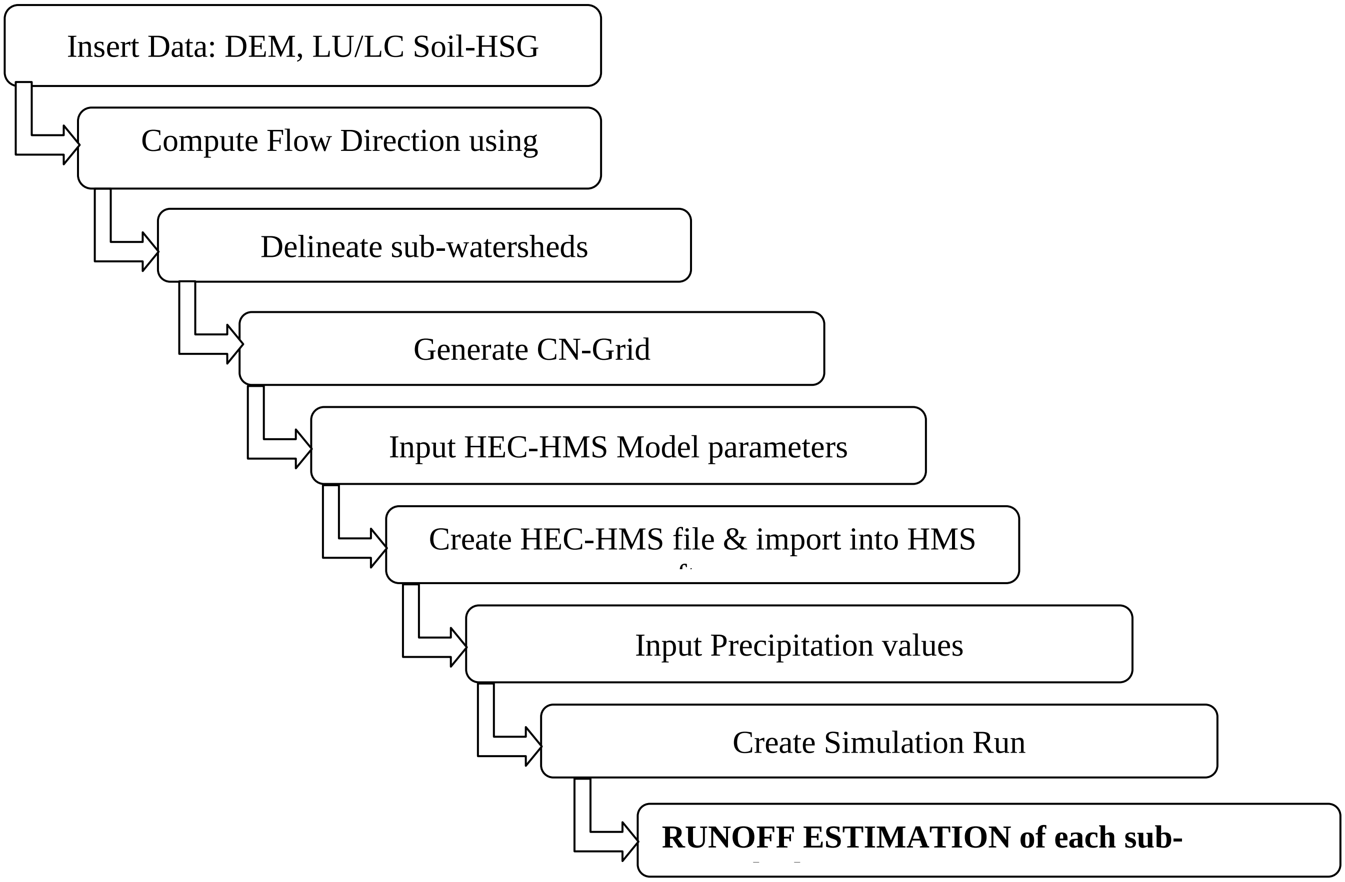


Fig 3.13 Flow Chart for Rainfall-Runoff estimation using HEC-HMS (Prem Kumar *et al.*)

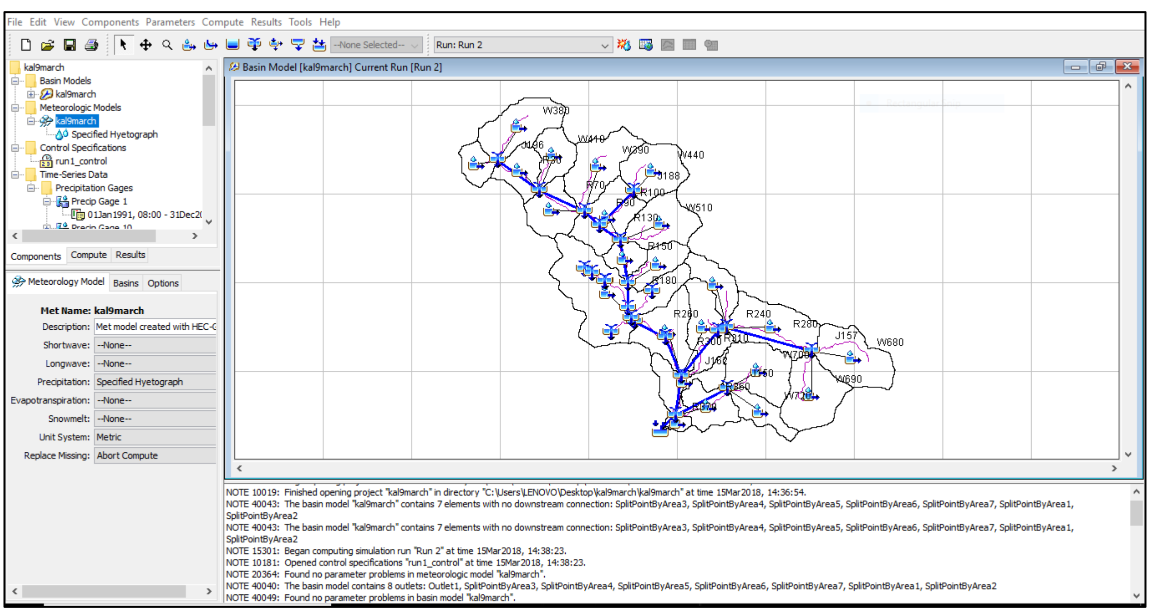


Fig 3.14 HEC-HMS Model for Kal river basin

3.8 SWAT model

The SWAT is one of the most recent model developed jointly by the United States Department of Agriculture – Agricultural Research Services (USDA–ARS) and Agricultural Experiment Station in Temple, Texas 8–10 (Singh *et al*., 2013). It is a physically based, continuous-time, long-term simulation, lumped parameter, deterministic and originated from agricultural models (Griensven *et al.*, 2012). The computational components of SWAT can be placed into eight major divisions: hydrology, weather, sedimentation, soil temperature, crop, growth, nutrients, pesticides and agricultural management. The SWAT model uses physically based inputs such as weather variables, soil properties, topography, vegetation and land-management practices occurring in the catchment (Michael and Jain 2013). The physical processes associated with water flow, sediment transport, crop growth, nutrient cycling, etc. are directly modelled by SWAT. The hydrologic cycle as simulated by SWAT is based on the water balance equation.

$$SW_t = SW_o + \left[R_{day} + Q_{sur} + E_a + W_{seep} + Q_{gw}\right] \quad \text{.......3.3}$$

where,

SWt is the final soil water content (mm H_2O),

SW_o the initial soil water content (mm H_2O),

R_{day} amount of precipitation on day i (mm H_2O),

Q_{surf} the amount of surface run-off on day i (mm H_2O),

E_a the amount of evapotranspiration on day i (mm H_2O),

W_{seep} the amount of percolation and bypass exiting the soil profile bottom on day i (mm H_2O) and

Q_{gw} is the amount of return flow on day i (mm H_2O).

3.8.1 SWAT project setup

The SWAT Project Setup menu contains items that control the setup and management of SWAT projects. A SWAT project consists of a project directory which contains an ArcMap document, geodatabases and a subdirectory structure for storing temporary GIS datasets and SWAT 2012 input files.

3.8.2 Watershed delineation

The Automatic Watershed Delineation command accesses the dialog box used to import topographic maps and delineate the watershed. Watershed is a hydrological unit from which runoff resulting from precipitation flows past a single point into a large stream, river, lake or pond. Watershed delineation plays an important role in watershed management. After, resolving all problems, watershed delineation was performed. The ArcSWAT delineated 340 km^2 study area.

3.8.3 Hydrologic Response Unit (HRU) Analysis Menu (Defining land use/soil data/Slope)

The HRU Analysis menu contains all the sub-menu that perform the land use, soils, and slope analysis used to generate SWAT HRUs. Under HRU Analysis, for each of the delineated sub-basins, Land use, Soil data and Slope were defined for modelling of various hydrological and other physical processes.

3.8.3.1 Land Use/Soils/Slope Definition

The Land Use/Soils/Slope Definition menu accesses the dialog box used to import land use, soil maps and slope map of study area to link the maps to SWAT databases and perform an overlay.

3.8.3.2 HRUs Distribution

The HRUs Distribution menu accesses the dialog box used to define the number of HRUs created within the watershed.

3.8.3.3 HRU Analysis Reports

The HRU Analysis Reports menu lists various HRU analysis reports generated by the interface. To access a particular report, highlight the name of the report and click the left mouse button. The report of interest will be displayed in a text editor.

3.8.4 Write Input Tables Menu

The Input menu contains the commands which generate the ArcSWAT geodatabase files used by the interface to store input values for the SWAT model.

3.8.4.1 Weather Stations

The Weather Stations command loads weather station locations and data for use (rainfall, min-max temperature, relative humidity, wind speed).

3.8.4.2 Write SWAT Input Tables

The Write SWAT Input Tables command opens up an interface to manage the creation of ArcSWAT geodatabase tables that store values for SWAT input parameters.

3.8.5 The Edit Swat Input Menu

The Edit SWAT Input menu allows to edit the SWAT model databases and the watershed database files containing the current inputs for the SWAT model.

