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Research Article

Hydrological modeling of Bagmati River Basin, Nepal

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Abstract

Water is most essential natural resource for life but in absence of rain fall drought occurs whereas excess rain fall causes floods and soil erosion. In Nepal accurate information of water availability is lacking. Therefore, accurate simulation of hydrological parameter is important for water resource management. The present study has been conducted in Bagmati River Basin for hydrological simulation of runoff, one of most important parameter of hydrology using SWAT model. Input data for model as soil map, land use land cover map and meteorological parameter were prepared with the help of Arc-Gis, ERDAS and Ms-Excel software. The model was calibrated using field-measured discharge data at gauged station for six years (1997 to 2002) and validation was performed for two years (2003 to 2004). The monthly simulated runoff of the calibration and validation periods were found to match with their measured discharge value of coefficient with correlation (R^2) in both the cases 0.917 and 0.92 respectively. The model simulated daily runoff is corroborated by reasonably high Nash–Sutcliffe simulation coefficients of 91.54% and 77.31% respectively for calibration and validation periods. Similarly, average annual surface runoff in 1997 to 2002 and 2003 to 2004 was 831.2 mm and 922mm, i.e. 40 and 43% of precipitation respectively. Similarly, total water yield and evapotranspiration was 71% and 23% of precipitation in both time period. Such type of runoff model plays vital role for water resource management. So, this model can be further utilized as a potential tool for water resource management of spring fed River Basin in Nepal.

Keywords: *Meteorology, River Basin, SWAT, Calibration, Validation, Bagmati, Hydrological simulation.*

1. Introduction

Nepal is the one of richest country of the world in water resource (WECS, 2011). Major population of the country depend on agricultural. Annual average rainfall is 1800mm (R. Selvaraju *et al*, 2014). However, in one hand people are not getting water at proper time for agriculture while in other hand people of downstream are facing flood problem in recent year. Water availability and quality are main issues/ challenges for, societies in climate change scenarios (IPCC 2007). Climate change impacts are mainly on agriculture, forest and water resource. Water resource sector will be affected very heavily due to global warming and temperature rise at an annual rate 0.04-0.06^{o}C per year over Nepal affects the (WECS, 2011). Therefore, information about trend of hydrological parameters are essential for resource and water induced disaster management. Hydrological models can be used to evaluate scenarios of climate change impact on hydrology. Understanding the hydrologic response of the Basin to physical (land use) and climatic (rainfall and air temperature) change is an important component of water resource planning and management (C.J. Vorosmarty *et al*, 2000).

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Developing reliable watershed simulation models and calibrating as well as validating them for watersheds with measured and simulated data is a challenging issue (D. K. Borah *et al*, 2002, D. Khare *et al* 2014). The increasing rate of water resources development activities have focused attention on development and application of physically based hydrological models to deal with constantly changing hydrological environment.

Numerous studies have been conducted by using SWAT model in the world few recent examples are Hydrological Modelling of Tropical Land Use Scenarios in Hulu Langat basin, Malaysia by H. Memarian *et al* 2014, Hydrological modeling of a catchment in the upper blue Nile Basin of E thiopia by T. Taffese *et al*. in 2014, Simulation of Catchment Hydrologic Response under Changing Land Use: Case of Upper Molo River Catchment, Kenya by W.K. Kirui *et al*., 2014, Hydrology modelling in Taleghan mountainous watershed in the north west of Tehran, Iran by H. Noor *et al* 2014, Hydrological Modelling of Barinallah Watershed of Chambal District in India by D. Khare *et al* 2014.

But in Nepal very little efforts have been made on the use of hydrologic models to develop management plan for such watersheds using systematic modelling approach. Application of hydrological models and adequate procedure of their calibration and validation is an important research issue (D. Khare *et al*, 2014). Therefore, Arc SWAT model applied to estimate the change in surface runoff in Bagmati River Basin, considering hydrological behavior of the River Basin and applicability of the existing models. It will help to know the trend of climatic impact on river behavior as well as its applicability in rest of the spring fed River Basin in Nepal.

