Application of SWAT model to assess the impact of land use changes on daily and monthly streamflow of Subarnarekha River Basin

Mousumi Ghosh

Department of Civil Engineering
National Institute of Technology Rourkela

Application of SWAT model to assess the impact of land use changes on daily and monthly streamflow of Subarnarekha River Basin

Dissertation submitted to the

National Institute of Technology Rourkela

in partial fulfilment of the requirements of the degree

of

Master in Technology

in

Water Resources Engineering

by

Mousumi Ghosh

(Roll Number: 214CE4080)

based on research carried out

under the supervision of

Prof. Kanhu Charan Patra

May, 2016

Department of Civil Engineering

National Institute of Technology Rourkela

Department of Civil Engineering
National Institute of Technology Rourkela

May 28, 2016

Certificate of Examination

Roll Number: *214CE4080*
Name: *Mousumi Ghosh*
Title of Dissertation: *Application of SWAT model to assess the impact of land use changes on daily and monthly streamflow of Subarnarekha River Basin.*

We the below signed, after checking the dissertation mentioned above and the official record book (s) of the student, hereby state our approval of the dissertation submitted in partial fulfilment of the requirements of the degree of *Master of Technology* in *Water Resources Engineering* at *National Institute of Technology Rourkela*. We are satisfied with the volume, quality, correctness, and originality of the work.

Prof. Kanhu Charan Patra
Supervisor

Prof. Sisir Kumar Sahoo
Head of the Department

Department of Civil Engineering

National Institute of Technology Rourkela

Prof. Kanhu Charan Patra
Professor

May 28, 2016

Supervisors' Certificate

This is to certify that the work presented in the dissertation entitled *Application of SWAT model to assess the impact of land use changes on daily and monthly streamflow of Subarnarekha River Basin* submitted by *Mousumi Ghosh*, Roll Number 214CE4080, is a record of original research carried out by her under my supervision and guidance in partial fulfilment of the requirements of the degree of *Master of Technology* in *Water Resources Engineering*. Neither this dissertation nor any part of it has been submitted earlier for any degree or diploma to any institute or university in India or abroad.

Kanhu Charan Patra
Professor

Dedication

This work is dedicated is to my parents who have been with me through thick and thin during the period of my study.

Mousumi Ghosh

Declaration of Originality

I, ***Mousumi Ghosh***, Roll Number ***214CE4080,*** hereby declare that this dissertation entitled "***Application of SWAT model to assess the impact of land use changes on daily and monthly streamflow of Subarnarekha river basin"*** represents my original work carried out as a postgraduate student of NIT Rourkela and, to the best of my knowledge, it contains no material previously published or written by another person, nor any material presented for the award of any other degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the section "Bibliography". I have also submitted my original research records to the scrutiny committee for evaluation of my dissertation.

I am fully aware that in case of any noncompliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

Date:

NIT Rourkela

Mousumi Ghosh

Acknowledgement

It is a privilege for me to express my profound gratitude and indebtedness to my supervisor Prof. Kanhu Charan Patra, Civil Engineering Department, National Institute of Technology Rourkela. It would have been impossible for me to proceed in my research work without his guidance. I shall be highly obliged for his full term support.

I would like to convey my sincere gratitude to Prof. S.K. Sahoo, Head of the Department, Water Resources Engineering Department, National Institute of Technology Rourkela, for his constant guidance and encouragement. I would also take the pleasure of thanking all faculty members, Prof. Kishanjit Kumar Khatua, Prof. Awadhesh Kumar and Prof. Sanat Nalini Sahoo who had shared their knowledge during our course work.

I would also like to thank my seniors Janaki Ballav Swain and Mrunmayee Manjari Sahoo for their immense help in my project.

I am grateful to parents for their love, affection and understanding. They have provided constant support throughout the period of my study.

I am also thankful to my friends Aatish Anshuman, Pallabi Bhuyan and many others for their help and support during my research work.

Special thanks to all my friends for motivating me and assisting me. Without their help and encouragement it would not have been possible for me to undertake this work. I would like to thank all my friends for making my stay at NIT Rourkela lively and without their help this work would not have been possible.

May 2016 *Mousumi Ghosh*

NIT Rourkela

Abstract

Quantifying the impacts of land use change and land cover practices on the hydrological response of a watershed has been an area of interest for the hydrologists in recent years as this information could serve as a basis for developing sound watershed management interventions. The degree and type of land cover influences the rate of infiltration, runoff, and consequently the volumes of surface runoff and total sediment loads transported from a watershed. It often results in significant degradation of land resources such as loss of soil by erosion, nutrient leaching and organic matter depletion. However very few studies in India, have used the physically based hydrological models along with the land use / land cover change conditions. Hence in this current work SWAT model has been used to assess the impact of LU/LC changes on daily and monthly streamflow of Subarnarekha River Basin. The SWAT model has been calibrated and validated against the daily and monthly streamflow for the gauging station of Govindpur in NH5 road situated along the Budhabalanga river. The results depict that SWAT model usually performs well in simulating runoff according to Nash-Sutcliffe efficiency (NSE), Coefficient of determination (R^2) and Percentage bias (PBIAS) values. For daily stream flow the NSE, R^2 and PBIAS values were 0.61, 0.64 and -12 during calibration period and 0.57, 0.60 and 14.2 during validation period respectively. For monthly stream flows the efficiency increased due to smoothening of curves and the NSE, R^2 and PBIAS values were 0.76, 0.81 and 9.2 during calibration period and 0.79, 0.83 and 10.4 during validation period respectively. The results of the study indicated that the though land use patterns have changed resulting in increase in agricultural, barren and buildup land and decrease in forest cover leading to increase in runoff but changes have not occurred as significantly as the changes in annual streamflow. However the number of days of high intensity rainfall has increased over decade which along with the land use changes explains for the increase in streamflow.

Keywords*: *SWAT model, LU/LC changes, daily and monthly runoff, SUFI-2.

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CHAPTER 01

1. INTRODUCTION

1.1.General

Water is one of the most significant natural resources found on the earth's surface and has a remarkable association with the earth's component. The climate of any place can be attributed to the continuous phase of redistribution of water through hydrological cycle (Chow *et al.,* 1988; Subramanya, 2008). The physical characteristics of a watershed such as morphology, soil and land use influence the components of water balance in a basin. In developing countries like India, substantial economic damage is caused due to extreme weather events in the present day climate variability (Monirul and Mirza, 2003). Adverse changes in precipitation and temperature of an ecosystem affects the hydrological cycle. Natural or anthropogenic activities contribute to such changes which may induce extreme aridity, excessive humidity, increased surface runoff, negligible rainfall, soil erosion, flood and drought. Hence, the climate of any region plays an important role in determining the availability of water for human and ecosystem use.

The optimum management of water assets is the need of time for the improvement and rising demands of population of India. The National Water Policy of India (2002) acknowledges that national perspectives are needed to regulate the improvement and management of water resources so that the scarce water resources can be developed and conserved in a balanced and environmentally sound basis. Impact of land use changes, watershed development to soil loss and growth of population, water quantity and quality is among the most noteworthy topics in a watershed. The hydrological cycle can be disturbed due to changes in land use by the altering the base flow (Wang *et al*., 2006) and annual mean discharge of the basin (Costa *et al.,* 2003). The speeding growth of population and desire for economic development has further accelerated the requirement of different land uses within the watershed. Thus the attempts of prosecuting an integrated optimal planning to attain the sustainable uses of these watershed resources has become important to examine the spread of such problems, as experienced by several developing countries.

Prediction of surface runoff is one of the most proficient potential of a GIS system. The prediction can be implemented to determine the aspects of flooding, be used in the forecasting of the transport of water born contamination or aid in reservoir operation (Jain, 1996). Hydrological modelling is a robust approach of hydrologic system investigation for both the practicing water resources engineers and the research hydrologists who are involved in the planning and development of integrated technique for management of water resources (Schultz, 1993). Hydrologic models can be referred as the mathematical or symbolic representation of recognised or assumed functions conveying the different elements of a hydrologic cycle. The susceptibility to the resulting environmental stresses depends on two sets of factors: one, losses in this water systems (such as rainwater runoffs, floods and groundwater contamination) which will eventually determine what fraction of resources are available for human use (where we focus mainly on irrigation and potable water), and two, existing use patterns.

1.2.Surface Runoff

Surface runoff (also known as overland flow) is a fraction of precipitation which occurs as excess storm water, melt water, or other sources of flow over the earth's surface (Subramanya, 2008). This may happen when the soil is saturated to its optimum capacity when the rain water faster than the soil can absorb it, or due to impervious surface such as pavements and roofs direct their runoff to the nearby soil. Surface runoff is a important element of the water cycle and the prime agent causing soil erosion by water. The runoff is called nonpoint source pollution when a nonpoint source consists of natural forms of pollution (such as rotting leaves) or man-made contaminants. In urban areas, surface runoff is the major cause of urban flooding which may lead to street flooding, damage to property and damp and mould in basements. Surface runoff is also responsible for pollution and soil erosion.

1.3.Hydrological Modeling

Drainage basins are the fundamental landscape units which integrate all aspects of the hydrological cycle within a defined area that can be studied, quantified and acted upon and produces runoff which drains to a common point. In case of non-availability of data, hydrological models play an important role to create baseline characteristics and deduce the long term effects which are difficult to calculate (Lenhart *et al*., 2002). The purpose of modelling is to decrease the unreliability in hydrological predictions. Hydrological model plays a major part in simulating the complex process of rainfall-runoff, soil erosion, under different situation. They replicate physical processes within watersheds and generate various hydrological outputs enables the user to estimate the impact of natural and anthropogenic activities on water resources. The term hydrological model is commonly misinterpreted to be a computer based mathematical model alone. Hydrologic models try to simulate the response of catchment by solving the equations which govern the physical processes occurring within the watershed. Hence hydrologic models are normally used to simulate the watershed behaviour for a given input. These models take one time series data as input and generate another time series as output.

1.4.Remote Sensing and GIS in Hydrological Modeling

These days, remote sensing serves as an essential tool to gather data and information for hydrological modeling (Engman *et al*., 1991). Remote sensing has the ability to predict or determine precipitation, snow cover, soil moisture, evapotranspiration and water quality spatially. In addition, satellite images can give details about properties of watershed (e.g. topography, stream network properties). Precipitation is a primary component in the hydrological cycle and remote sensing has the ability to give precipitation estimation where rain gauge observations are limited. There are various remotely sensed methods to estimate the precipitation (e.g. Microwave-link methods, Artificial Neural Network methods). The geographical information system (GIS) is also combined with remote sensing in order to analyze various forms of data with the same geographic state. Remote sensing can provide the desired data for GIS, following which and then the analyses can be accomplished in the GIS. Nowadays, several hydrological models are being interfaced with GIS for easy analysis of data. ArcSWAT is a SWAT interface with ArcGIS and gives more provisions for a user to tackle the hydrological problems. For example, spatial data like DEM, land use and soil can be fed into the interface model through the GIS.

1.5.Impact of Land Use/ Land Cover Changes

Land cover data gives an estimate of how much of an area is covered by forests, vegetation, impervious surfaces, wetlands and other land and water types. Water types consists of open water or wetlands. Land use gives an idea about how the landscape is being used by people – whether for development, conservation, or for mixed uses. Quantifying the impacts of land use change and land cover practices on the hydrological response of a watershed has been an area of interest for the hydrologists in recent years as this information could serve as a basis for developing sound watershed management interventions (Ayana *et al.*,2014). The effects of land use and land cover changes on the hydrological response of a watershed are most likely where the surface characteristics of a watershed undergoes alternation due to changes. The degree and type of land cover influences the rate of infiltration, runoff, and consequently the volumes of surface runoff and total sediment loads transported from a watershed. It often results insignificant degradation of land resources such as loss of soil by erosion, nutrient leaching and organic matter depletion. For example, land use change can result in change of flood frequency, flood severity, fluctuation in base flow, and change in annual mean discharge. Moreover, land use change has a direct effect on land management practices, economic health and social processes of concern at regional, national and global levels.

1.6.Environmental Flow Assessment

The increasing threat of freshwater resources due to anthropogenic activities, both in terms of exploitive and non-exploitive use has led to the establishment of science of environmental flow assessment which comprises of determination of quality and quantity of water for conservation of ecosystem and protection of resources. In a developing country like India with increase in population and water demand stabilising the necessities of the aquatic environment and other uses is becoming essential as in many of the river basins of the world. Environmental requirements are usually represented as a suite of flow discharges of definite magnitude, timing, frequency and duration.

Environmental flows can be defined as ecological acceptable flow regimes which are designed to maintain river in agreed or predetermined state and sustain intricate set of aquatic habitats and ecosystem activities. In the recent years many techniques have emerged to determine these requirements commonly known as environmental flow assessments. The four general categories classified on the basis of techniques used in assessment of environmental flow regime are hydrological, hydraulic rating, holistic methodologies and habitat simulation and frameworks. These methodological categories differ significantly in accuracy, required input information, range and costs of implementation and hence are suitable for various categories of assessment of environmental flow regimes. Q_{m}, Q_{5} and Q_{95} are the three major categories of stream flow regimes normally used in environmental flow assessment. Q_{m} is the mean annual stream flow which corresponds to long-term availability of stream flow, Q_{5} corresponds to high flows which are the flows exceeded 5% of the time within a year and Q_{95} corresponds to low flows which are the flows exceeded 95% of the time within a year.

However for a developing country like India an alternative rapid assessment method popularly known as the **Shifting Flow Duration Curve (FDC) Technique** has been formulated taking into consideration the constraints of obtainable hydrological and ecological details at present in India. It is also ensured that the components of natural flow variability are conserved in the evaluated environmental flow time series as suggested by the contemporary hydro-ecological theory. The concept of flow duration curve which is a cumulative function of monthly flow time series forms the basis of this method which has been described in detail in the later chapters.

In this present study an attempt has been made to use the SWAT model to find the land use change impact on the water resources of Budhabalanga River basin which is a tributary of Subarnarekha river. This is a very much important river to satisfy the water demand (Irrigation, Industrial and Municipal demand) of Odisha to simulate the hydrological response of a river basin in an efficient way depending upon the catchment characteristics. Further the observed and calibrated monthly flows of the SWAT model have been implemented in Environmental Flow Assessment i.e. the Shifting FDC Technique to determine the type of changes the ecosystem has undergone and thus the applicability of the model has thus been evaluated for Indian watersheds.

1.7.Significance and Objectives for the Research

As discussed, hydrological modelling in any catchment; gauged, partially gauged or ungauged gives us an idea about the catchment features and its responses.

The objectives of the present study are as follows

1. To estimate the daily and monthly stream flow in Subarnarekha river basin by using SWAT model.
2. To calibrate and validate the SWAT model against daily and monthly stream flow using SUFI-2 algorithm.
3. To analyze the impact of land use/land cover changes in the basin for the past decade using remote sensing and GIS techniques.
4. To analyze the impact of hydrological changes on streamflow of the basin for the past decade.
5. To determine the impact of changes in stream flow pattern on ecology using shifting FDC approach.

1.8.Thesis Outline

Chapter 01 gives an introduction to surface runoff, land use/land cover changes, environmental flow assessment, importance of hydrological modelling and application of remote sensing and GIS in modelling and objectives of the present work.

Chapter 02 gives details regarding the previous research work regarding hydrological modelling and the models used in various basins of the world.

Chapter 03 describes about the geographical extent of study area and its features. It also gives a description about the data set used in SWAT model.

Chapter 04 gives an insight about the use of SWAT model to simulate runoff and the use of SWAT-CUP tool to calibrate and validate it. It also describes the technique used for environmental flow assessment.

Chapter 05 describes the results obtained from the current study and analysis about the same.

Chapter 06 describes important conclusions derived from the use of SWAT model to estimate the runoff.

