1. Introduction

"Disasters do not cause effects; the effects are what we call a disaster" Wolf Dombrowsky (1995).

Above quotation conveys a message that the disaster is an effect of an event that brings vulnerability in environment. Thus, it implies that there is a need to study the effects of disasters (Vaghani V.A; 2005). Floods are the most common occurring natural disasters that affect human and its surrounding environment (Hewitt; 1997).

Flooding forecasting is a complex problem for scientists and, potentially, a life-a-death concern for the general public. Understanding of critical meteorological and hydrological processes involved has increased markedly in the past half-century as computers have emerged. Concurrent with progress on the scientific side, however, has come growing human toll. As previously undeveloped areas become populated, water flow is inevitably altered, thus enhancing the potential for devastating floods. Clearly, weather forecasters need to comprehend fully the hydrological phenomena that influence where and when flood occurs (Georgakakos; 1986).

Concerns about flooding issues have been rising in the last decades as their frequency and their magnitude seem to be increasing continuously. Climate change is often seen as responsible for changes in storm patterns and the use of land for accelerating the runoff process. Another element that appears obvious is that the vulnerability of the catchment has increased. Urbanization tends to concentrate population and economic activity around cities which for most of them have historically been built along rivers (for reasons of arable lands, transportation or water supply). This development often takes advantages of virgin flood plains to expand and thus enhances the risk of flooding (Steinmann E; 2005).

Flooding induced by storm events is a major concern in many regions of the world (Dutta et al.; 2000; Blanchard-Boehm et al.; 2001; Horrit and Bates; 2002; knebl et al. ; 2005). It causes over one third of the total economic loss from natural catastrophes and is responsible for two thirds of people affected by natural disasters (Kafle T.P; 2007). In Nepal each year, on an average 330 lives are lost due to floods and landslides and infrastructures and property amounting to more than US$ 100 million is damaged (DWIDP;2004) causing negative impacts on the social and economic development of the country. The first severe flood in Kathmandu valley was recorded in 1954 AD. Since then, there have been numerous flood events.

Evaluations of the extreme flood events are essential but cannot wait for them to take place, so modeling technique is used to simulate these events. Hence, modeling gives the capability to analyze the events that are likely to take place in the future and to develop the skills to cope with these problems.

Various computer models (i.e., hydrological models) are available to fulfill these purposes. All these models have their own pros and cons and limitations. These models are also prepared considering the topography and the climatic conditions. The models in rainfall-runoff are designed to simulate catchment runoff using daily rainfall and evapotranspiration. The tank model, a lumped conceptual hydrological model, is well known due to its simplicity of concept, simplicity in computation while achieving forecasting accuracy comparable with more sophisticated models. The tank model was originally developed by Sugawara and Funiyuki (1956) from Japan. It is well known as a lumped conceptual hydrological model. Many hydrologists are using this model due to its simplicity of concept and computation while achieving forecasting accuracy comparable with more sophisticated models.

1.2. Objectives of the study:

- To Simulate water flow in Bagmati basin using tank model
- To collect the necessary input data to run the model.
- To use the given peaks by the Tank model for flood forecast.
- The assessment of the potential use of the model for flood forecasting on the Bagmati river basin of Kathmandu valley.

1.3. Limitations of Study:

- Lack of literatures on flood forecasting on Bagmati basin regarding Tank model.
- Meteorological stations were not established enough at the project sites.

- Data’s being incomplete for some stations and errata in data being prevailed due to technical errors.
- Adequacy of a Selected Flood Forecasting Model
- Adequacy of Model Calibration
- Real-time Operation Constraints

1.4. Station selection for the study:

Only nine stations namely Godavari, Panipokhari, Bhaktapur, Chapagaun, Khokana, Thankot, Khumaltar, Kathmandu Airport and Nagarkot are selected for precipitation data. For discharge data the station at Khokana of Bagmati River is selected. Also for evaporation data, the station at Kathmandu Airport is selected.

Table1.1: list of stations

S.N.	Station name	Index No.	Type of station	District	Lat.	Log.	Ele.
					deg. min.		meter
1	THANKOT	1015	PRECIPITATION	Kathmandu	2741	8512	1630
2	GODAVARI	1022	CLIMATOLOGY	Lalitpur	2735	8524	1400
3	KHUMALTAR	1029	AGROMETEOROLOGY	Lalitpur	2740	8520	1350
4	KATHMANDU AIRPORT	1030	AERONATICAL	Kathmandu	2742	8522	1337
5	PANIPOKHARI(KATHMANDU)	1039	CLIMATOLOGY	Kathmandu	2744	8520	1335
6	NAGARKOT	1043	CLIMATOLOGY	Bhaktapur	2742	8531	2163
7	BHAKTAPUR	1052	PRECIPITATION	Bhaktapur	2740	8525	1330
8	CHAPA GAUN	1060	PRECIPITATION	Lalitpur	2736	8520	1448
9	KHOKANA	1073	CLIMATOLOGY	Lalitpur	2738	8518	1212

1.5. Thesis layout:

This thesis consists of six chapters and the general contents of each chapter are outlined here. Chapter one gives the introduction of the thesis work. Chapter two is focused on the literature review done by different scholars related to the study. Chapter three present the study area and source of data while chapter four gives information about the methodology involved in this thesis. Chapter five contains the result and discussion. And last chapter six contains conclusions and recommendations.

2. Literature Review:

Heavy rainfall usually causes flood, big flood, and flash flood in most of the parts of Nepal causing lot of damages about people's lives and properties.

It is very difficult to observe measure, warn and forecast all natural disasters such as heavy rainfall and flood. Currently, with ability of profession, knowledge, techniques and equipments, hydro-meteorological agencies have been trying to ensure supplying all information for natural disaster preventing and mitigating work and for development of the country. Particularly, flash flood warning and forecasting work have only just reached the quality warning level for big areas and regions. It has ability for quantity forecasting for specific small areas yet.

In order to strengthen initiative abilities for preventing and mitigating damage causing by flood, and heavy rainfall, hydro-meteorological agencies have been invested many general projects to modernize remote monitoring, observing, measuring, transmitting data, warning and forecasting natural disasters in all the country. Innovating and developing techniques used in domestic, importing and handing over new advanced techniques in the region and in the word, developing numerical forecasting model, software and techniques have also been main targets. Strengthening researches about forecasting science and forecasting survive is a basis to acquire, apply and develop advanced forecasting techniques (Thi, N.V; 2003).

2.1. Precipitation

Precipitation is the input to the system of catchment, which may have different forms, rainfall, storms, dew or any form of water landing from atmosphere. The amount of precipitation can be defined as an accumulated total volume for any selected period. Precipitation as a function of time and space is highly variable. Systematic averaging methods such as Thiessen polygon, isohyte and reciprocal distance methods have been developed to account for variations in space to obtain a representation of areal precipitation values from point observation. Singh and Chowdhury, (1986) after comparing the various methods for calculating areal averages, concluded that all methods give comparable results, especially when the time period is long. For short time step records, the conversion of a point observation to an aerial rainfall has a large influence. The net precipitation at a place and its form depends upon wind, temperature, humidity and pressure within the regions enclosing the cloud and the ground surface at the given place. The well distributed rain gauges in the stations measures the rainfall amount and intensity (Pant. Y; 2011)

2.2. Peak Discharge:

It is the maximum volume flow rate passing a particular location during a storm event. Peak discharge has units of volume/time (e.g. ft^3/sec, m^3/sec, acre-feet/hour).The peak discharge is a primary design variable for the design of storm water runoff facilities such as pipe systems, storm inlets and culverts, and small open channels. It is also used for some hydrologic planning such as small detention facilities in urban areas. There have been many different approaches for determining the peak runoff from an area. As a result many different models (equations) for peak discharge estimation have been developed. Ideally, we would like to have a 30-year flood record available at every site where a peak discharge estimate is needed for design work. If such data were always available, then a frequency analysis of the flood record could be used to characterize the flood potential at the site of the design work. More often than not, flood records are rarely available where peak discharge estimates are needed for design work. Therefore, it is necessary to use either a prediction method that was developed from flood frequency analyses of gagged data in the region or an uncalibrated prediction equation that was designed for use at ungagged sites.

Evaporation and transpiration

Catchment evaporation demand is generally defined as that evaporation which would occur if there were no deficiencies in the availability of moisture for evapotranspiration by that area's particular plant regime. The two main factors influencing evaporation from an open water surface are the supply of energy to provide latent heat of vaporization and the ability to transport the vapour away from the evaporative surface: solar radiation and wind. Evapotranspiration from land surface comprises evaporation directly from the soil and vegetation surface and transpiration through plant leaves, in which water is abstracted from the sub soil. The third factor is the supply of moisture at evaporative surface, which brought about the definition of potential and actual evaporation. Evaporation involves a highly complex set of processes, which themselves are influenced by factors dependent on the local conditions (land use, vegetation cover, and meteorological variables). Mostly the potential evaporation is the quantity obtained either by using some simple empirical formula such as Thornthwaite, (1948), Penman formula (Penman, 1948) and a process-based model of Penman-Monteith (Monteith, 1965).

Since potential evaporation and evaporation from pans are governed by the same meteorological factors they have strong correlation. The relation between them is often give as a simple ratio. Burnash (1995) suggests using seasonal coefficients for converting pan data to potential evaporation rather than a single coefficient. In conceptual rainfall runoff modeling one of the two terms, pan evaporation and potential evapotranspiration are equally used as input, which exerts energy to extract water from open surface or soil moisture storage.

2.3. Infiltration:

The precipitation, which is not intercepted or evaporated from the land, will eventually infiltrate into the soil or flow as overland flow. Infiltration is one of the most difficult hydrological processes to quantify. The difficulty arises due to many physical factors affecting the rate of infiltration such as rainfall intensity, initial moisture content, soil property, etc. Some experimental and empirical formulas such as Horton (1939), Philip (1957), and others are available to compute infiltration rates during a rainfall event. Depending on the soil strata, the infiltrated water gradually percolates to the groundwater or either flows as subsurface flow supplying river or springs within the catchment.

2.4. Stream flow:

Runoff occurs when parts of the landscape are saturated or impervious. Two runoff concepts include infiltration-excess and saturation excess runoff. The infiltration-excess runoff paradigm assumes that overland flow occurs when the rainfall intensity is greater than the infiltration rate at the surface soil. The water in excess of that which infiltrates through the soil surface, flow across the soil surface to nearby channels (kirkby,1985). This process has also been termed hortonian runoff. As first described by Horton (1939), two conditions must be satisfied to generate hortonian flow (Freeze,1980).firstly, rain must fall on the landscape with an intensity or rate in excess of the dynamic permeability of the surface soil. Secondly, the duration of rainfall must last longer than the time required to saturate the surface.

The second type of rainfall generation also occurs where the soil surface is saturated and any further rainfall, even at low intensities, generates runoff that contributes to stream flow. This more dominant process is termed as saturation-excess runoff generation. A rise in water table occurs because of a large infiltration rate of water into the soil and down to the saturated subsurface (Wolock,1993). The variable spatial extent of the landscape saturated from below that fluctuates dynamically with watershed witness is termed the variable source areas can arise from direct rainfall on the landscape or from return flow of subsurface water to the surface (Dunne and Black,1970). Saturated surface areas typically develops near existing stream channels and in depressions or hollows (Dunne et.al;1975) and expand as more water infiltrates and moves down slope as saturated subsurface flow (Wolock,1993).

2.5. Flood estimation:

Many previous research works have not dealt with the issue of urban flooding in Nepal, though many works on flood disaster effects and mitigation measures, estimation of floods and vulnerability have been done. The first documentation of flood related event in Nepal was done in 1958. After the flood of 1954, a report on disaster relief program was published in 1958. Swollen by torrential rains, one of the Nepal major rivers “the Bagmati”, brought destruction to large section of the country (Upadhayay S; 2006).

MoWR (1993) prepared a report on floods of 1993 in Bagmati river basin. Nepal’s central region was hit by severe storm of 19-21 July, 1993. The resulting effect of the storm was heavy precipitation in and around Bagmati river basin. Various methods such as Rainfall-Runoff relation, slope area method, based on previous day flood, Dicken’s formula, specific flows and world enveloping formula were used to estimate flood in the Bagmati River. The flood event in Bagmati river at Karmiya found to be ranging from 10,500 to 15,900m^3/s. a flood peak of 11,700m^3/s calculated from slope-area method was adopted. The mean annual and flood discharge analysis (Gautam, 2000) for Bagmati river basin was studied. The regression analysis with mean annual discharge and basin area was conducted. The linear and curvilinear curves were also depicted. Bagmati have slight falling trends very close to their mean values. The instantaneous discharges in linear and curvilinear regression analysis for Bagmati are 292.24m^3/s and 82.98m^3/s respectively.

Estimation of floods at ungauged locations within Nepal is challenging due to complex topography (Shakya B., 2001). Empirical formulas are widely used to estimate floods at ungauged location within Nepal.

In report “Bagmati command area Development Project” (Department of irrigation, 1990) statistical distributions like Gumble, Iwai, Hazen and Pearson Type III were used. The report recommended Gumble method as standard distribution for flood frequency analysis.

2.6. Rainfall-Runoff models:

The development and the application of rainfall-runoff models have been a corner-stone of hydrological research for many decades. In general, the purpose of the development of these models is a two-fold. The first is to advance our understanding and state of knowledge about the hydrological processes involved in the rainfall-runoff transformation. The second is to provide practical solutions to many of the related environmental and water resources management problems. Common features of all of these developed models are that, each is a simplified form of the real-world system and that all such models are to a greater or lesser extent, in error. Progress in the development of rainfall-runoff models has been accelerated by the fast advancement in the technology of digital computers which has allowed the storage and the processing of long records of data. These technological advances have provided fertile ground for the development of what might now be called a glut of rainfall-runoff models (Mutua,F.M and Al-Weshah R).

The development of computer models to simulate rainfall-runoff relationships has been a prime focus of hydrological research for at least since the 1960s (Crawford and Linsley,1966) and has resulted in a pro life ration of models. The models in Rainfall-Runoff are designed to simulate catchment runoff using daily rainfall and evapotranspiration. The actual model chosen foe use in a particular it and the detail required in the application. The models currently available are all spatial simplistic. They use a simple system of a single unit or can be linked as a series of sub-catchment but cannot be used in a truly distribute fashion. The model Tank is the simplest of the models in the rainfall-runoff. It consists of four tanks that represent surface stores. The amount of water in each tank is affects the amount of evaporation, infiltration and runoff. The tank storage is calculated in order so that conceptually it is moving down soil/bedrock profile (Dave T;2004).

Conceptual models are generally composed of a number of interconnected storages representing physical elements in a catchment. These storages are recharged through fluxes of rainfall, infiltration or percolation and depleted through evapotranspiration, runoff etc. assembling the real physical process in the catchment. Parameters and fluxes typically represent the average values over the entire catchment. The equations used to describe the process are semi-empirical, but still with a physical basis. The model parameters cannot usually be assessed from field data alone, but have to be obtained through the help of calibration. Although the conceptual models are simple and can be easily implemented in the computer code, they need sufficiently long meteorological and hydrological records for their calibration which may not be always available. The calibration of the conceptual models involves curve fitting, thus making physical interpretation of the fitted parameter very difficult and predicting effects of land use change by changing parameter values cannot therefore be done with confidence (Abbott et al., 1986a). There are many conceptual models with different levels of physical representational and varying degree of complexity. Crawford and Linsley (1966) are credited for the development of the first major conceptual model by introducing the well known Stanford Watershed Model IV. Numerous other widely used conceptual models include Sacramento Soil Moisture Accounting model (Burnash et al., 1973), NAM model (Nielsen and Hansen, 1973), TOPMODEL (Beven and Kirkby, 1979), TANK model (Sugawara, 1967, 1995), HBV model (Bergström and Forsman, 1973) and so on. A brief description of several conceptual models is given in an early work by Fleming (1975). Comparison results of 10 different conceptual models used in the sixties for operational hydrological forecasting are presented in

WMO (1975). More comprehensive descriptions of a large number of conceptual models are provided in Singh (1995a).

The tank model, a lumped conceptual hydrological model, is well known due to its simplicity of concept, simplicity in computation while achieving forecasting accuracy comparable with more sophisticated models (Kuok K.K; 2010). The tank model was originally developed by Sugawara and Funiyuki (1956) from Japan. It is well known as a lumped conceptual hydrological model. Many hydrologists are using the model due to its simplicity of concept and computation while achieving forecasting accuracy comparable with more sophisticated models.

The relationship between rainfall and runoff is highly nonlinear and complex and its determination is very important for hydrologic engineering design and management purposes. It is dependent on numerous factors such as initial soil moisture, land use, watershed geomorphology, evaporation, infiltration, distribution and duration of rainfall and so on. Many of the watersheds are gauged to provide continuous record of stream flow data. But situations such as high flood season, instrument failure, etc force the engineers or hydrologists to generate the stream flow records using rainfall by simulation models. Many rainfall-runoff models such as empirical, lumped and distributed models have been developed and used for simulating the stream flow at the catchment outlet. Empirical models estimate the peak runoff from the whole catchment for the purpose of design of storage structures. Lumped models like unit hydrograph (Chow et al., 1988) have been developed to estimate the runoff hydrograph from a storm event. Distributed models such as SHE (Danish Hydraulic Institute, 1988), TOPMODEL (Bevan et al., 1995) consider the hydrologic processes taking place at various points in space and define the model variables as functions of the space dimensions. Distributed models can be used to synthesize runoff volumes from ungauged catchments. Calibration of distributed models requires large quantity of data compared to lumped models and large computer resources for successful implementation. Sometimes complexity and less accuracy of these conventional models force the modeler to think of alternative modeling techniques such as Tank model, which provide better results. Many applications of Tank model in rainfall-runoff modeling are reported.

Research on watershed scale runoff modeling for flood forecast has been carried out (Kafle, et al, 2007). Employing the hydrologic model HEC-HMS to convert the precipitation excess to over land flow and channel runoff, the study was conducted on Bagmati basin in Nepal. The simulation was conducted in June to September 2004. Estimated hydrograph was calibrated against observed one and the model parameters were manually optimized for good simulation. The predicted peak discharge, using rain gauge data, was close to the observed value and the smaller discharges followed the observed trend. Spatial variation in the runoff response of the watershed is a consideration to build model framework. Consequently Curve Number is used on a basis of soil type, land use and spatial distribution of rainfall over the whole watershed.

According to the Phien, H.N; peak discharge are underestimated by the tank model. When the computed peak discharges were increased to be of the same range as the observed data, the annual discharges and hydrograph ceased to be close to this historical one. These results together with those obtained by Thang (1981) indicated that the tank model would be very useful for the extension of stream flow records. Having calibrated its parameters using the available data for rainfall, runoff and evaporation, the model can be used to transfer rainfall to runoff when data on the former are available for a longer period. However, due to the fact that the peaks of computed daily discharges were lower than those observed, the tank model would not be good for flood forecasting.

According ISHIHARA, Y; KOBATAKE, S (1979); the tank model is employed to calculate a hydrograph from a divided sub-basin in the light of observational results in the experimental basin. The merits of using the tank model instead of the physical runoff model are that the parameters of the tank model can be identified relatively easily and the effective rain-water are automatically determined in the process of calculation. Moreover, it seems that some parameters of the tank model directly correspond to the parameters of the physical runoff model.

According to T.P. Kafle et. al. the rainfall-runoff model predicted the peak discharge, based on point gauge data, fairly accurately. But the model needs further refinement for smaller discharges. Hence the methodology could be applied for peak flow computation for flood forecasting. Decision makers and communities are often concerned with inundation area extent and flood depths corresponding to a given discharge at specific locations. Hence the rainfall-runoff model in combination with the flood maps could provide a good basis for real time flood forecasting.