2. Study area

The study area is Bagmati river basin of Nepal. This river originates at an elevation of around 2700m in Shivpuri National park and flows towards south up to the Koshi River in Bihar state of India. The basin area of this river up to the Indo-Nepal border is about 3828km^2 at about 53m above the mean sea level. The total length of the river from its origin to the Indo-Nepal border is 204 km. The river passes through three physiographic regions i.e. Middle Mountain, Siwalik and Terai. Soil found in the area are sand, loamy sand, sandy loam, silt loam, silty clay loam and silty clay. The dominant soil type is loamy soil (S.K. Manjan *et al* 2014).

3. Methodology

The study was conducted using SWAT model. ASTER DEM and LANDSAT image was used for delineation of basin and land use land cover within that area. Soil parameter as well as climatic data of the area were assigned. Priestley– Taylor method for potential evapotranspiration was selected. Similarly, discharge data taken at Pandheradovan a gauged station were used for validation after manually calibrating different parameter for that area based on physical catchment understanding and sensitive parameters. Performance of the model was evaluated by calculating value of Nash–Sutcliffe efficiency (E_{NS}) and coefficient of determination (R^2). Hydrograph of observed and simulated discharge were plotted to evaluate the trend of observed and simulated runoff in the basin.

3.1. Brief description of swat model

The study was conducted using SWAT 2005 with Arc-SWAT interface. SWAT is a continuous, continuous-time, semi-distributed, process based river basin model for water resources in river basins (J.G. Arnold *et al*, 2012). The SWAT can analyse large to small catchments by dividing into sub-basins and then further into hydrological response units (HRUs) with homogeneous land use, soil type and slope. The SWAT system embedded within Arc-GIS can integrate various spatial environmental data including land use land cover, soil, climate and topographical features. It estimates daily volume of overland rainfall excess over each HRU by solving the water budget components of precipitation, runoff, evapotranspiration, percolation and return flow from subsurface and groundwater flow (J.G. Arnold *et al*, 1998). Surface runoff is computed by using Green-Ampt method or the modification of the SCS curve number method (USDA Soil Conservation Service, 1972). Similarly, rate of peak runoff is estimated by using a modification of the 'rational method' (V.T. Chow *et al*, 1998). The measured daily potential evapotranspiration can be computed directly for the Basin using one out of three method ie. Penman–Monteith method, the Priestley–Taylor method or the Hargreaves method (J.G. Arnold *et al*, 1998). Lateral subsurface flow is simulated using kinematic storage model, whereas empirical approaches are adopted for groundwater (J.G. Arnold *et al*, 1998; D.K. Borah *et al*., 2003; S.L. Neitsch *et al*, 2005).

Flow rate and velocity in the streams is computed using SWAT, Manning's equation. Flow routing is based on either the variable storage or the Muskingum routing method and (S.L. Neitsch *et al*, 2005). In the present study, SCS curve number and Muskingum routing methods, along with daily climate data, were used for surface runoff and stream discharge computations (J.V. Tyagi *et al*, 2014). The Priestley–Taylor method was used to estimate potential evapotranspiration.

3.2. Model input data

The model required basic spatial input datasets are digital elevation model (DEM), land use/cover data, soil data, meteorological data. The brief methodology for preparation of the data is described as follows:

3.2.1. Digital elevation model

First and main input required for SWAT model is DEM to define topography of the study area. ASTER DEM of 30m resolution was used to delineate the boundary of the River Basin up to the Indo- Nepal border. Stream network, longest path watershed within basin were derived from DEM.

3.2.2. Land Use Land Cover data

Land Use Land Cover (LULC) is one of the most important factors affecting different processes in the Basin, such as surface and sub-surface runoff, soil erosion and evapotranspiration (L.M. Mango *et al* 2011) during simulation (S.L. Neitsch *et al*, 2005). Hybrid approach on geo-referenced in UTM/WGS 84 projection Landsat image of 2001 having 30m resolution were taken for LULC classification. It is found that major LULC in the area is forest. Field verification of the prepared LULC map was also conducted. LULC Map is shown in fig. 2. Similarly its type and their coverage percent are shown in table 1.