3.8.5.1 Databases

After the HRUs have been created, the SWAT view is generated. The SWAT view allows the user to input precipitation and temperature gauges. These input files are made in accordance with the format given in the SWAT user manual (Winchell *et al*. 2013).The weather data are fit into individual files (rainfall and temperature data) as required for the time specified in the gauge file. Apart from weather parameters, the SWAT view also allows for changes in a large number of other parameters of the micro watersheds. Soil data (.sol), weather generator data (.wgn), were the databases command allows to access the SWAT model databases from within a project. SWAT databases may be edited at any time during the development of a SWAT project. The SWAT databases must be edited to their desired content prior to writing the SWAT Input tables in order to be reflected in the model input files. Editing the SWAT database will modify the content of the SWAT2012.mdb database being used for the project. The edits made to the SWAT2012.mdb tables will be available for other SWAT projects in addition to the current project. It is good practice to make a backup copy of the SWAT2012.mdb prior to working on a SWAT project.

3.8.6 The SWAT Simulation Menu

The SWAT Simulation menu allows to run the SWAT model and perform sensitivity analysis and calibration. It consists of Run SWAT and Read SWAT output menu.

3.8.6.1 SWAT view

SWAT view is crelated with each sub watershed. All the sub watersheds were modified in the SWAT view.

3.8.6.2 Model Set Up and Run

The 'Set Up and Run SWAT model simulation' interface gives the option of selection of the time period for which the simulation is to be run, Set up and simulation run with basin parameters for ArcSWAT is shown in Fig.3.15 and 3.16. After the model is setup, the 'Run SWAT' option executes the simulation. After the model is successfully run, all the results of the simulation can be read through the read results option. The flow chart for operation of SWAT model is given in Fig. 3.17

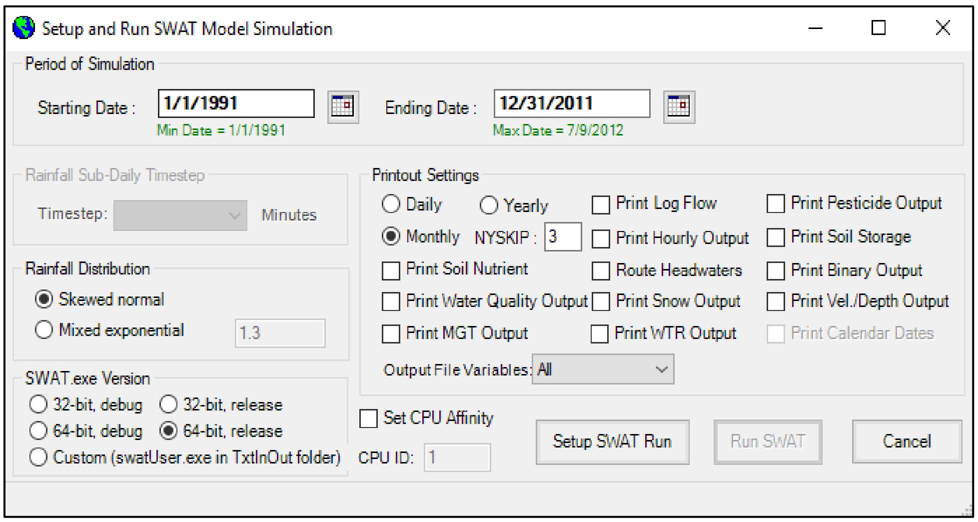


Fig 3.15 Set up and simulation run with basin parameters for ArcSWAT

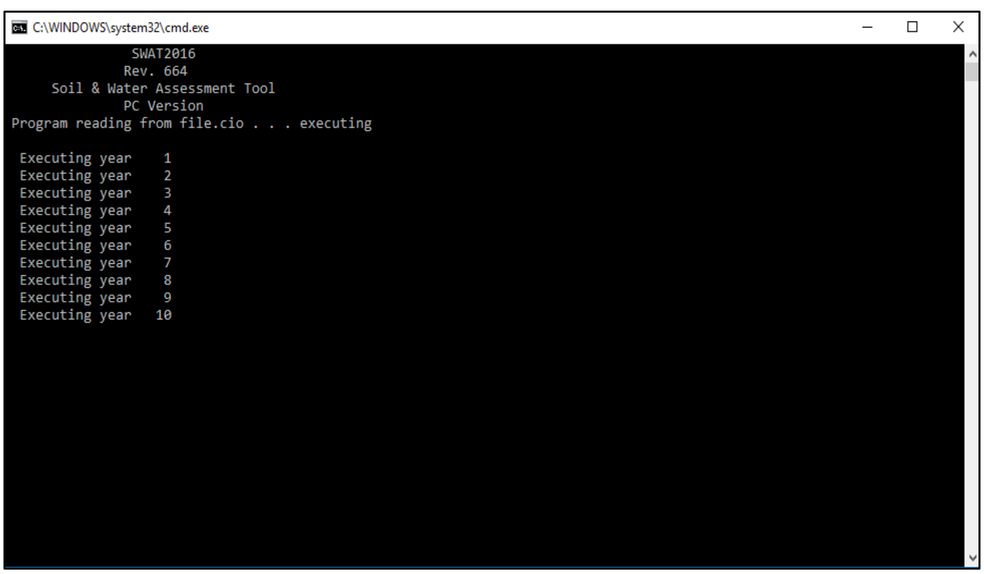


Fig 3.16 ArcSWAT simulations run

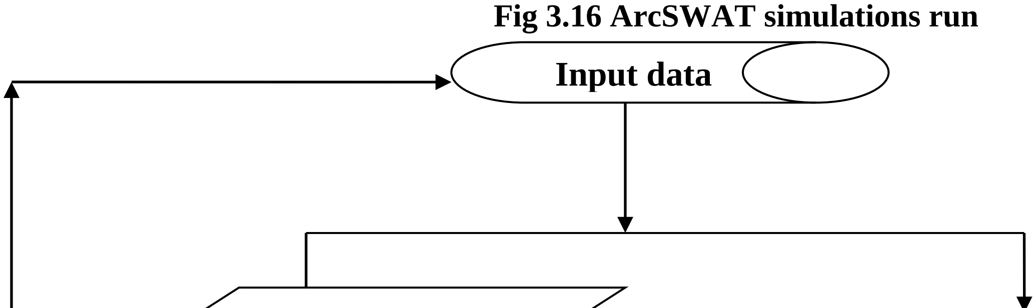


Fig 3.17 Flow chart of methodology for rainfall runoff estimation using ArcSWAT (Narasaya *et al.* 2013)

3.9 Statistical Parameters for evaluation of model results

The performance of the both HEC-HMS and Swat model was evaluated four performance indices, namely: coefficient of determination (R2), Nash-sutcliffe efficiency (NSE), Percent bias (PBIAS), root mean square error and standard deviation ratio (RSR)

3.9.1 Coefficient of determination (R^2)

The coefficient of determination (R^2) describes the proportion of the total variance in the measured data that can be explained by the model. It ranges from 0.0 to 1.0, with higher values indicating better agreement, and is given by,

$$R^2 = \left\{ \frac{\sum_{i=1}^{N}(O - O_{avg})(S_i - S_{avg})}{\left[\sum_{i=1}^{N}(O_i - O_{avg})^2 \sum_{i=1}^{N}(S_i - S_{avg})^2\right]^{0.5}} \right\}^2 \quad \text{……….3.4}$$

Where,

O_i is the i[th] observed data, O_{avg} is mean of observed data, S_i is the i[th] simulated value, S_{avg} is the mean of model simulated value and N is the total number of events.

3.9.2 Nash-sutcliffe efficiency (NSE)

Nash–Sutcliffe efficiency can range from −∞ to 1. An efficiency of 1 corresponds to a perfect match of modeled discharge to the observed data, and is given by,

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O})^2} \quad \text{……….3.5}$$

Where,
O_i is Observed data and S_i is Simulated data.

3.9.3 Percent Bias (PBIAS)

It measures the average tendency of the simulated values to be larger or smaller than their observed ones, and is given by,

$$PBIS = 100\times \frac{\sum_{i=0}^{n}(Qm-Qs)i}{\sum_{i=0}^{n} Qmi} \qquad ......3.6$$

Where, Qm_i is Observed data and Qs_i Simulated data

3.9.4 Root Mean Square Error and Standard Deviation Ratio (RSR)

It is the ratio of Root Mean Square Error (RMSE) and Standard Deviation, and is given by, $RSR = \frac{RMSE}{SD}$ 3.7

Where, RMSE is root mean square error and SD is Standard deviation

The recommended permissible values of different indices adopted to check the performance of model is given in table 3.2.

Table 3.2 General reported performance ratings for ENS, PBIAS, and RSR (Rossi *et. al.*, 2008)

No.	**Criteria**	**Value**	**Rating**
1.	**ENS***	>0.65	Very good
	ENS*	0.54-0.65	Adequate
	ENS*	≥0.50	Satisfactory
2.	**PBIAS†**	≤± 20%	Good
	PBIAS†	±20% to ±40%	Satisfactory
	PBIAS†	>± 40%	Unsatisfactory
3.	**RSR‡**	0.00 ≤ RSR ≤ 0.50	Very Good
	RSR‡	0.50 < RSR ≤ 0.60	Good
	RSR‡	0.60 < RSR ≤ 0.70	Satisfactory
	RSR‡	RSR > 0.70	Unsatisfactory

***** Nash-Sutcliffe efficiency value.

† Percent bias.

‡ Root mean square error-standard deviation ratio.

IV. RESULT AND DISCUSSION

This chapter deals with the prediction of surface runoff from Kal river of Konkan region in Maharashtra using HEC-HMS and SWAT model. Also Comparison of observed runoff and simulated runoff developed with HEC-HMS model are presented in this chapter. Also comparison of observed runoff and simulated runoff developed with SWAT are presented in this chapter. Also the comparative performance of HEC-HMS model and SWAT model for the prediction of surface runoff is presented in this chapter.