2.7. Flood Frequency analysis:

Flood frequency analysis involves the fitting of a probability model to the sample of annual flood peaks recorded over a period of observation, for a catchment of a given region. The model parameters established can then be used to predict the extreme events of large recurrence interval (Pegram and Parak, 2004) Reliable flood frequency estimates are vital for floodplain management; to protect the public, minimize flood related costs to government and private enterprises, for designing and locating hydraulic structures and assessing hazards related to the development of flood plains (Tumbare, 2000). Nevertheless, to determine flood flows at different recurrence intervals for a site or group of sites is a common challenge in hydrology. Although studies have employed several statistical distributions to quantify the likelihood and intensity of floods, none had gained worldwide acceptance and is specific to any country (Law and Tasker, 2003).

2.8. Summary:

In order to select among the plethora of different mathematical models available today, it is possible to identify models according to a priori knowledge. The latter ranges from total ignorance (pure stochastic models) to the full description of system dynamics based upon differential equations describing the balance of mass and momentum. The final choice on which model to use mainly depends on the purpose of application, the accuracy desired the available data and economics.

3. Study area:

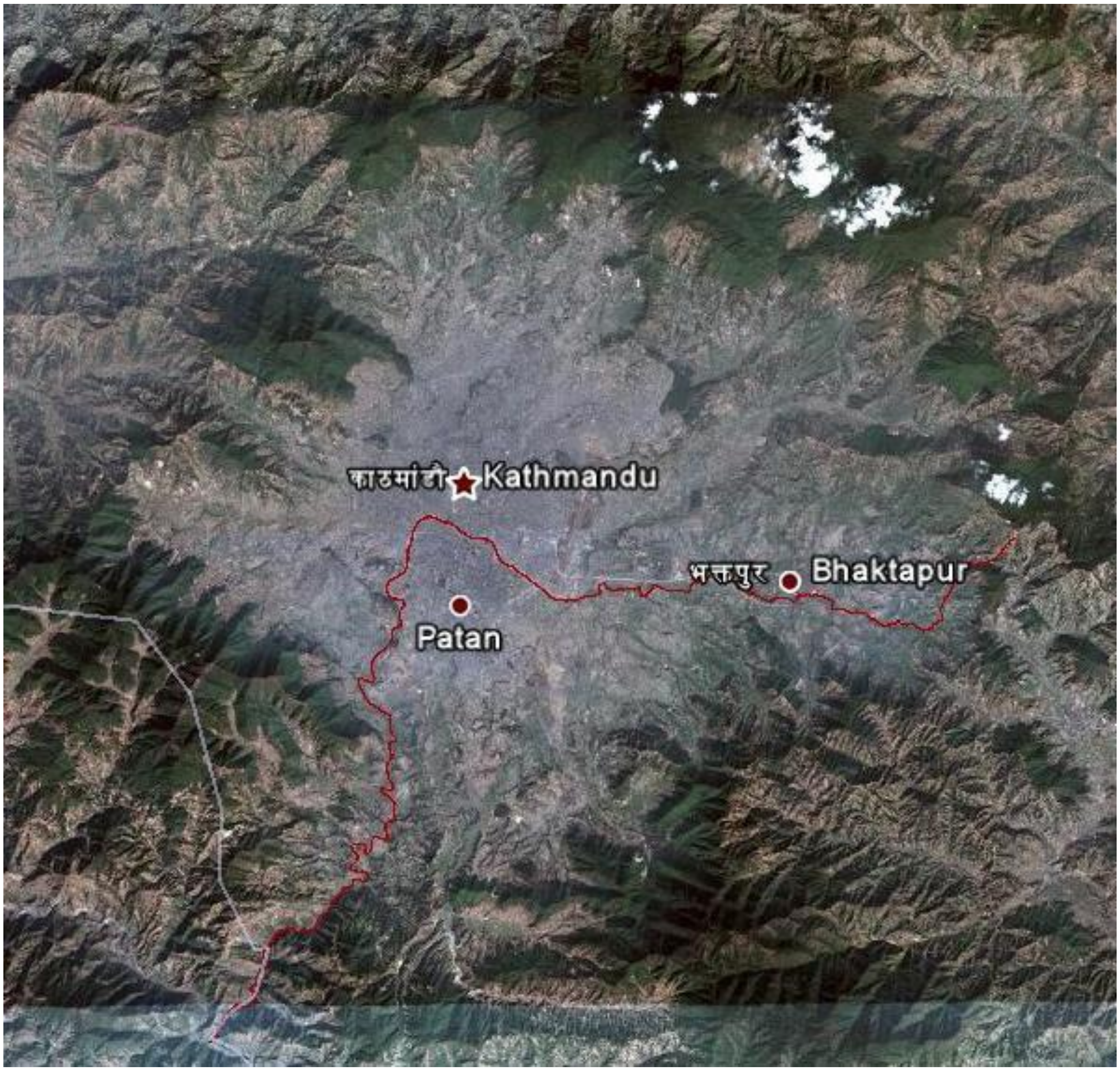

Fig.1: Satellite image of the Bagmati River Basin in the Kathmandu Valley

3.1. Topography:

The capital city of Nepal, Kathmandu, is surrounded by mountains on all sides and is almost circular in shape having a length of about 30km in the east west direction and 25 km in the north south direction. The elevation of surrounding hills of Kathmandu valley ranges from 2000 to 2750 m whereas the valley is flat with elevation ranging from 1300 to 1400 m. the valley is situated between the longitudes 85°32’34’’ to 27°49’11’’north with catchment area of 585sq. km. the average elevation of Kathmandu above mean sea level is 1336m (Kathmandu Airport). The valley is located between the Himalayan in the north and the Mahabharat Mountain in the south.

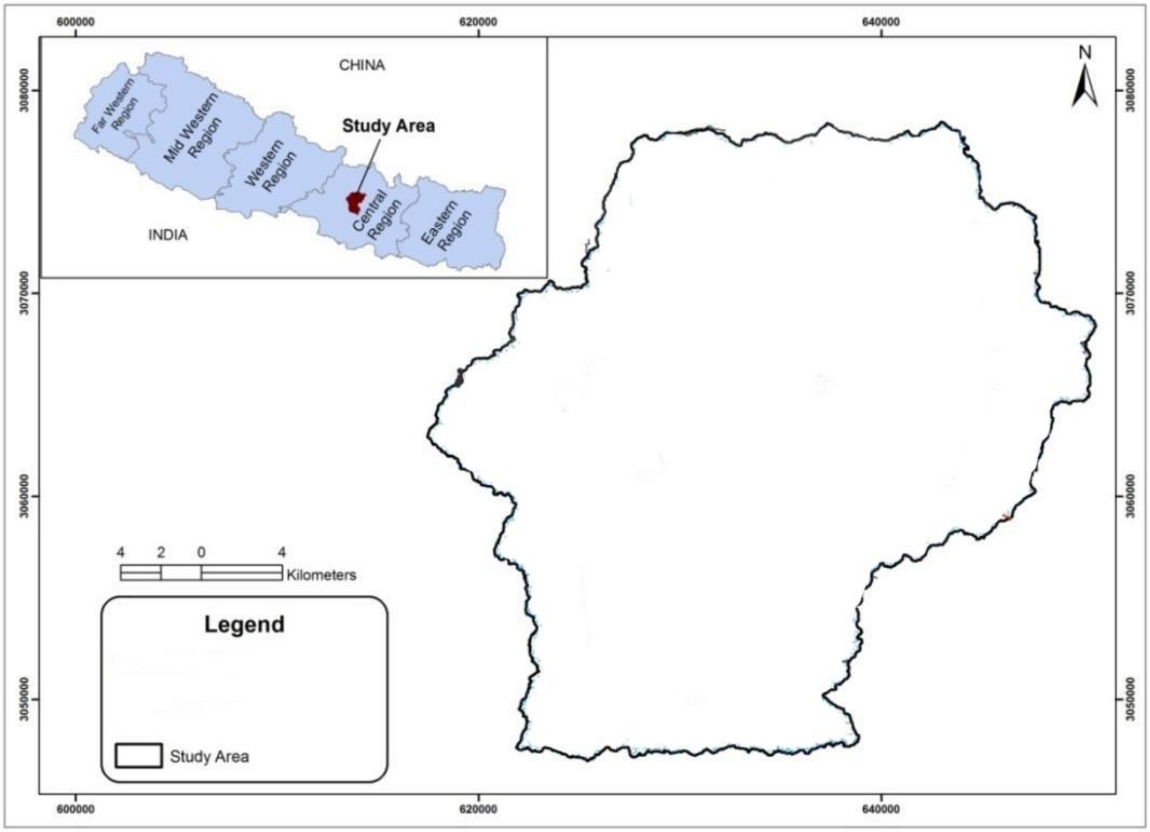

Fig.3.1: Study Area

3.2. Climate:

The climate in Kathmandu valley is warm temperate. The summers are hot and rainy whereas winters are cold and dry. In the summer and early autumn the prevailing wind regime in Kathmandu valley is the southwest monsoon (i.e. easterly). In the winter the prevailing winds are more westerly. During March to May the valley experiences pre-monsoon thunder shower activities and there is a strong wind in this season (karki, 2007). The temperature in Kathmandu drops below freezing in winter and in summer it may rise to 35°c. The mean annual air temperature in Kathmandu is 18°c. The coldest month is January, with a mean temperature of 10°c. The warmest month is July and august with an average temperature of 24°c. Fog is common in the morning during the months of October to February (pandey, 1987 and Yogacharya, 1998). Bulk of the rainfall occurs in the months between June to September. The western disturbance brings rainfall in the winter. The valley receives a mean rainfall of about 1900mm, but this figure varies between 1100 and 2500mm from year to year (Dixit, 1997).

The Annual average temperatures at different nine stations taken in the study areas from 1999-2008 are shown from figure 3.2-3.7. The discharge observed at Khokana station from 1999 to 2008 is also shown in figure 3.8.