3.2.3. Soil data

The response of a river basin to a rainfall event depends on the nature and conditions of underlying soils. The soil textural and physicochemical properties required by SWAT model include bulk density, soil texture, available water capacity, saturated hydraulic conductivity, organic carbon content and electric conductivity for each soil type (S.G. Setegn *et al*, 2009). Undisturbed soil samples were collected from the depths of 0 to 15 and 15 to 30 cm using core cutter from 78 locations representing all soil type considering slope and aspect. Soil texture was determined by sieve method, Bulk density of the soil samples were determined using core cutter method. Total organic matter (TOM) were determined following Walkley-Black wet combustion method. Soil electric conductivity were analysed with help of electric conductivity meter. Saturated hydraulic conductivity was determined in field using double ring infitrometer (S.K. Manjan *et al*. 2014). River basin soils data were appended to the SWAT database.

3.2.4. Meteorological data

Meteorological data required as input of SWAT model consist of daily precipitation, temperature, humidity, solar radiation and wind velocity. These data were collected from Department of Hydrology and Meteorology, Government of Nepal. The data were of three metrological stations representing upper, middle and lower river basin for the period of 1995 to 2004 to run the model. Similarly, other hydrological parameter discharge data collected the gazed station for calibration and validation of the model.

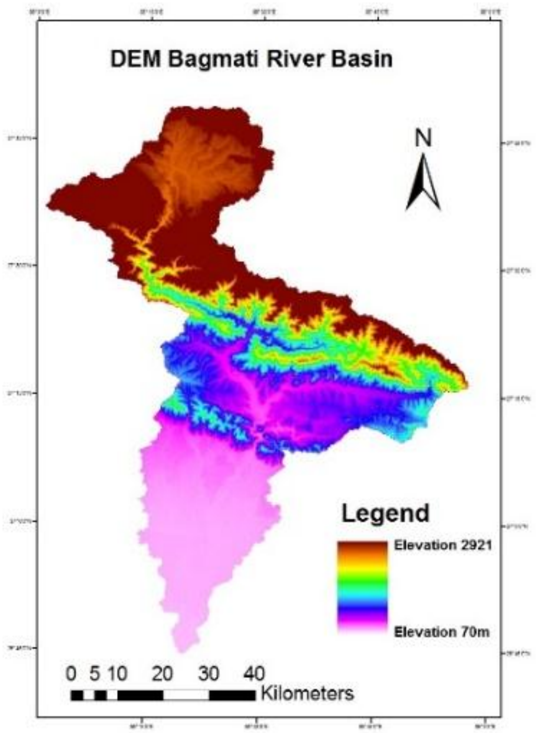

Figure 1 DEM of Bagmati River Basin.

Table 1 Major Land Use Land Cover Class

	LULC of 2001	
Land Use	Area (ha)	Area (%)
Settlement	6038.73	1.57
Agriculture	164676.06	42.94
Dense Forest	178171.56	46.45
Open Forest	22544.64	5.88
Water	3750.39	0.98
Barren	8358.3	2.18
Total	383539.68	100