CHAPTER 02

2. LITERATURE REVIEW

2.1.Hydrological modelling

Beven *et al.*, (1979) stated hydrologic models to be mathematical or symbolic depiction of assumed or known functions which expresses the different elements of a hydrologic cycle.
Cheng *et al.*, (2001) mentioned that rainfall, ground water and runoff are the prime elements of a water system in any region. The interaction and complexity of these subsystems relies on various factors like hydrological, geological, geographical and environmental features of the region.
Schultz, (1993); Seth, (2008) stated that hydrological modelling is a robust method of inspection of hydrologic system for the practicing water resources engineers and hydrologists who are engaged in the development and planning of assimilated method for water resources management.

2.2.Regarding various Hydrological models used

Sherman (1932) used the principle of superposition to introduce the concept of Unit Hydrograph. Many assumptions could be deduced from the superposition principle though this was not a common method at that point.

Box and Jenkins (1976) used the autoregressive moving average (ARMA) technique to express the unit hydrograph. This technique subsequently led to the use of a widely implemented technique, Artificial Neural Network (ANN).

Williams *et al*.(1985) developed a model called SWRRB (Simulator for Water Resources in Rural Basins) for simulation of hydrologic and associated processes in rural basins. The objective in model development was to predict the outcome of decisions of management on sediment yields and water with acceptable precision for ungauged rural basins all over the United States. The three basic elements of SWRRB are hydrology, weather and sedimentation.

Bouraoui *et al*.(1986) established ANSWERS-2000, a non-point source pollution management model for simulation of long-term mean annual sediment yield and runoff from agricultural catchments. The ANSWERS model which is even based is the basis of this model and is meant for application without calibrating it.

Dawson *et al*., (2001) classified rainfall-runoff models to be deterministic (physical), mathematical and parametric (empirical) models.

Yuan *et al*.(2001) implemented the Annualized Agricultural Non–Point Source Pollutant Loading model (AnnAGNPS). The purpose of this study were to collect all required information from the Mississippi Delta Management System Evaluation Area (MDMSEA) Deep Hollow watershed so that AnnAGNPS can be validated, and evaluation of the potency of BMPs can be done for reduction of sediment with the validated data.

Ming-Shu *et al*. (2004) used the newly developed GIS interface for Annualized Agricultural Non–Point Source Pollutant Loading model (AnnAGNPS) and implemented it in Redrock Creek Watershed, Kansas, a small agricultural watershed. The calibrated model accurately made simulation of monthly runoff and sediment yield with the exercises in the study and suggested the potential methods of sediment reduction by evaluation of the modifications of land use and operations in the model for the aim of management of watershed.

Rostamian *et al*.(2008) used Soil and Water assessment tool (SWAT) for modelling of runoff and sediment in the Beheshtabad (3860 km2) and Vanak (3198 km2) watersheds in the northern Karun catchment in central Iran. Runoff and sediment data of four hydrometric stations in central Iran in each basin were calibrated and validated which gave good results. Similarity was found between discharge and estimated runoff data.

Yang *et al*., (2008) made a comparison between uncertainty techniques by determining the similarity and differences between them by using SWAT model in Chahoe basin in China. He used uncertainty analysis procedures such as SUFI2, GLUE, ParaSol and MCMC for the same

Mueller *et al*. (2009) implemented the the procedure-based, spatially semi-distributed WASA-SED model for the meso-scale Canalda catchment in Catalonia, Spain the changes in land-use pattern were modelled for the last 50 years with successive impact on water and sediment transport. This model was found to be efficient in quantification of the effect of actual and potential environmental changes, but the dependency of the simulated results is still bounded by noteworthy parameterisation and model uncertainties.

Loi (2010) used SWAT model for assessment of factors leading to water discharge and reservoir sedimentation in Dong Nai watershed, Vietnam. The results depicted that the land use change and practices influenced the surface runoff and sediment yield loading to Tri An reservoir.

Nunes *et al*., (2011) studied the responses erosional and soil hydrological parameters to different land use and cover types in a small region of Portugal. The results depicted remarkable hydro geomorphic responses within land uses/covers which indicated that runoff and soil erosion were most predominant in arable land and coniferous afforestation.

Lin Jing *et al*.(2012) checked the suitability of SWAT for simulation of runoff and sediment load of Zhifanggou watershed simulated in hilly-gullied region of China. The model results for daily runoff simulation were satisfactory, but the runoff for high -flow events was underestimated for the model. The pattern of sediment load was well captured by the model but the sediment load was underestimated for both calibration and validated periods.

Mamo *et al*. (2013) applied SWAT model for Gumera catchment, Ethiopia. The evaluation coefficients for performance of model were found to be reasonable for both runoff and sediment yields with limited availability of data.

Ayana *et al*. (2014) used SWAT model in Fincha watershed, Blue Nile to predict the effects of land use and management practices on runoff and sediment yields. The model gave satisfactory estimation of runoff and sediment yield as depicted from the calibrated results.

Shrestha *et al*. (2015) used SWAT model to analyse the impact of land use changes on runoff and sediment yield in Da River Basin of Hoah Binh province, Northwest Vietnam. The results showed that SWAT was adequately capable of simulation of runoff and sediment yield as depicted from Nash-Sutcliffe Efficiency, percentage bias and Observation's Standard Deviation Ratio values. Vegetation significantly effects the runoff and sediment yield of the area.

Son *et al*. (2015) assessed runoff discharge and sediment yield from Da river basin in the north west of Vietnam using SWAT model. As per the Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS) and Observation's standard deviation ratio (RSR) values SWAT was found to adequately simulate the runoff and sediment yields.

2.3.Regarding Studies on Indian Catchment

Bhaskar *et al*., (1997) implemented the physically based rainfall-runoff methods to derive the Geomorphological Instantaneous Unit Hydrograph (GIUH) from watershed geomorphological characteristics and then found a relation between it and the Nash instantaneous unit hydrograph.

(IUH) model's parameters in order to derive its complete shape. This technique was been applied to the Jira river sub-catchment of eastern India for simulation of floods from 12 storm events. Results for both these methods were similar to observed events.

Seth., (1997,1998) used Hydrological Simulation Model (HYMSIM) to generate daily flow in Brahmani and Rushikulya river basin of Odisha.

Tripathi *et al*., (2003) used SWAT in Nagwan watershed in order to identify and prioritize the critical sub-watersheds and developed a adequate management plan.

Rees *et al*., (2004) performed a study in the ungauged catchments of Nepal and Himachal Pradesh to estimate the dry season flows by developing a hydrological model with the help of recession curves.

Gosain *et al*., (2006) used SWAT model and HadRM2 daily weather data to assess the effect of climate change on water resources of Indian rivers. Over 12 Indian river basins were considered to simulate the stream flow using 40 years of simulated weather data.

Raghuvanshi *et al*., (2006) used Artificial neural network (ANN) models for prediction of runoff and sediment yield, for a small agricultural watershed in of Upper Siwane river, India on daily and weekly time scale. Those ANN models which had a double hidden layer were found to perform better than those with one hidden layer. When the input variables and neurons increased the prediction performance of the model also enhanced. Training and testing results showed that the daily and weekly runoff and sediment yield were adequately predicted by the model.

Gajbhiye *et al*., (2012) used NRSC-CN method and remote sensing and GIS techniques to determine the effect of slope on CN values and runoff depth for Bahmani catchment situated in Mandla district of Madhya Pradesh.

Roy *et al*. (2013) used viz., Hydrologic Modelling System, a catchment simulation model to predict the hydrologic response of Subarnarekha river basin in Eastern India. The tension zone storage, soil storage, and groundwater 1 storage coefficient were found to be the most sensitive parameters for stream flow simulation. The model performed well for simulation of runoff and quantification of water.

Singh. V., *et al*., (2013) implemented SWAT in Tungabhadra Catchment in India for stream flow measurement. The model gave excellent results for monthly calibration time steps and good results for daily calibration time step between the observed and simulated data.

Patil *et al.* (2014) simulated stream flow in Bhima River basin using SWAT model and calibrated the results with the built-in auto-calibration tool of SWAT in parameter optimization. Satisfactory agreement was found to exist between simulated and observed data as depicted from calibrated and validated results.

Kumar, P., *et al*., (2015) evaluated the impact of climate change on the geo-hydrological system of Subarnarekha river basin which has a notable influence on water balance component of an ecosystem. The SWAT model was used for simulation under monthly time step and the results were evaluated and interpreted with the help of statistical tools. The model was found to perform satisfactorily.

2.4.Regarding Environmental Impact Assessment

Tharme. (2003) studied the evolving trends and the global perspectives of environmental flows and stated various methods through which EFs can be analysed.

Pyrce (2004) used multi regression techniques for development of low flow regionalizations to predict low flows at ungauged catchments and in stream flow methods were applied to compute the base flows. The uses of hydrological low flow indices were described.

Smakhtin *et al*., (2005) reconstructed the unregulated flow regime and assessed the land use changes for the last 40 years for the Walawe river basin and hydrological reference condition was established. Following this the quantification of the environmental flow regime was carried out.

Blake (2006) performed hydrologic modelling in the Nam Songkhram river basin of Thailand and used it to assess the environmental flows of the river.

Smakhtin *et al*., (2006) examined the evolving trends of environmental flows in India and reviewed the developed desktop methods of EFA so that it can be used for preparatory planning purpose in other places.

Kiragu *et al*., (2007) conducted a study on Mara river, Kenya to analyse the effect of suspended sediment loadings on the environmental flows. The geomorphological features of the river basin were used and it was observed that the sediments were hindering the flow leading to turbid quality of water.

Jha *et al*., (2008) gave the environmental design flow values for various locations of Baitarani and Brahmani river basins and had recommended a suitable technique for assessing the EFs.

Jha (2010) used various methods like FDC, RVA, sediment yield etc and matched which method served the best purpose to maintain the ecological balance of a typical Indian catchment.

McCartney *et al*., (2013) quantified the flow regulating functions of moimbo forests, headwater wetlands and flood plains using a realistic method. In this approach the flow duration methods and monitored records of streamflow were exploited to establish a simulated flow time series and comparison was made with the observed series to examine the effect of ecosystem on flow regime.

CHAPTER 03

3. THE STUDY AREA AND DATA

3.1.The study area

The present study is conducted for Budhabalanga river which is a tributary of Subarnarekha River Basin that lies in the eastern part of India. The Subarnarekha River Basin, an interstate basin flows through the Indian states of Jharkhand, West Bengal and Odisha. About 49%, 13% and 38% of the rivers area falls in these three states respectively. Rising to the south of Simhpalgarh village in the Mayurbhanj district, the Budhabalanga river first flows in a northerly then south-easterly direction along the Balasore and Mayurbhanj district of Odisha and joins the Bay of Bengal. The Budhabalanga is about 175 kilometres long the major tributaries being the Gangadhar, the Sone, and the Catra.

A catchment area of Subarnarekha River basin has been considered as our study area which covers the gauging station of Govindpur (NH5 Road Bridge), situated in the Balasore district of Odisha. The geographical extent of this catchment is 4495 square kilometers spreading from longitude 86^0 06’ to 87^0 05’E and from latitude 21^0 29’ to 22^0 19’N.

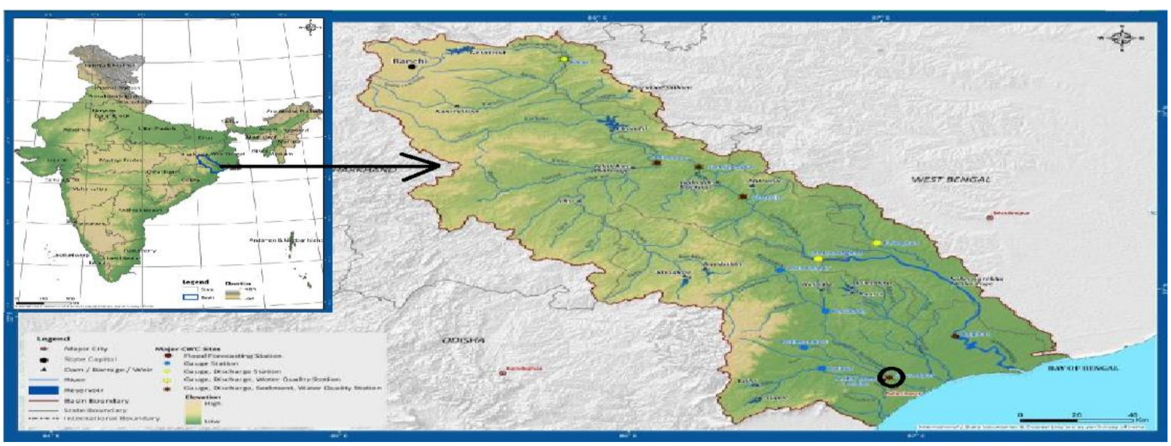


Figure 3.1.Location of study area (Source: India WRIS website).

Location of the study area is shown above in Figure 3.1. The digital elevation model and boundary of the study area is shown in Figure 3.2.

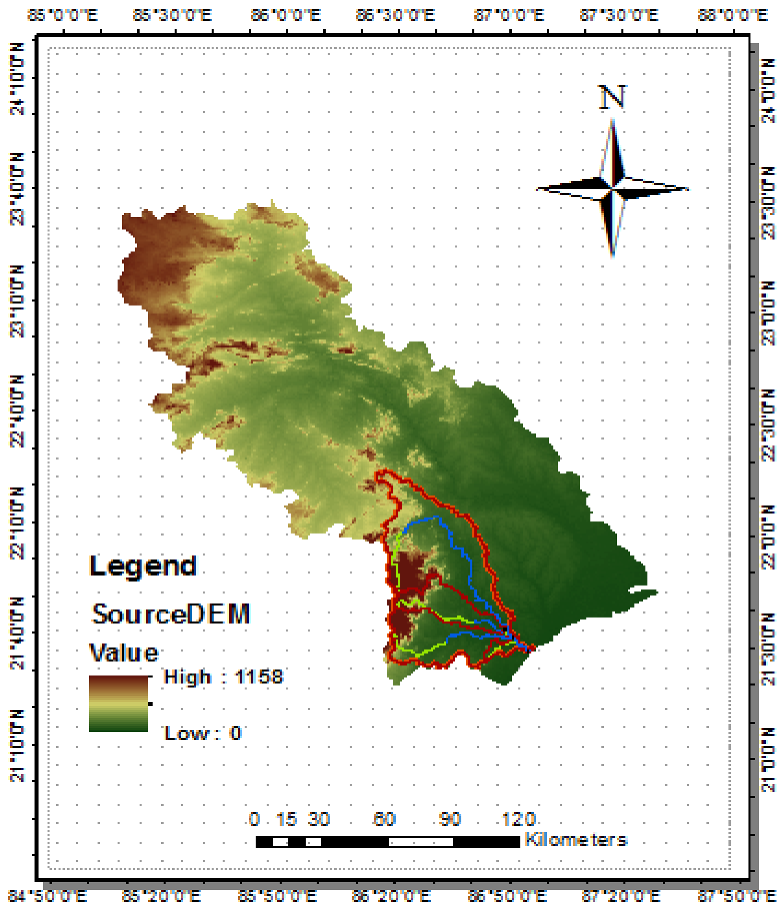


Figure 3.2. Sub basin of Subarnarekha river basin

3.1.1. Topography

The study area lies in the coastal plains of Balasore district of Odisha with a slope from north-west to south-east. Major part of the river basin falls under 50-150m elevation zone. Coal and ore deposits are found in plenty in this region

3.1.2. Climate

South-west monsoon prevails over the basin during the months of June to October. Abundant precipitation occurs during monsoons followed by long dry period. 15% of the rainfall contributes to infiltration and around 57% is lost through evapotranspiration (CWC report 2014). The maximum and minimum rainfall recorded till date for the area are 1,520 and 1,150 mm respectively with an average annual rainfall of 1400 mm. South-West monsoon which occurs during June to October contributes to around 90% of this rainfall. There is tremendous variations in precipitations, both annually and seasonally. There is a gradual increase in precipitation from the upper to lower part of the basin. The mean monthly temperature varies from 40.5°C in May to 9°C in December. 47.2°C is the highest temperature and 2.8°C is the lowest recorded till date for the area, the average annual maximum and minimum temperature being 32.4°C and 18°C respectively which has been represented below in Figure 3.3.