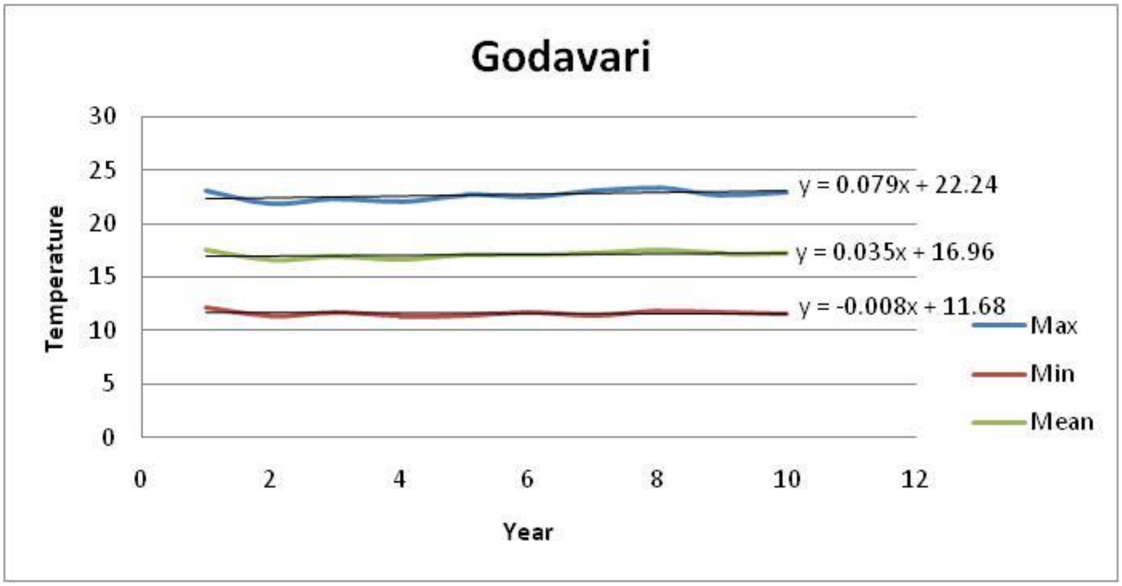

Fig.3.2: Annual average temperature at Godavari from 1999-2008

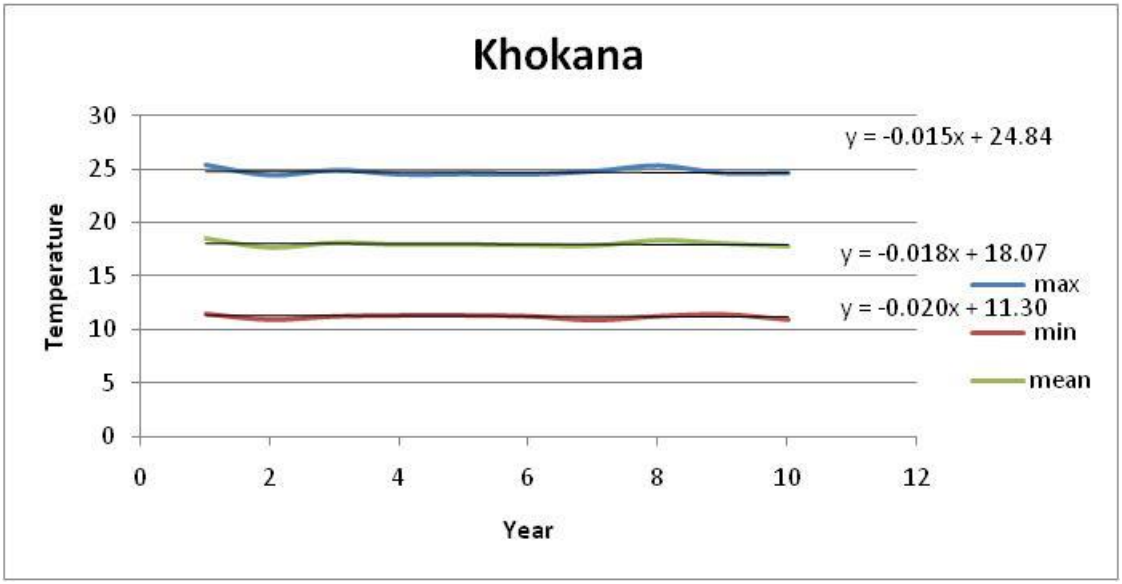

Fig.3.3: Annual average temperature at Khokana from 1999-2008

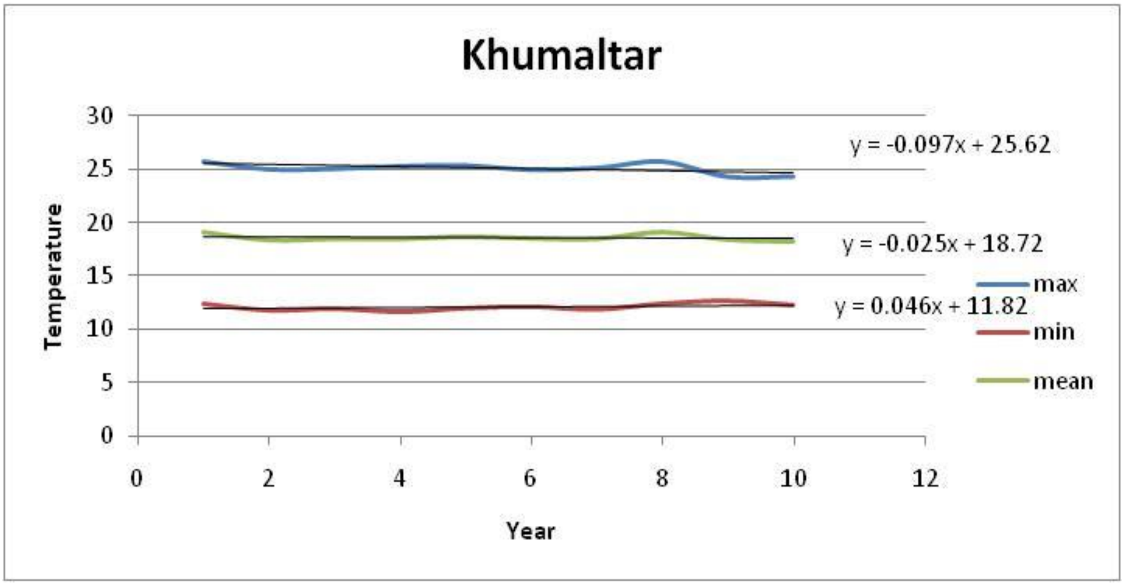

Fig.3.4: Annual average temperature at Khumaltar from 1999-2008

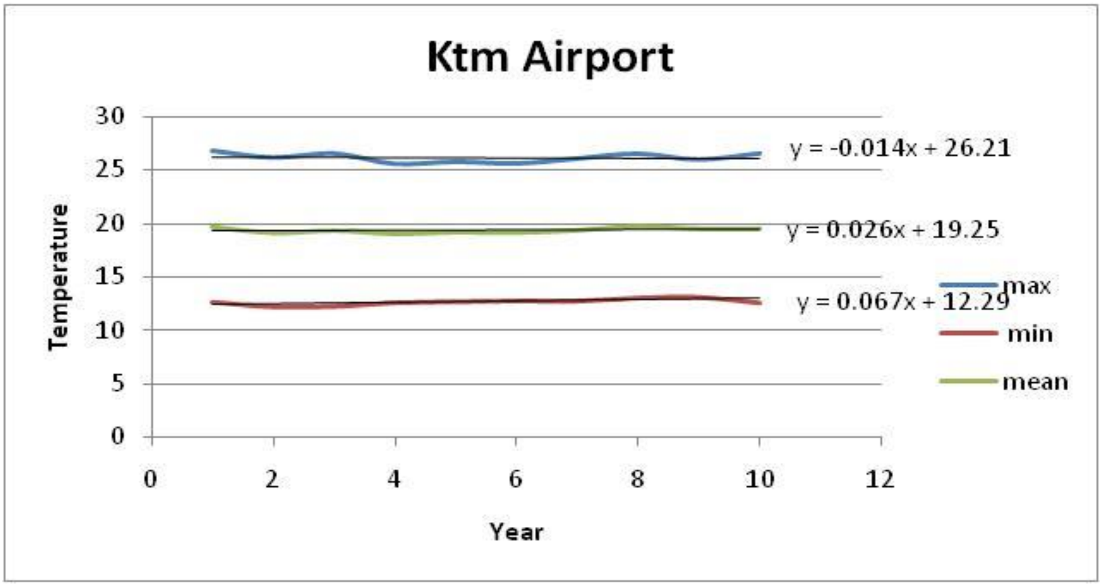

Fig.3.5: Annual average temperature at Ktm Airport from 1999-2008

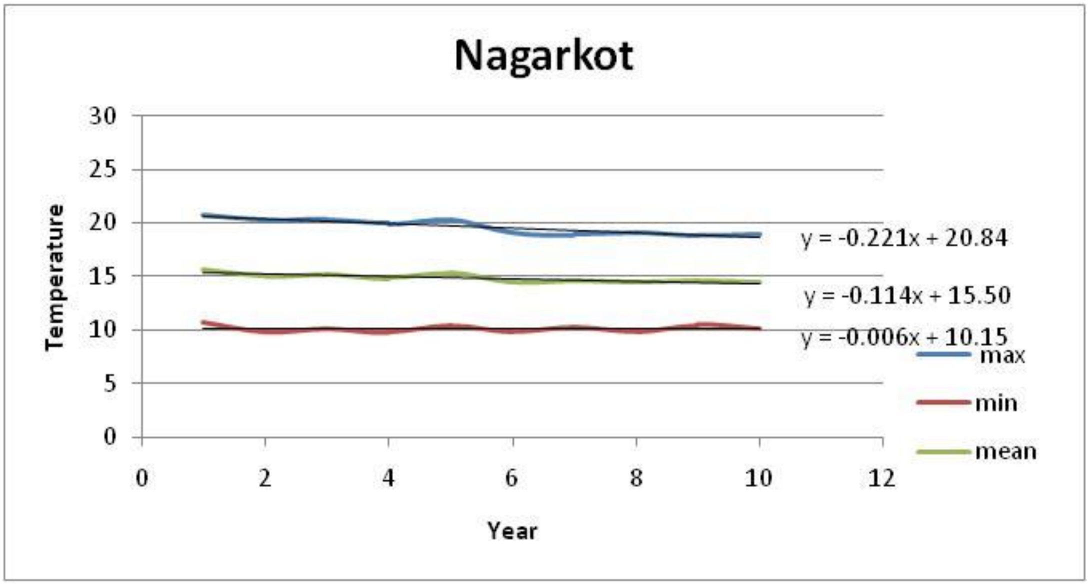

Fig.3.6: Annual average temperature at Nagarkot from 1999-2008

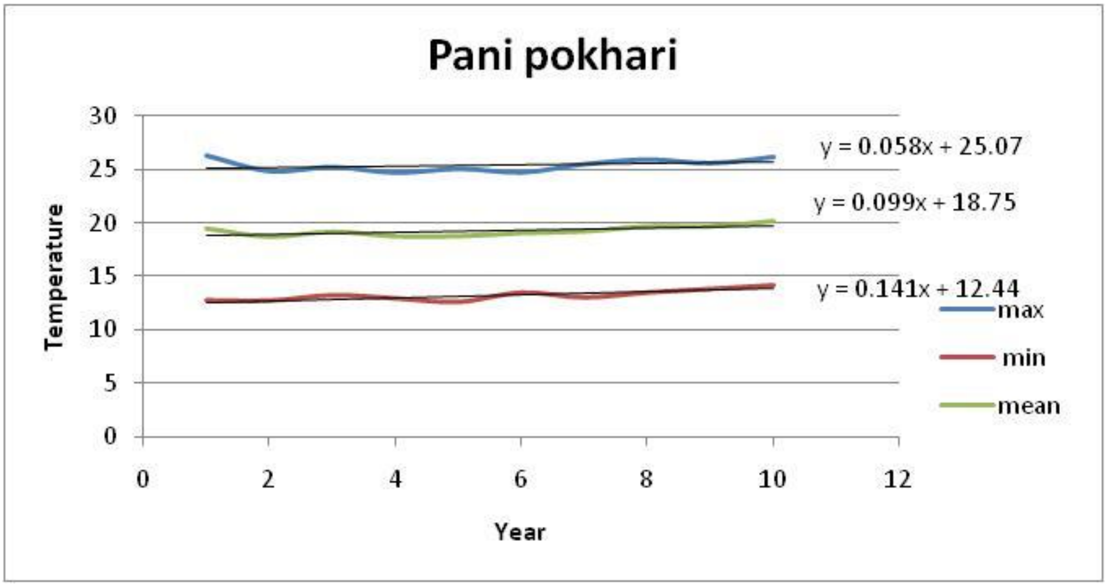

Fig.3.7: Annual average temperature at Panipokhari from 1999-2008

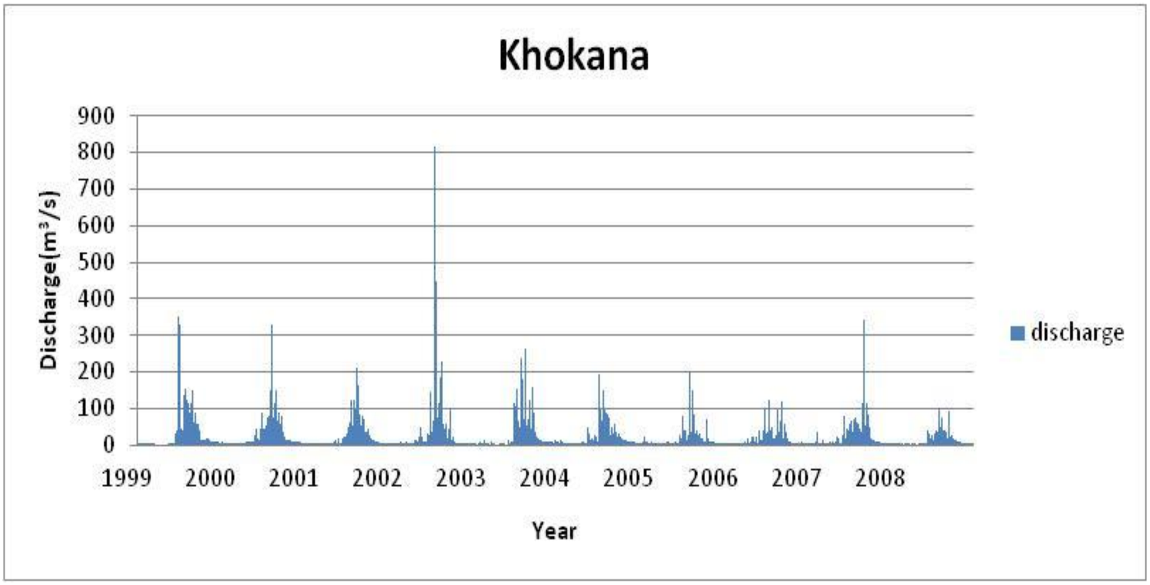

Fig.3.8.a: Discharge at Khokana from 1999-2008

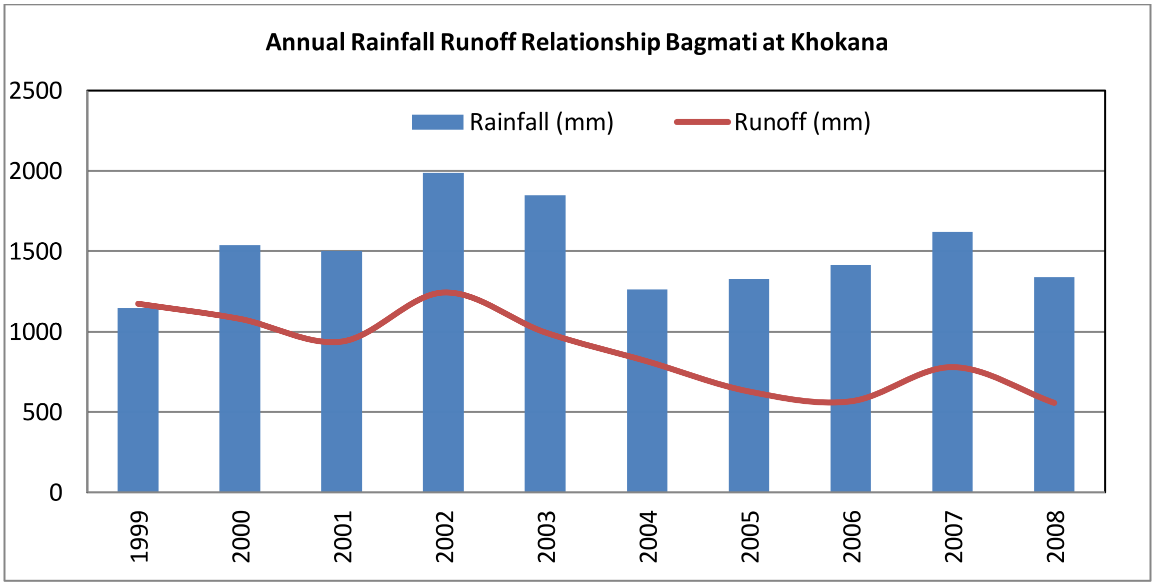

Fig.3.8.b: Annual Rainfall Runoff Relationship Bagmati at Khokana

3.3. River System:

The Bagmati river system originate at Bagdwar about 15 km northeast of Kathmandu city; in the Shivapuri hills at an elevation of about 2500 meters. It then drops to 1340 meters over a distance of about 8km. at Sundarijal, two river streams namely Nagmati and Sialmati joins the river. From Sundarijal, flowing to the south, it transverses towards the northern and western boundaries of Gokarna forest and passes the holy place called Pashupati Nath temple. Manohara joins Bagmati at Koteshwor where the river changes its direction to the west. At Teku, it takes a turn towards south where Vishnumati joins Bagmati originating in Shivapuri hills; Bagmati River drains a total area of 3710sq. km in Nepal. The upper part of Bagmati river basin lies in the Kathmandu valley a length of 30km. the total catchment area is 585sq.km (Dixit, 1998). But recent studies show that the total length is 597km of which 206.8 km lies in Nepal (DWIDP, 2005). Bagmati River flows from northwest to southwest direction in the northern half part of the valley and its outlet is at Khokana, Chobar. At Chobar, the mean flow of Bagmati is 15.5m^3/s. In dry season, the minimum average flow at Chobar is 0.15m^3/s (Dixit, 1997).

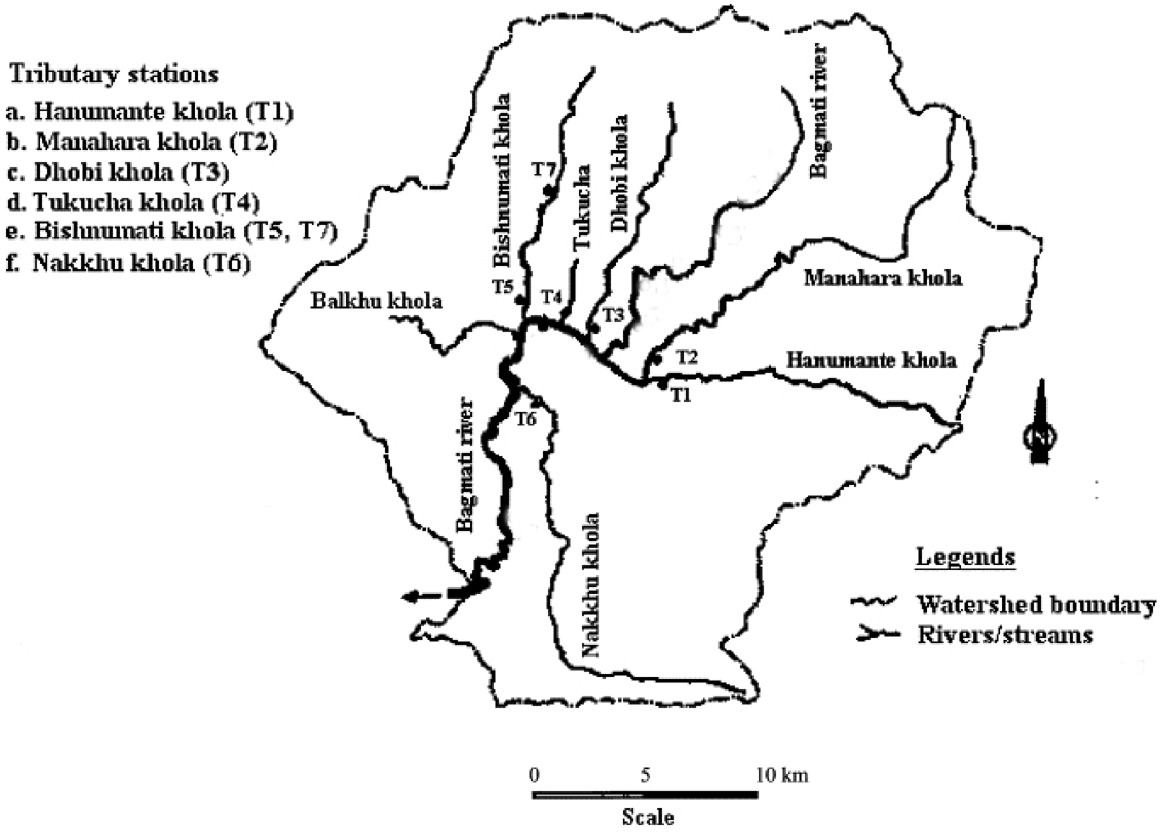

Fig.3.9: River System of Bagmati Basin

3.4. Source of Data:

The present study includes precipitation and evaporation data of Kathmandu valley. The daily precipitation data of nine stations for the period 1999-2008 is used and obtained from Department of hydrology and Meteorology of Nepal. The daily evaporation data of Kathmandu Airport was obtained for the period 1999-2008 from Department of Hydrology and Meteorology (DHM) of Nepal.

The daily discharge data of Bagmati at Chovar (Khokana) is obtained for the period 1992-2008 from DHM of Nepal.

4. Methodology:

4.1. Tank Model:

The data file for rainfall, evaporation and discharge should be entered in a text format prior to simulation. The data are entered in to the note pad file, in a text format

4.1.1. Data file (*.dat)

These file (rainfall, discharge, and evaporation) are then browsed in the data entry dialog box, and the data entry dialog box is saved with the extension (*.dat).

Initial date (data entry): This term implies the date of initial data entry. For example, we enter the daily data for 5 year (1999-2003), then the initial data entry implies 1999/1/1, and suppose we want to analysis splitting the time series in to yearly basis, then for simulating for 2002, the start data of simulation, is for example 2002/1/1. The end date of simulation corresponds to the ending date of simulation period.

The observed discharge data file, the rainfall data file and evaporation data file are browsed in to corresponding text box, and finally the data file dialog box is saved.

4.1.2. The parameter file (*.par)

Enter the corresponding parameter in the parameter file dialog box, for manual simulation, and save the parameter file with *.par extension.

If the automatic calibration is to be done then there is no need to enter the value of parameter, in the parameter file dialog box.

4.1.3. Initial condition file (*.ini)

Please enter the initial condition in the corresponding initial condition dialog box, and save the file with *.ini extension. This file is needed both for manual calibration and automatic calibration.

4.1.4. Simulation file (*.sim)

The simulation file dialog box comprises two sections; one is the “Model” and next is the “Input”.

4.1.5. Model:

There are three options provided,

a) Manual calibration: In this method the user should supply the value of parameter to run the model. For detail about the parameter please refer Fig 1.To run the file using this option, user should click load simulation button, first and next button, which will lead the user to simulation page dialog box, then simulation button is clicked to start simulation.

b) Optimization: In this method, the application itself optimizes the value of parameter for tank model. If this option is selected then user should supply the weighted for the Nash efficiency criteria and Lichty efficiency criteria. Such that the summation should not exceed 1. User should also supply the value of total number of generation, and the population size (>1). Typically these values are 100 to 200 for generation, and 5 to 10 for population size.

Automatic calibration procedures typically require the selection of a single objective function for optimization of the model to identify the best model parameters. This implies proper choice of an objective function. Different criteria has been developed to evaluate the performance of simulation, least square objective function, equation (4), evaluates the sum of the squares of the flow residuals and may give good fits to long periods of low flow but poor fits to higher and more peaky portions of the hydrograph, Another option is the least squares of logarithms objective (Lichty et al 1968), equation (5) Which evaluates the sum of the squares of the residuals of the logarithms of the flow and prevents the optimization becoming biased towards the largest flows. Nash-sutcliffe (1970) equation (6) is a normalize form of least square objective function which is widely used to assess performance of continuous model, so the problem of calibrating continuous model could be realized as multi-objective problem. Single objective function, may not adequately reflect the important characteristics.

$$\mathrm{OBJ}(\mathrm{LSL}) = 1 - \sqrt{\frac{1}{\mathrm{N}}\sum_{\mathrm{i}=1}^{\mathrm{n}}(\mathrm{Q}_{\mathrm{obs,i}} - \mathrm{Q}_{\mathrm{sim,i}})^2} \qquad (4)$$

$$\mathrm{L} = 1 - \frac{1}{\mathrm{N}}\sum_{\mathrm{i}=1}^{\mathrm{n}}(\mathrm{Log}(\mathrm{Q}_{\mathrm{obs,i}}) - \mathrm{Log}(\mathrm{Q}_{\mathrm{sim,i}}))^2 \qquad (5)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(O_{obs,i} - Q_{sim,i})^2}{\sum_{i=1}^{n}(Q_{obs,i} - \overline{Q})^2} \qquad (6)$$

Where $Q_{obs,i}$ and Q_{simi} are the observed and simulated flow at ‘i’ time period, N is the total time step, OBJ (LSL) is the normalized least square objective function, L is the Lichty efficiency criteria, and R2 is the Nash efficiency criteria.

All the above objective function when subjected to optimization leads to different parameter value so Scalar-aggregate approach is implemented which combines various objectives in to a single scalar fitness values, reflecting the multi-objective trade off preference of the user. The simplest representation of the scalar fitness value is a linear function combining the various objectives. So the Multi-Objective hydrologic model calibration problem with scalar aggregate approach can be formulated as follows.

Maximize F (θ)= $\sum_{i=1}^{n} W_i \times f(\theta)$ (7),

For, i = 1, N such that $\sum Wi = 1$, where N, is the number of objective function.

In a present study two objective functions were selected, the Nash efficiency criteria, which is slightly, biased towards to peak flow, and Lichty criteria, which is slightly biased towards the lower flow. The Following objective function was used for optimization of the model.

$$Max\ F = L * W_1 + R^2 * W_2 \qquad (8)$$

Where W1 is the weighted for Nash criteria and W2 is the weighted for Lichty efficiency criteria. User can provide different weighted as per the requirement and objective of simulation.

4.1.6. Input:

It comprises five Text box, where the relevant data file are browsed using browse button.

1. Time series file: Here the data file previously saved as *.dat is browsed, which consists of the duration of simulation, discharge data file, evaporation data file, rainfall data file and catchment area (square Km).

2. Parameter file: Here the parameter file previously saved as *.par is browsed; this is only needed when the manual calibration option is selected.

3. Initial file: Here the initial condition file previously saved as *.ini is browsed.

4. Result file for opt parameter: This text box will only be only enabled when the automatic optimization option is selected. Here the user should provide the file name where user would like to save the optimized parameter with *.par extension. This file is later browsed at parameter file text box, when manual calibration is selected to view the simulation result.

5. Simulation result file: This text box will only be enabled when user selects the manual calibration option. Here the user should provide the file name, where user would like to save the simulation results. It includes the observed discharge, simulated discharge, rainfall, evaporation, and flow component from different tank.

After supplying the relevant data file, for optimization please press optimization button, this will give you the optimum efficiency, and for manual calibration first press the load button and then the next button, which will lead you to the simulation page dialog box. In this page graphic option is provided to view the observed discharge, simulated discharge, rainfall, fast flow and base flow, before pressing the simulation run command button, please check the check box, as required for different option and then press the simulation run.

4.2. A short theoretical description of the application introduction:

The rainfall runoff relationship is among the most complex hydrologic phenomena to comprehend due to the tremendous spatial and temporal variability of watershed characteristics, snow pack, and precipitation patterns, as well as a number of variables involved in modeling the physical processes.

Model calibration is the process by which the values of model parameters are identified to use in a particular application. It consists of the use of rainfall runoff data and a procedure to identify the model parameter that provides the best agreement between simulated and recorded flow. The overall importance of calibration varies with the type of model. In conceptual modeling, calibration is extremely important, since the parameter bears no direct relation to the physical processes. Therefore, calibration is required in order to determine appropriate values of these parameters. Parameter identification can be accomplished either manually by trial and error, or automatically, by using mathematical optimization. The complexity of calibration, in general, depends on the number of calibration parameters. For models with only few parameters repetitive graphical inspection or minimization of least squares error can be used, however, for models with a large number of calibration parameters, a more systematic and automatic calibration scheme is required. Automatic calibration involves the use of a numerical algorithm that finds the optimum of a given numerical objective function. It searches through the space, testing a minimal number of combinations and permutations, to locate the optimal point satisfying the criterion of accuracy.