4.1 Surface Runoff Prediction by using HEC-HMS

The Hydrologic Modelling System (HEC-HMS) model was run for period of 1994-2011 for the prediction of surface runoff from the Kal river basin. These results are shown in monthly scales from daily simulation for the 1994-2011 Period. The Model was run for simulation of surface runoff for period of 1994 to 2002 (9 years) and for calibration of model data were used for the period of 2003 to 2011 (9 years). The observed runoff was compared with simulated runoff by HEC HMS model during simulation and calibration period. The observed surface runoff is given in Table 4.1 and the simulated surface runoff by HEC-HMS model is given in Table 4.2. The comparative performance of observed and simulated runoff by HEC-HMS is presented in Fig 4.1.

It is observed from Table 4.1, Table 4.2 and Table 4.3 and Fig. 4.1 that, the simulated surface runoff by HEC-HMS is perfectly computed and it is matched with observed surface runoff. This indicates that the HEC-HMS is estimates the surface runoff in monthly basis is very good. The statistical indices performed to compute the surface runoff by HEC HMS is given in Table 4.4. It indicates that R^2 is 0.95 for simulation period and R^2 for calibration period is 0.94 whereas for all study period 1991 to 2003 is 0.94. The model R^2 is more than 0.85 is said to prediction is very good and fitted well for current condition. Like that, Nash-Sutcliffe efficiency (NSE), Percent Bias (PBIAS) and Root mean Square error and standard deviation ratio (RSR) were estimated to check the performance of the model during simulation and calibration period and presented in the table 4.4. It is observed from that Table 4.4 that the NSE values for simulation is 0.90 and during calibration period is 0.92 whereas for whole study period is 0.91. The PBIAS value observed during simulation is -14.45 per cent and for calibration period 8.63 per cent whereas for whole study period is -3.79 per cent. The negative value of the PBIAS is indicating the model under predict the surface runoff. It clear from PBIAS that, HEC-HMS is under predicting during simulation period whereas during calibration period over predict the surface runoff and for study period it also under predict the surface runoff. The RSR for simulation period is 0.34 and calibration period is 0.29 whereas for study period is 0.32. It indicates from all indices that, the model predict surface runoff during simulation and calibration period satisfactorily. The HEC HMS is lumps parameter based semi distributed model found to be estimated surface runoff by SCS Curve Number method by putting inputs as spatial data and considering the time base simulation found to very good model in estimating surface runoff for Konkan region ecosystem.

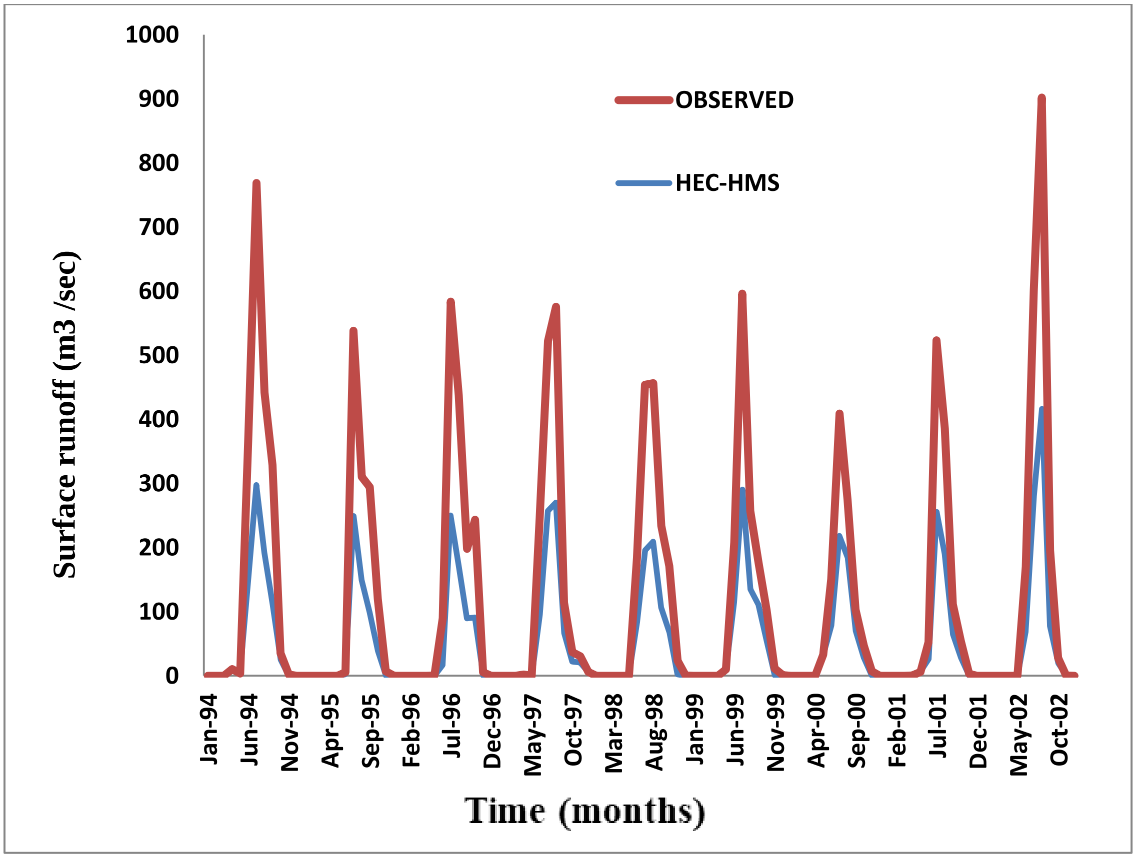


Fig 4.1 Comparison of observed and HEC-HMS model simulated surface runoff values for 1994-2002 (9 years)

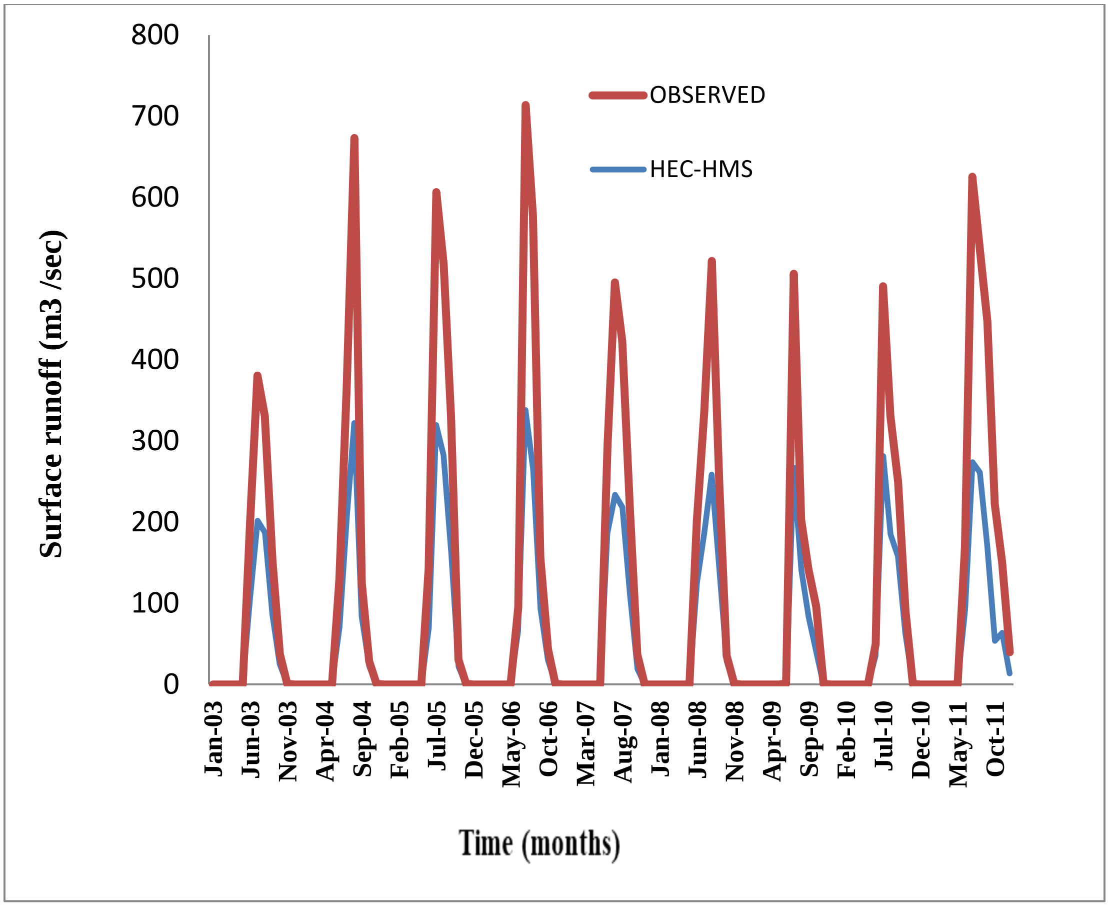


Fig 4.2 Comparison of observed and HEC-HMS model calibrated surface runoff values for 2003-2011 (9 years)

Table 4.1 Monthly Runoff Observed at Birwadi Station (m3/sec)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1994	0	0	0	0	0	213.55	471.47	249.75	218.08	10.26	1.37	0.00
1995	0	0	0	0	0	3.07	289.12	160.64	195.33	81.67	7.01	0.00
1996	0	0	0	0	0	72.99	333.38	267.87	108.77	152.12	5.50	0.00
1997	0	0	0	0	0	151.48	265.08	305.39	47.71	14.53	9.73	0.72
1998	0	0	0	0	0	99.88	258.42	247.17	127.53	103.85	20.85	0.31
1999	0	0	0	0	0	93.10	305.52	122.55	65.36	46.34	10.74	1.09
2000	0	0	0	0	0	72.10	191.24	90.80	33.08	18.57	6.43	0.00
2001	0	0	0	0	0	26.04	267.55	195.31	47.53	26.16	2.47	0.00
2002	0	0	0	0	0	101.52	320.74	485.45	118.38	8.57	0.00	0.00
2003	0	0	0	0	0	95.33	178.77	143.27	65.24	12.32	0.00	0.00
2004	0	0	0	0	0	58.25	160.37	351.30	41.11	6.38	0.00	0.00
2005	0	0	0	0	0	73.51	287.06	234.66	166.63	8.72	0.00	0.00
2006	0	0	0	0	0	28.89	375.67	311.75	63.48	12.92	0.00	0.00
2007	0	0	0	0	0	108.34	261.67	204.45	101.32	18.05	0.00	0.00
2008	0	0	0	0	0	75.20	146.99	263.27	108.10	7.36	0.00	0.00
2009	0	0	0	0	0	0.00	238.98	61.74	58.54	54.53	0.00	0.00
2010	0	0	0	0	0	14.96	209.41	145.63	91.82	27.82	0.00	0.00
2011	0	0	0	0	0	77.05	351.57	272.77	275.90	168.73	86.78	26.16