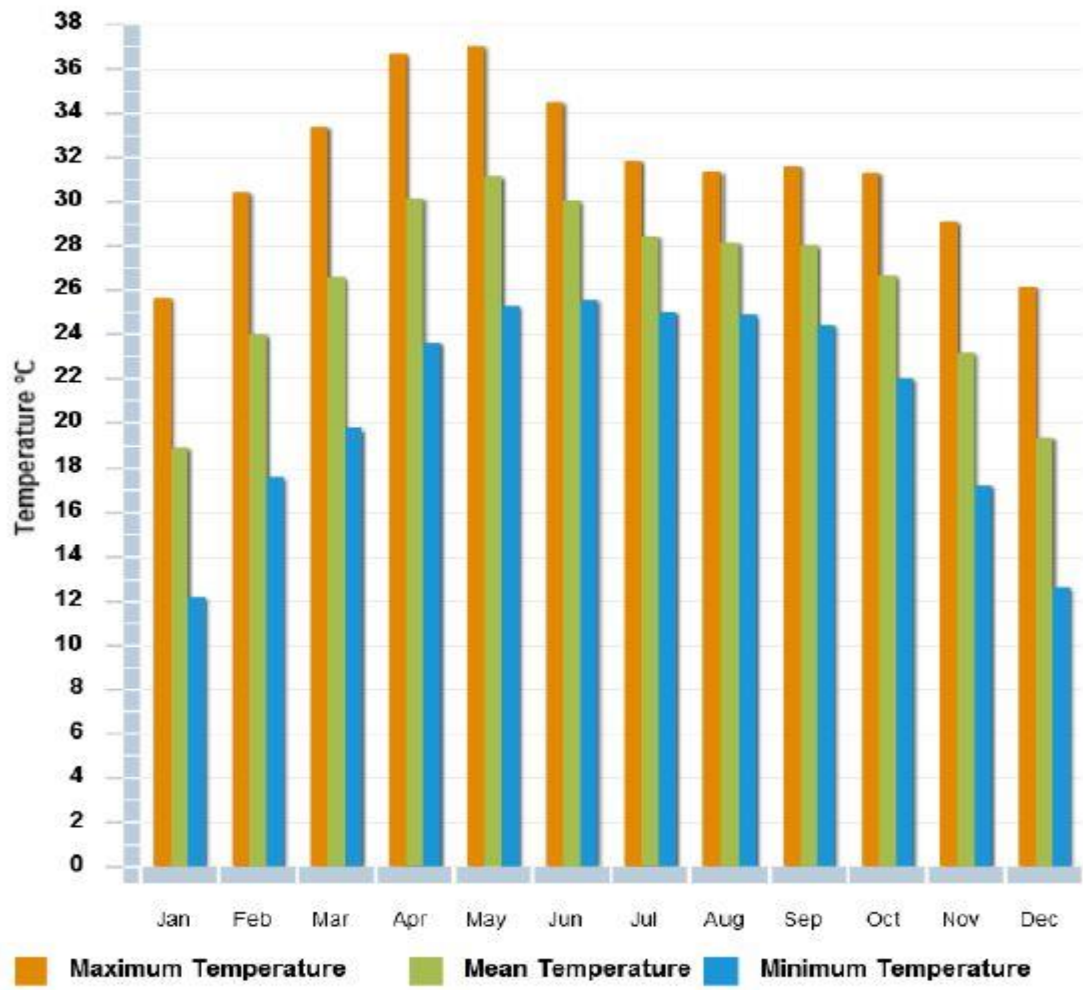


Figure 3.3. Average monthly maximum, mean and minimum temperature

Several regions of the basin, mainly the coastal areas of West Bengal and Odisha come within the flood prone zones. In 2009, flash floods occurred over the Subarnarekha basin followed by heavy rainfall was in the upper catchment area of the river. Large regions of Bhograi, Jaleswar and Baliapal blocks and some parts of Balasore district of Odisha were affected during floods leading to huge loss in life and property. The year 2011 also witnessed tremendous variations in precipitation. In fact floods have become quite frequent in the area for the past few years.

3.1.3. Land Use/ Land Cover

Agricultural land covers the major part of the basin (54%) followed by forested area (30%) which is mainly dominated by deciduous forests. The presence of alluvial soil in the basin attributes to extensive agriculture in the lower reaches of basin. The land use/ land cover in the region has not undergone very significant changes over the last decade with agriculture and forests covering the major part of the region. The built up area (8%), waterbodies (2.5%) and barren land (5.5%) are the other main categories of land use/ land cover of the area.

3.1.4. Soils

Around 80% of the basins consists of fine to medium textured soils. 12% of the basin comprises of rocky and other types of soils. About 23.74% and 1.4% of the basin area is influenced by severe soil erosion and very severe soil erosion respectively. Red sandy and lateritic soils are the predominant soils found in this area.

3.2.Data set for SWAT model

The terrain information, soil, land use data, daily precipitation, maximum and minimum temperature and discharge data are the major data sets required for the SWAT model. The daily precipitation, maximum and minimum temperature data are collected for six neighbouring recording stations near the study area of Govindpur and are averaged before being used in the model and the discharge data is collected from the gauging station of Govindpur (NH5 Road Bridge). The sources and description of data sets used have been presented in Table 3.1

Table 3-1. Data set for SWAT model

DATA TYPE	SOURCE	SCALE/ PERIODS	DATA DESCRIPTION
TERRAIN	SRTM digital elevation data produced by NASA	30m x 30m	Digital elevation model
SOIL	ISRIC-World soil information website	1/25000	Soil classification and physical properties
LAND USE	NSRC, ISRO Hyderabad	2004-2014	Landsat land use classification(19 classes)
CLIMATE	Indian Meteorological Department (IMD)	2000-2014	Daily precipitation, minimum and maximum temperature
DISCHARGE	Central Water Commiss-ion (CWC), Bhubaneswar	2000-2014	Daily discharge data at selected gauging station

CHAPTER 04

4. METHODOLOGY

This chapter gives an insight about use of SWAT model to simulate runoff and calibrate and validate the runoff using SWAT-CUP tool. The impact of land use changes on the runoff is assessed. The method followed for environmental flow assessment is described further. The details of the processes have been mentioned below.

4.1.Soil and Water Assessment Tool

The Soil and Water Assessment Tool (SWAT) is a continuous, long term, physically based conceptual model. This model operates at basin scale on daily time step (Arnold *et al*., 1998, 2000; Neitsh *et al*., 2001). It is a hydrologic model with Arcview GIS interface which has been developed by the USDA-ARS and the Blackland Research and Extension Centre (Arnold *et al.*, 1998). SWAT was developed from an earlier continuous time step model named Simulator for Water Resources in Rural Basins (SWRRB) (Williams *et al.*,1985, Arnold *et al.*, 1990) which simulated non-point source loading from watershed. This model has had wide application for modelling of watershed hydrology and for prediction of the impact of land management practices on water, agricultural chemical yields and sediment in small as well as large complex basins with varying land use land cover conditions and soil type over long periods of time.

In the SWAT model, the catchment is primarily divided into sub-basins or sub-watersheds based on topographic criteria followed by further division into a series of HRUs ie. Hydrological Response Units on the basis of unique soil, slope and land use combinations. Simulations can be carried out for components of hydrological cycles, nutrient cycles and sediment yield and then aggregated for the sub-basins. The SWAT model provides the users with various options when simulation is conducted for the hydrological processes, which can be selected based on the data availability.

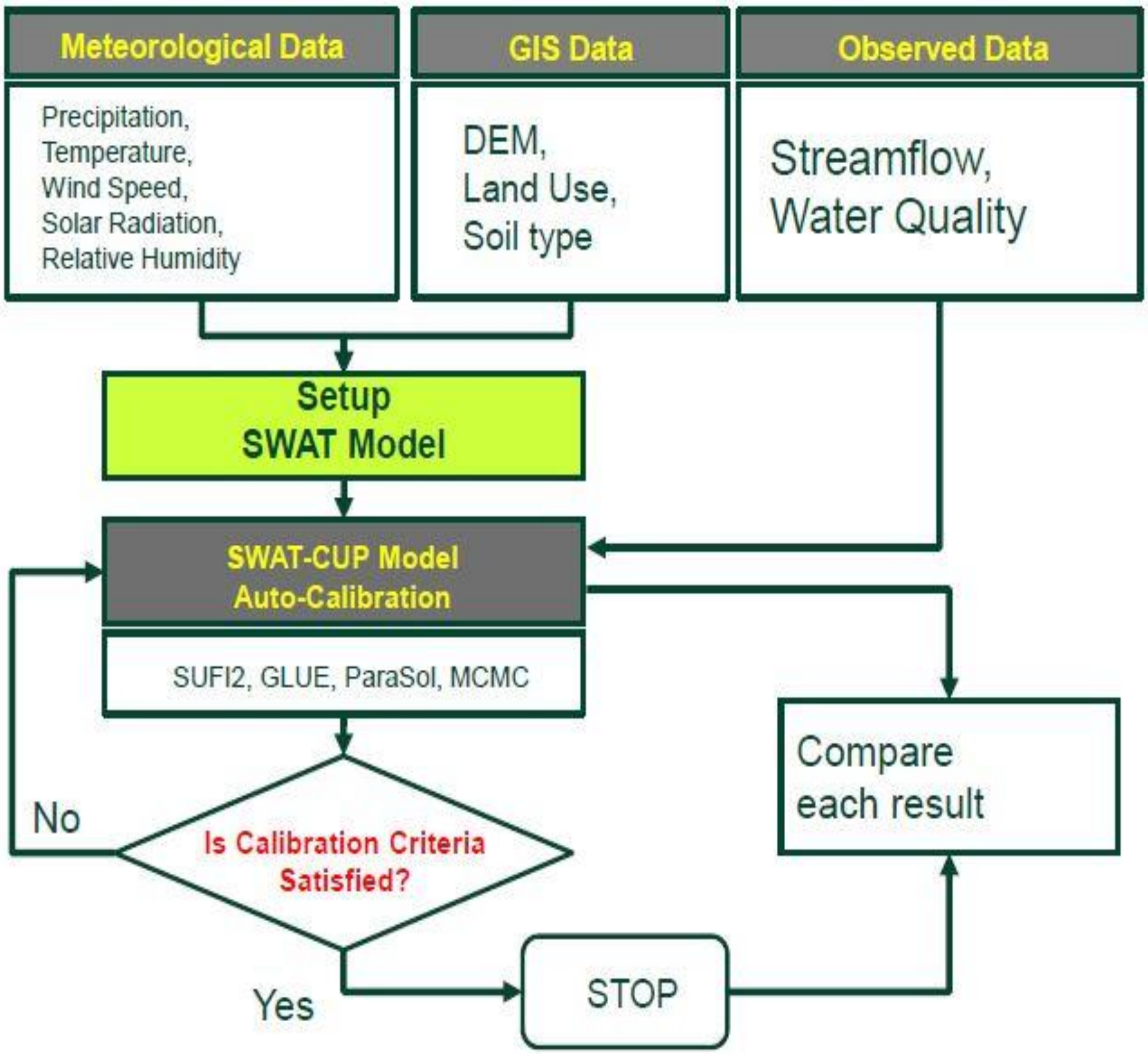


Figure 4.1.SWAT model Flow Diagram

Generally water enters in the form of precipitation into the SWAT watershed system. In the model flow routing and water quality parameters is carried out on the basis of HRU to each sub-basin and eventually to the outlet of watershed. In the current study SWAT 2012 model has been integrated with Arc GIS software to perform the simulation of the runoff yield of the study area.

- **Hydrologic water balance**

The simulation of hydrologic cycle within a watershed consists of a land phase and a water phase as shown in Figure 4.1 (Neitsch *et al.*, 2005). For the simulation of land phase water balance equation is the key, and calculation is done separately for each HRU. The water phase of hydrological cycle also referred as routing phase gives a description about the routing of runoff in the river channel. It is carried out either by using the Muskingum routing method or the variable storage coefficient method (Williams 1969). In the current project land phase equation has been used.

The climatic variables like precipitation, wind speed, maximum and minimum temperature, solar radiation, and relative humidity provide the energy and moisture inputs required for driving of the hydrologic cycle. These variables can be adapted from the measured time series at data recording stations or can be simulated by the weather generator. Processes like evapotranspiration, interception, infiltration, runoff and water movement in the soil profile are taken into account in a HRU. The following water balance system is implemented in SWAT to simulate the hydrological cycle within the watershed.

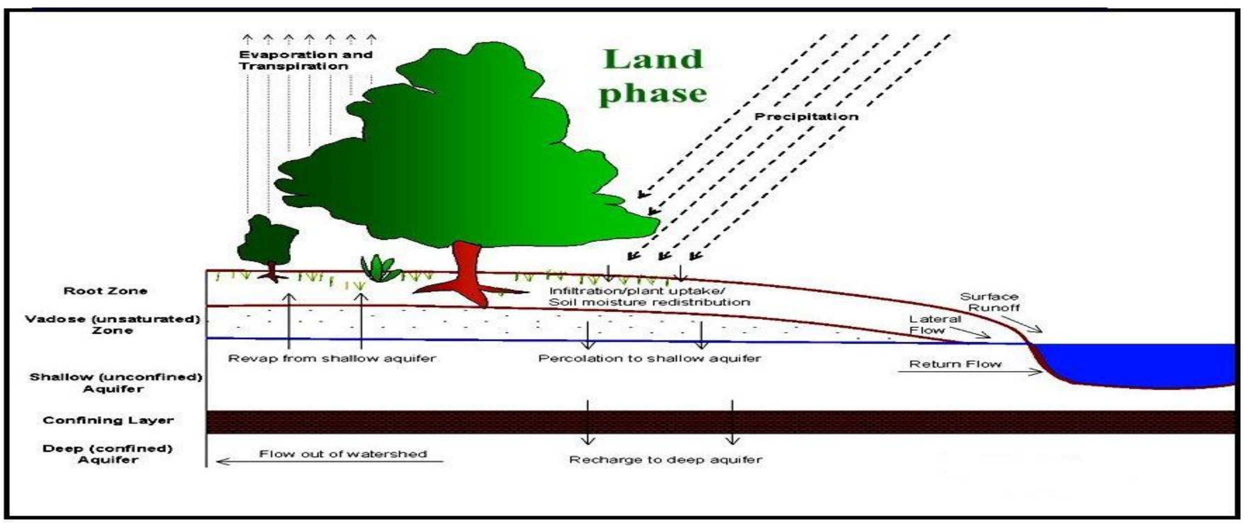


Figure 4.2. SWAT Hydrological cycle consideration (Source: Neitsch et al., 2001)

The water balance equation implemented in the model can be expressed in the following way

$$SW_t = SW_0 + \sum_{t=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad (1)$$

Where SW_t= Final soil water content in mm

SW_0= Initial soil water content on day i (mm)

R_{day}= Amount of precipitation on day i (mm)

Q_{surf}= Amount of surface runoff on day i (mm)

E_a= Amount of evapo-transpiration on day i (mm)

W_{seep}= Amount of water entering the vadose zone from soil profile on day i (mm)

Q_{gw}= Amount of return flow on day i (mm)

- **Surface Runoff**

The runoff from each HRU is predicted separately and routed for determination of the aggregate yield for the catchment separately in the SWAT model thereby increasing the precision and giving a improved physical description of water balance. The concept of infiltration excess runoff is used in SWAT 2012 where it is assumed that runoff takes place whenever the rate of infiltration exceeds the rainfall intensity. SWAT uses the soil conservation curve number method (SCS, 1972) and Green and Ampt infiltration method (1911) for estimation of surface runoff. In this particular study the soil conservation services (SCS) curve number has been implemented.