4.3. Introduction to genetic algorithm:

Genetic algorithms are the algorithms of optimization and search based on the concept of natural selection and heredity. The genetic algorithm is inspired by Darwin's theory about evolution. Solution to a problem solved by genetic algorithms is evolved. The characteristic features of genetic algorithm compared to other search techniques are, they do not optimize directly on the variables but on their representations, searching are conducted form some population of points other than from a single point, they use probabilistic rules of choice, and can be applied to wide variety of problems. Holland (1975) first proposed the use of GA's as a search procedure in combinatorial optimization and machine learning problems. He proposed the use of artificial processes Patterned on natural selection, evolution, and the principle of "the survival of the fittest" The GA's has been shown in various applications to be both efficient and robust (Goldberg, 1989). The basic mechanism of GA ensures that the average "fitness" of the population improves as the search progresses. Thus, convergence is ensured. However, in many instances, the convergence rate can be quite slow. Algorithm is started with a set of solutions, Called population. Solutions from one population are taken and used to form a new population; this is motivated by a hope, that the new population will be better than the old one. Solutions that are selected to form new solutions (Offspring) are selected according to their fitness. The more suitable they are the more chances they have to reproduce; this is repeated until some condition is satisfied. The outline of the Basic Genetic Algorithm is

1) Generate random population of n chromosomes,

2) Evaluate the fitness f (x) of each chromosome ‘x’ in the population,

3) Create a new population by repeating following steps until the new population is complete,

Select two parent chromosomes from a population according to their fitness,

With a crossover probability, cross over the parents to form a new offspring,

Place new offspring in a new population,

4) Use new generated population for a further run of algorithm,

5) If the end condition is satisfied, stop, and return the best solution in current population,

6) Go to step 2.

The chromosome in some way contains information about the solution, which it represents. The length of the chromosome is one of the vital parameter of genetic algorithm. It represents the number of genes present in the chromosome. Longer chromosomes allow better conversion from the binary number to the real number variable. However, the longer chromosome is computationally more inefficient and generally takes longer to find the optimal region. So the number of chromosomes is such chosen that they are always equal to 2^n, where n is the no of parameter. (David Carrol) The most used way of encoding is a binary string. Each chromosome has one binary string. Each bit in this string can represent some characteristic of the solution. In the present study, the Genetic algorithm used for the optimization of the parameter uses the binary encoding. Crossover scheme is vital in the performance of GA. It selects genes from parent chromosomes and creates a new offspring. It should be capable of producing a new feasible solution by combing good characteristics of both parents. There are different types of crossover scheme; it can be single point crossover, and two point crossover, uniform crossover, and Arithmetic crossover. The uniform crossover method, which is used in the present study, has become popular recently. If crossover is performed, the genes between the parents are swapped and if no crossover is performed, the genes between the parents are left intact. This crossover method has a higher probability of producing children, which are much different from their parents. In uniform crossover scheme, bits are randomly copied from the first to form the second parent. Chromosomes are selected from the population to be parents to crossover. According to Darwin's evolution theory the best one should survive and create new offspring. There are many methods developed for the selection of the best chromosomes, for example roulette wheel selection, Boltzman selection, tournament selection, rank selection, steady state selection and some others. The Genetic algorithm employed for the optimization of the tank model parameters in the present study uses the tournament selection process for the selection of chromosomes. In tournament selection, the selection process comprises two steps, in first, a group of N individual is selected, and in next the individual with the highest fitness from the group are selected and others are discarded.

4.4. Tank Model with soil moisture storage:

Hydrology is the study of various components of the hydrological cycle. There are many approaches to study these components. Models representing the behavior of the catchment have been used for the study of the hydrological cycle since 60's. A catchment model is a set of mathematical abstractions describing relevant phases of the hydrological cycle, with the objective of simulating the conversion of precipitation in to runoff.

Hydrological models are divided in to two groups. The deterministic models seek to simulate the physical process in the catchment involved in the transformation of rainfall to stream flow. The stochastic model describes the hydrological time series of the general measured variables such as rainfall, evaporation and stream flow involving distribution in probability. Generally models are classified as stochastic, lumped, integral and distributed. The model that ignores the spatial variation in the parameters of the hydrological systems in their formulation is classified as lumped. Distributed parameter models account for behavior variations from one point to another in the physical system. The model can be either event driven or continuous process models. Event models are short term, designed to simulate individual rainfall runoff effects. Continuous process models take explicit account of all runoff components, including the soil moisture storage.

The tank model used here in the present study is a continuous, lumped, deterministic model and comprises four vertical tanks with the provision of primary and secondary storage. The structural diagram of tank model is shown in Fig.4.1, and the general flow chart of the tank model is shown in Fig.4. 2.

The model comprises of number of simple tanks with outlets arranged vertically one above other. The Rainwater is put in to the top tank. Water in each tank partially discharges through a side outlet or outlets and partially infiltrates through a bottom outlet to the next lower tank. River discharge can be simulated as the sum of outputs from the side outlets. Tank model represents a zonal structure of groundwater. The intensity of rainfall governs the behavior of the model. The top and middle tank contributes to the surface runoff, third and fourth contributes to the base flow. The soil moisture storage of the tank model comprises of primary storage and secondary storage. First the input, the rainfall, increases the primary soil moisture storage and in gradual process the continued input is utilized in increasing the secondary soil moisture. The storage level and the capacity of these two storages govern the provision of exchange of water between these two storages. The transfer of water from the primary tank to secondary tank and vice-versa is governed by equation (1).

$$T_2 = K_2\left(\frac{Xp}{H_{11}} - \frac{Xs}{Ss}\right), \quad (1)$$

Ss is the height of secondary storage tank, and Xs is the depth of secondary storage. Xp is the depth of primary storage. T2 is the transfer of water form lower free water to primary soil moisture. When the moisture deficit is higher in the primary soil moisture storage, then the transfer of water from the second tank to the primary storage occurs, and this transfer rate depends upon the moisture deficit of the tank i.e. XP/H11. And this transfer rate is governed by equation (2).

$$T_1 = K_1 = (1 - \frac{Xp}{H11}), \qquad (2)$$

T1 is the transfer rate from primary to secondary soil moisture. Evapotranspiration loss demands are at first attempted to meet at the potential rate from the top tank, when the primary storage is fully saturated. If the moisture content in the surface storage is less than these requirements, the remaining fraction is withdrawn by from the primary storage at an actual rate. The actual Evapotranspiration Ea is assumed equal to the potential

Evapotranspiration Ep multiplied by the relative moisture content h11/xp. The equation (3) describes the relation between the actual evaporation and potential evaporation.

$$E_a = E_p \times \frac{H11}{Xp} \qquad (3)$$

The Runoff from each tank is controlled by the runoff coefficient of the side outlet provided in each tank and the amount of infiltration is controlled by the outlet coefficient of the bottom outlet.

The behavior of model is largely dependent on the intensity of rainfall. In the case of rainfall with small intensity, most of the rainfall infiltrates to the lower tank, as the water level doesn’t rises up to the outlet level of top tank, so immediate response is low, but the outflow from the second tank increases, however in case of high intensity rainfall, the water level rises above the outlet level of the top tank, so in this case the immediate response is considerably high.

A12, A13, A22, A32 and A4 are the runoff coefficient of each tank, and A11, A21, and A31 are the infiltration coefficient of the tank. H11, H12, H13, H2, H3 are the height of the side outlets of each tank and St, Sm, Sb, Sd, Ss are the initial storage value of different tank included for the simulation of rainfall and runoff. Xp and Xs are the initial storage value of primary and secondary storage tank. The detailed are shown in the Fig. 4.1.

The tank model is coupled with genetic algorithm to optimize the parameter of the tank model. The genetic algorithm implemented in the present study is Micro GA. The initial population of Micro GA is generated using random number generator to provide the initial set chromosomes. The advantage of using random number generators is the minimization of human intervention and thus reduces the bias.

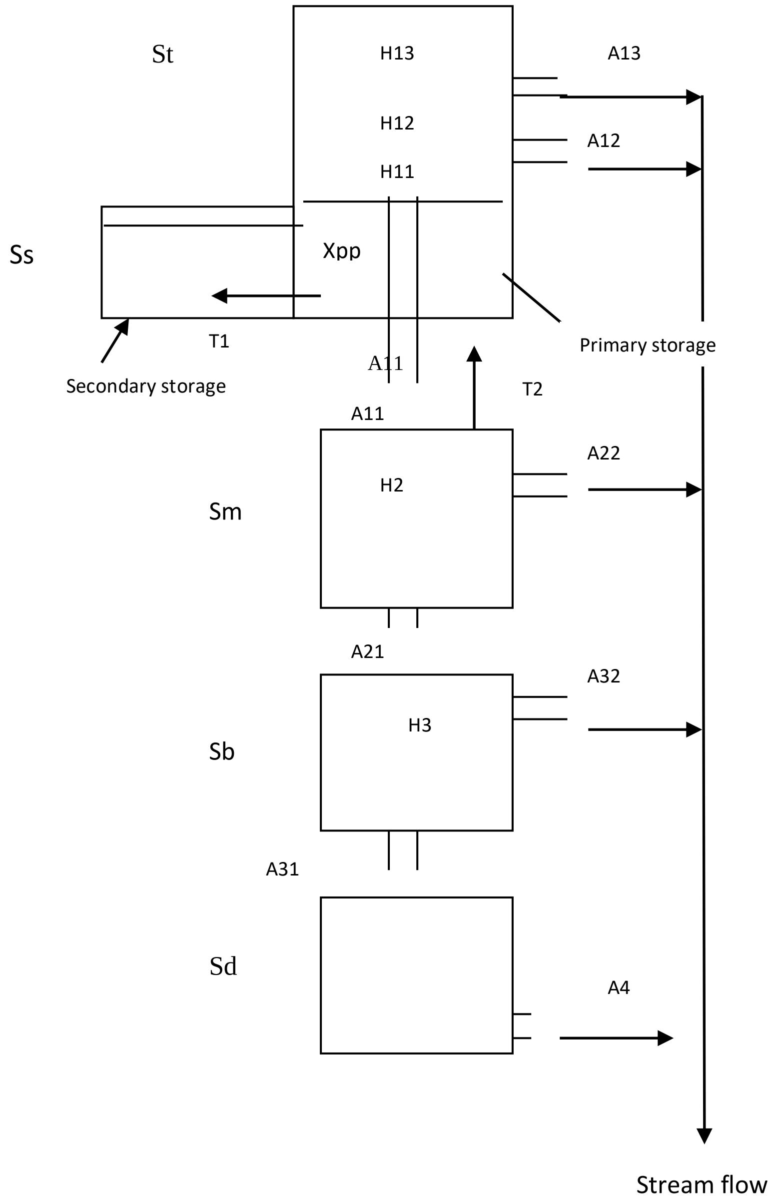

Fig.4.1: Structure of Tank Model

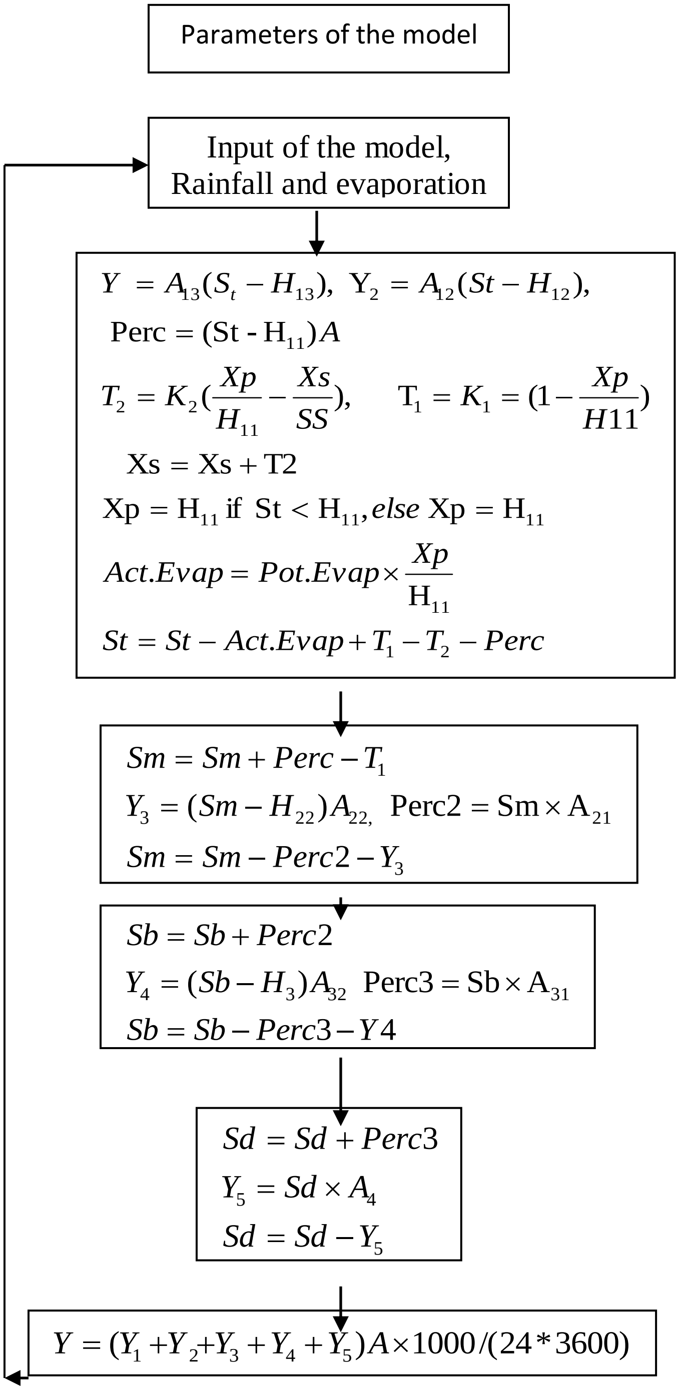

Fig.4.2: General Flow Chart of Tank Model

4.5. Model Calibration

Most simulation models have several parameters that the user can adjust for different cases or purposes of use. The results produced by the models are usually different when using different value of parameters. In order to have the model represent as accurately as possible the system being modelled, there is a need to determine these model parameters by using known system inputs and responses. The process of determining the optimal value of these parameters is called "calibration".

Calibration is the basic in modeling process. Significant advances have been made in automated watershed model calibration during the past 2 decades, with focus on four main issues (Gupta et al., 1998):

a) Development of specialized techniques for handling errors present in data.
b) Search for a reliable parameter estimation algorithm.
c) Determination of an appropriate quantity and information-rich kind of data.
d) Efficient representation of the uncertainty of the calibrated model (structure and parameters) and translation of uncertainty into uncertainty in the model response.

4.6. Model validation

Hassanizadah and Carrera (1992) suggest full model validation is impossible, and therefore models can only be referred to as partially validated or semi-validated. Despite this they note several common reasons why model validation is undertaken, namely; establishing the ability of the model to make predictions, comparing model predictions to measurements and quantifying uncertainty and inaccuracies. Konikow and Bredehoeft (1992) suggest that validation demonstrates the ability of a site specific model to represent cause and effect relations at a particular field area. Oreskes et al. (1994) argue that the primary value of models is heuristic and that because of the impossibility of validation, predictive modelling is less important. Philosophical arguments surrounding validation are abundant and it is difficult to develop an overarching definition of what it is. Even if this were possible, the practical problem of how to meet that definition still remains.

Accuracy of the flow predictions is the essential part of a flood forecasting model. The accuracy of flow estimation by tank model using the inputs details as above and the calibrated parameters was tested on different flood events that occurred in Bagmati basin between 1999 and 2008.

Verification (also known as validation) takes place after calibration to test if the model performs well on a portion of data, which was not used in calibration. Model verification aims to validate the model's robustness and ability to describe the catchment's hydrological response, and further detect any biases in the calibrated parameters (Gupta et al., 2005). Model performance is usually better during calibration than verification period, a phenomenon called model divergence (Sorooshian and Gupta, 1995). When the degree of divergence is considered unacceptable, modeller has to examine the model structure and the calibration procedure for valid or inappropriate assumptions and then revise accordingly.

4.7. Gumbel's Method

This extreme value distribution was introduced by Gumbel (1941) and is commonly known as Gumbel's distribution. It is one of the most widely used probability-distribution functions of extreme values in hydrological and meteorologic studies for prediction of flood peaks, maximum rainfalls, maximum wind speed, etc.

Gumbel defined a flood as the largest of the 365 daily flows and the annual series of flood flows constitute a series of largest values of flows. According to his theory of extreme events, the probability of occurrence of an event equal to or larger than a value xo is

$$P(x \geq x_o) = 1 - e^{-e^{-y}} \quad \text{………………….1}$$

in which y is a dimensionless variable given by

$$y = \alpha \, (x - a)$$

$$a = \bar{x} - 0.45005 \, \sigma_x \quad \text{……………………2}$$

$$\alpha = 1.2825 \, / \, \sigma_x$$

Thus

$$y = (1.2825(x - \bar{x})/ \sigma_x) + 0.577$$

Where $\overline{x}$= mean and σ_x= standard deviation of the variate X. In practice it is the value of X for a given P that is required and as such Eq. (1) is transposed as

$$y_p = - \ln [- \ln (1 - P)] \quad \text{……………………..3}$$

Noting that the return period T = 1/P and designating

Y_T = the value of y, commonly called the reduced variate, for a given T

$$y_T = -[\ln.\ln.(T/(T-1))]$$

or

$$y_T = -[0.834 + 2.303 \log.\log.(T/(T-1))] \quad \text{……………4}$$

Now rearranging Eq. (2), the value of the variate X with a return period T is

$$x_T = \overline{x} + K\sigma_x \quad \text{…………………5}$$

Where

$$K = (y_T - 0.577)/1.2825 \quad \text{………………6}$$

Note that Eq. (6) is of the same form as the general equation of hydrologic frequency analysis. Further, Eqs. (5) and (6) constitute the basic Gumbel's equations and are applicable to an infinite sample size (i.e. N→∝).

To verify whether the given data follow the assumed Gumbel's distribution, the following procedure may be adopted. The value of x_T for some return periods T < N are calculated by using Gumbel's formula and plotted as x_T vs T on a convenient paper such as asemi-log, log-log or Gumbel probability paper. The use of Gumbel probability paper results in a straight line for x vs T plot.

Gumble's distribution has the property which gives T = 2.33 years for the average of the annual series when N is very large. Thus the value of a flood with T = 2.33 years is called the mean annual flood. In graphical plots this gives a mandatory point through which the line showing variation of x_T with T must pass. For the given data, values of return periods (plotting positions) for various recorded values, x of the variate are obtained by the relation T = (N+1)/ m and plotted on the graph described above. A good fit of observed data with the theoretical variation line indicates the applicability of Gumbel's distribution to the given data series. By extrapolation of the straight line x_T vs T,values of x for T> N can be determined easily.

5. RESULTS AND DISCUSSION

5.1. Result

5.1.1. Model Calibration

Most simulation models have several parameters that the user can adjust for different cases or purposes of use. The results produced by the models are usually different when using different value of parameters. In order to have the model represent as accurately as possible the system being modeled, there is a need to determine these model parameters by using known system inputs and responses. The process of determining the optimal value of these parameters is called “calibration”.

Calibration is the basic in modeling process. Significant advances have been made in automated watershed model calibration during the past 2 decades, with focus on four main issues (Gupta et al., 1998):

a) Development of specialized techniques for handling errors present in data.

b) Search for a reliable parameter estimation algorithm.

c) Determination of an appropriate quantity and information-rich kind of data.

d) Efficient representation of the uncertainty of the calibrated model (structure and parameters) and translation of uncertainty into uncertainty in the model response.

The objective of the calibration was to obtain a close fitting of hydrograph between the observed and simulated stream flow data at Khokana station of at Bagmati basin. All storm events were calibrated simultaneously by referring to the same set of Tank model parameters. This process is tedious because of the trial and error method used to obtain the closest results compared to the real situation.

The TANK model was calibrated using the continuous discharge of 1999-2006 at the outlet of Bagmati basin. The rainfall data of nine stations and evapotranspiration data of one station are used as model inputs.

The optimized parameters and initial conditions of the model for the basin before calibration and validation are presented in Table5.1.