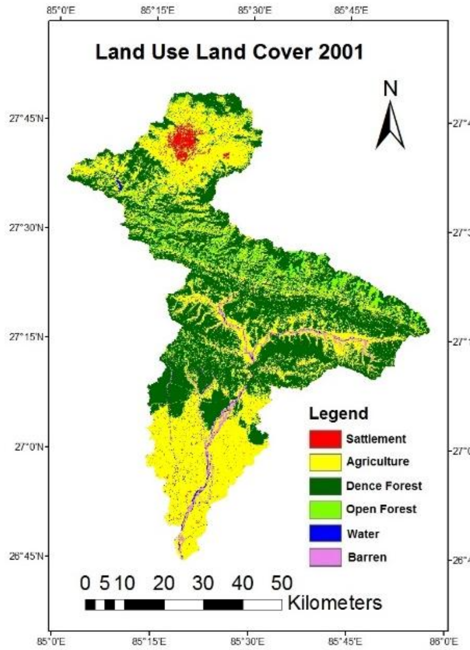

Figure 2 LULC map of Bagmati River Basin

3.3 Application of swat model set-up

The Arc-SWAT was used for the setup and parameterization of the model. A digital elevation model (DEM) was imported into the SWAT model. Flow direction and accumulation was completed. The threshold area for generation of streams was taken as 5000 ha. Stream network and outlet was created. Last outlet at Indo-Nepal boarder was selected for delineation of River Basin and watershed dividing River Basin. 37 watersheds were obtained as in fig. 3. The LULC map and soil maps of the area in grid format were also imported with slope into the model for overlay to obtain a unique combination of land use, soil and slope. Multiple HRUs with 5% LULC, 10% soil and 10% slope thresholds were set to eliminate minor land uses and slope classes in each watershed. A total of 225 HRUs were delineated. Weather station meteorological data as daily rainfall, minimum and maximum temperature, relative humidity, wind speed and solar radiation were also imported into the model as recommended in the SWAT user manual (S.L. Neitsch *et al*, 2002).

3.4. Model calibration and validation

The calibration and validation were carried out at monthly time period using gauged discharge data at Pandhera dovan. The data from 1995 to 1996 was used for warming up and initialization of the model variables this period was not used for evaluation of the model predictions. The data from 1997 to 2002 was used for calibration. Similarly, data from 2003 to 2004 were used for validation of the model. The SWAT model includes a large number of parameters that describe different hydrological conditions and characteristics across the watershed. These parameter need to be calibrated to adequately simulate stream discharge. The parameters were calibrated manually based on physical catchment understanding and sensitive parameters (J.V. Tyagi *et al* 2014).

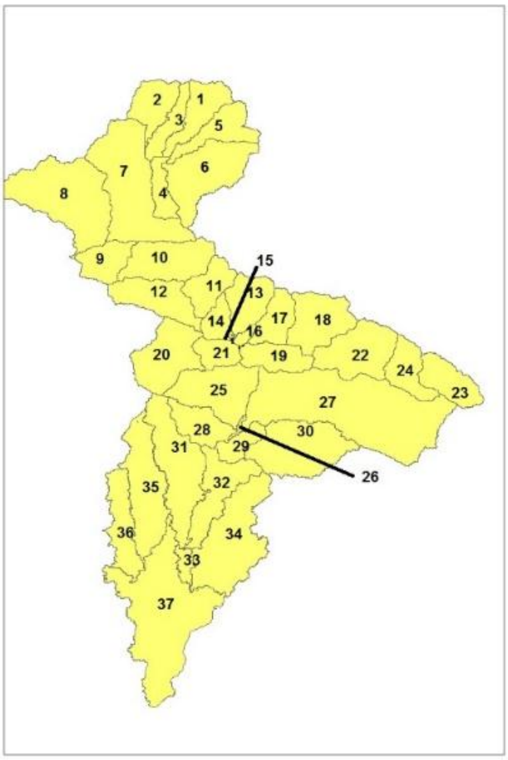

Figure 3 Sub-watershed in Bagmati River Basin

3.5. Criteria for model evaluation

Model performance was evaluated graphically as well as and by Nash– Sutcliffe efficiency (E_{NS}) and coefficient of determination (R^2). The Nash and Sutcliffe (1970) efficiency is one of the most frequently used criteria and is expressed in percentage form as:

$$E_{NS} = \left[1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}\right] x\ 100$$

Where O_i and S_i are the observed and simulated values, n is the total number of paired values and $\bar{O}$ is the mean observed value.

The efficiency varies from 0 to 100, where 100 denoting perfect fit. Generally, E_{NS} is very good when E_{NS} is more than 75%, satisfactory when between 75 and 36%, and unsatisfactory when it is less than 36% (J.E. Nash, 1970). However, a shortcoming of the Nash–Sutcliffe statistic is that it does not perform well in periods of lowflow, as the denominator of the equation tends to zero and E_{NS} approaches negative infinity with only minor simulation errors in the model (C. Oeurng *et al*, 2011). This statistic works well when the coefficient of variation for the data set is large.

The coefficient of determination (R^2) is the proportion of variation explained by fitting a regression line and is viewed as a measure of the strength of a linear relationship between observed and simulated data. It is computed as:

$$R^2 = \frac{\sum_{i=1}^{n}(O_i - \bar{O})(S_i - \bar{S})}{[\sum_{i=1}^{n}(O_i - \bar{O})^2]^{0.5}\ [\sum_{i=1}^{n}(S_i - \bar{S})^2]^{0.5}}$$

Where, $\bar{O}$ and $\bar{S}$ are the mean of observed and simulated values, R^2 also ranges between 0 and 1. Where value of 1 indicates that the computed values have perfect contract with the observed data (D.N. Moriasi *et al* 2007).