Table 4.2 Monthly simulated Runoff HEC-HMS Model (m^3/sec) for period 1991 to 2002 (9 years)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1994	0.00	0.00	0.00	10.24	3.57	152.07	297.42	192.19	110.71	25.32	0.33	0.00
1995	0.00	0.00	0.00	0.00	0.00	2.35	249.20	149.42	99.21	38.42	0.00	0.00
1996	0.00	0.00	0.00	0.13	0.25	16.69	250.12	169.60	89.49	91.21	0.00	0.00
1997	0.00	0.00	0.00	1.76	0.01	95.27	257.21	270.29	66.53	22.32	20.74	5.29
1998	0.00	0.00	0.00	0.00	0.00	84.22	195.70	209.41	106.66	67.34	2.37	0.00
1999	0.00	0.00	0.00	0.00	10.00	114.65	290.80	134.81	110.69	56.22	0.64	0.00
2000	0.00	0.00	0.00	0.00	33.07	78.26	217.98	184.11	70.15	28.49	0.64	0.00
2001	0.00	0.00	0.00	0.56	6.14	26.12	255.66	190.20	64.37	27.91	0.64	0.00
2002	0.00	0.00	0.00	0.00	0.00	68.69	280.38	416.35	77.35	19.47	0.64	0.00

Table 4.3 Monthly calibrated runoff by HEC HMS Models for period of 2003 to 2011 (9 Years)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2003	0.00	0.00	0.00	0.00	0.00	104.60	201.88	187.13	86.55	25.04	0.64	0.00
2004	0.00	0.00	0.00	0.00	0.00	70.92	207.51	321.89	83.95	22.25	0.64	0.00
2005	0.00	0.00	0.00	0.00	0.00	69.79	319.58	282.53	162.31	21.79	0.64	0.00
2006	0.00	0.00	0.00	0.00	0.00	66.00	338.05	264.89	93.22	30.42	0.64	0.00
2007	0.00	0.00	0.00	0.00	0.00	186.26	233.53	218.13	113.40	18.90	0.00	0.00
2008	0.00	0.00	0.00	0.00	0.00	125.68	187.21	258.42	141.37	28.58	0.64	0.00
2009	0.00	0.00	0.00	0.00	0.00	0.94	267.15	141.25	82.83	41.58	0.64	0.00
2010	0.00	0.00	0.00	0.00	0.00	35.12	281.34	184.64	157.73	63.39	0.64	0.00
2011	0.00	0.00	0.00	0.00	0.00	92.60	273.88	261.19	171.19	53.85	63.67	13.66

Table 4.4 The statistical indices for checking the performance of HEC-HMS Model

Statistical Parameter	Simulation Period	Calibrated Period	Full Period
	1994-2002	**(2003-2011)**	**(1994-2011)**
R^2	0.95	0.94	0.94
NSE	0.90	0.92	0.91
PBIAS	-14.45	8.63	-3.79
RSR	0.34	0.29	0.32

4.2 Surface Runoff Prediction by using SWAT

The Soil and Water Assessment Tool (SWAT) model was run for period of 1994-2011 on for the prediction of surface runoff from the Kal river basin. These results are shown in monthly scales from monthly simulation for the 1994-2011 Period. Model simulated surface runoff is compared with observed discharge values which were collected from Hydrologic project, Water Resource Department, Nashik for period of 1991-2011 of Birwadi station. The observed surface runoff is given in Table 4.1.

The surface runoff and response of Kal river basin was studied using ArcSWAT-10.3 (of 2012) and Arc-GIS10.3 interface. The SWAT model was used to model runoff considering its ability to characterize complex watershed explicitly accounting for spatial variability of soils, rainfall distribution and vegetation heterogeneity. Also its ability to shows the effect of different land management practices on surface runoff.

The Kal basin was delineated by the model taking to account suggested flow accumulation threshold of 340 sq km, and which were further divided into 104 HRUs. Each HRU was evaluated by the multiple hydrologic response unit option by considering land used cover area, soil class and slope parameter for the study area. The simulated surface runoff from Kal river was compared with the runoff measured at Birwadi hydrologic station.

The calibration process was adopted to finding out the sensitive parameters through sensitivity analysis. Results of sensitivity analysis showed that most sensitive parameters for the SWAT model in Kal river watersheds are curve number, available water capacity, average slope steepness, saturated hydraulic conductivity, soil evaporation compensation factor and soil depth. Therefore, all these parameters were used for calibration of model. In present study, daily runoff data recorded at the outlet of the Kal river at Birwadi hydrologic station, were used for calibration of results of SWAT model. The model parameters were calibrated using the different values of input parameters followed by several simulation runs. The ranges of input parameter and their calibration values are presented in Table 4.5. The values of inputs parameters were choose within their prescribed ranges as suggested in user's manual (Bouraoui and Dillaha, 2000; and Neitsch et al. 2001a) of SWAT 2012. The weather data generator file was created for Kal river and used for simulation. The runoff was simulated for Birwadi station of Kal river. The model was run for the Kal river for surface runoff modeling for duration of January 1, 1994 to December 2002 under calibration mode and January 2003 to December 2011 was taken as forecasting period.

Table 4.5: Model parameters used for calibration

Sr. No.	Model parameters	Prescribed ranges	Calibrated value
1	Mannings 'n' for over land flow	0.01 -0.12	0.048
2	Mannings 'n' for main channels	0.01- 0.30	0.025
3	Mannings 'n' for tributary channels	0.01 – 0.30	0.035
4	Effective hydraulic conductivity in the main channel (mm/hr)	0.01 – 150.0	1.00
5	Effective hydraulic conductivity in the tributary channel (mm/hr)	0.01 – 150.0	35.55
6	Alfa factor for ground water	0.00 – 1.00	0.80
7	Specific yield (m/m)	0.00 – 0.40	0.003

8	‘revap’ coefficient	0.00 – 1.00	0
9	‘revap’ storage	0.00 – 500.0	0
10	Channel erodibilty factor	0.05 – 1.00	0.60
11	Channel over factor	0.001 – 1.00	0.80
12	Base flow alpha factor	0.00 – 1.00	0.1

The models were run through GIS and windows interface to get the desired output. The surface runoff simulated from the model were compared with Kal river outlet gauged data using the graphically and regression approaches. The model performance were validated by using statistical indices such as coefficient of determination (R^2), Nash-sutcliffe efficiency (NSE), Percent bias (PBIAS), root mean square error and standard deviation ratio (RSR) calibration and validation mode.

The monthly time series of surface runoff adopted for simulation for Kal river during calibration and validation period are presented in Fig 4.3 and Fig 4.4 respectively. It observed from figure that the peaks of runoff were reflected with the increasing rainfall amount during calibration and validating period. It is also observed that runoff over Kal river catchment changes with seasons and proportional to the rainfall received. The observed monthly runoff for simulation and calibration period is presented in Table 4.6 and Table 4.7 respectively. The observed monthly rainfall for study period measured at Birwadi station is presented in Appendix-1.

It is observed from Table 4.6, Table 4.7 and from Fig 4.3and Fig 4.4 that runoff estimated by SWAT model during simulation and calibration period is well fitted with observed surface runoff.

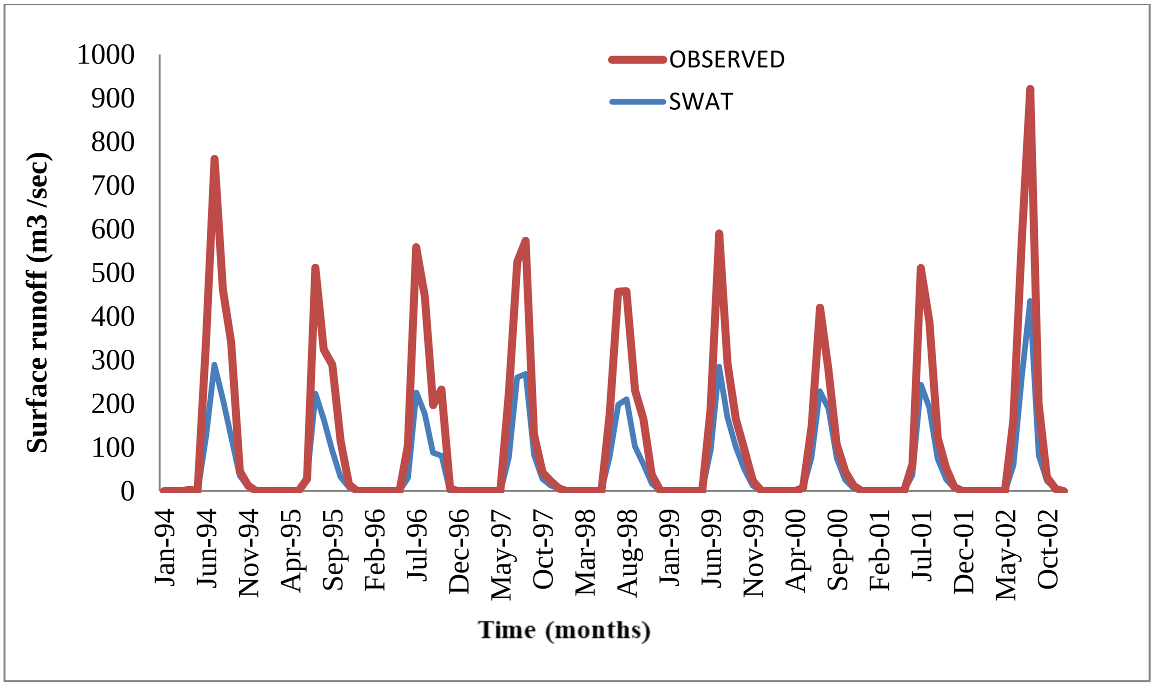


Fig 4.3 Comparison of observed and SWAT model simulated surface runoff for 1994-2002 (9 years)