Table 5.1. Tank model parameters used for calibration

	Outflow parameters	Value
A11	The bottom outlet coefficient of side outlet of Top Tank	0.4788
A12	The runoff coefficient of side outlet of Top Tank	0.1013
A13	The runoff coefficient of top outlet of Top Tank	0.7043
A21	The bottom outlet coefficient of Second Tank	0.7206
A22	The runoff coefficient of Second Tank	0.34245
A31	The bottom outlet coefficient of Third Tank	0.25163
A32	The runoff coefficient of bottom outlet of Third Tank	0.39009
A4	The runoff coefficient of bottom outlet of Fourth Tank	0.12632
	Outflow level parameters	
H11	The position of bottom outlet of Top Tank	2.51091
H12	The position of side outlet of Top Tank	8.84545
H13	The position of top outlet of Top Tank	15.40495
H2	The position of top outlet of Second Tank	4.702902
H3	The position of top outlet of Third Tank	0.241707
K1		0.340037
K2		0.793847

Table 5.2. Initial condition for Tank model used for calibration

	Initial condition	Value
ss1	Secondary storage	5
Xs1	Primary water storage	4
St1	Top tank storage	8
	Middle tank storage	10
Sb1	Lower tank storage	70
Sd1	Bottom tank storage	80

The optimized parameters of the model for the basin during the calibration are presented in Table 5.3.

Table 5.3. Calibrated Tank model parameters

year	A11	A12	A13	A21	A22	A31	A32	A4	H11	H12	H13	H2	H3	K1	K2
1999	0.38	0.18	0.06	0.07	0.04	0.01	0.60	0.01	4.61	7.49	12.25	6.79	5.54	0.28	0.46
2000	0.95	0.11	0.16	0.75	0.14	0.00	0.45	0.02	3.53	9.66	16.35	1.04	5.61	0.34	0.04
2001	0.37	0.09	0.08	0.69	0.07	0.03	0.06	0.01	3.15	8.33	14.27	9.66	6.52	0.29	0.96
2002	0.26	0.44	0.06	0.60	0.17	0.09	0.96	0.00	4.96	9.94	16.63	4.13	3.15	0.63	0.23
2003	0.94	0.20	0.13	0.11	0.05	0.25	0.96	0.00	4.66	6.99	13.99	7.96	3.37	0.61	0.98
2004	0.42	0.04	0.10	0.59	0.03	0.03	0.39	0.02	4.35	7.55	13.60	4.83	5.12	0.15	0.77
2005	0.66	0.02	0.13	0.53	0.08	0.02	0.13	0.00	4.57	6.97	13.09	1.60	7.78	0.83	0.91
2006	0.50	0.02	0.13	0.29	0.04	0.03	0.76	0.00	4.79	7.06	13.81	7.38	0.20	0.83	0.99

5.1.2. Model validation

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The calibrated model was validated using the discharge data of 2007 and 2008 and the efficiency was found to be 70% and 67% respectively (Fig.5.25-5.30). This result shows that the model can be confidently applied to simulate the discharge in the Bagmati basin using the values of optimized parameters. The model was used to simulate the discharge of Bagmati basins from 1999 to 2008 (Fig. 5.1-5.30).

The optimized parameters of the model for the basin during the validation are presented in Table 5.4.

Table 5.4. Validated Tank model parameters

year	A11	A12	A13	A21	A22	A31	A32	A4	H11	H12	H13	H2	H3	K1	K2
2007	0.44	0.03	0.21	0.29	0.07	0.00	0.96	0.01	3.72	10.72	17.72	9.05	2.53	0.27	0.97
2008	0.44	0.05	0.07	0.57	0.07	0.03	0.80	0.00	4.37	5.43	12.02	0.84	5.48	0.42	0.87

The model was run for a total of ten years data, eight years during calibration and two years during validation, using calibrated parameters in Table.5.4 to predict the discharge at the outlet of the watershed. The scattered diagrams for measured and predicted river flows of different time steps are presented in Figures below. some Figures below compares the daily time step of measured and simulated discharges during calibration and validation, respectively. The graph clearly shows that the model, despite its simplicity and the watershed's high rainfall variability and distribution, simulates discharge with reasonable agreement during both calibration and validation.

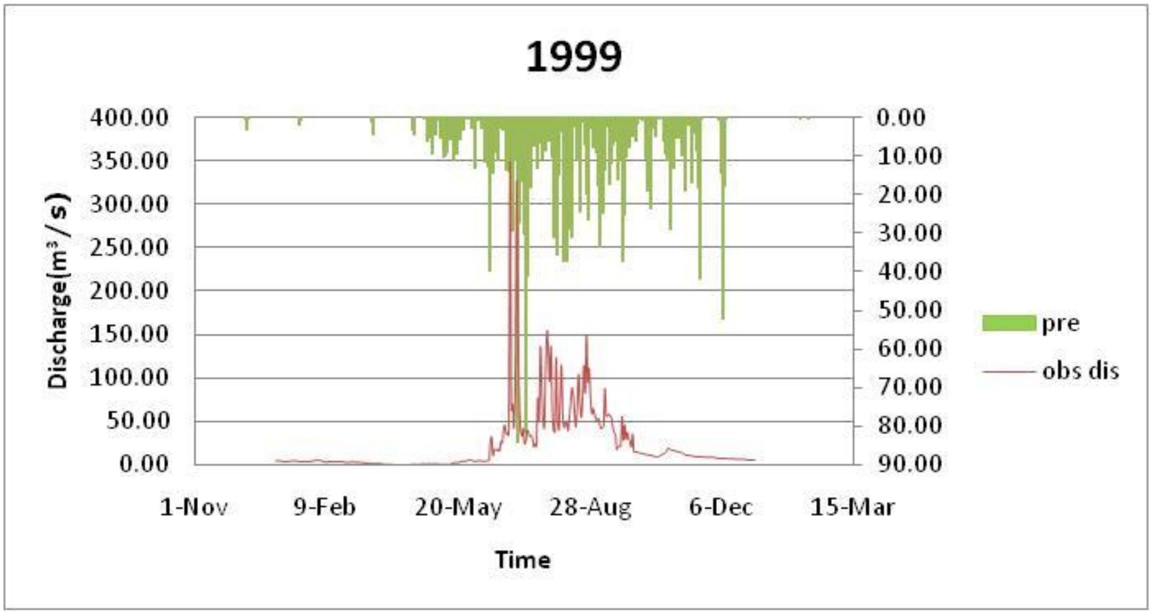

Fig.5.1: Daily observed flows and rainfall in the year 1999

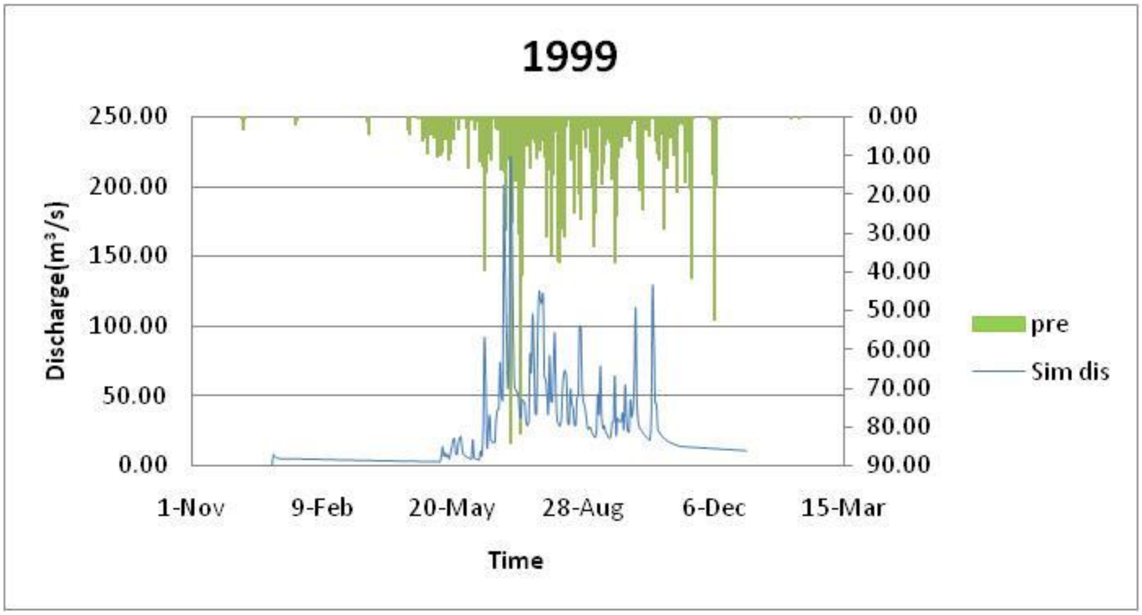

Fig.5.2: Daily Simulated flows and rainfall in the year 1999

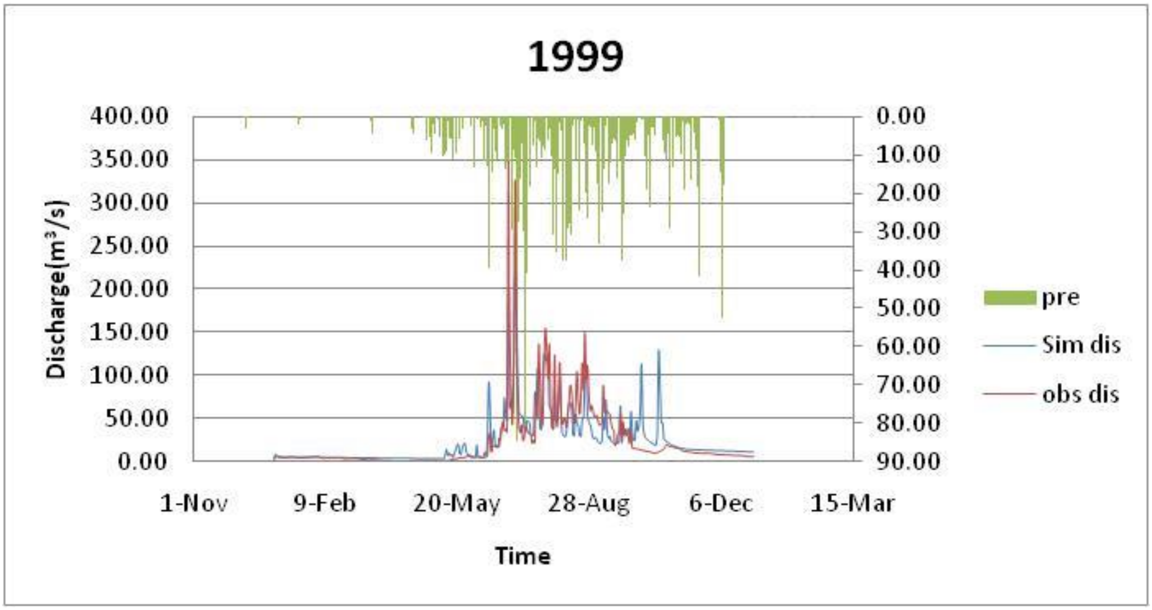

Fig.5.3: Daily observed and simulated flows and rainfall in the year 1999 using tank model

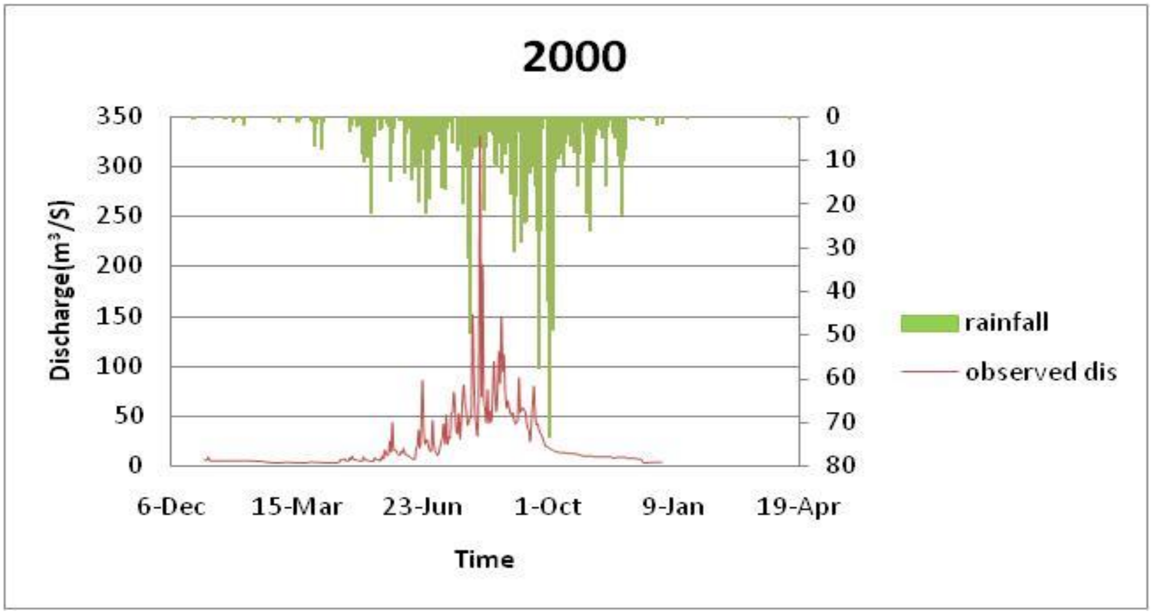

Fig.5.4: Daily observed flows and rainfall in the year 2000

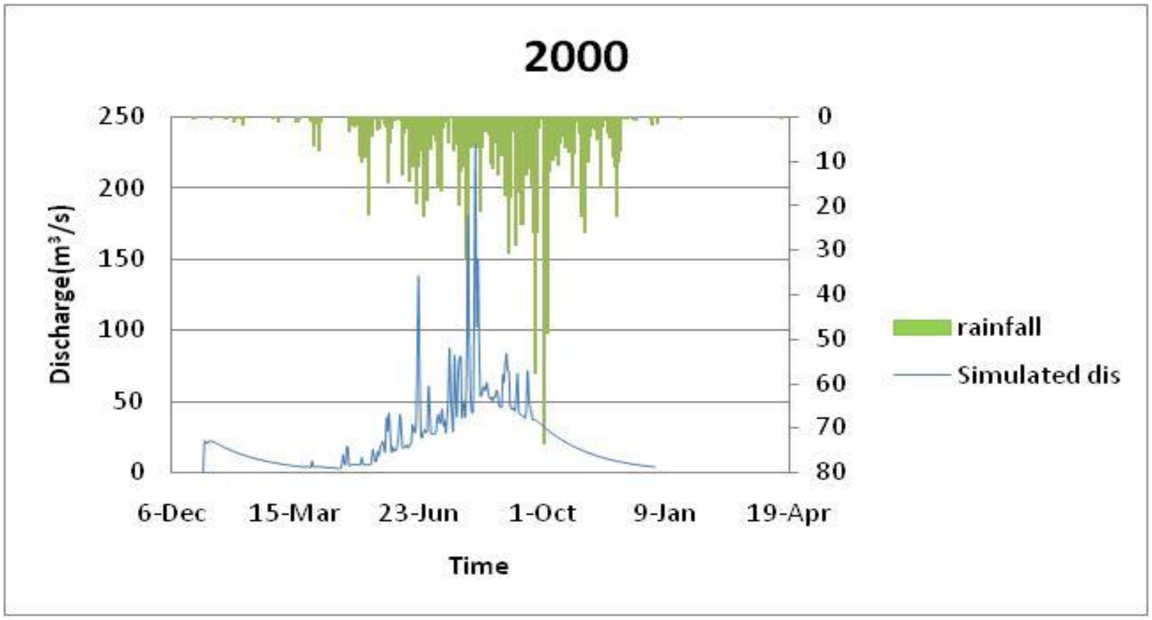

Fig.5.5: Daily simulated flows and rainfall in the year 2000

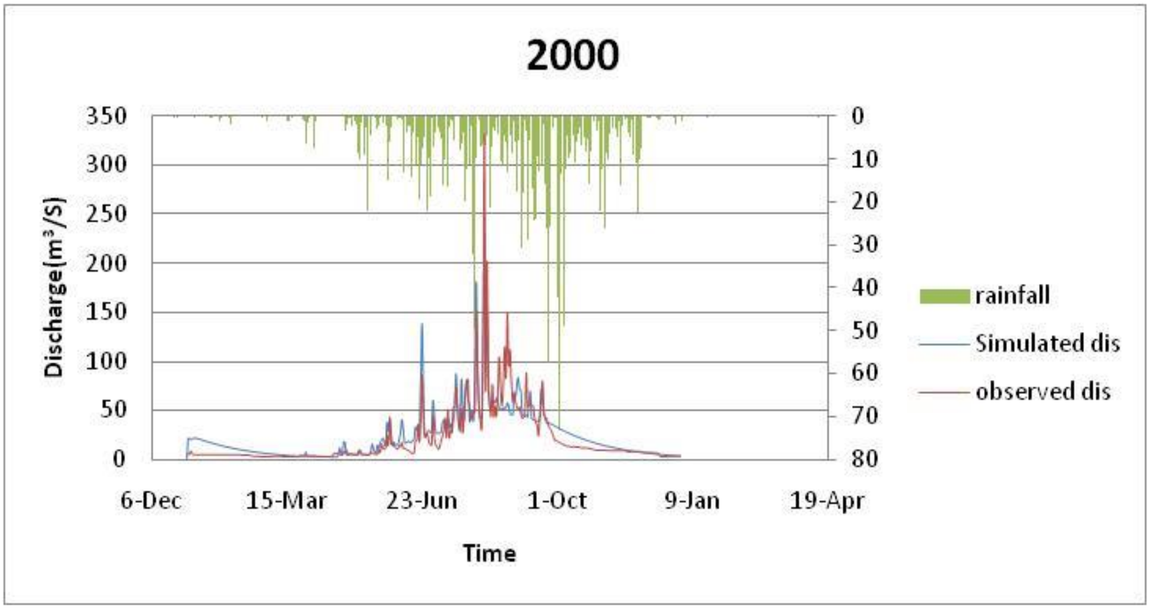

Fig.5.6: Daily observed and simulated flows and rainfall in the year 2000 using tank model