4. Result and Discussion

4.1 Assessment of Calibration results

Calibration of hydrological parameter for time period from 1997 to 2002 was conducted. Different parameters were varied numerous time for matching the pattern of observed and simulated discharge to achieve high value of E_{NS} and R^2. The best calibration is graphically presented in figure no. 5.

The results show a good correlation between the predicted and observed discharge. The calculated E_{NS} and R^2 were 91.54% and 0.917 respectively. The E_{NS} value is indicating that the simulated and observed discharge have very good correlation and that the model can properly simulate the catchment response. The R^2 approached 0.917 showing that the root mean square errors are minimal and therefore the model can satisfactorily simulate the catchment response with reasonable accuracy (D.N. Moriasi *et al* 2007). Thus R2 value indicates that the model can be applied to simulate catchment response in the study area. A critical comparison of the runoff hydrographs shows that the flow peaks of observed are slightly higher than the simulated peaks during monsoon seasons of 1998. But, flows simulated by the model generally match well with the observed values.

ANOVA test has been conducted to check role of individual year and sub basin on runoff coefficient. It reveals that runoff coefficients were influenced with both by year and sub basin. It is also found average runoff coefficient at upper, middle and lower parts of basin were minimum (0.35), maximum (0.39) and intermediate (0.36) respectively. Though upper part of basin is dominated by agricultural with sandy loam soil as well as middle part by forest with sandy soil and boulder. Middle part having more slope than upper one, so, it increases runoff coefficient in that area. Similarly lower part of the basin having gentle slope with loamy soil so, runoff coefficient is less than middle part but more than upper part of the basin.

Table 2 Runoff coefficient in different Elevation

Year/ Basin	Upper	middle	lower
1997	0.29	0.49	0.41
1998	0.37	0.43	0.45
1999	0.39	0.39	0.39
2000	0.32	0.42	0.40
2001	0.37	0.29	0.37
2002	0.36	0.38	0.00
2003	0.35	0.34	0.53
2004	0.32	0.39	0.33
average	0.35	0.39	0.36