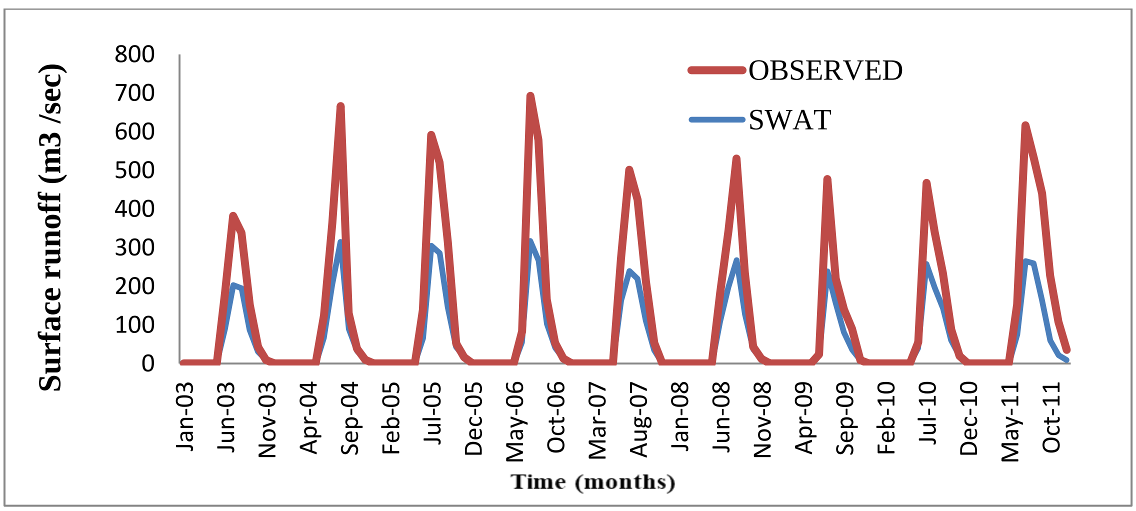


Fig 4.4 Comparison of observed and SWAT model calibrated surface runoff for 2003-2011 (9 years)

The performance of the SWAT model for predicting surface runoff were check by statistical indices such as coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE), Percent bias (PBIAS), root mean square error and standard deviation ratio (RSR) calibration and validation period is given in Table. 4.8. It is observed from Table 4.8 that, it indicates R^2 is 0.94 for simulation period and R^2 for calibration period is 0.93 whereas for all study period i.e 1994 to 2003 is 0.93. The model R^2 is more than 0.85 is said to prediction is very good and fitted well for current condition. Like that, Nash-Sutcliffe efficiency (NSE), Percept Bias (PBIAS) and Root mean Square error and standard deviation ratio (RSR) were estimated to check the performance of the model during simulation and calibration period and presented in the table 4.4. It is observed from that Table 4.4 that The NSE values for simulation is 0.89 and during calibration period is 0.91 whereas for whole study period is 0.90. The PBIAS value observed during simulation is -14.55 per cent and for calibration period 7.80 per cent whereas for whole study period is -4.23. The negative value of the PBIAS is indicating the model under predict the surface runoff. It clear from PBIAS that, SWAT is under predicting during simulation period whereas during calibration period over predict the surface runoff and for study period it also under predict the surface runoff. The RSR for simulation period is 0.36 and calibration period is 0.31 whereas for study period is 0.34. It indicates from all indices that, the model predict surface runoff during simulation and calibration period satisfactorily. The SWAT is parameter based physical based processed model found to be estimated surface runoff by SCS Curve Number and Green Ampt Model by putting inputs as spatial Data and considering the time base simulation found to very good model in estimating surface runoff for Konkan region ecosystem.

Table 4.6 Monthly simulated Runoff SWAT Model (m^3/sec) for period 1991 to 2002 (9 years)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1994	0	0	0	2.37	0.51	125.2	289.5	212.1	121.7	35.06	10.68	0
1995	0	0	0	0	0	24.5	222.6	163.7	93.52	32.16	8.14	0
1996	0	0	0	0	0	30.52	225.4	178.25	87.86	80.65	0	0
1997	0	0	0	0	0	76.25	260.1	268.2	82.42	27.95	12.54	5.02
1998	0	0	0	0	0	78.32	198.23	210.7	102.89	61.2	17.2	0
1999	0	0	0	0	0	94.49	284.9	169.45	99.49	49.98	12.77	0
2000	0	0	0	0	7.21	77.37	228.9	188.83	74.64	26.15	6.03	0
2001	0	0	0	0.23	0.77	36.22	243.1	191.36	74.19	26.67	6.29	0
2002	0	0	0	0	0.11	59.5	260.86	435.5	82.39	23.08	5.03	0

Table 4.7 Monthly calibrated Runoff SWAT Model (m^3/sec) for period 1991 to 2002 (9 years)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2003	0	0	0	0	0	89.61	203.11	194.52	86.94	30.44	8.7	0
2004	0	0	0	0	0	65.91	203.21	314.6	89.01	32.3	9.46	0
2005	0	0	0	0	0	65.42	304.6	285.6	146.4	43.21	16.44	0
2006	0	0	0	0	0	54.48	317.1	266.8	102.74	40.19	12.92	0
2007	0	0	0	0	0	163.1	239.3	218.9	110.92	34.87	0	0
2008	0	0	0	0	0	107.28	196.79	267	127.48	36.19	11.86	0
2009	0	0	0	0	0	23.72	238.3	157.82	81.18	35.14	8.38	0
2010	0	0	0	0	0	39.82	257.5	195.78	142.3	60.35	19.72	0
2011	0	0	0	0	0	75.57	264.8	259.4	164.3	59.2	21.05	9.07

Table 4.8 The statistical indices for checking the performance of SWAT Model

Statistical Parameter	Calibration Period	Validation Period	Full Period
	1994-2002	**(2003-2011)**	**(1994-2011)**
R^2	0.94	0.93	0.93
NSE	0.89	0.91	0.90
PBIAS	-14.55	7.80	-4.23
RSR	0.36	0.31	0.34

4.3 Comparative Performance of HEC-HMS and SWAT model

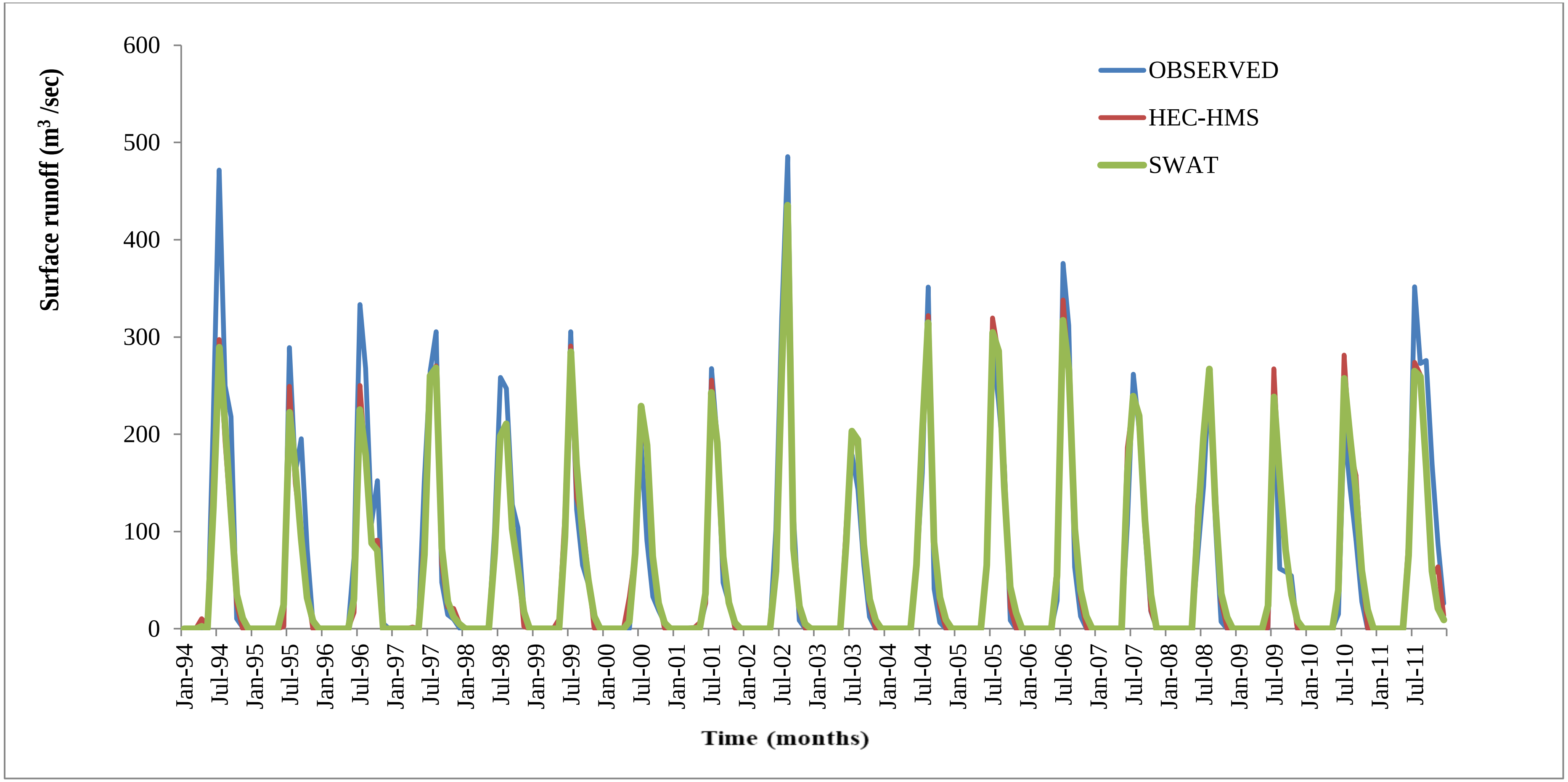
The performance of the both HEC-HMS and SWAT model for prediction of surface runoff from Kal river catchment was evaluated from four performance indices, namely: coefficient of determination (R^2), Nash-sutcliffe efficiency (NSE), Percent bias (PBIAS), root mean square error and standard deviation ratio (RSR) for period of 1991-2011 of Birwadi station. The estimated surface runoff by HEC-HMS and SWAT is given in Fig. 4.5. It is clear from the Fig.4.5 that, both models were performing better in estimating surface runoff of Kal river during simulation and calibration period of study. The estimated and observed vales are closely fitted with R^2 value more than 0.90. Hence both model performance is satisfactory predicting the surface runoff.