The soil and land use properties are merged into a single parameter in the SCS-CN method (White *et al.*, 2009). On the basis of infiltration properties of soil, the Natural Resources Conservation Service (NRCS) soil classification is used in SWAT (Neitsch *et al.*, 2005) where soils are categorized to four classes (A, B, C, D) with high, moderate, low and very low infiltration rate respectively. Permeability, average clay content, infiltration characteristics and effective depth of soil are some of the significant soil characteristics which effects the hydrological classification of soils. In this classification, under similar cover and storm condition a soil group has similar hydrologic classification. In the SWAT model the antecedent moisture condition is defined on the basis of Curve- Number Antecedent moisture condition (CN-AMC) (USDA – NRCS, 2004). This is done on the basis of soil moisture content calculated by the model (Neitsch *et al.*, 2005) to determine CN.

Antecedent moisture condition (AMC) is defined as the initial moisture content which exists in the soil at the start of the rainfall-runoff event under consideration. AMC governs the infiltration and initial abstraction. SCS recognizes three levels of AMC for the purpose of practical application which are mentioned below

AMC-I: Soils are dry but not to the wilting point

AMC-II: Average condition

AMC-III: Sufficient rainfall has occurred within the immediate last 5 days. Saturated soil condition prevails.

On the basis of total magnitude of rainfall during the previous 5 days, the limits of the three AMC classes have been depicted in Table 4.1. This depends up on two seasons 1) dormant season 2) growing season.

Table 4.1: AMC for determining the value of CN (Source: Engineering Hydrology)

AMC Types	Total rain in previous 5 days	
	Dormant season	Growing season
I	Less than 13 mm	Less than 36 mm
II	13 to 28 mm	36 to 53 mm
III	More than 28 mm	More than 53 mm

The variation of CN according to AMC-I, AMC-II, AMC-III are known as CN_I, CN_{II} and CN_{III} respectively. CN_{II} can be converted to the other two moisture conditions through the use of equations (2) and (3):

$$CN_I = CN_{II} - \frac{20.(100 - CN_{II})}{(100 - CN_{II} + exp[2.533 - 0.0636.(100 - CN_{II})])} \quad (2)$$

$$CN_{III} = CN_{II} - \ exp[0.00673.(100 - CN_{II})] \quad (3)$$

Using the daily CN value the retention parameter S is then depicted.

$$S = 25.49 \left[\frac{1000}{CN} - 10\right] \quad (4)$$

CN lies in the range of 100 ≥ CN ≥ 0. When value of CN is 100 it symbolizes a condition which has zero potential retention i.e. impervious catchment and value of CN 0 corresponds to an infinitely abstracting catchment with S=∞.

By integration of the above empirical equation with SCS runoff equation the direct runoff is determined.

$$Q_{surf} = \frac{[P_{day} - I_a]^2}{P_{day} - I_a - S} \quad (5)$$

Where Q_{surf} is the surface runoff or rainfall excess, P_{day} is the precipitation depth for the day, S is the retention parameter and I_a is initial abstraction normally taken as $0.2S$.

4.2.Model Setup

4.2.1. General

The model set-up was done with the help of ArcSWAT interface package that runs under ArcGIS environment. The set up consisted of preparation of the input data, delineation of watershed using the digital elevation model (DEM) data, HRU definition using soil, slope, land use and agricultural practice data, weather data definition and finally a test run of the model. It is followed by calibration and validation of the data considered.

4.2.2. Model Data Inputs

- **Meteorological Data**

Meteorological data is one of the most important datasets for analysis of watershed. Daily climate inputs for the time span of 2000-2014 including precipitation and minimum and maximum temperature were obtained from the Indian Meteorological Department. The parameters like wind speed, solar radiation and humidity were obtained from the weather generator tool of the ArcSWAT model when precipitation and temperature data were fed into it.

- **GIS data**

1. DEM (Digital Elevation Model)

Digital Elevation Model is the geographic grid of an area where the contents of each grid cell gives a description of the elevation of any point at a given location and specific spatial resolution in form of a digital file. It is one of the essential spatial input essential for delineation of watershed in to a number of sub basins on the basis of elevation in SWAT model. In this work, a DEM map of 1:50,000 scale and a 30m x 30m resolution has been obtained from SRTM digital elevation data produced by NASA originally in form of tiles from the world data base. These tiles have been mosaiced to obtain a single map. A shape file was created for the river basin considered by us with the help of ArcGIS software which was then clipped in the mosaicked DEM map to obtain the required DEM of the Subarnarekha river basin.

2. Soil Data

Soil data acquired from ISRIC-World soil information website was used to generate soil input data for the model. The global soil map was clipped with the shape file of the river basin to obtain the soil map of the required area.

3. Land Use Data

The land use maps for Odisha, Jharkhand and West Bengal were obtained from NSRC,ISRO Hyderabad and mosaiced to obtained a single map which was again clipped with the shape file to obtain the required land use map of the Subarnarekha river basin. Originally NSRC classifies the land use into 19 classes which was reduced to 5 categories with the help of supervised classification in ArcGIS software to reduce the number the HRUs and easy interpretation.

Supervised classification is a method of classification in which thematic classes are defined by spectral characteristics of pixels within an image corresponding to training areas in the field chosen to represent known features. The 5 major categories were build up area, agricultural land, forest cover, waterbodies and wasteland. The land use data of 2004-05, 2008-09 and 2013-14 was collected and has been considered for the analysis after the required processing as described above.

4. Slope Data

Watershed slope refers to the rate of change of elevation with respect to distance along the principal flow path. After the delineation of the principal flow paths, the watershed slope is obtained from the difference in elevation between the end points of the principal flow path divided by the length of the flow path. In this particular study, the slope of the watershed was discritized into 5 classes for varying elevations viz, 0-5m, 5m-20m, 20m-50m, 50m-100m and 100m-9999m.

- **Observed Data**

The daily discharge data for the considered catchment was obtained for the time period January 2000 to May 2014 from Central Water Commission, Bhubaneswar. This set of data was used for comparison with set of simulated data generated by the SWAT model and for further calibration and validation.

- 15 years of data have been considered in this particular study.
- Two model runs have been performed here, one for the calibration period where the land use map of 2004-05 has been considered, and another for the validation period where the land use map of 2013-14 has been considered.
- Number of years to skip (NYSKIP) i.e. Warmup period = 3 years (2000-2002).
- Calibration period = 8 years (2003-2010)
- Validation period =4 years (2011-2014).
- The model simulation has been done using ArcSWAT model following which the calibration and validation of the model has been done using SWAT CUP tool using SUFI-2 (Sequential Uncertainty Fitting version 2) algorithm.

4.2.3. Model Simulation

The entire process of simulation basically involves five steps namely SWAT project setup, watershed delineator, HRU analysis, writing input tables and lastly SWAT simulation which have been described in detail below.

- **Watershed Delineation**

Delineation implies creation of a boundary that depicts a contributing area for a particular outlet or control point. In this process of delineation, watershed is divided into discrete land and channel segments for the analysis of behaviour of the watershed. In Arc SWAT the user is provided with the watershed delineator for delineation of the watershed and sub basins with the help of DEM. On the basis of DEM data stream definition was done followed by flow direction and accumulation due to which stream network and outlets were created.

- **HRU definition**

A Hydrological Response Unit (HRU) is defined as a unique combination of various land use, land cover, soil and slope classes. In HRU definition 100% overlapping of the land use map as well as the soil map is done with the delineated watershed and different slope classes are incorporated as well for classification of HRU. This resulted in creation of 5 sub basins and 24 HRUs.

Watersheds ⟶ **Subbasins** ⟶ **HRUs (Hydrological Response Units)**
unique LU/LC, soil, slope combinations

- **Weather data definition**

The obtainable meteorological data (i.e. precipitation, maximum and minimum temperature) and location of the six meteorological stations located near the study area are prepared in the SWAT format and integrated with the model using weather data input wizards. The wind speed, solar radiation and relative humidity data for the stations were generated using the weather generator tool.

Following this the input tables were written, and the model was setup and model run was performed on daily and monthly time step. For further analysis of result, the applicability of the model should be evaluated through the process of sensitivity analysis, calibration and validation (White and Chaubey, 2005) for the intended purpose.

4.3. Sensitivity Analysis

The influence of different parameters on simulation result, i.e. the response of output variable to a change in input parameter is evaluated through the sensitivity analysis (White and Chaubey, 2005). It is often difficult to determine which parameters to calibrate such that it reflects the field parameters as closely as possible. In such situations sensitivity analysis helps to identify and rank the parameters which have noteworthy effect on specific model outputs of interest (Saltelli *et al*., 2000). The most sensitive parameters correspond to the greater change in the output response. Initially 14 parameters were considered which were thought to influence outputs. After an initial iteration run of model, the most sensitive parameters were identified and only those parameters were adjusted so that the calibration efficiency can be improved and calibration variances can be minimized in the study area.

4.4. Model Calibration and Validation

Calibration followed by validation was done in order to maximize the model efficiencies and finally using the parameter values obtained through those calibration techniques. Model calibration comprises of modifying the input function and comparing the estimated output with the observed values until the achievement of a definite objective function(James and Burges, 1982). Only those parameters having noteworthy impact on the simulation result which have been identified in sensitivity analysis have been used in calibration of the model. In this research, sensitivity analysis of the model, calibration and validation has been done using the SWAT-CUP (SWAT Calibration Utility Program) tool.

SWAT- CUP was developed by Eawag* Swiss Federal Institute, to analyze the prediction uncertainty of SWAT model calibration and validation results. It provides the user to make a choice between a number of algorithms to perform the calibration such as **SUFI2** (**S**equential **U**ncertainty **Fi**tting ver.**2)**, **GLUE** (**G**eneralized **L**ikelihood **U**ncertainty **E**stimation), **MCMC** (**M**arkov **C**hain **M**onte **C**arlo), **ParaSol** (**Para**meter **Sol**ution),. In this study SUFI2 has been used as the calibration algorithm since it has been widely used popular calibration tool and has achieved good calibration and uncertainty results. In SUFI2 the uncertainty in parameters portrays all sources of uncertainties like uncertainty in parameters, conceptual model, driving variables (e.g., rainfall) and measured data.

Several iterations of 500 simulations each were carried out for the calibration period of 2003-2010 for daily and monthly flows by adjusting the sensitive parameters obtained through sensitivity analysis until the shapes of predicted and measured stream flows were found to be in reasonable agreement and the criteria of objective functions are satisfied. To test the ability of the model to predict the system response, the model was validated using daily and monthly measured stream flow data for 2011-2014 without changing the calibrated parameters.

- **Abbreviations used in SWAT-CUP :**
  1) **95PPU**: **95 P**ercent **P**rediction **U**ncertainty, This value is calculated for the 2.5% and 97.5% levels of an output variable, and 5% of the very bad simulations are disallowed.
  2) **Objective Function:** Nash-Sutcliffe efficiency (NS),Coefficient of determination (R^2), Root Mean Square Error (RMSE) etc.
  3) **p-factor**: It represents the percentage of observations which comes under the 95PPU.
  4) **r-factor**: Represents the relative width of 95% probability band.
  5) **t-Stat**: Provides a measure of sensitivity, larger absolute values are considered to have higher sensitivity.
  6) **P-Value**: Determination of the significance of sensitivity. A value is more significant if it is close to zero.

- A simulation in which P-factor is 1 and R-factor is zero exactly corresponds to measured data.

- **Model Performance:**

The consistency, adaptability performance and accuracy of the model must be evaluated (Goswami *et al*., 2005). The performance of the model can be assessed by subjective and/or objective estimate of simulated result to that of observed data. Nash-Sutcliffe efficiency and Coefficient of determination have been used as the efficiency criteria to evaluate the performance of models in this study. The performance of model is acceptable and is considered satisfactory when coefficient of determination $R^2 \geq 0.65$, Nash Sutcliffe efficiency NSE ≥ 0.5 and PBIAS lies between -20 to +20 (Moriasi *et al.*, 2007).

1. Coefficient of determination (R^2) :

It is a value that depicts how well a data fits into a statistical model. The range of coefficient of determination lies between 0 and 1. When R^2 is 1 it can be depicted that the regression line perfectly fits the data, while an R^2 is 0 indicates that the line does not fit the data at all**.**

$$R^2 = \frac{[\sum_{i=1}^{n}(Q_{si} - Q_{sm})(Q_{oi} - Q_{om})]^2}{\sum_{i=1}^{n}(Q_{si} - Q_{sm})^2 \sum_{i=1}^{n}(Q_{oi} - Q_{om})^2} \tag{6}$$

Where Q_{si} is the simulated value, Q_{oi} is the measured value, Q_{om} is the average observed value and Q_{sm} is the average simulated value.

2. Nash Sutcliffe efficiency (NS) :

The Nash–Sutcliffe model efficiency coefficient is used to depict the predictive power of hydrological models. The Nash-Sutcliffe efficiency has a range between -∞ to 1. When efficiency is equal to 1 it indicates a perfect match of estimated discharge with the observed data whereas an efficiency of 0 suggests that the predictions of model are as accurate as the observed data's mean, while an efficiency which is less than zero ($E < 0$) corresponds that the observed mean is a better predictor than the model

$$NS = 1 - \frac{\sum_{i=1}^{n}(Q_{oi} - Q_{si})^2}{\sum_{i=1}^{n}(Q_{oi} - Q_{om})^2} \tag{7}$$

Where $Q_{oi}$is observed, Q_{si} is the simulated and Q_{om} is the observed average values.

3. Percentage bias(PBIAS) :

It is the deviation of simulated data from observed data being evaluated, which is expressed as percentage. The low magnitude values indicates accurate simulation of model.

4.5. Model Applications

To assess the impact of land use and land cover changes on runoff for the years 2004-05, 2008-09 and 2013-14, the modeled discharges obtained from calibrated and validated models under the land use scenarios of 2004-05 and 2013-14 respectively were compared with the observed discharges of the three years considered to analyze how well the model is able to predict the discharge under varying land use scenarios and analyze the effect of these changes on runoff.

4.6. Environmental Flow Assessment

Smakhtin and Anputhas (2006) proposed a variant of the flow duration curve method for data deficient situation such as those in India where practically all river discharge data are either restricted or classified for a variety of reasons and the ecological data of the river biota are also very poor. Based on monthly discharge time series of the unregulated river (observed and modelled), a naturalized FDC is produced and how much the flow can be modified for a specified desired condition of a river is calculated in this technique. The FDCs are then potrayed by a table of flows corresponding to 17 fixed percentage point: 0.01, 0.1, 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 99, 99.9 and 99.99 percent to cover the entire range of flows. Environmental management class (EMC) refers to the desired or negotiated condition of the rivers. More water with greater flow variability is required for higher EMC for ecosystem maintenance or conservation. The rivers in India are placed into one of the six EMCs, by expert judgment similar to those identified in South Africa (DWAF, 1997). These classes are purely conceptual and does not depend on any empirical relationship between flow and ecological conditions (Puckridge *et al*., 1998). These were: unmodified and largely natural (class A), slightly modified (class B), moderately modified (class C), largely modified (class D), seriously and critically modified (classes E and F).

The FDC for each class is produced by shifting the FDC which is considered for reference to the left. Here the reference FDC is considered to be class A river and hence for class B river the default environmental FDC is determined by shifting the class A by one step, for class B by two steps and so on. The mentioned 17 percentage points have been used as the steps in this shifting technique. A FDC shift by one step implies that the flow which was exceeded 99.99 percent of time in the original FDC will now be exceeded 99.9 percent of time, the flow at 99.9 percent becomes flow at 99 percent and so on. A linear extrapolation has been used for the definition of the ‘new low flows’. A low flow corresponds to the flow which has been exceeded 95% of the time (95 percentile on FDC).

A FDC shift to the left implies several things:

- The general order of variability of flow is preserved although a part of it is lost with every shift.
- This loss can be attributed to the lowered reliability of monthly flows, i.e. same flow will exist less frequently.
- The aggregate amount of environmental flow is reduced.