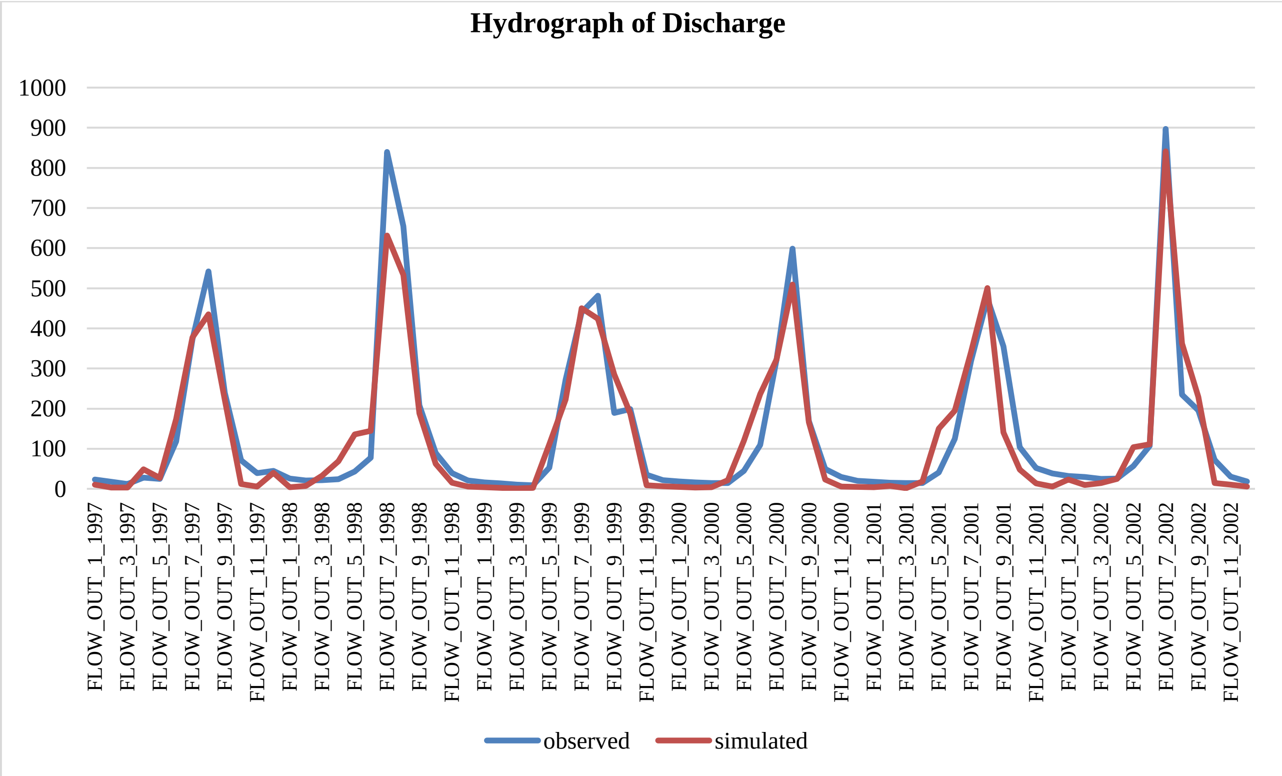

Figure 5 Observed and simulated daily discharge during calibration

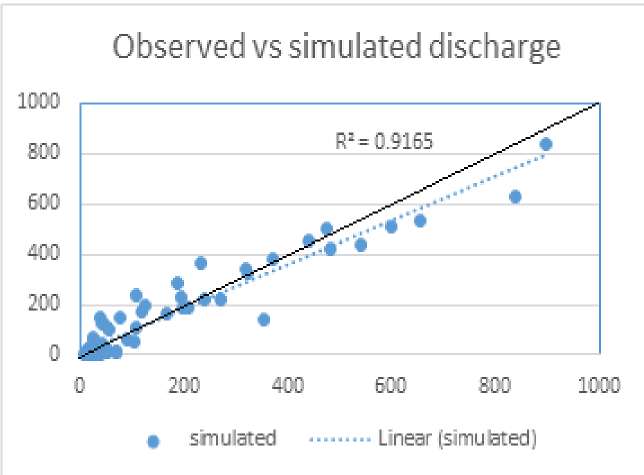

Figure 6 Scatter plot of observed and simulated daily discharge during calibration

It is observed from above scatter plot figure. 6 that the simulated runoff values are distributed uniformly about the 1:1 line for low values of observed runoff. For high values of observed runoff, majority of the simulated values are slightly below the line of perfect fit, indicating that the model under-predicts the high values of runoff.

4.2 Assessment of validation results

For validation of hydrological parameter from 2003 to 2004. Determined parameters at the time of calibration were used for matching the pattern of observed and simulated discharge to achieve E_{NS} and R^2 values. It is graphically presented in figure no. 7.

The results show a good correlation between the predicted and observed discharge. The calculated E_{NS} and R^2 were 77.31% and 0.93 respectively. The E_{NS} value is indicating that the simulated and observed discharge have good correlation and that the model properly simulated the catchment response. The R^2 approached 0.93 showing that the root mean square errors are (0.07) minimal and therefore the model satisfactorily simulate the catchment response with reasonable accuracy (D.N. Moriasi *et al* 2007). Thus R2 value indicates that the model can be applied to simulate catchment response in the study area.