Table 4.9 The HEC HMS and SWAT Model performance during simulation and calibration period of Kal river

Statistical Parameter	Models	Calibration Period	Validation Period	Full Period
		1994-2002	(2003-2011)	(1994-2011)
R^2	HEC-HMS	0.95	0.94	0.94
	SWAT	0.94	0.93	0.93
NSE	HEC-HMS	0.90	0.92	0.91
	SWAT	0.89	0.91	0.90
PBIAS	HEC-HMS	-14.45	8.63	-3.79
	SWAT	-14.55	7.80	-4.23
RSR	HEC-HMS	0.34	0.29	0.32
	SWAT	0.36	0.31	0.34

The statistical indices (R^2, NSE, PBIAS, and RSR) are presented in Table 4.8. It is observed from Table 4.8 that, R^2 values for HEC-HMS and SAWT model in predicting the surface runoff during simulation and calibration period is more than 0.9 and approaches to the 0.95. This indicated the both model were very good in simulating the surface runoff compared to the observed runoff. The other indices such as PBIAS, values are very realist and approaches toward the real estimating the surface runoff by both HEC-HMS and SWAT model as their values are ranging between -14.14 to 8.6. Both model also under predict the surface runoff during simulation period whereas over predict during the calibration period. The values of the NSE and RSR estimated are in the permission limits as per suggested in Table 3.2.

As per above discussion, it is felt that, both model performance for predicting the surface runoff is very good for Kal river of Konkan region. The model parameters adopted and calibrated for Kal river may be suitable for predicting the surface runoff by HEC-HMS and SWAT model. The results for predicting the surface runoff by HEC-HMS and SWAT found to similar due the basic approached in both model same and SCS-CN methods is adopted for simulating the surface runoff.



Surface runoff (m3 /sec)
600
500
400
300
200
100
0
OBSERVED
HEC-HMS
SWAT
Jan-94
Jul-94
Jan-95
Jul-95
Jan-96
Jul-96
Jan-97
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
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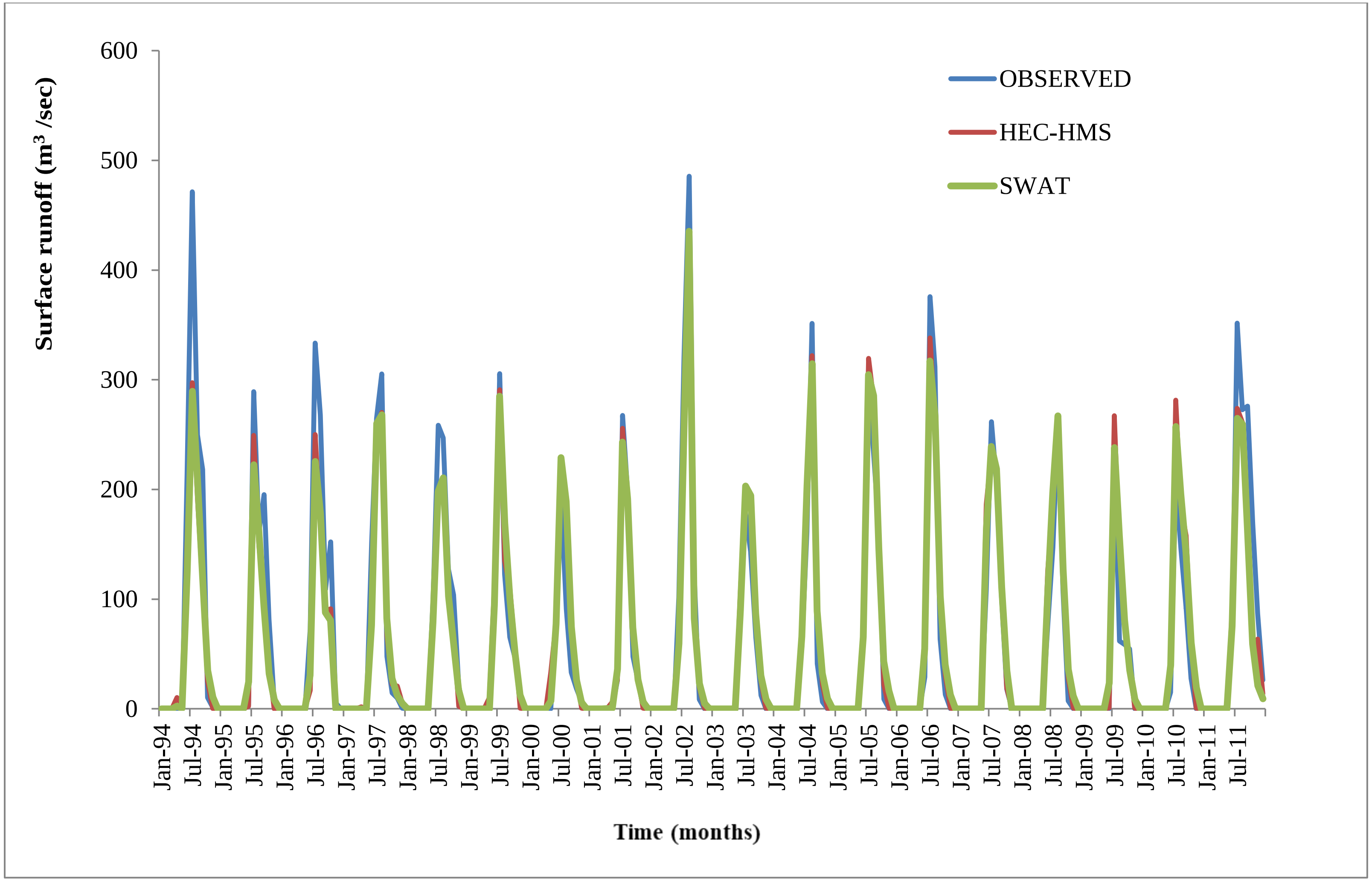
Jan-11
Jul-11
Time (months)



Surface runoff (m³ /sec)
600
500
400
300
200
100
0
OBSERVED
HEC-HMS
SWAT
Jan-94
Jul-94
Jan-95
Jul-95
Jan-96
Jul-96
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Jan-10
Jul-10
Jan-11
Jul-11
Time (months)

V. SUMMARY AND CONCLUSIONS

Rainfall-runoff estimation is a difficult task due to influence of different factors. So the surface runoff estimation in a watershed is important in hydrologic studies. Improper estimation of runoff in river basin causes some problems in optimum management of water resources and reservoir dams. Therefore, simulation of rainfall-runoff is a proper solution for runoff estimation. This simulated runoff from catchment will helpful for future prediction of runoff and planning of water resources in catchment and their management strategies. So main objective of this study to predict the surface runoff of Kal river using both HEC-HMS and SWAT model and study the comparative performance of simulation of surface runoff from Kal river catchment in Konkan region of Maharashtra.

The present study was carried out with the specific objectives of to predict the surface runoff of Kal river using HEC-HMS and SWAT model and study the comparative performance on simulation of surface runoff from Kal river catchment in Konkan region of Maharashtra. So for the fulfillment of the objectives, Arcs-GIS 10.3, HEC-GeoHMS 10.2, HEC-HMS 4.2.1, and ArcSWAT 2012 these software's were used to simulate and predict the surface runoff from Kal river catchment of Konkan region of Maharashtra. The Kal river is tributary of Savitri river flowing in Raigad district of Maharashtra. The Kal river basin lies between North latitudes of $17^0$51' to $18^0$20' and East longitudes of $73^0$22' to $73^0$41'.

The main purpose of this study was to compare the performance of the HEC-HMS and SWAT models for prediction of surface runoff from Kal river of Konkan region in Maharashtra. So both the models were run for period of 18years from 1994-2011. The performance of the both HEC-HMS and SWAT model for prediction of surface runoff from Kal river catchment was evaluated from four statistical performance indices, namely: coefficient of determination (R^2), Nash-sutcliffe efficiency (NSE), Percent bias (PBIAS), root mean square error and standard deviation ratio (RSR). Both the models were Simulated and calibrated for 9 years period each and results were compared with observed surface runoff which was collected from Hydrologic project, Water Resource Department, Nashik for period of 1991-2011 of Birwadi station.

The statistical parameters show that both model performances for predicting the surface runoff is very good for Kal river of Konkan region. The model parameters adopted and calibrated for Kal river may be suitable for predicting the surface runoff by HEC-HMS and SWAT model. The results for predicting the surface runoff by HEC-HMS and SWAT found to similar due the basic approached in both model same and SCS-CN methods is adopted for simulating the surface runoff.