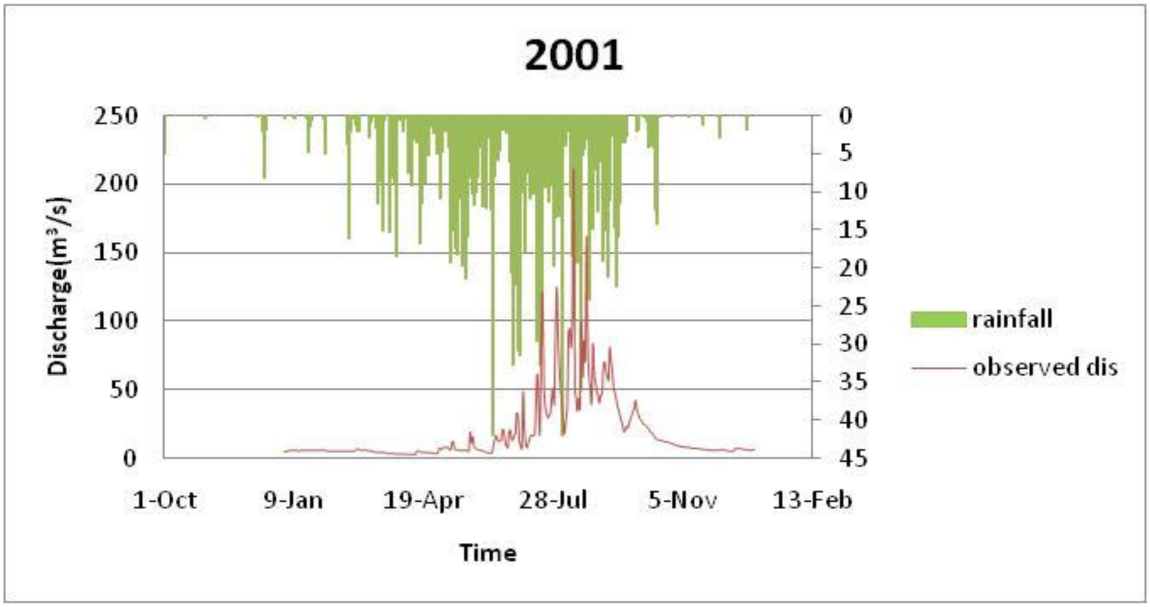

Fig.5.7: Daily observed flows and rainfall in the year 2001

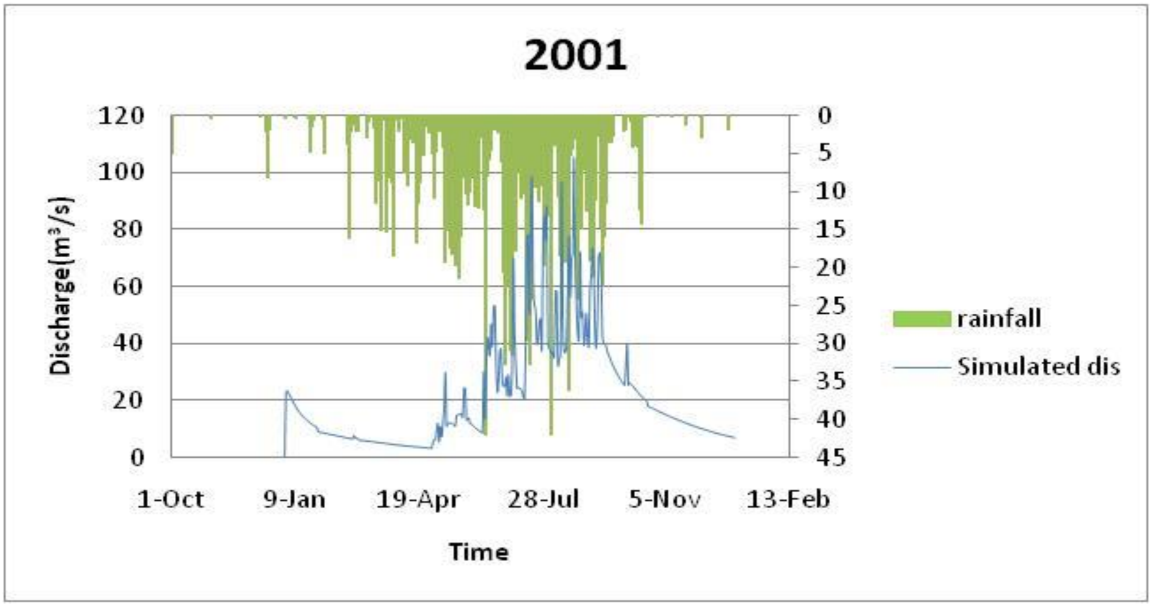

Fig.5.8: Daily simulated flows and rainfall in the year 2001

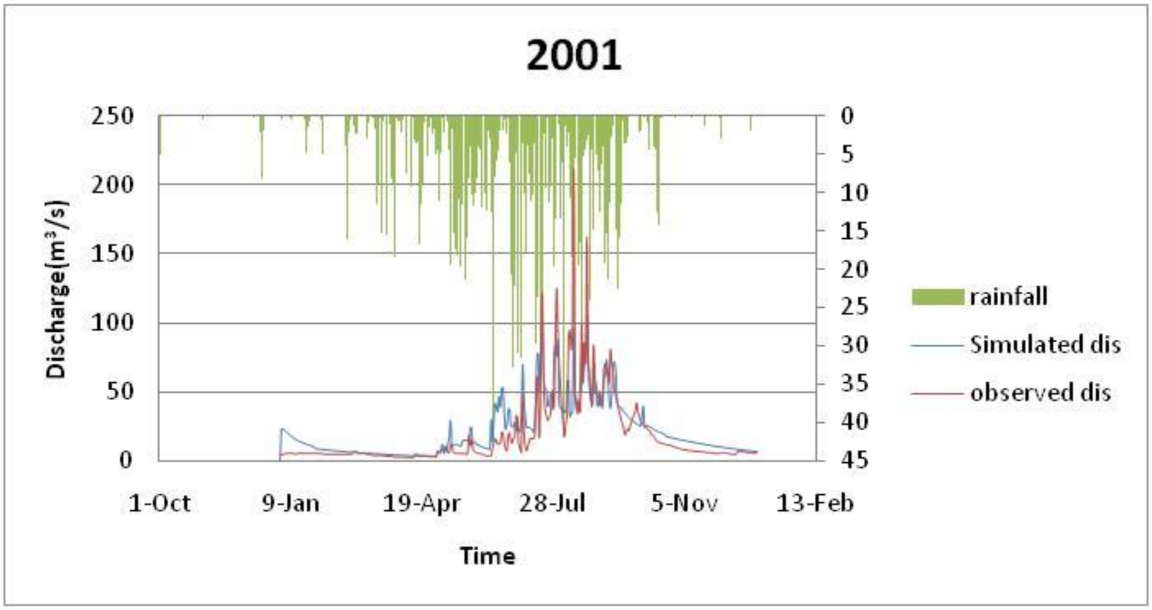

Fig.5.9: Daily observed and simulated flows and rainfall in the year 2001 using tank model

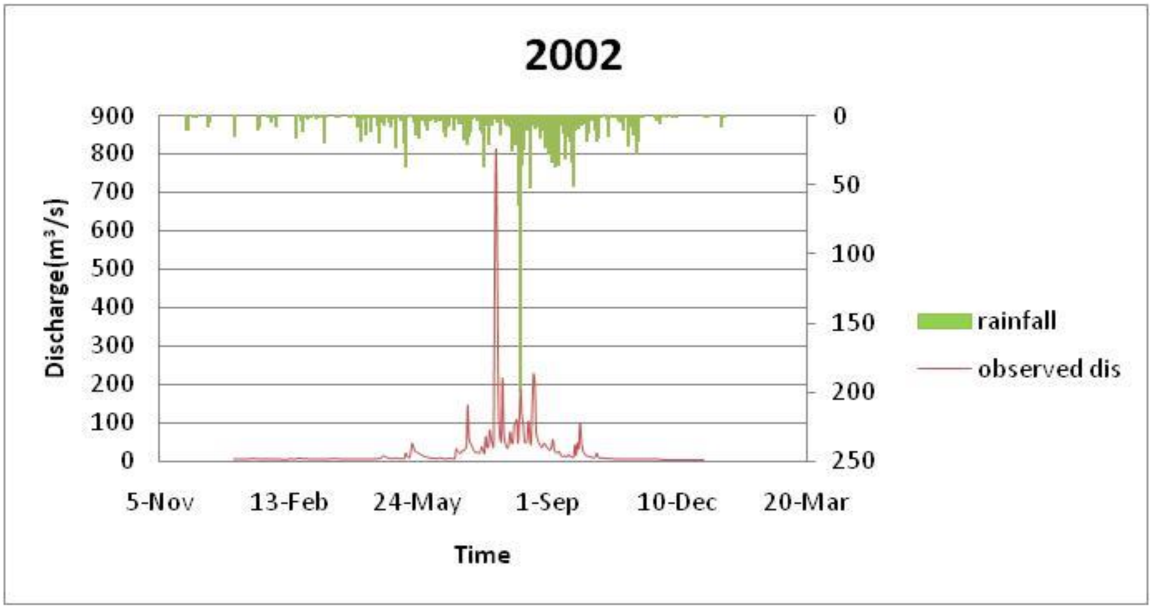

Fig.5.10: Daily observed flows and rainfall in the year 2002

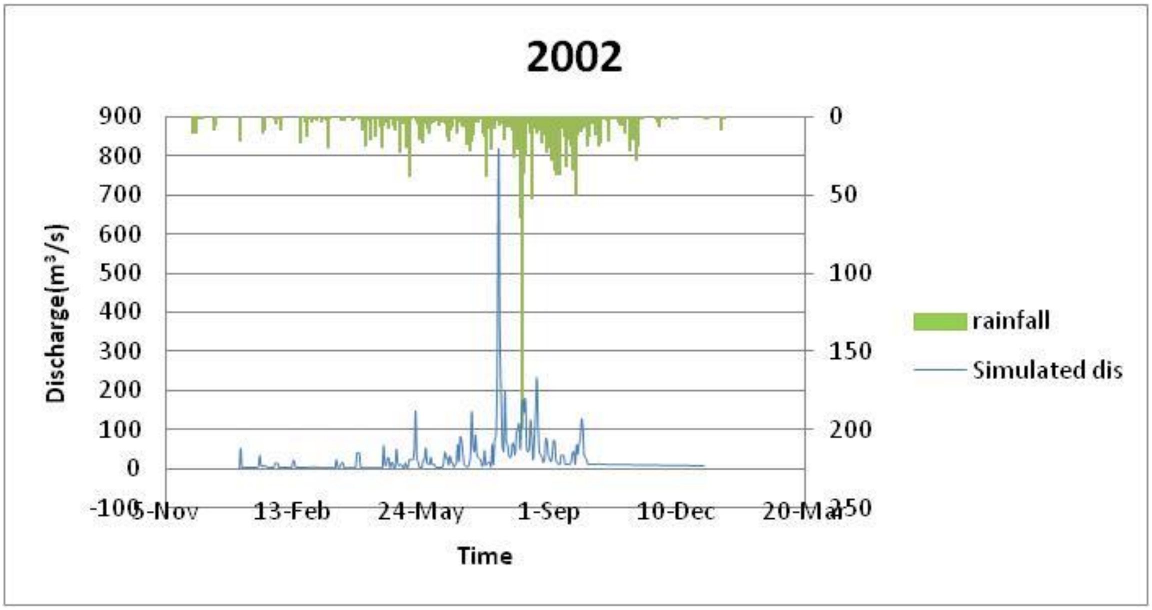

Fig.5.11: Daily simulated flows and rainfall in the year 2002

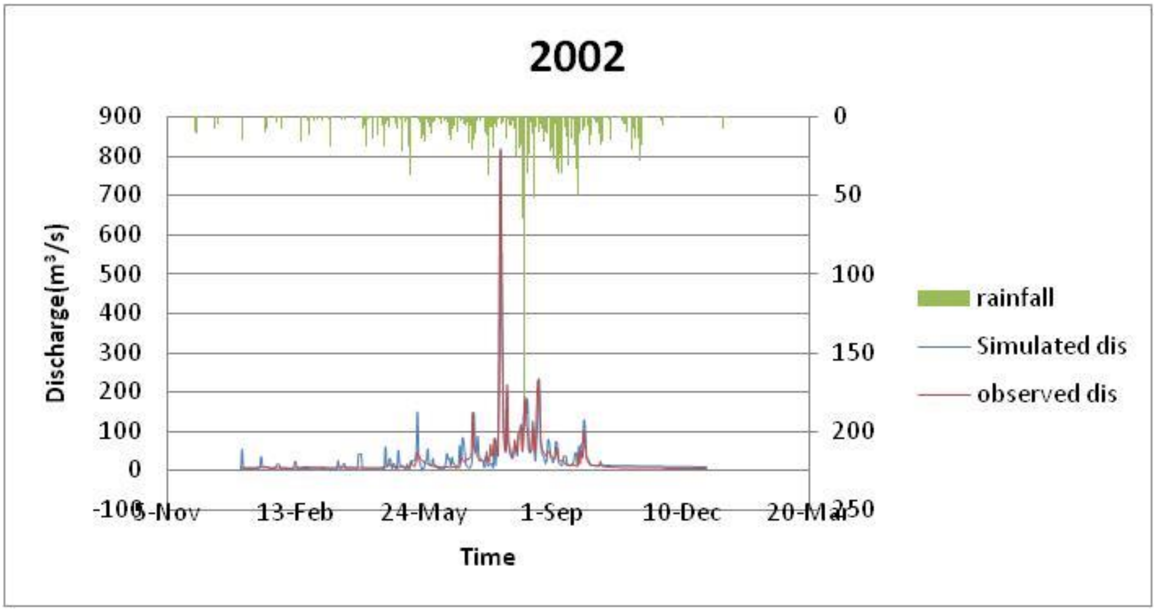

Fig.5.12: Daily observed and simulated flows and rainfall in the year 2002 using tank model

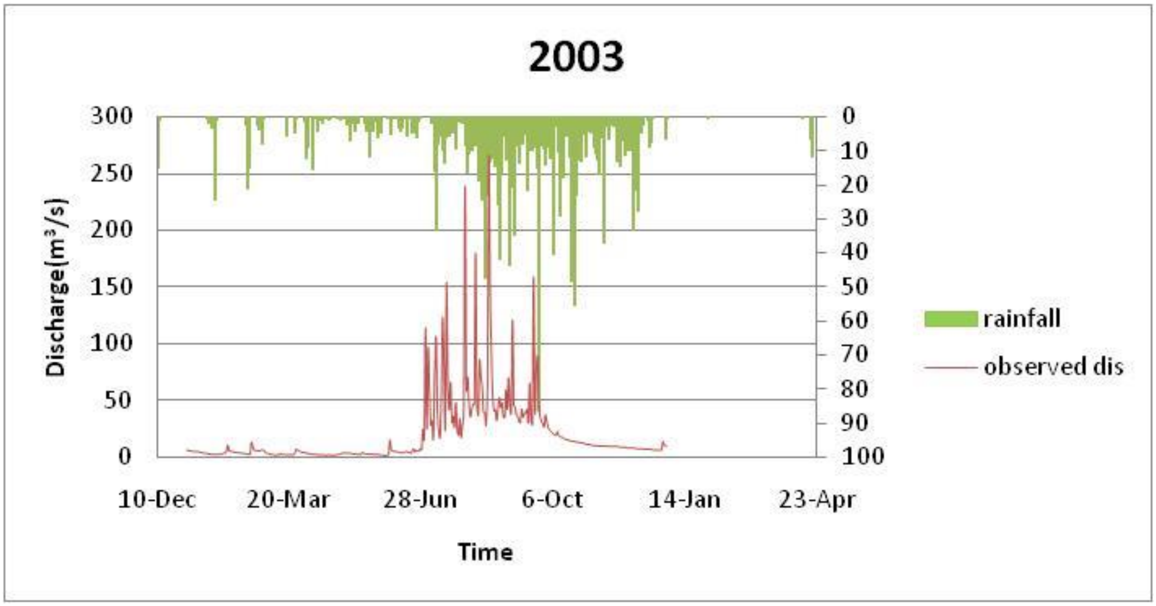

Fig.5.13: Daily observed flows and rainfall in the year 2003

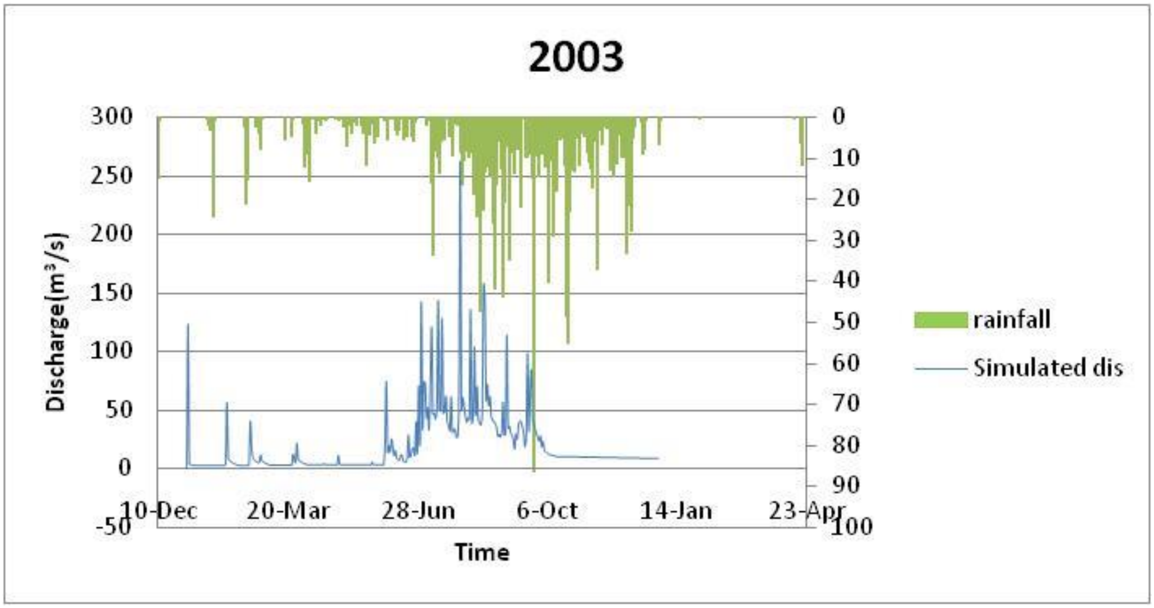

Fig.5.14: Daily simulated flows and rainfall in the year 2003

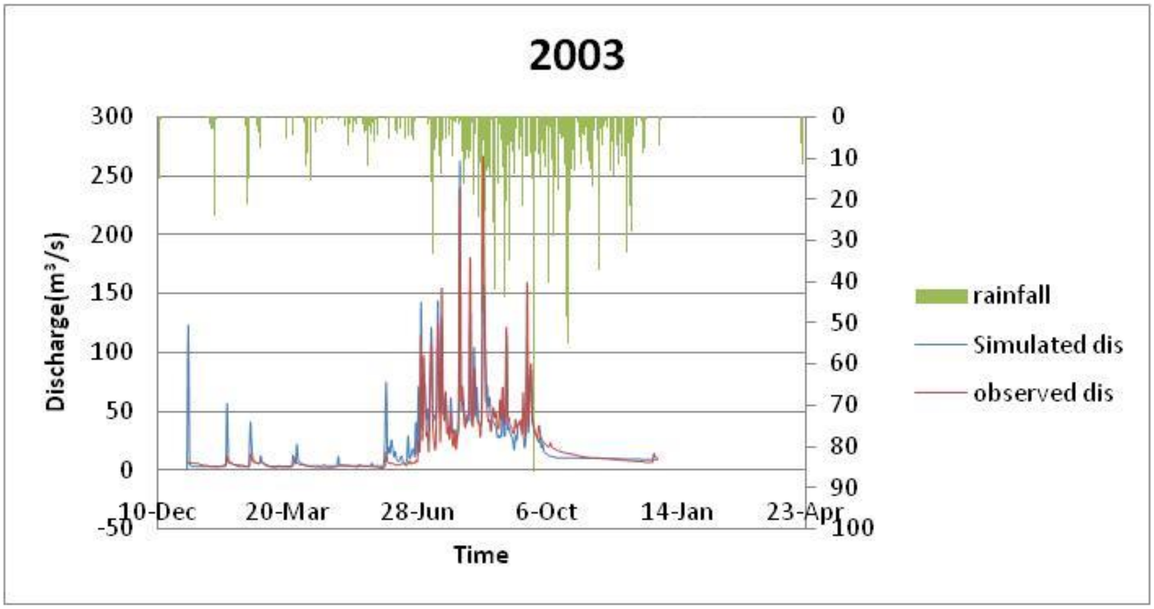

Fig.5.15: Daily observed and simulated flows and rainfall in the year 2003 using tank model