In this study the shifting FDC technique is implemented to determine how much modification a river has undergone over a period of time and whether the SWAT model is successfully able to capture this modification. The monthly flows between the time period of 2000 to 2007 are considered to determine the reference flow duration curve for the 17 fixed percent points and is referred as class A flow. Following this the FDC for other 5 classes i.e. class B to class F is produced by the shifting flow duration curve technique. Thereafter a FDC for the flows between the time period of 2008-2104 is determined for the 17 fixed percentage points and is compared with six predefined environmental management classes to determine the type of modification the river ecosystem has gone through over the period of time.

CHAPTER 05

5. RESULTS AND DISCUSSION

This chapter consists of five sections: (a) sensitivity analysis of the flow parameters, (b) simulated, calibrated and validated results of SWAT model and SWAT-CUP tool, (c) analysis of impact of land use changes and climatic changes and (d) environmental impact assessment of the observed and modelled discharge.

5.1.Maps obtained from input data

The DEM map, land use map, soil class map and slope class may have been represented below in figures 5.1, 5.2, 5.3 and 5.4 respectively.

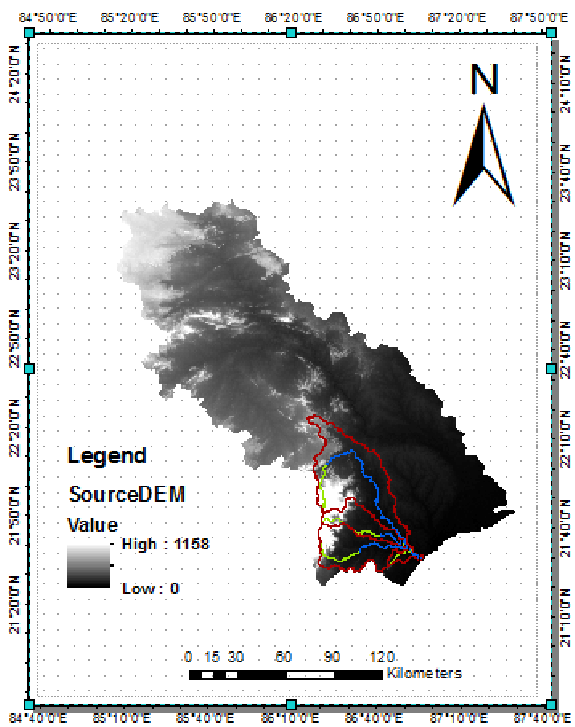


Figure 5.1.Source DEM

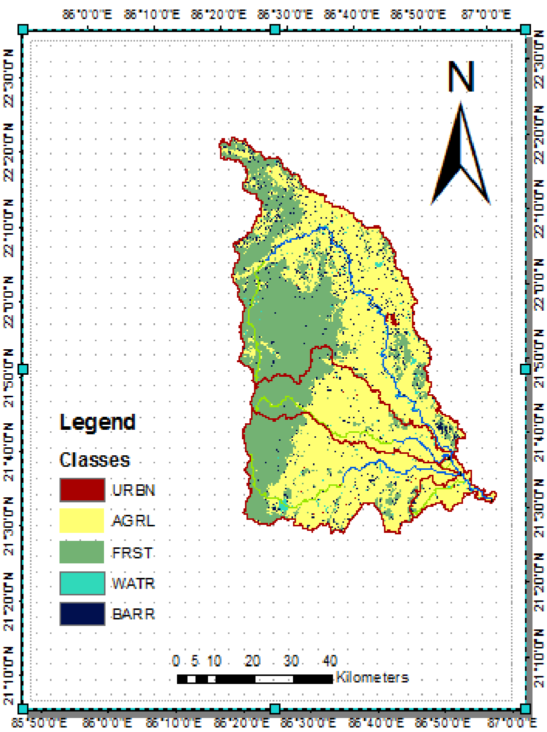


Figure 5.2.Land Use Class

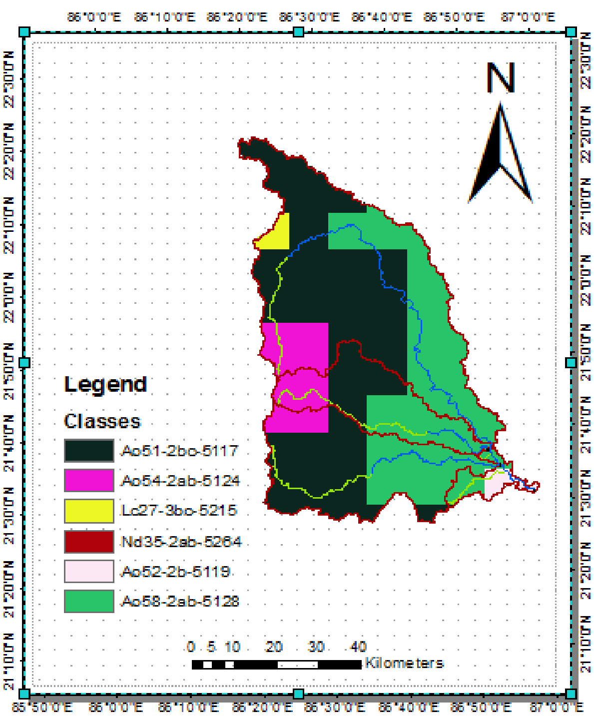


Figure 5.3. SWAT Soil Class

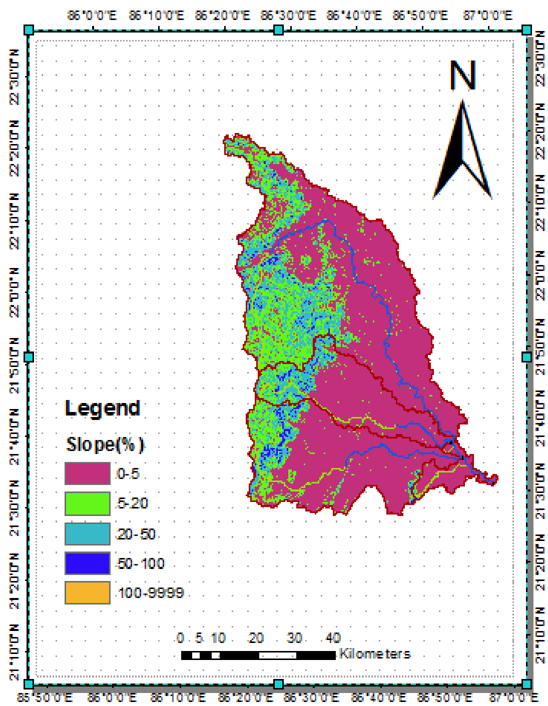


Figure 5.4. Slope Class

Delineation of the map has been carried out using ArcSWAT tool interfaced with ArcGIS followed by HRU definition. Figure 5.1 shows the DEM of the area which covers the elevation ranging from 0 to 1158m. Five land use classes are present as shown in Figure 5.2. Six soil classes have been defined following the SWAT soil codes as represented in Figure 5.3. Figure 5.4 shows five slope classes taken into consideration thought the average slope is found to be within range of 5m to 150m.

5.2.Sensitivity Analysis

Fourteen parameters were considered and sensitivity analysis was done to identify the most sensitive parameters. The sensitive parameters were further adjusted to carry out further calibration. The range of various flow calibration parameters were considered by referring to the SWAT CUP user manual and by literature review of the previous studies. The description, ranges of the parameters and their best fitted values used in the SWAT-CUP tool for the considered catchment have been represented in Table 5.1

Table 5-1. Ranges and best fitted values of flow calibration parameters

SL	FLOW CALIBRATION PARAMETERS	QUALIFIER	MINIMUM	MAXIMUM	FITTED VALUE
1	Curve Number (CN2)	r_	-0.5	0.5	-0.035375
2	Base flow alpha factor (ALPHA_BF)	v_	0	1	0.119868
3	Groundwater delay(days) (GW_DELAY)	v_	30	350	199.57
4	Threshold depth of water(mm) (GWQMN)	v_	0	5000	4316.364
5	Groundwater revap coefficient (GW_REVAP)	v_	0.02	0.3	0.472723
6	Soil evaporation compensation factor (ESCO)	v_	0.01	1	0.589846
7	Manning’s n value for main channel (CH_N2)	v_	0.01	0.5	0.440980
8	Effective hydraulic conductivity (SOIL_K2)	v_	-50	100	-59.991
9	Base flow alpha factor for bank storage (ALPHA_BNK)	v_	-0.5	0.5	0.34742
10	Available water capacity of the soil (SOL_AWC)	r_	-0.5	0.5	1.205750
11	Saturated hydraulic conductivity (SOL_K)	r_	-0.8	0.8	-0.218733
12	Average slope steepness (HRU_SLP)	r_	0	0.6	0.435079

13	Average slope length (SLSUBBSN)	r_	10	150	82.262680
14	Threshold depth of water for revap to occur (mm) (REVAPMN)	v_	6	14	8.398216

The qualifier (v__) refers to the substitution of a parameter by a value from the given range, while (r__) refers to a relative change in the parameter were the current values is multiplied by 1 plus a factor in the given range.

Out of the fourteen parameters considered for calibration, seven parameters were found to be most sensitive for runoff calibration namely, threshold depth of water, available water capacity, base flow alpha factor, average slope steepness, base flow alpha factor for bank storage, soil evaporation compensation factor and effective hydraulic conductivity as deduced from the above figure and the definitions of p-value and t-stat. Hence for further calibration of runoff only these parameters were adjusted to increase the calibration efficiency of the model. The sensitivity analysis has been represented in Figure 5.5.

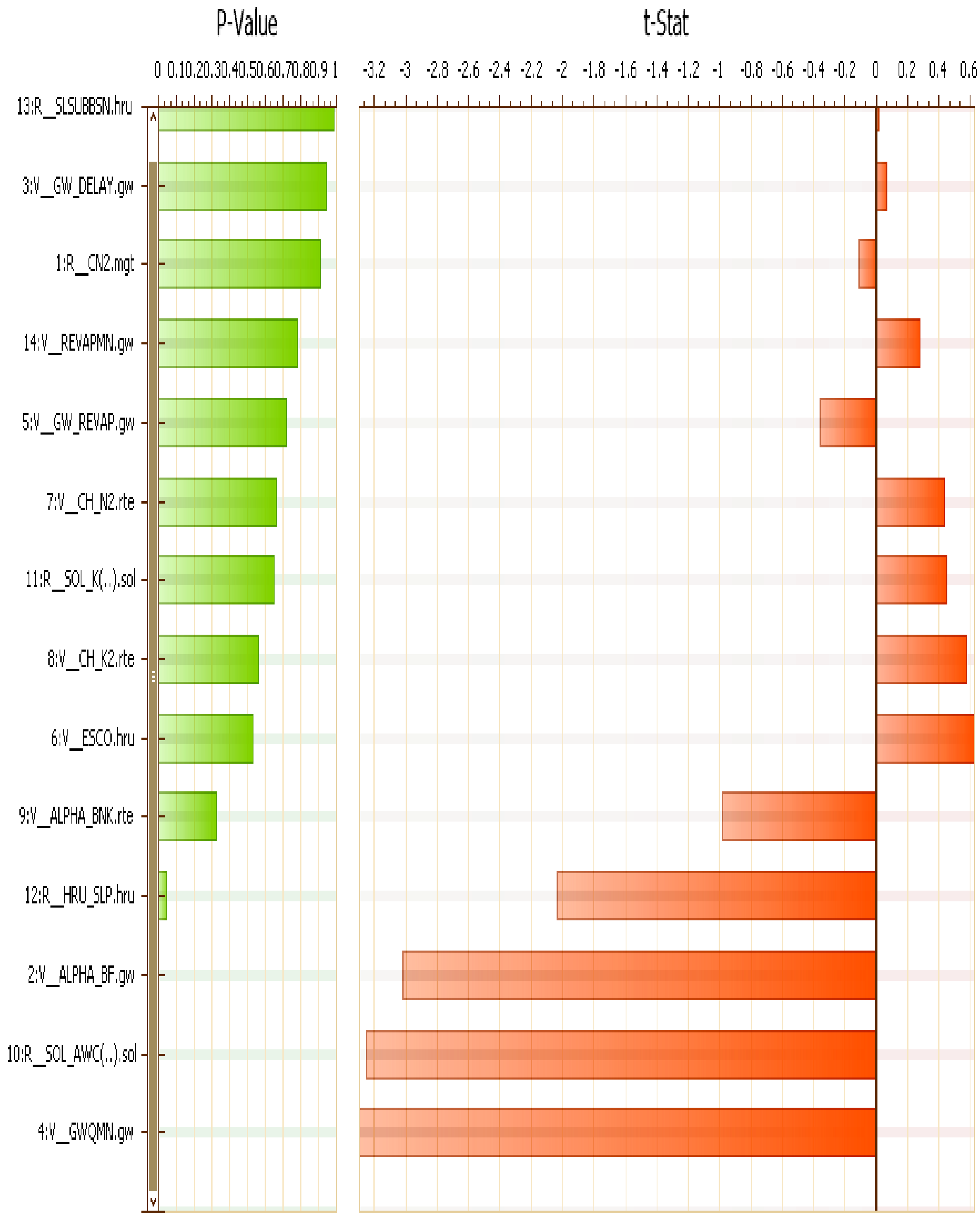


Figure 5.5. Sensitivity Analysis of Flow Calibration Parameters

5.3.Calibrated and Validated Results

5.3.1. Daily Time Step

Simulation and calibrated of the model was carried out for the time period of 2000 to 2010 which included the warmup period of three years i.e. from 2000 to 2002. The calibrated model was further validated for the period of 2011 to 2014 which is about one-third of the total study period.

- **Simulated Period**

The initial simulation results showed that the model over predicted the flows particularly the peak flows. The Nash-Sutcliffe efficiency, NSE is found to be 0.186 and correlation coefficient, $R^2$is found to be 0.469 for the initial simulated data for surface runoff which has been represented in Figure 5.6 and 5.7. These are not satisfactory, hence the sensitive parameters were adjusted to improve the calibration.