The HEC HMS model was operated in ARC GIS 10.3 using the spatial data such as DEM, LULC, Soil data of the Kal river catchment and whether parameters (Rainfall on monthly basis, temperature, relative humidity, wind speed, etc) for duration of 1994 to 2011. The model was run for simulation period of 1994 to 2002 (9 years) and calibration period of 2003 to 2011 (9 years). The surface runoff on monthly basis during simulation and calibration period were compared with observed surface runoff measured at Birwadi station of Kal river. The brief of statistical parameter checks for HEC HMS model as

- R^2 values for HEC-HMS model in predicting the surface runoff during simulation and calibration period is ranging from 0.94 to 0.95.
- NSE values for HEC-HMS model in predicting the surface runoff during simulation and calibration period is ranging from 0.90 to 0.92.
- Percent Bias for HEC-HMS model in predicting the surface runoff during simulation and calibration period is ranging from -14.45 per cent to 8.63per cent.
- RSR value for HEC-HMS model in predicting the surface runoff during simulation and calibration period is ranging from 0.29 to 0.34.

The Soil and Water Assessment Tool (SWAT) developed by USDA ARS, USA (Ranole et al 2001) latest version of 2012 adopted for prediction of surface runoff using spatial data (DEM, LULC, Soil, data and whether parameter etc) in GIS environment. The input parameters were written as per the format of the model and run the model setup in simulation during 1994 to 2002 (9 years data and calibration period of 2003 to 2011 (9 years). The results were calibrated using SUFI Cup interlinked with SWAT. The predicted surface runoff was compared with actual surface runoff measured at Birwadi station of Kal river. The statistical parameters correlation with observed and simulated surface runoff for Kal river estimated using R2, PIABS, NSE and RSR.

- R^2 values for SWAT model in predicting the surface runoff during simulation and calibration period is more ranging from 0.93 to 0.94.

- NSE values for SWAT model in predicting the surface runoff during simulation and calibration period is more ranging from 0.89 to 0.91.
- Percent Bias for SWAT model in predicting the surface runoff during simulation and calibration period is ranging from -14.55 per cent to 7.80 per cent.
- RSR value for HEC-HMS model in predicting the surface runoff during simulation and calibration period is ranging from 0.31 to 0.36.

Conclusions

The surface runoff of Kal river on monthly basis was predicted using HEC-HMS and SWAT model for period of 1994 to 2011. The both models were run in simulation period i.e 1994 to 2002 and calibration period of 2003 to 2011. The results also checks using statistical indices such as R2, PIABS, NSE and RSR. The conclusions of the study are as follows.

- The surface runoff predicted busing HEC HMS Model found to be predicting the surface runoff very accurately having R^2 value more than 0.91 during simulation and calibration period and rest indices also performed well in predicting the surface runoff.
- The HEC-HMS is over predict the surface runoff during simulation and under predict during calibration period but overall model over predict the surface runoff compared to the observed surface runoff for Kal river.
- The HEC-HMS is lumpsump semi distributed parameters based model is found to suitable for hilly undulating transacts topography with heavy rainfall receiving with humid climate of the Konkan region in modeling the surface runoff.
- The Soil and Water Assessment Tool (SWAT) is physical based parameter distributed model was adopted using spatial data for predicting the surface runoff of Kal river with R^2 values more than 0.92 and other statistical parameters are in permissible limits.
- The SWAT is found to be over predict the surface runoff during simulation period and under predict the surface runoff during calibration period whereas overall the model over predict the surface runoff by the model.

- The SWAT model found to be very satisfactory adoptable in simulation of surface runoff of the Kal river of Konkan region using spatial information in GIS environment.
- It is found to be both model HEC-HMS and SWAT models are performing very satisfactory in simulation of surface of Kal river but HEC-HMS is have certain limitation in handling the data and conversion of data format loss the quality of data.

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VII. APPENDICES

Appendix I: Monthly Rainfall data of Birwadi station (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	0	0	0	81	34	1396	1777	1002	492	60	3	0
1995	0	0	0	0	0	207	1418	594	447	160	0	0
1996	0	0	0	1	2	315	1422	758	373	596	0	0
1997	0	0	0	14	0	959	1482	1550	193	38	165	39
1998	0	0	0	0	0	897	924	924	509	400	19	0
1999	0	0	0	0	82	1090	1743	484	552	297	5	5
2000	0	0	0	0	280	794	1143	898	217	81	5	0
2001	0	0	0	4	52	391	1457	933	175	81	5	0
2002	0	0	0	0	0	732	728	1156	274	12	5	0
2003	0	0	0	0	0	1034	990	918	346	57	5	0
2004	0	0	0	0	0	745	1073	1997	333	32	5	0
2005	0	0	0	0	0	771	1987	1640	948	31	5	0
2006	0	0	0	0	0	721	2134	1530	394	101	5	0
2007	0	0	0	0	0	1747	1180	1177	552	5	0	0
2008	0	0	0	0	0	1228	849	1487	783	86	5	0
2009	0	0	0	0	0	194	1547	546	313	192	5	0
2010	0	0	0	0	0	460	1692	881	906	359	5	0
2011	0	0	0	0	0	917	1610	1569	954	292	5	0

Appendix II: Effective Hydraulic Conductivity of the Channel Alluvium (mm/hr) for Various Channel Bed Materials (Arnold et al, 1995)

Bed material hydraulic group	**Bed material characteristics**	**Effective conductivity**
Very high loss rate	Very clean grave and large sand D50 > 2 mm	>127
High loss rate	Clean sand and gravel under field conditions D50 > 2 mm	51-127
Moderate high loss rate	Sand and gravel mixed with less than a few per cent silk clay	25-76
Moderate loss rate	Mixture of sand and gravel with significant amount of silky clay	6.4-2.5
Very low Loss rate	Consolidated bed materials with high silt clay content	0.025-2.5

Appendix III: Hydrologic Soil Group Classification (USDA SCA, 1972)

Group Code	Soil Characteristics (USDA, 1972)	Infiltration rate (mm/hr)	Runoff potential
A	Deep, well to excessive drained sand or gravel (sand, loamy sand and sandy loam)	High (>7.6)	Very low
B	Moderately deep to deep, moderately drain to well drained soil with moderately fine to moderately coarse texture (silt loam and loam)	Moderate (3.8 to 7.6)	Low
C	Soil having low hydraulic conductivity, poorly drained moderately fine to fine texture (Sandy clay loam)	Low (1.3 to 3.8)	Moderate
D	Clay soil with a high selling potential, soil with permanent high water table, soil with clay layer at or near surface, and shallow soil cover a nearly imperious material. (Clay loam, silly clay loam, sandy clay and clay)	Very low (0.0 to 1.3)	High

Appendix IV: Seasonal Rainfall Limits for AMC Classes (After SCS, 1972)

AMC Class	5 days antecedent rainfall (mm)		
	Dormant	Growing	Average
I	<13	<36	<23
II	13-28	36-53	23-40
III	>28	?53	>40

Appendix V: Manning's Roughness Coefficients for Different Land Use and Conditions (SCS, 1972)

Si No	Land Use	N
1	Concrete Asphalt	0.010-0.016
2	Bare sand	0.010-0.016
3	Gravel	0.012-0.080
4	Fallow land (No use)	0.05
5	Bare clay loam (eroded)	0.012-0.033
6	Cultivated soils	
7	Residual cover <20%	0.06
8	Residual cover>20%	0.17
9	Natural ranged land	0.010-0.320
10	Blue grass paired	0.39-0.63
11	Short grass paired	0.10-0.20
12	Dense grass (Barmuda blue grass)	0.17-0.48
13	Forest land	0.20-0.80
	For Channel	
1	Gravel	0.023
2	Smooth earth	0.018-0.40
3	Natural channel stream	0.025-0.08

Appendix VI: Curve Numbers for Hydrological Soil-Cover Complexes for Antecedent Moisture Condition, Class 11 and I;, = 0.2 S (after Soil Conservation Service 1972).

Land use	Treatment	Hydrologic condition	Hydrologic soil group			
			A	B	C	D
Fallow	Straight	poor	77	86	91	94
Row crops	Straight row	poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	81	88
	Contoured	Good	65	75	82	86
	Contoured/Terraces	Poor	66	74	80	82
	Contoured/Terraces	Good	62	71	78	81
Small Grains	Straight row	poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Contoured/Terraces	Poor	61	72	79	82
	Contoured/Terraces	Good	59	70	78	81
Closed seeded legumes or straight medow	Straight row	poor	66	77	85	89
	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured/Terraces	Poor	63	73	80	83
	Contoured/Terraces	Good	51	67	76	80
Pasture range		Poor	68	79	86	89
		Faire	49	69	79	84
		Good	39	61	74	80
	Contour	Poor	47	67	81	88
	Contour	Faire	25	59	75	83
	Contour	Good	6	35	70	79
Medow (Permanat)		Good	36	58	71	78
Woodlamd (Farm wood)		Poor	45	66	77	83
		Faire	36	60	73	79
		Good	25	55	70	77
Farm Steads			59	74	82	86
Road, Dirt			72	82	87	89
Roads, Hard Surface			74	84	90	92

Appendix VII: CNS for Hydrological Soil Curve Complex for AMC II and Ta=0.2S (After Springer, 1978)

Land use	**Slope**	**Hydrological Soil Groups**			
		A	**B**	**C**	**D**
Rice Filed or Mangrooves or Swamp	I	0	0	3	5
	II	0	5	8	10
	III	5	10	13	15
	IV	-	-	-	-
	V	-	-	-	-
Pasture range in good Hydrological conditions	I	39	55	68	74
	II	39	61	74	80
	III	42	64	77	83
	IV	44	66	79	85
	V	45	67	80	86
Wood in Poor Hydrologic condition	I	39	66	71	77
	II	45	66	77	83
	III	49	70	81	87
	IV	52	73	84	90
	V	54	75	86	92
Pasture or range in poor Hydrological Conditions	I	69	74	81	84
	II	68	79	86	89
	III	71	82	89	92
	IV	73	84	91	94
	V	74	85	92	95
Slope ranges, I =<1%, II= 1-5%, III=5-10%, IV=10-20%, V=>20%					

Appendix VIII: Conversion Table for Curve Numbers (CN) from Antecedent Moisture Condition Class II to AMC Class I or Class 111 (after Soil Conservation Service 1972)