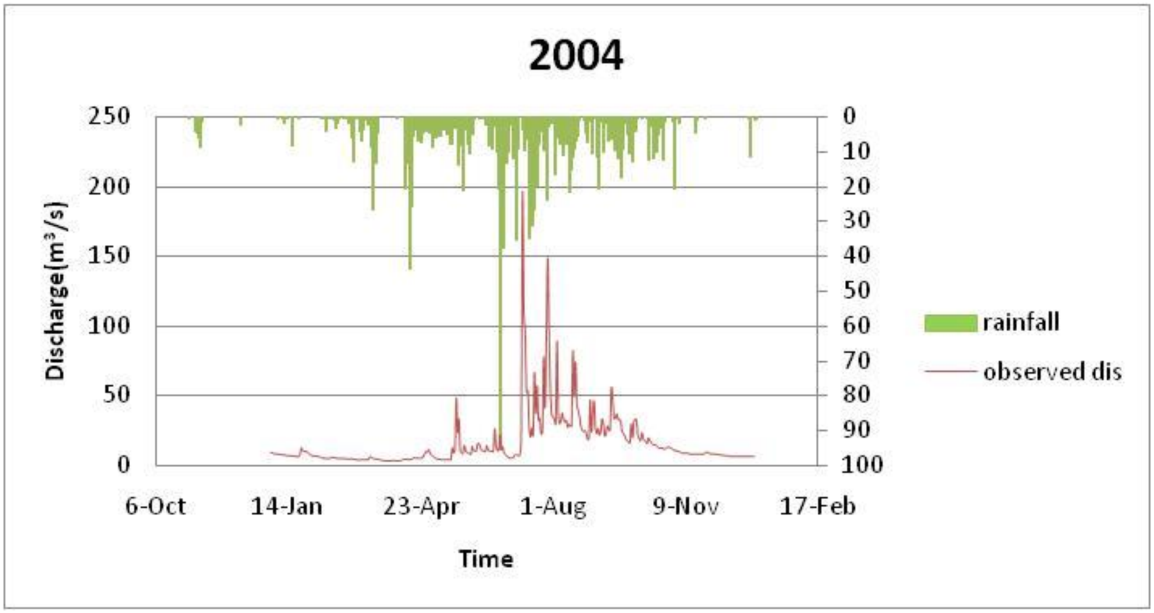

Fig.5.16: Daily observed flows and rainfall in the year 2004

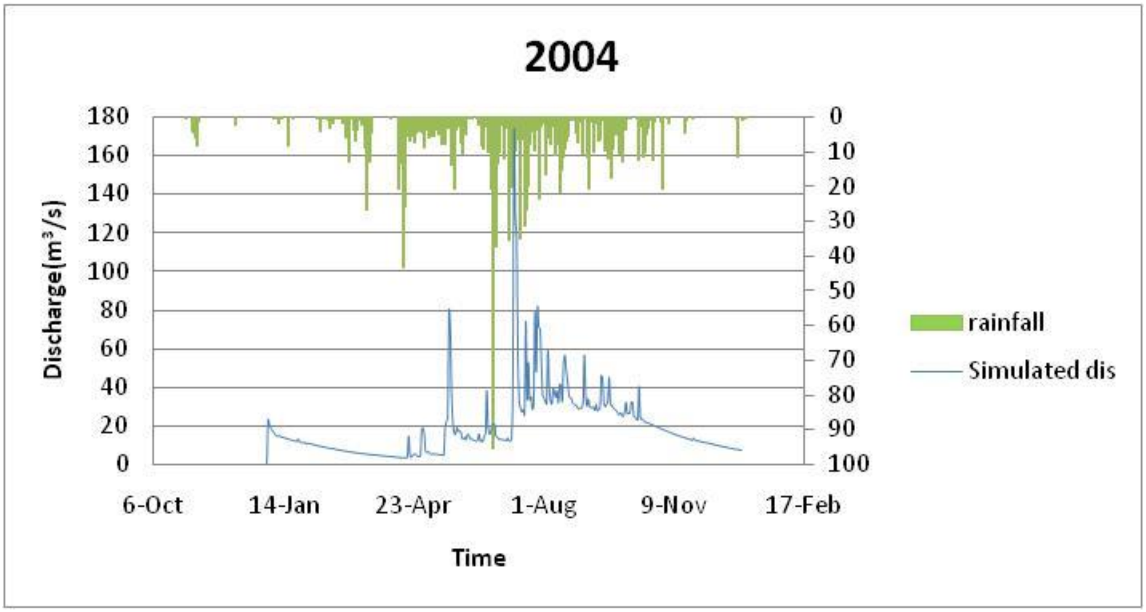

Fig.5.17: Daily simulated flows and rainfall in the year 2004

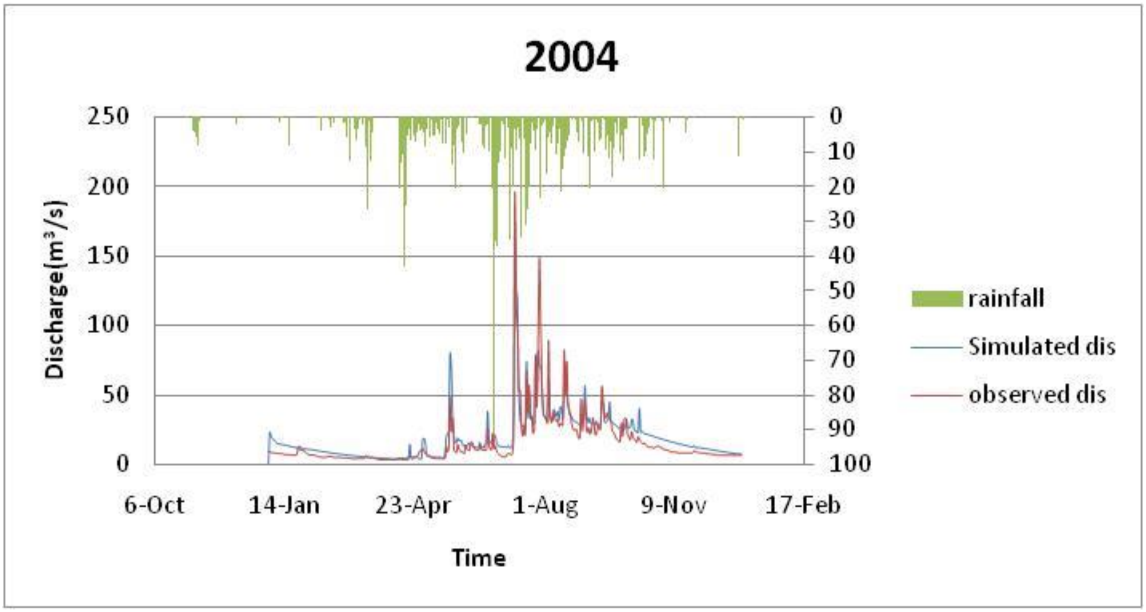

Fig.5.18: Daily observed and simulated flows and rainfall in the year 2004 using tank model

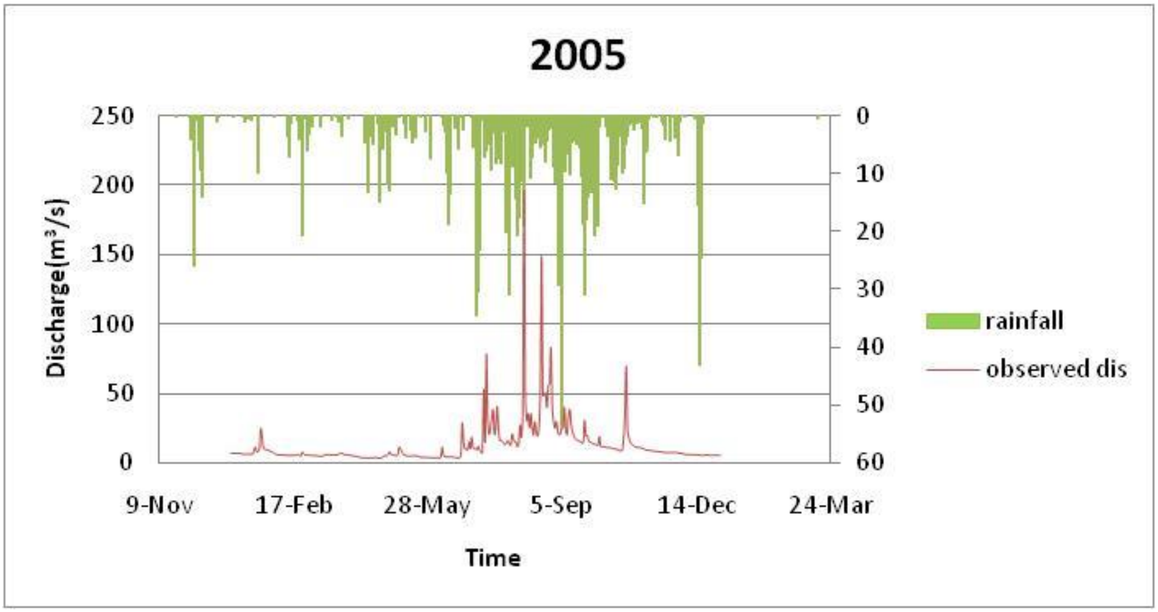

Fig.5.19: Daily observed flows and rainfall in the year 2005

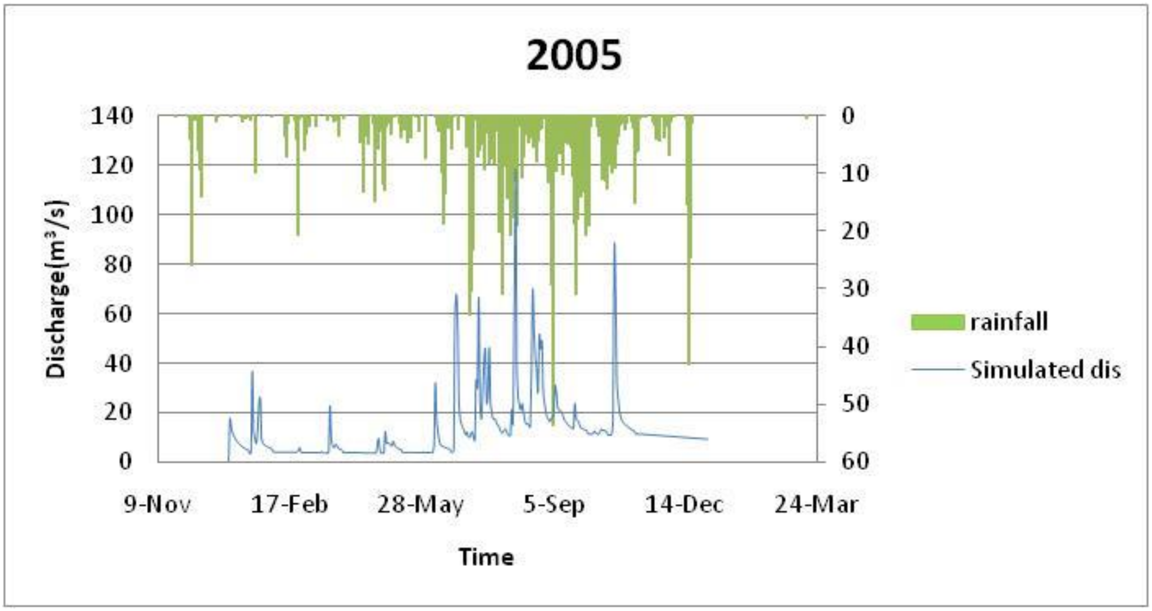

Fig.5.20: Daily simulated flows and rainfall in the year 2005

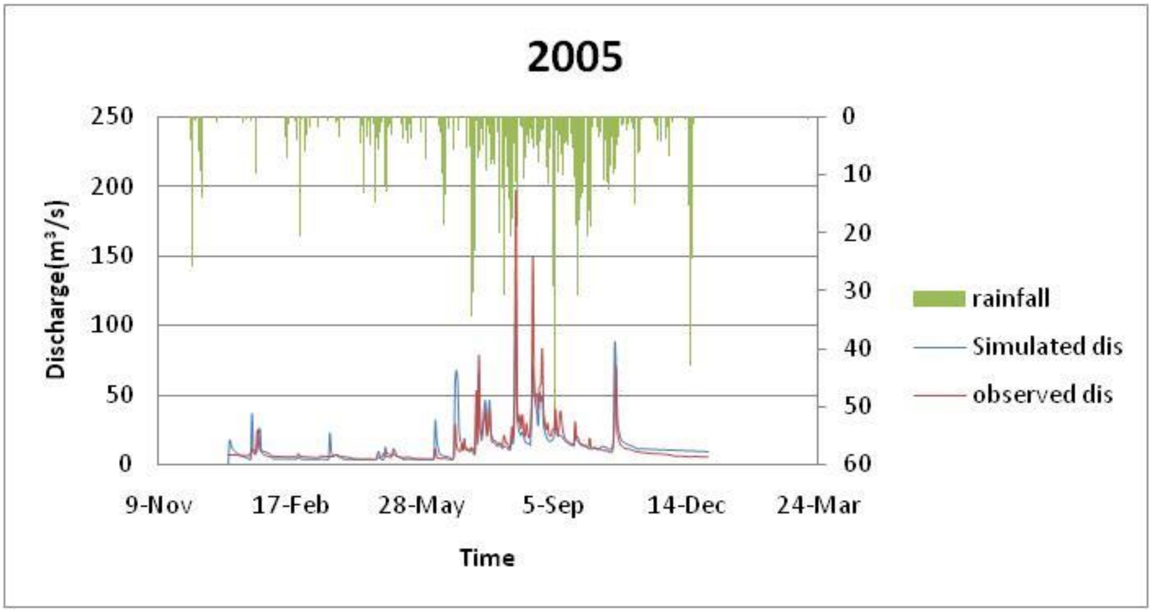

Fig.5.21: Daily observed and simulated flows and rainfall in the year 2005 using tank model

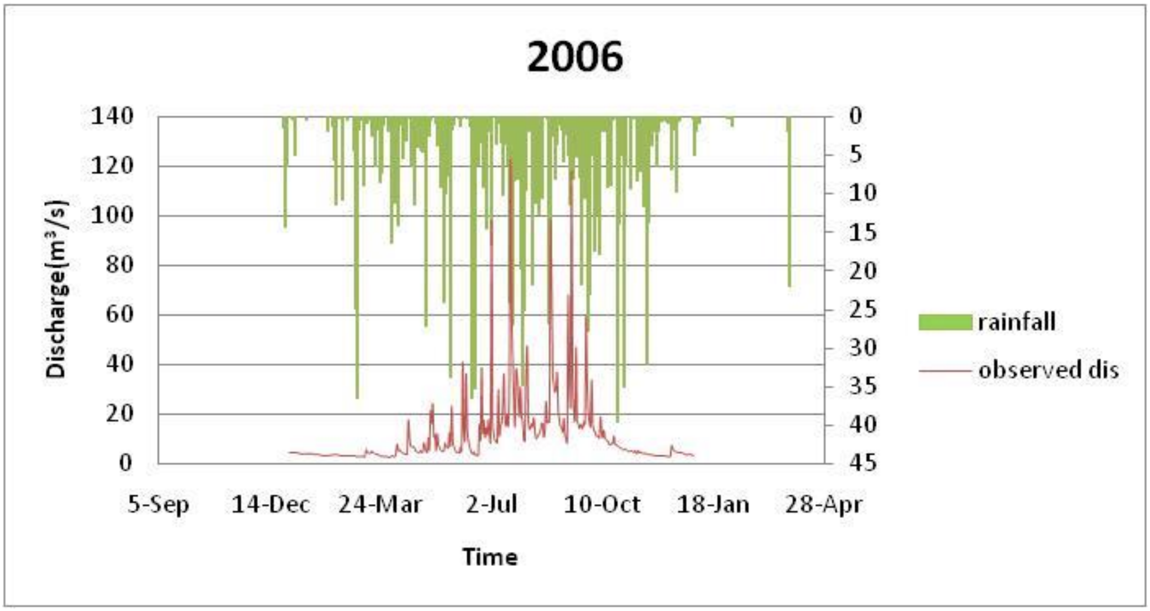

Fig.5.22: Daily observed flows and rainfall in the year 2006

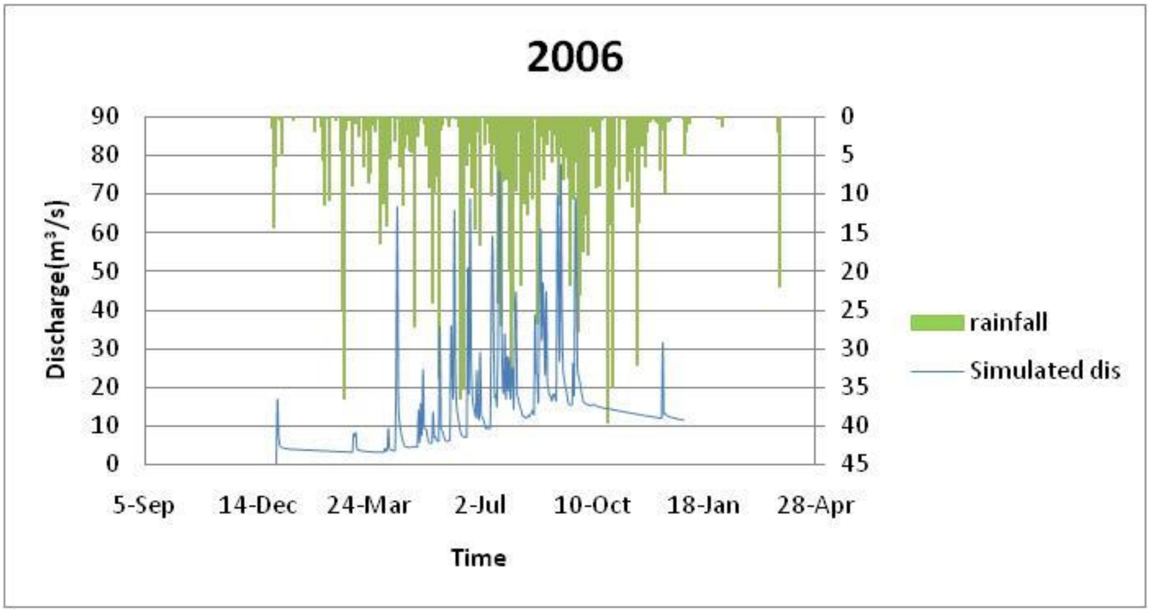

Fig.5.23: Daily simulated flows and rainfall in the year 2006

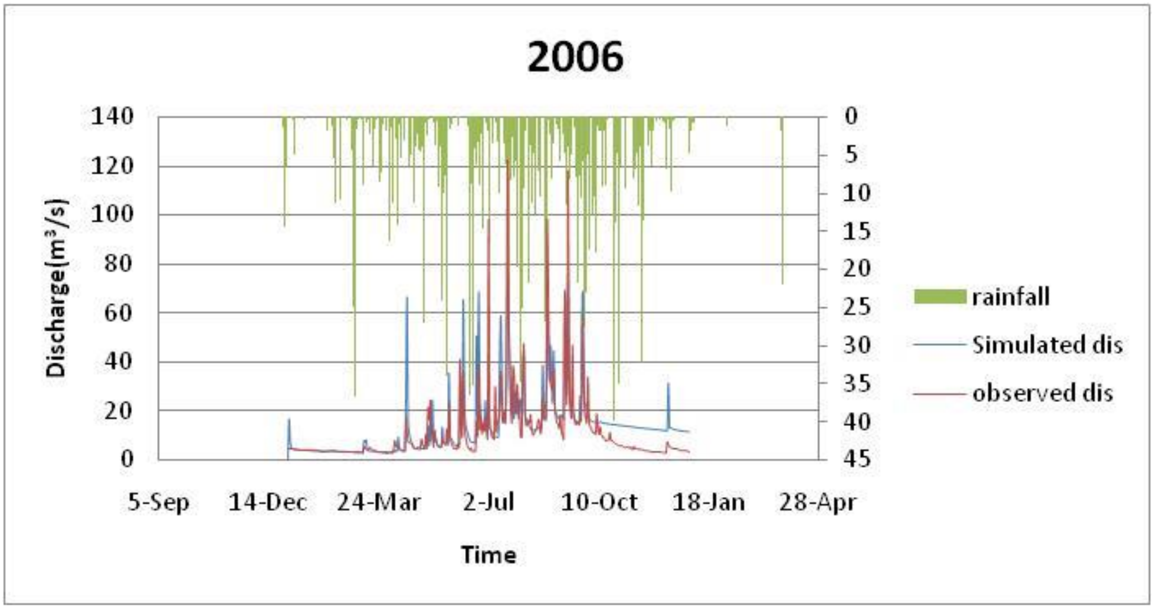

Fig.5.24: Daily observed and simulated flows and rainfall in the year 2006 using tank model