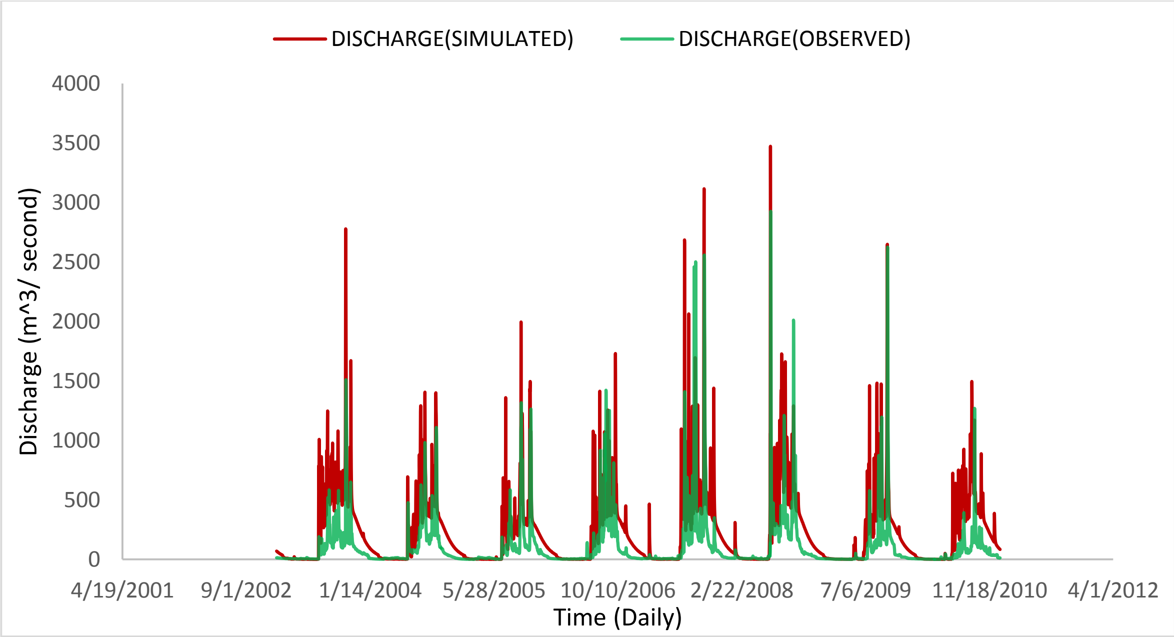


Figure 5.6. Simulated vs Observed data for daily time step

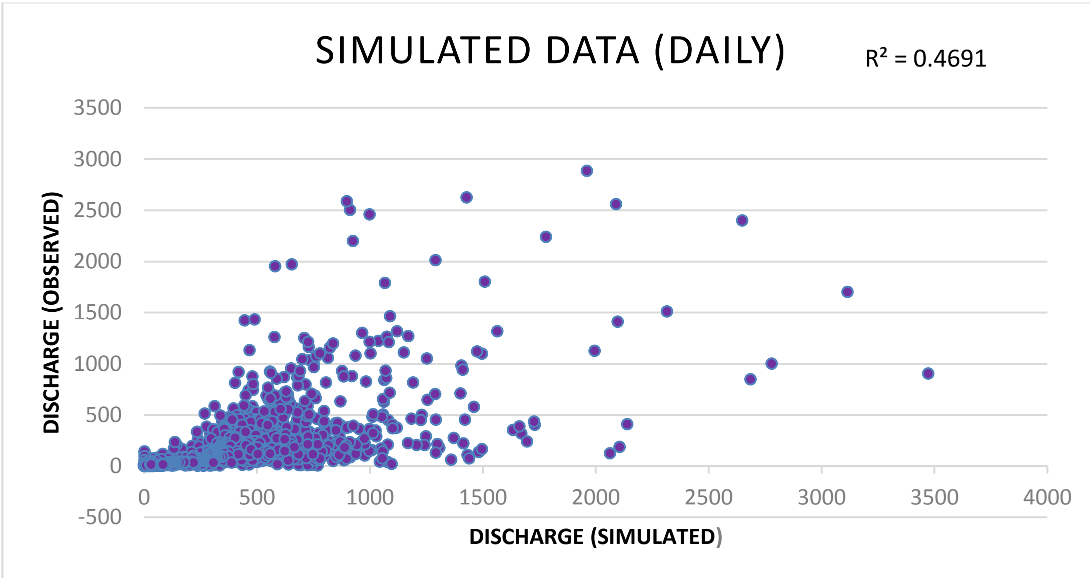


Figure 5.7. Correlation between observed and simulated data

- **Calibrated Period**

To improve the calibrated results the high flows predicted by the model need to reduced. Hence the threshold depth of water was decreased and available water capacity and soil evaporation compensation factor were increased as suggested in the SWAT CUP user manual. The Nash-Sutcliffe efficiency, NSE is found to be 0.61 and the correlation coefficient R^2 is found to be 0.6367 for the calibrated data for surface runoff as shown in Figure 5.8 and 5.9. This is found to be satisfactory according to the performance evaluation criteria.

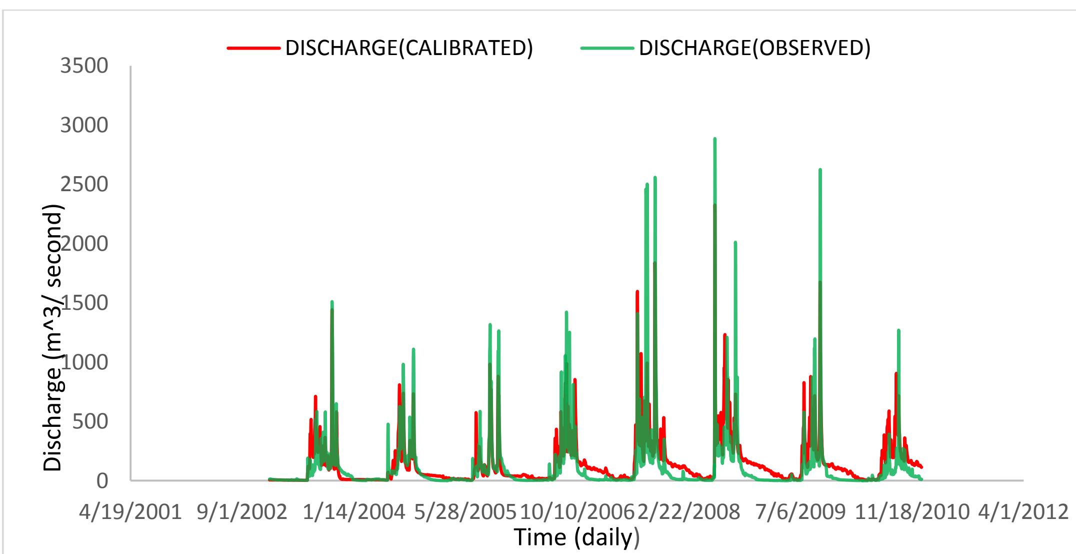


Figure 5.8. Calibrated vs Observed data for daily time step

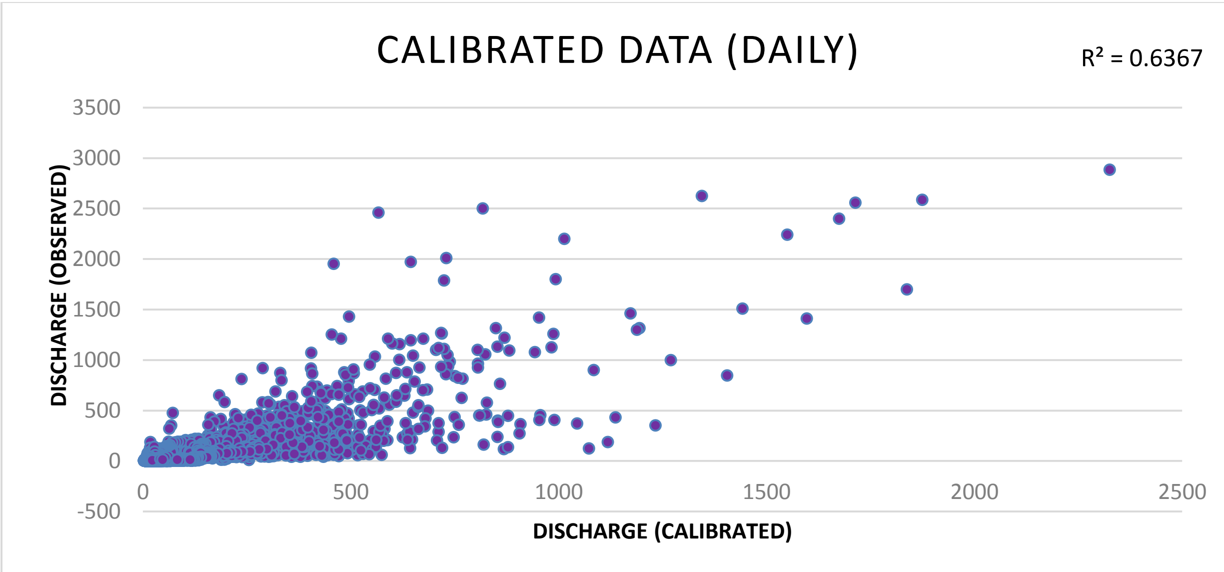


Figure 5.9. Correlation between observed and calibrated data

- **Validation Period**

Calibrated model efficiency was validated for the period 2011 to 2014. The Nash-Sutcliffe efficiency, NSE is found to be 0.57 and the correlation coefficient $R^2$is found to be 0.602 for the validated data for surface runoff as shown in Figure 5.10 and 5.11. The model is not able to capture the peak flows for the period of 2011. The reason can be attributed to the abnormal precipitation during that year.

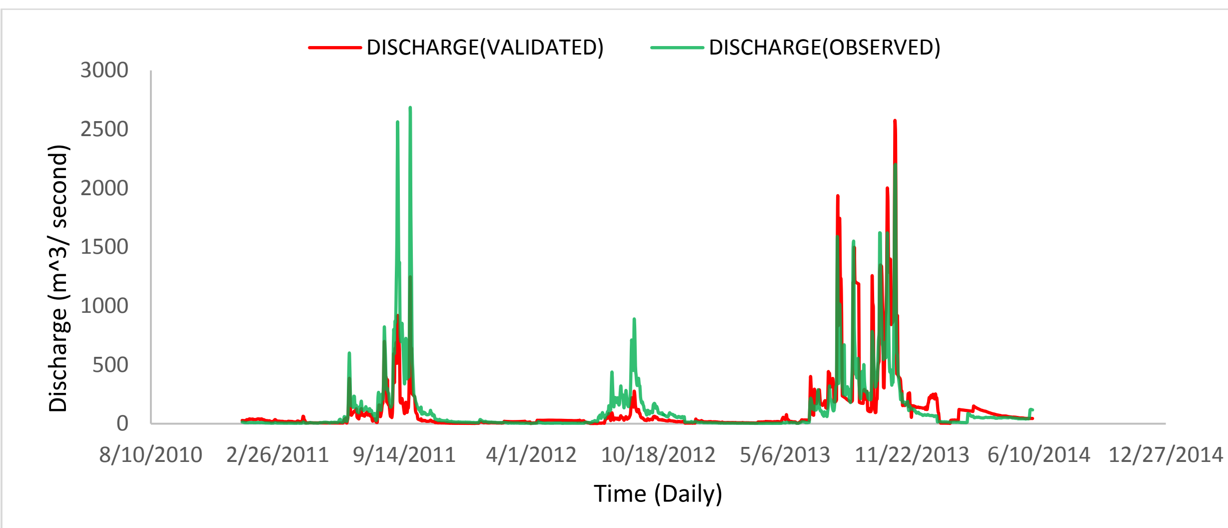


Figure 5.10.Validated vs Observed data for daily time step

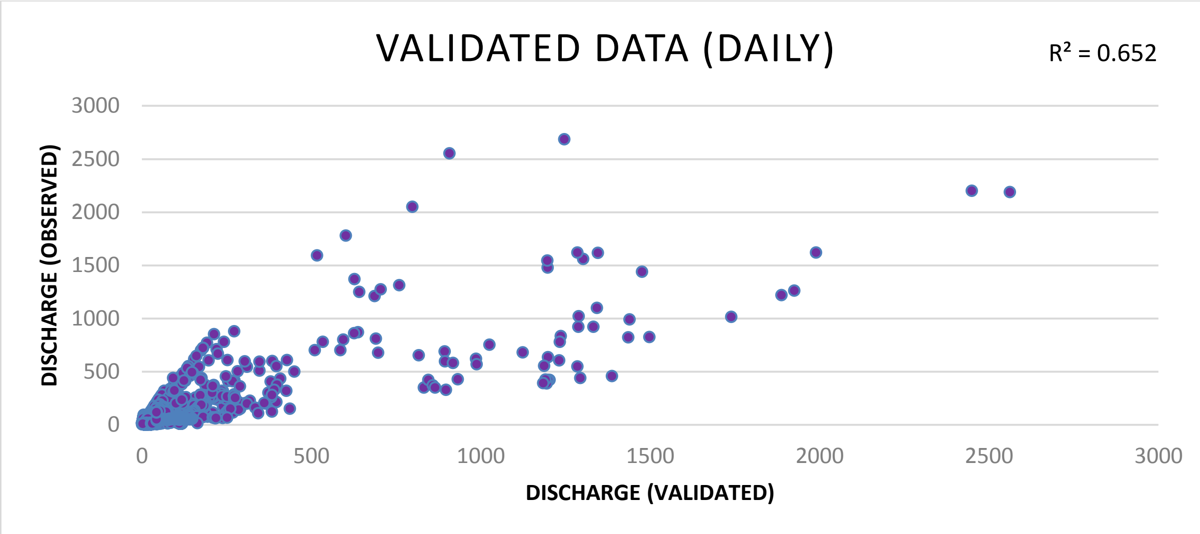


Figure 5.11. Correlation between observed and validated data

All the results of goodness of fit of simulated, calibrated and validated data have been represented below in tabular form below in Table 5.2.

Table 5-2. Performance evaluation for daily time step

DATA SETS	R^2	NASH-SUTCLIFFE EFFIENCY	PBIAS
SIMULATED DATA (2003-2010)	0.469	0.186	39.9
CALIBRATED DATA (2003-2010)	0.6367	0.61	-12.0
VALIDATED DATA (2011-2014)	0.602	0.57	14.2

5.3.2. Monthly Time Step

Similarly calibration was also carried out for monthly time step and results were compared with that of daily time step which have been represented as follows. The curves smoothen for monthly time step compared to daily time step.

- **Simulated Period**

The Nash-Sutcliffe efficiency, NSE is found to be 0.3556 and correlation coefficient R^2 for the initial simulated data for surface runoff is found to be 0.774 and for initial run for monthly time step as shown in Figures 5.12 and 5.13.

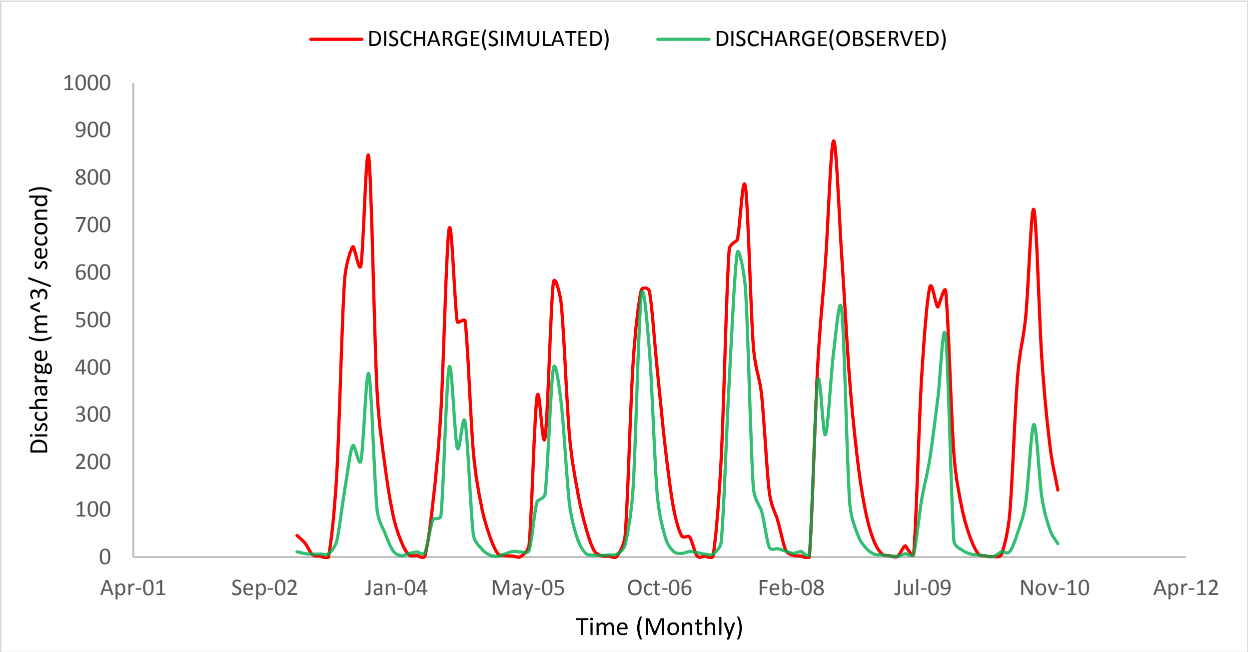


Figure 5.12. Simulated vs Observed data for monthly time step

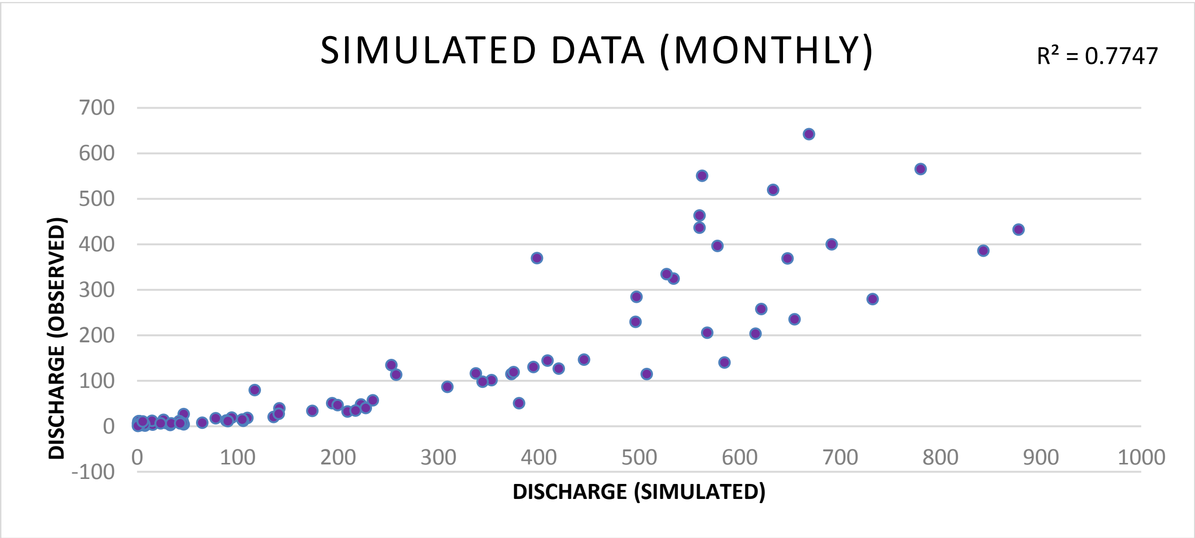


Figure 5.13. Correlation between observed and simulated data

- **Calibrated Period**

The Nash-Sutcliffe efficiency, NSE is found to be 0.7604 and correlation coefficient R^2 for the calibrated data for surface runoff is found to be 0.81 for initial run for monthly time step as shown in Figure 5.14 and 5.15. These values can be considered good as per the performance evaluation criteria**.**