CN AMC1	**CN AMCII**	**CN AMCIII**	**CN AMC1**	**CN AMCII**	**CN AMCIII**
100	100	100	58	38	76
98	94	99	56	36	75
96	89	99	54	34	73
94	85	98	52	32	71
92	81	97	50	31	70
90	81	97	48	29	68
88	75	95	46	27	66
86	72	94	44	25	64
84	68	93	42	24	62
82	66	92	40	22	60
80	63	91	38	21	58
78	60	90	36	19	58
76	58	89	34	18	54
74	55	88	32	16	52
72	53	86	30	15	50

70	51	85	25	12	43
68	48	84	20	9	37
66	46	82	15	5	30
64	44	81	10	4	22
62	42	79	5	2	13
60	40	78	0	0	0

Appendix IX: Water Erosion and Control Practice Factor (P) (Arnold et al., 1995a)

Land slope length, ft*(%)	P value	Maximum
1 – 2	0.60	400
3 – 5	0.50	300
6 – 8	0.50	200
9 – 12	0.60	120
13 – 16	0.70	80
17 – 20	0.80	60
21 – 25	0.90	50

*****limit may increased by 25 % if residue cover after plant seeding will regularly exceed 50%

Appendix X: Channel Data for Chemical Input File (.chm) (Arnold et al., 1995 a)

Input parameters	Values
Initial organic N concentration in upper soil layer (mg/kg)	300
Initial phosphorous concentration in upper soil layer (mg/kg)	150
Initial concentration of liable P in upper soil layer (mg/kg)	20

Appendix XI: Information of Kal riverbasin LUC, Soil, and Slope

Watershed information	**Area, Ha**	**% area**
Total area of Savitri basin (auto delineated in SWAT)	33946.26	
Land Use		
Water bodies	265.2	0.78
Barren	8255.2	24.31
Forest	13623.8	40.133
Agriculture	11607.6	34.19
Settlement	241.4	0.71
Soils code		
31	8140.31	23.98
46	27.15	0.08
61	4755.87	14.01
62	858.84	2.53
77	20164.07	59.40
Slope, per cent		
0 – 5	2912.58	8.58
5-15	6504.10	19.16
15-25	6398.87	18.85
25-35	6728.14	19.82
35<	11405.94	33.60

Appendix XII: Basin Input Data File (.bsn)

Input Parameters	Values
Area of the Basin (Sq km)	965.886
Conservation of nitrogen in rainfall (mg N/L)	1.000
Surface runoff coefficient	4.50
Peak rate adjustment factor for sediment routing in tributary channel	1.0
Peak rate adjustment factor for sediment routing in main channel	1.0
Linear parameter for calculating maximum amount of sediment that can be re-entered during channel sediment routing	0.001
Exponent parameter for calculating sediment re-entered in channel sediment routing	1.0
Reach evaporation adjustment factor	1.0
Leaf area index at which no evaporation occurs from water surface	4.50
Initial soil water storage expressed as a fraction of field capacity water content	0.0
Rate factor for humus mineralization of active organic nutrients (N and p)	0.0
Nitrogen uptake distribution parameters	0.0
Phosphorous uptake distribution parameters	0.0
Nitrate percolation coefficient	0.0
Phosphorous percolation coefficient (10 m^3/mg)	0.0
Phosphorous soil portioning coefficient (m^3/mg)	0.0
Phosphorous availability index	0.0
Residue decomposition coefficient	0.0

Appendix XIII: Ground Water Input Data File (gw)

Input Parameters	Values
Initial depth of water in shallow aquifer (mm)	2500.00
Initial depth of water in deep aquifer (mm)	40000.00
Ground water delay time (days)	20.00
Base flow alpha factor (days)	0.0
Threshold depth of water in shallow aquifer required for returned flow(mm)	10000.00
Ground water revap coefficient	0.020
Threshold depth of water in shallow aquifer for revap	1.000
Deep aquifer percolation fraction	0.050
Initial ground water height (m)	15.00
Specific yield of shallow aquifer (m^3/m^3)	0.040

Concentration of nitrate in ground water contribution to runoff from sub basin (mg N/L)	0.00
Concentration of soluble phosphorous in ground water contribution to runoff sub basin (mg P/L) Optional	0.00

Source;Arnold et al. 1995a

Appendix XIV : Attribute Value for HRU Data File

Parameters	MIN_	MAX_	FORMAT	POS
[NOT EDITABLE] Fraction of total watershed area contained in HRU.	0	1	31	0
Average slope length.	10	150	5	1
Average slope steepness.	0	0.6	5	2
Manning's "n" value for overland flow.	0.01	30	5	3
[OPTIONAL] Maximum canopy storage.	0	100	5	7
Soil evaporation compensation factor.	0	1	5	8
Plant uptake compensation factor.	0	1	5	9
[OPTIONAL] Initial residue cover (kg/ha).	0	10000	5	10
Organic N enrichment ratio.	0	5	5	11
Organic P enrichment ratio.	0	5	5	12
Width of edge-of field filter strip (m)	0	100	5	13
Urban simulation option.	0	2	1	14
Urban land type identification number from urban.dat.	0	10	1	15
Irrigation option.	0	5	1	16
Irrigation source location.	0	5	1	17
Minimum in-stream flow for irrigation diversions.	0	100	5	18
Maximum daily irrigation diversion from the reach.	0	150	5	19
Fraction of available flow.	0	1	5	20
The total number of different types of pesticides applied/modeled in the .mgt and .chm file.	0	10	1	24

[OPTIONAL] HRU (Landuse-Soil in the subbasin) that is ponding water.	0	100	1	25
Fraction of HRU area that drains into the pothole.	0	1	5	26
Average daily outflow to main channel from tile flow if drainage tiles are installed in the pothole.	0	100	5	27
Maximum volume of water stored in the pothole	0	100	5	28
Initial volume of water stored in the pothole.	0	100	5	29
Normal sediment concentration in pothole.	0	100	5	30
Fraction of HRU area that drains into floodplain	0	1	0	0
Fraction of HRU area that drains into riparian area	0	1	0	0
Average slope steepness	0	1	0	0
[OPTIONAL] Depth to impervious layer for modeling perched water tables	0	6000	0	0
Average distance to stream (m)	0	100000	0	0

Appendix XV: Weather Generator Input Data File (.wgn)

Input parameter	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Average daily maximum air temperature for month (^oC)	33.25	34.68	37.54	38.27	37.32	34.02	29.70	28.67	29.76	32.94	34.05	33.48
Average daily minimum air temperature for month (^oC)	16.27	17.06	19.63	22.74	25.84	24.69	23.63	23.06	22.87	22.20	19.36	16.51
Std deviation for average daily maximum air temperature for month (^oC)	0.65	0.86	0.64	0.42	0.73	0.49	0.42	0.29	0.88	0.79	0.35	0.46
Std deviation for average daily minimum air temperature for month (^oC)	0.37	0.63	1.22	0.90	2.68	0.65	0.30	0.32	0.22	1.20	0.91	0.82
Average total monthly precipitation (mm)	0.00	0.00	0.00	4.17	25.83	735.05	1297.97	1075.93	506.10	193.57	47.49	14.75

Std deviation for average total monthly precipitation (mm)	0.00	0.00	0.00	0.49	1.12	14.40	8.85	11.07	5.30	5.50	2.02	0.76
Skew coefficient for average total monthly precipitation (mm	0.00	0.00	0.00	4.46	1.45	0.91	0.56	0.54	0.53	2.11	2.40	1.95
Probability of wet day followed by dry days in a months	0.99	0.99	0.99	0.95	0.9	0.06	0.05	0.03	0.11	0.6	0.85	0.85
Probability of wet day followed by wet days in a months	7.12	6.78	7.36	8.15	9.04	6.67	6.2	5.45	5.91	5.86	5.82	6.46
Average number of days of precipitation in months	0.12	0.78	0.36	1.15	10	26.67	29.2	25.45	15.91	12.86	5.82	1.46
Maximum 0.5 hr hours rainfall in	0	0	0	0	238.35	235.56	134.04	145.21	136.83	65.65	0	0

entire period of record for month (mm)												
Average daily solar radiation for month (Mj/m^2/day)	9.42	12.27	16.41	19.4	22.95	25.01	24.5	23.12	19.22	15.54	11.4	9.05
Average daily dew point temperature in months (^oC)	0	0	0	0	0	0	0	0	0	0	0	0
Average daily wind speed in months (m/s)	1.82	1.74	1.92	2.26	2.55	2.28	1.85	1.75	1.16	0.76	0.65	0.73

Appendix XVI: Soil properties required for SWAT model (NBSS&LUP Nagpur)

ID_1	**31**	**46**	**61**	**62**	**77**
SNAM	MANGAON	JAWAHAR	VAI	MANGAON	SINNER
HYDGRP	A	A	A	A	B
SOL_ZMX	820	900	250	300	300
ANION_EXCL	0.47	0.4911	0.46	0.412	0.412
SOL_CRK	47	49.11	46	41.2	41.2
TEXTURE	Loam	Silt Loam	Loam	Loam	Loam
SOL_Z	1800	1500	500	500	500
SOL_BD	1.4	1.34	1.45	1.56	1.46
SOL_AWC	12.1	10.22	9.88	8.94	8.77
SOL_K	25.01	25.91	25.82	25.91	25.91
SOL_CBN	0.68	0.68	1.21	0.88	0.58
SOL_CLAY	48.5	32.4	50	50	50
SOL_SILT	18.3	25.6	26	26	26
SOL_SAND	33.2	42	24	24	24
SOL_ROCK	35	10	20	20	20
SOL_ALB	0.24	0.38	0.21	0.21	0.21
USLE_K	0.422325	0.240498	0.514303	0.536309	0.556315
SOL_EC	0.2	0.2	0.2	0.2	0.2
SOL_CAL	0	0	0	0	0
SOL_PH	3.1	5.2	6.1	6.1	6.1
SOL_CEC	25.8	16.2	18.2	18.2	18.2

Introduction

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Summary and Conclusions

2.1 *Bibliograph*

2.2 *Appendices*