A critical comparison of the runoff hydrographs shows that the flow peaks of simulated are slightly higher than the observed peaks during monsoon seasons of 2004 but

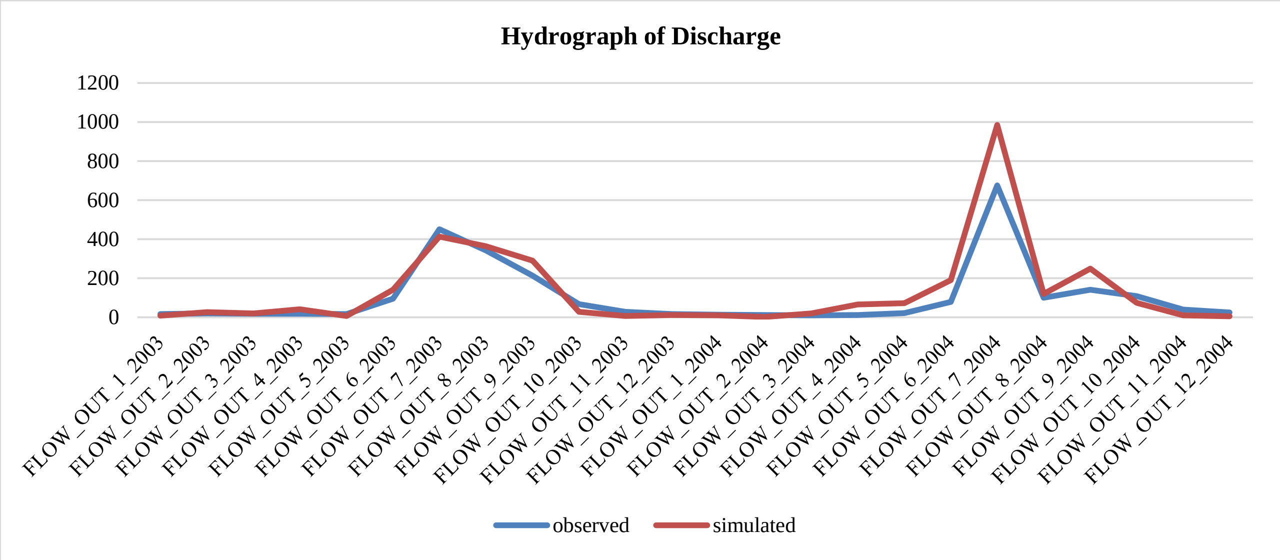

Figure7 Observed and simulated daily discharge during validation

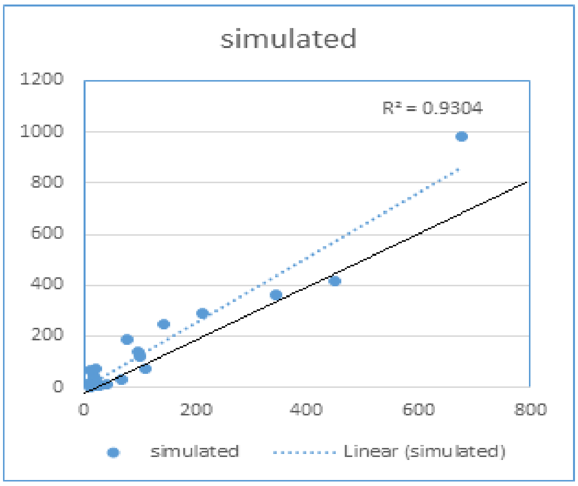

Figure 8 Scatter plot of observed and simulated daily discharge during calibration

flow trend of simulated and observed discharge are followed by the model.

It is observed from above scatter plot figure 8 that the simulated runoff values are distributed uniformly about the 1:1 line for low values of observed runoff. For high values of observed runoff, all of the simulated values are slightly above the line of perfect fit, indicating that during validation the model over-predicts the high values of runoff.

Conclusions and recommendations

The research was conducted for hydrological modelling of Bagmati river basin using SWAT model. The E_{NS} calculated for calibration and validation were 91.54 and 77.31% respectively. Similarly R_2 values were 0.917 and 0.93 respectively. This shows that the observed and predicted discharge are closely matches its trend. So, there is strong positive correlation between observed and predicted discharge. It also indicates that performance of the model during calibration was better than validation. But, low values of R2 acquired show that the root mean square errors were kept at minimal. Therefore, it can be concluded that SWAT model using the identified parameters could properly simulate hydrologic response of the river basin for the study area. Annual average surface runoff for the period of 1997 to 2002 and 2003 to 2004 was 40% and 43% of the precipitation respectively. The increase in surface runoff is during validation period, it is due to impact of climate change. In conclusion, the present study demonstrated that the performance of SWAT model was highly acceptable. Therefore, this model can be applied in the similar type of river basin.

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