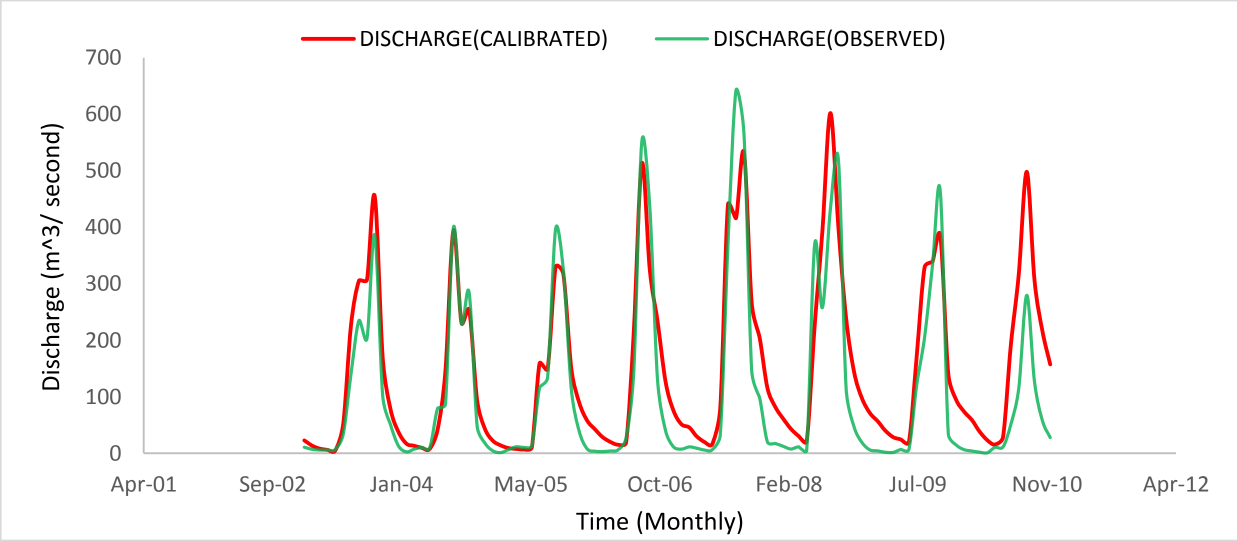


Figure 5.14. Calibrated vs Observed data for monthly time step

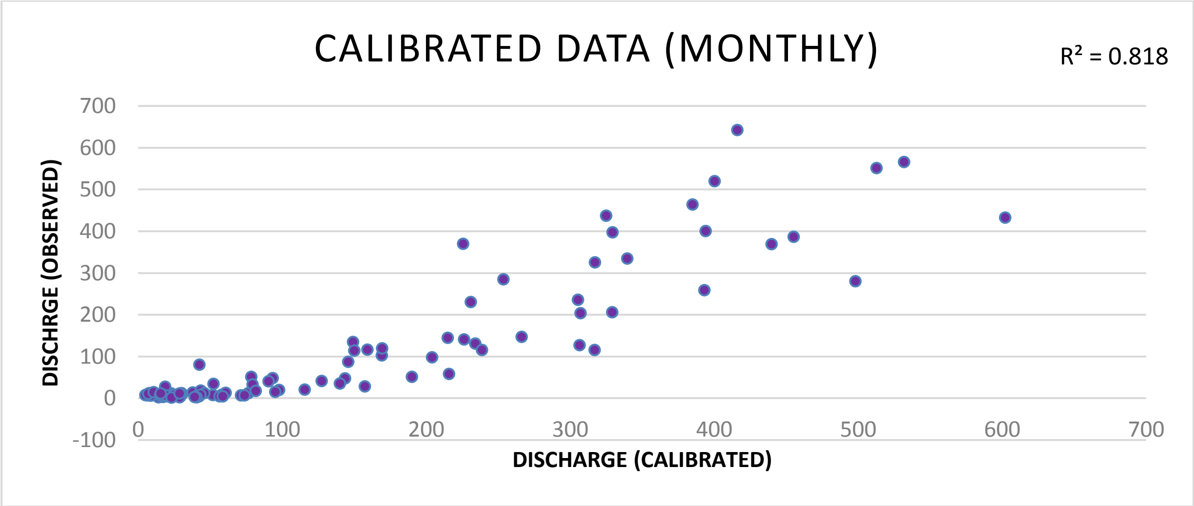


Figure 5.15. Correlation between observed and calibrated data

- **Validation Period**

Similarly the calibrated model efficiency was validated for monthly time step as well. The Nash-Sutcliffe efficiency, NSE is found to be 0.7872 and correlation coefficient R^2 for the validated data for surface runoff is found to be 0.83 as shown in Figure 5.16 and 5.17 and for initial run for daily time step which is good as per the performance criteria.

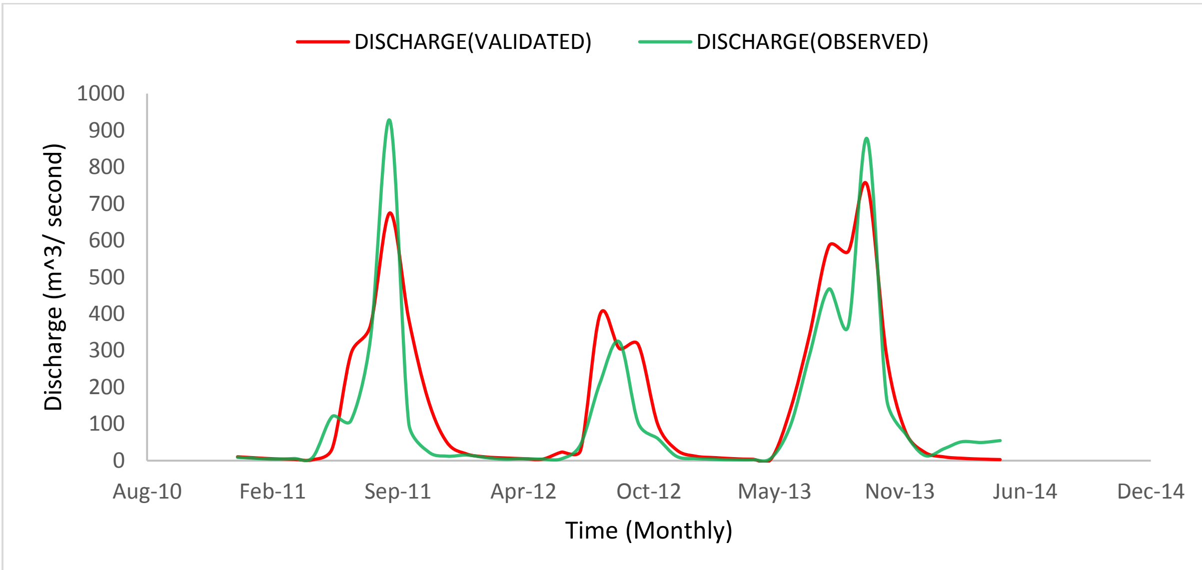


Figure 5.16. Validated vs Observed data for monthly time step

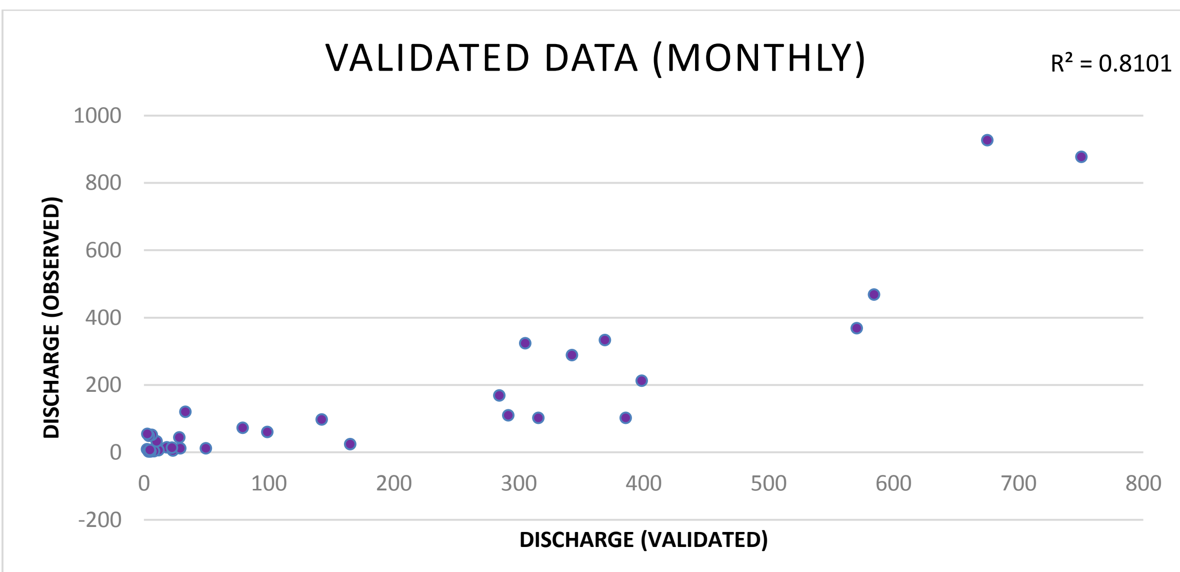


Figure 5.17. Correlation between observed and validated data

All the results of goodness of fit of simulated, calibrated and validated data have been represented in the following page in tabular form below in Table 5.3.

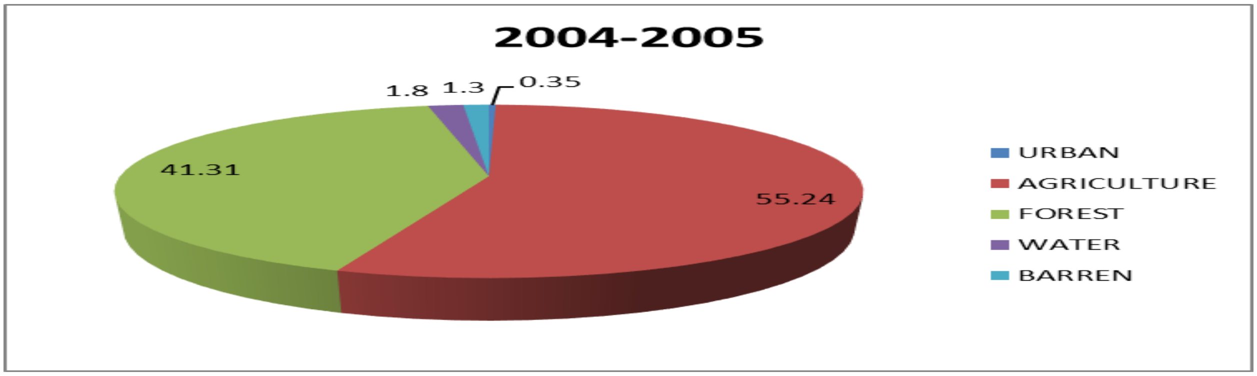
Table 5-3. Performance evaluation for monthly time step

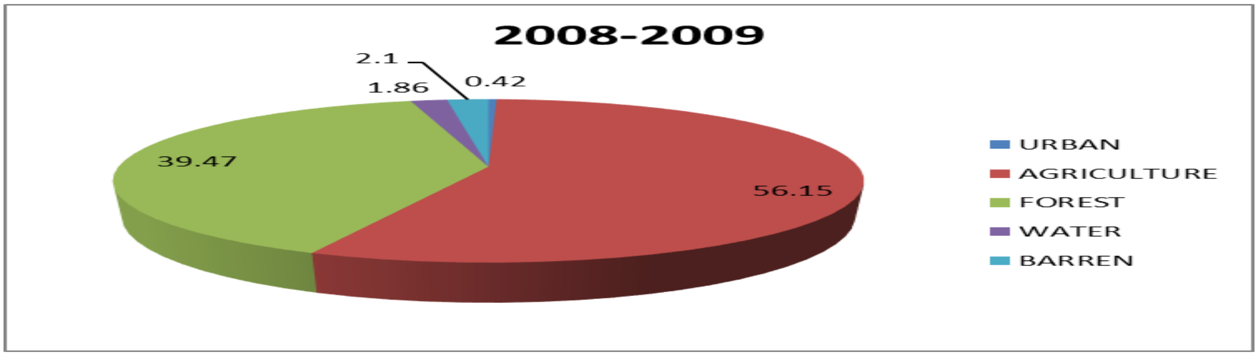
DATA SETS	R^2	NASH-SUTCLIFFE EFFIENCY	PBIAS
SIMULATED DATA (2003-2010)	0.77	0.355	-33
CALIBRATED DATA (2003-2010)	0.81	0.76	9.2
VALIDATED DATA (2011-2014)	0.83	0.79	10.4

5.4.Impact of Land Use Changes on Runoff

The impact of land use changes on observed and simulated runoff has been analysed for the past decade by considering three time period viz., 2004-05, 2008-09 and 2013-14. The land use/land cover pattern of the considered time periods have been represented below.

The major part of our study area is covered with agricultural land which is about 56% of the total area. The western part of the Subarnarekha basin in which our study area also lies is particularly rich in forests with deciduous forest covering 25% of the total basin area. Comparatively the urban land, barren land and water bodies constitute lesser percentage of the study area. These have been represented in Figure 5.17.





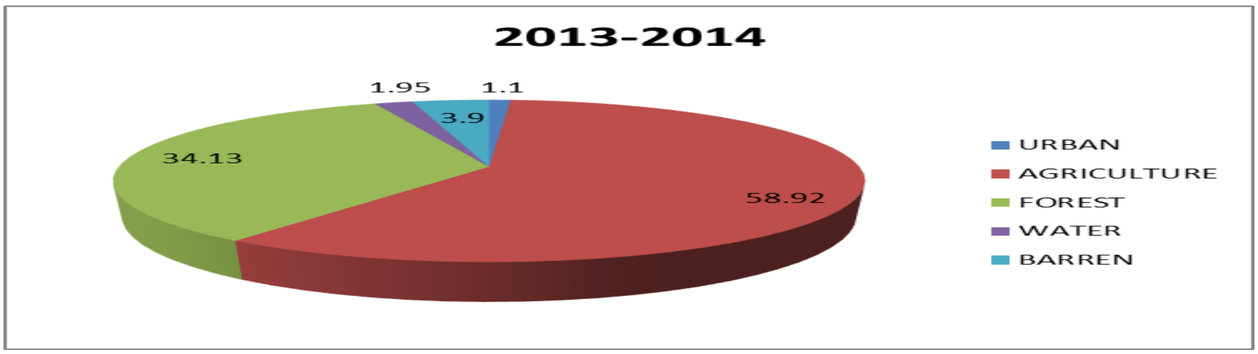


Figure 5.18. Land Use/ Land Cover for the past decade

Table 5-4. Observed vs Simulated Discharge for daily time step

YEAR	OBSERVED DISCHARGE (m^3/sec)	SIMULATED DISCHARGE (m^3/sec)
2003	36482	40505
2008	55293	80825
2013	72558	94285

Table 5-5. Observed vs Simulated Discharge for monthly time step

YEAR	OBSERVED DISCHARGE (m^3/sec)	SIMULATED DISCHARGE (m^3/sec)
2003	1189	1651
2008	1815	2340
2013	2361	2789

The variation in annual discharge runoff for the river basin over the past decade has been represented in the tables 5.4 and 5.5 for daily time step and monthly time step respectively. From the above tables we can observe that the runoff discharge has almost doubled in the past decade. We can also see that the SWAT model has successfully captured the variation in discharge to a large extent. The model run under monthly time step captures the variation with a greater accuracy than that of daily time step though both the models are acceptable. This tremendous increase in surface runoff of the catchment can be accounted to the decrease in the forest cover of the watershed and increase in agricultural land, urban areas and barren land in the past decade. However as we can see not very significant changes for the land use land cover of the area has taken place in the past decade though runoff discharge has undergone huge variation as compared to the land use changes. The climatic variations such as rainfall, temperature, humidity may also be a possible reasons for such changes. The abnormality in rainfall pattern in the later years and storms and floods can also be a reason for such high stream flows. Therefore a precipitation analysis has been done for the past decade for these three years as shown in figure 5.18.

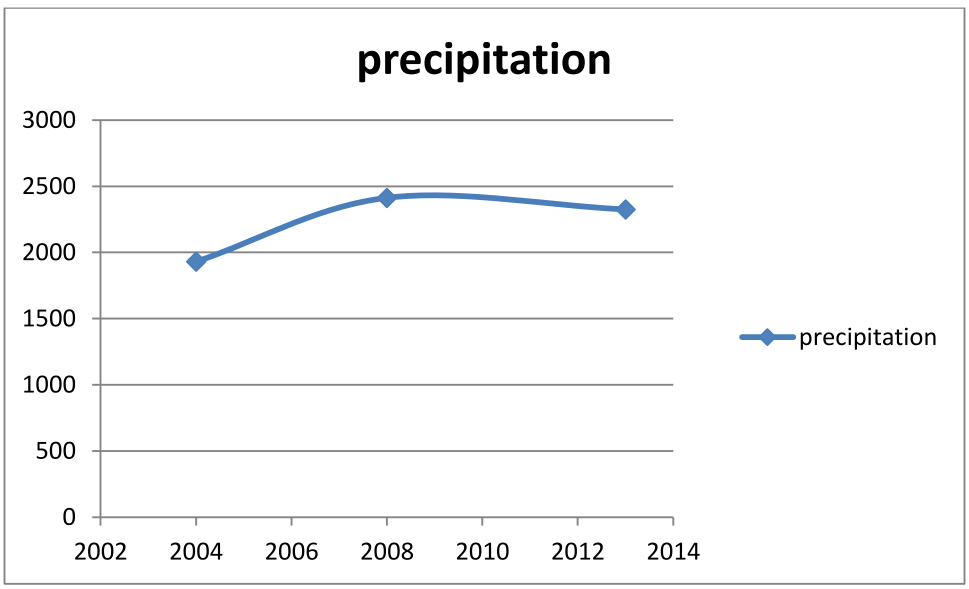


Figure 5.19. Plot of precipitation vs year

As we can see no trend is observed in rainfall data for the past decade therefore the number of days which exceeded 35mm of rainfall (high intensity rainfall) for each year was evaluated for these three years as shown in figure 5.20.

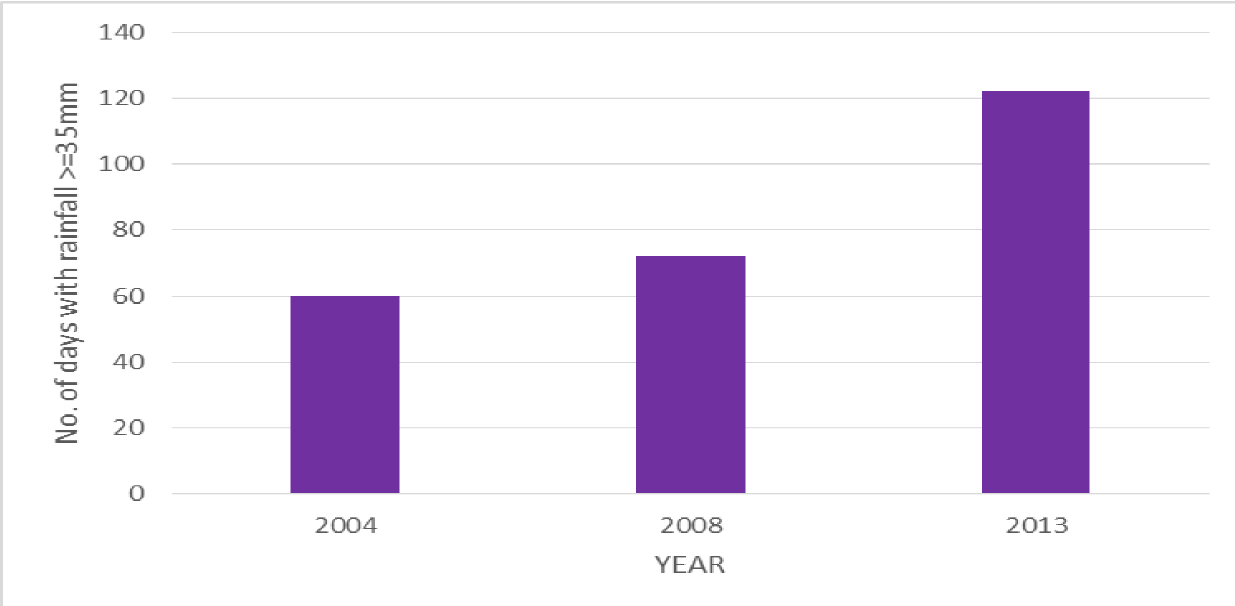


Figure 5.20. Plot of number of days with rainfall >=35mm vs year

The plot clearly indicates the number of days of rainfall of high intensity have increased over the decade the highest rainfall being 60mm, 72mm and 122mm for the years 2004, 2008 and 2013 respectively. Hence this can be inferred as the reason for increase in amount of runoff for the past decade along with land use changes for the region.

5.5.Environmental Impact Assessment

Environmental impact assessment of the flows has been done to find the modification of the aquatic ecosystem over a period of time. Here a time period of fifteen years have been considered for analysis of the environmental flows. A comparison between environmental flows in the reference period i.e. 2000-2006 and observed period i.e. 2007-2014 have been represented in the following figures. The time period of 2000-2006 has been taken as the reference period because very few changes in the land use changes were observed during this period as compared to the later years as seen in the land use changes figures.

The graphs represented in Figures 5.18 and 5.19 for observed and modelled monthly flows respectively show that environmental flows lies between original reference Class A and Class B indicating that the aquatic ecosystem is slightly modified. However as we can see high flows for observed period exceed that of the reference period and fall beyond Class A as well. This reason for such variation is that the highest flow during the observation periods exceeds that of the highest flow during reference period due to increase in rainfall and runoff during the years.

Similar trend is observed for modelled flow as well but the high flows exceed that of reference period for greater number of exceedance probabilities than that of observed flow. This is because the model over predicts the discharge than the observed period.

The slight modification in the aquatic ecosystem can be accounted to the fact that the land use and land cover of the area has not undergone much significant change during the period, agriculture and forest being the major land use and land cover for the area for a long period of time. Since the urban area does not cover major part of area the discharge of effluents into water bodies is comparatively less than that of highly urbanized areas. Hence the anthropogenic activities have not quite increased during the course of time helping the ecosystem to retain its original state to a large extent.

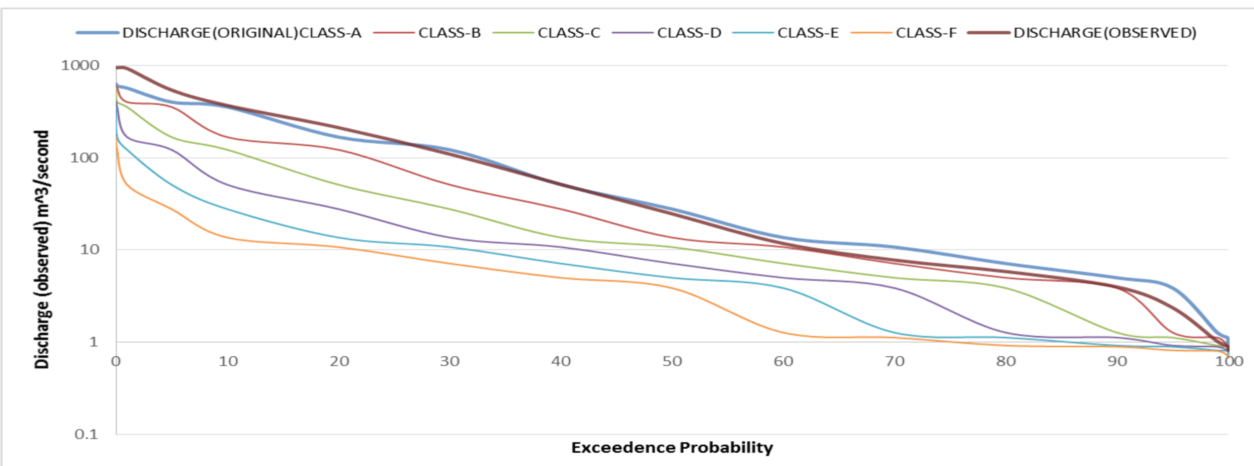


Figure 5.21. Environmental impact assessment of observed monthly flows

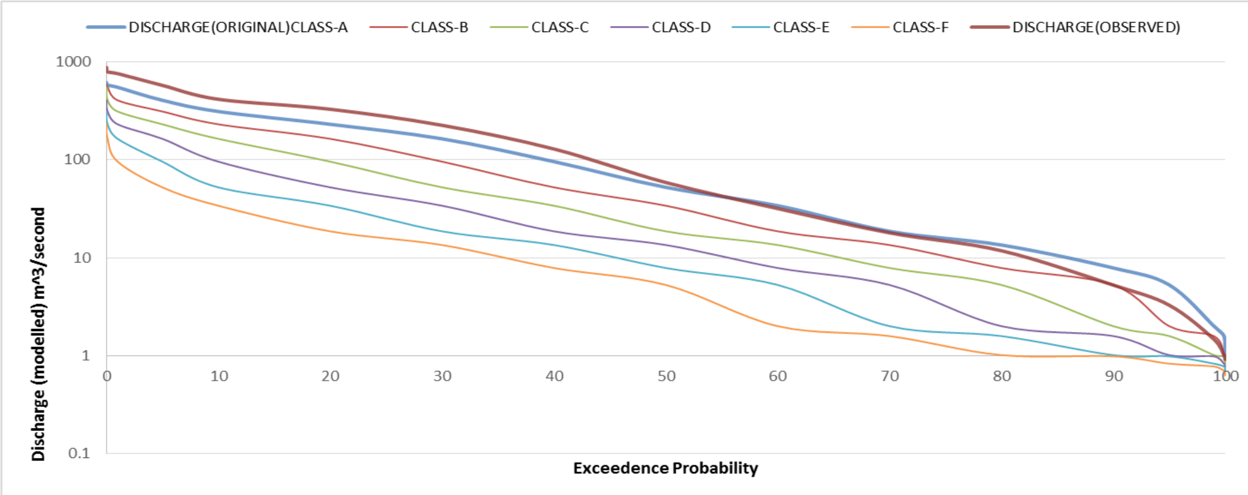


Figure 5.22. Environmental impact assessment of the modelled monthly flows

SWAT model has proved satisfactory for modelling the runoff and predicting the effects of land use changes on the basin for the past decade in the considered catchment of the Subarnarekha river basin. The results obtained from SWAT model improved when calibration was done by adjusting the parameters which influence the runoff. Comparison of observed and simulated runoff shows a good correspondence between observed and simulated runoff during both the calibration and validation period. However it is observed that the curves smoothen and better results are obtained for monthly time step than daily time step as the flows are averaged and variations are reduced for monthly time step. Taking into account the criteria for objective functions the model shows satisfactory results for daily time step and good results for monthly time step for runoff discharge data. Hence this model can be applied in other catchments of the Subarnarekha river basin for modelling of runoff and analyzing the land use changes. The model is not able to capture the peak flows completely for daily time step. The reason for this might be that the flow calibration parameters have been considered by literature review and self-interpretation. But the parameters and the values of the parameters which actually might be influencing the runoff of that area are not known. The results could have improved if the parameters which influence the runoff of the basin could be ascertained. However the user friendly approach of SWAT model and flexibility to be used for smaller to larger basins and giving satisfactory results at the same time makes it a useful and widely accepted model.

6. CONCLUSIONS

The current study can be concluded in the following manner:

The area considered for the present work is a catchment area of Subarnarekha river basin. The study has been conducted for Budhabalanga river, a tributary of Subarnarekha river. SWAT tool which runs under ArcGIS interface has been chosen to model the runoff discharge for the basin. Simulated discharges have been calibrated with the observed discharges for the time period of 2003 to 2010 and validated for the time period 2011 to 2014.

- Five sub-basins and twenty four HRUs are found to exist for the region from the delineation result.
- The comparison between the observed and calibrated data shows the NSE and R^2 values to be 0.61 and 0.64 respectively. Comparison between observed and validated results gives the NSE and R^2 to be0.57 and 0.60 respectively for daily time step.
- Similarly the comparison between the observed and calibrated results interprets the NSE and R^2 values to be 0.76 and 0.81 respectively and for observed and validated data to be 0.78 and 0.83 respectively for monthly time step. The results improved for monthly time step as the flows are averaged and smoothened out.
- The observed runoff increased by about 98.1% and 98.6% from the year 2004-2013 for both daily and monthly time step respectively. The modelled runoff also showed similar trend for daily and monthly time step respectively from the year 2004-2013.
- The forested areas have decreased and agricultural land, urban areas and barren land have increased in the past decade though the changes are not very significant. The number of days of high intensity rainfall have also increased very remarkably during the past decade which along with the land use changes explains the tremendous increase in runoff for the area.
- The environmental flows for the stream were found to lie between original reference Class A and Class B both for observed and modelled flows indicating that the aquatic ecosystem is slightly modified which can be accounted to the less change in land use land cover changes in the area.

SCOPE OF THE STUDY IN FUTURE

- Though the changes in land use and land cover pattern and hydrological changes can be accounted for the increase in runoff for the chosen study area, but other climatic variables might be also affecting the changes in runoff. Study can be conducted on the area further taking the climatic changes into account.
- The results obtained from current study are quite satisfactory. Hence this model can be successfully applied to other small and large catchments of the basin. This model is flexible and can be implemented as per the availability of data in different sub-basins.

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