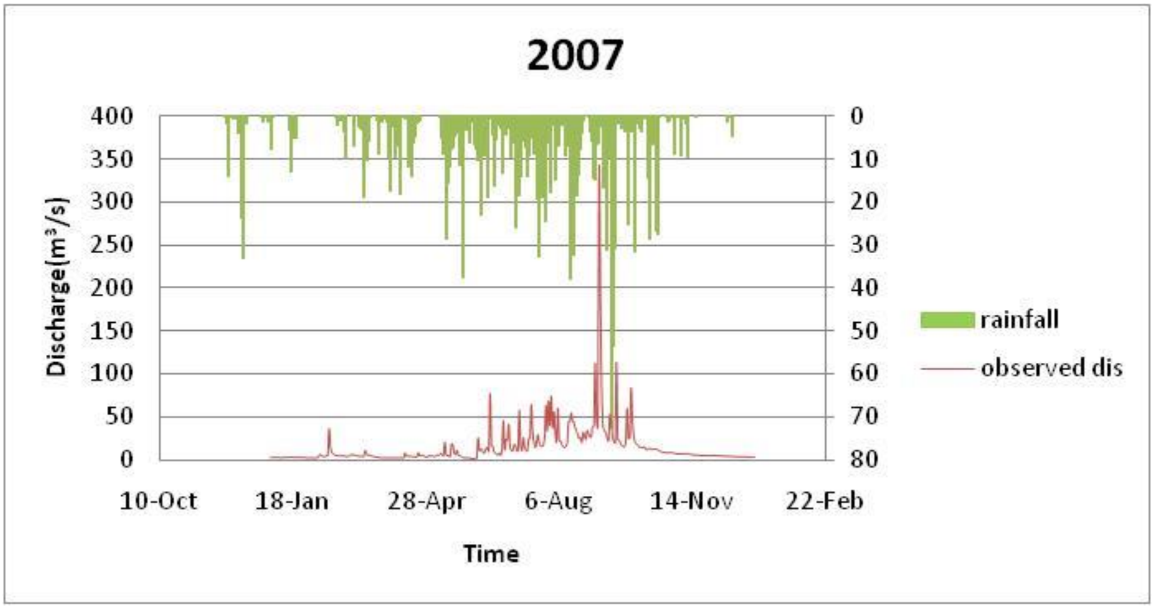

Fig.5.25: Daily observed flows and rainfall in the year 2007

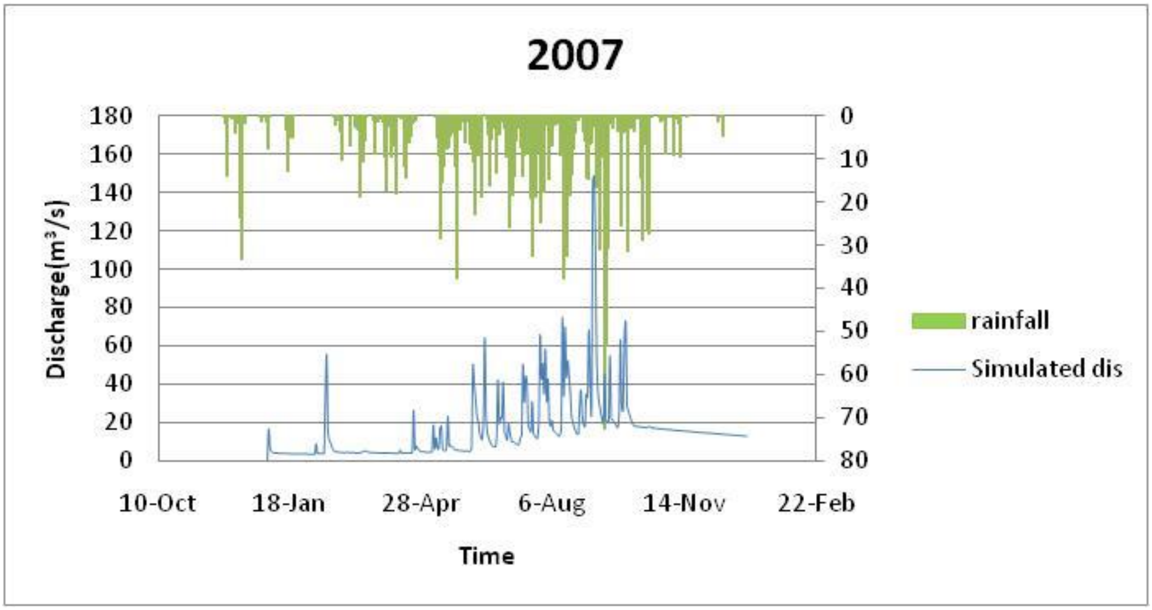

Fig.5.26: Daily simulated flows and rainfall in the year 2007

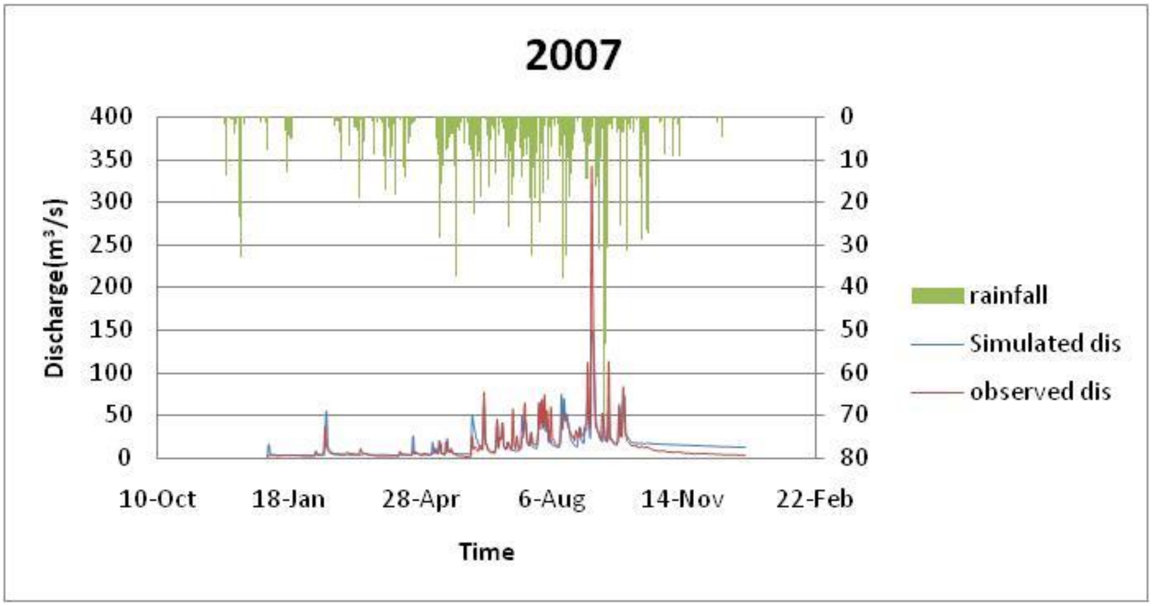

Fig.5.27: Daily observed and simulated flows and rainfall in the year 2007 using tank model

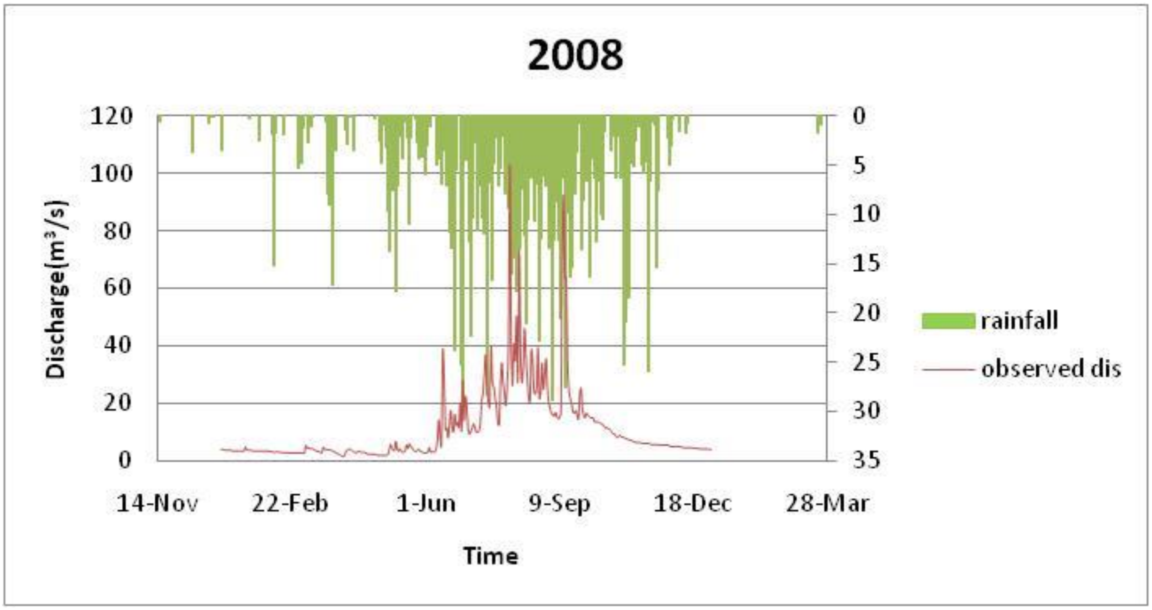

Fig.5.28: Daily observed flows and rainfall in the year 2008

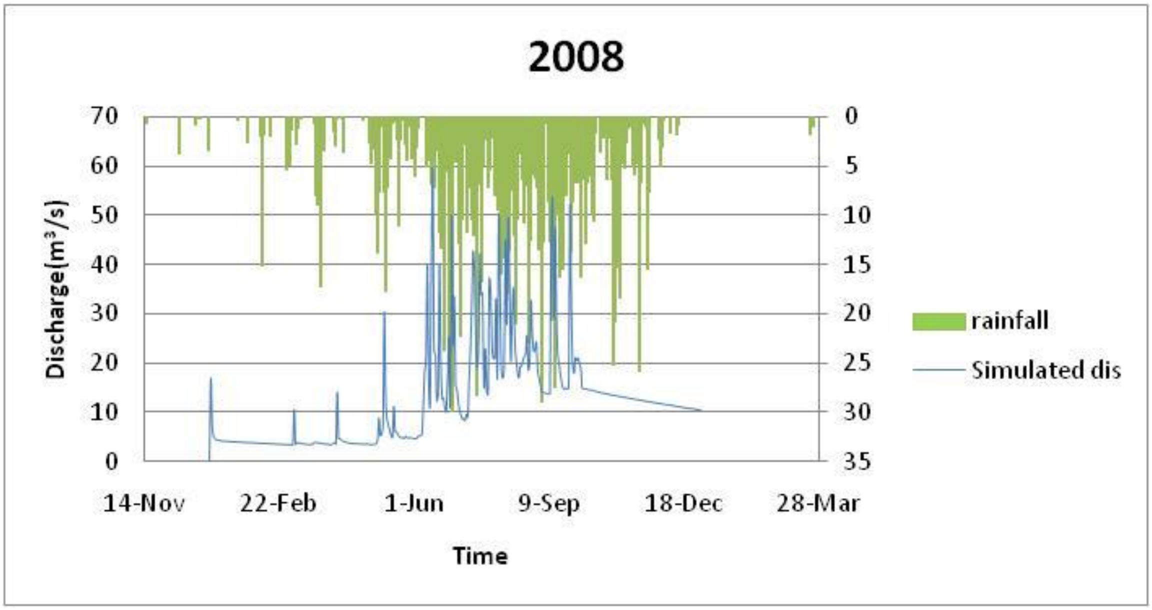

Fig.5.29: Daily simulated flows and rainfall in the year 2008

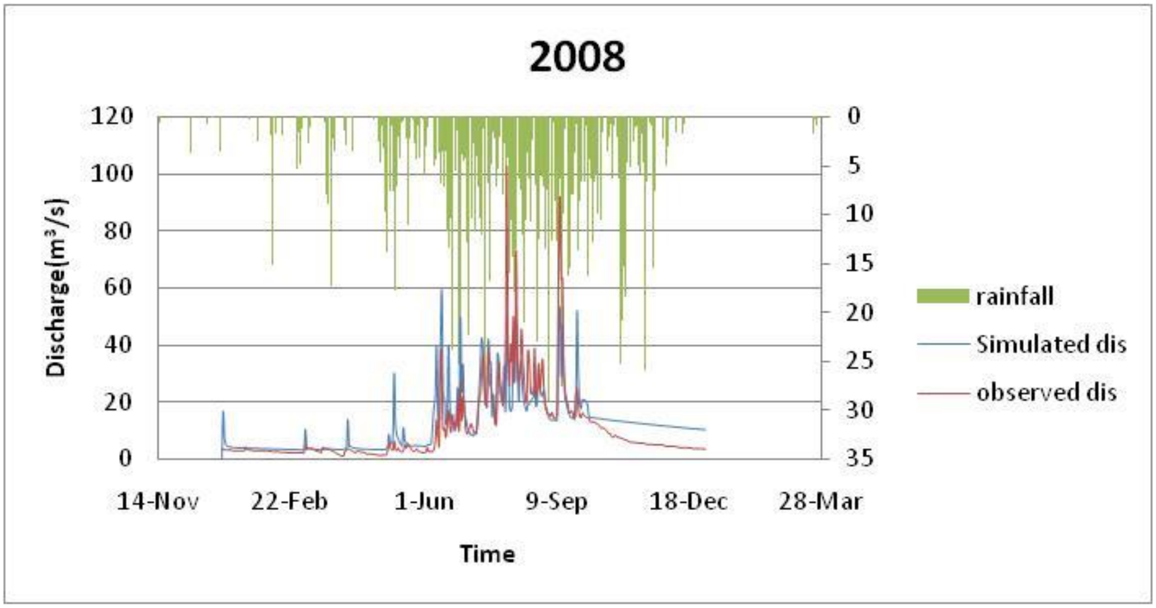

Fig.5.30: Daily observed and simulated flows and rainfall in the year 2008 using tank model

The tank model was calibrated using the genetic optimization algorithm implemented in the tank model version 1.0.0coded by Bastola et al. (2000) on the basis of the tournament selection process. The input data consisted of the daily precipitation, monthly reference evapotranspiration and the daily observed discharge at site Khokana of the Bagmati basin. The model parameters suggested after the calibration and used in the validation of the model are shown in table 5.3 and 5.4. For a first comparison of the observed and simulated flows using this model, rifer to figures5.1-5.30, the daily observed and simulated flows.

Comparison of observed and the simulated hydro graph showed that the simulated runoff is underestimated than the observed runoff. The low flows (dry season flows) were somewhat well captured. The highest peak flows were underestimated. However, the model has reproduced most parts of the observed hydrograph and simulated well the seasonal and annual variations in runoff. The flow in July 23, 2002 was recorded 814m^3/s, the highest during the study period and which might be due to the continuous rain fall in part of the basin that lies in Nepal as a result of monsoonal effect.

The statistical characteristics of the observed hydrograph were preserved by the simulated hydrograph. A mean of 23m^3/s, 21 m^3/s, 18 m^3/s, 24 m^3/s, 19 m^3/s, 16 m^3/s, 12 m^3/s, 11 m^3/s was calculated for the observed discharge while the mean of the simulated discharge was 24m^3/s, 24 m^3/s, 22 m^3/s, 27 m^3/s, 20 m^3/s, 19 m^3/s, 13 m^3/s, 14 m^3/s during the calibration processes in the year of 1999-2006 respectively.

The standard deviation was 38m^3/s, 31m^3/s, 25 m^3/s, 63 m^3/s, 31 m^3/s, 20 m^3/s, 17 m^3/s, 15m^3/s for the observed discharge and 30 m^3/s, 26m^3/s, 20m^3/s, 58m^3/s, 29 m^3/s, 18 m^3/s, 13 m^3/s, 13m^3/s for the simulated discharge during the calibration processes in the year of 1999-2006 respectively.

A mean of 15m^3/s, 11 m^3/s was calculated for the observed discharge while the mean of the simulated discharge was 16m^3/s, 12 m^3/s, during the validation period of 2007 and 2008 respectively.

The standard deviation was 25m^3/s, 13m^3/s for the observed discharge and 17m^3/s, 10m^3/s for the simulated discharge during the validation period of 2007 and 2008 respectively.

The overall correlation coefficient between observed and simulated discharge was 0.84, 0.90, 0.85, 0.91, 0.91, 0.91, 0.83, and 0.79 during calibration period.

Also the overall correlation coefficient between observed and simulated discharge was 0.88 and 0.87 during validation period as shown in table 5.5. These values roughly correspond with the values proposed by Bastola (2000) who used a different rainfall input series as well as a different evapotranspiration input series.

The qualitative comparison of the simulated and observed discharges on a daily basis shows that the simulated peaks are generally lower than the observed peaks. The simulated recession curves after the monsoon season reach the low base flows later than the observed recession curves. In addition, the simulated hydrograph is smoother than the observed hydrograph.

In general, a good simulation can be achieved with the Tank model. However, the low monthly flows during the dry season generally are underestimated by the model. The efficiency expressed with the Nash-Sutcliffe criterion ranged from 0.60 to 0.85. Bastola (2002) obtained similar efficiencies with a rainfall dataset interpolated using the thiessen polygon approach and a different evapotranspiration data set.

Table 5.5. Efficiency of the Tank Model on the basis of daily data.

				Calibration				
Year	Mean		Standard Deviation		Annual Flow Volume		Correl Coefficient	Nash Effeciency
	Observed	Simulated	Observed	Simulated	Observed	Simulated		
1999	23	24	38	30	1217	1282	0.837053	0.693425
2000	21	24	31	26	1122	1319	0.898706	0.782311
2001	18	22	25	20	974	1165	0.852147	0.714806
2002	24	27	63	58	1290	1468	0.913868	0.855614
2003	19	20	31	29	1032	1067	0.914000	0.825076
2004	16	19	20	18	847	1042	0.914499	0.819404
2005	12	13	17	13	651	698	0.831938	0.691747
2006	11	14	15	13	588	742	0.788873	0.606472
				Validation				
2007	15	16	25	17	809	870	0.880649	0.701379
2008	11	12	13	10	579	673	0.870273	0.678311

5.1.3. Flood Frequency analysis:

Frequency analysis is a technique of fitting a probability distribution to a series of observing for defining the probabilities of future occurrences of some events of interest. e.g. an estimate of a flood magnitude corresponding to a chosen risk of failure. The use of this technique has played an important role in hydrological practice. The maximum rainfall amount for a given duration and for selected return period is often required for the planning and design of urban drainage systems. Gumbel’s method is used as the basic approach in this thesis to determine the return periods of extreme values.

The Gumbel distribution is particularly convenient for extreme value distribution purposes and has been commonly used for the estimation of discharge peaks. Therefore, the gumbel distribution is assumed as the underlying probability distributions for next 50-100 return periods. Extreme discharge events were analyzed using annual daily maximum discharge observed data at Khokana station.

Available 17 years (1992-2008) instantaneous maximum flood events probability distribution shows the Gumble distribution fits better. So for this study purpose, flood magnitude, its frequency and return periods are taken from the Gumbel distribution (Table 5.6). The Comparison between Gumbel Distribution of annual daily maximum discharge of observed and simulated is shown in the figure 5.31.which seems to be fit better.

Table5.6. Flood estimation using the Gumbel distribution.

Tr	sim(Q)	obs(Q)
2	191.313589	384.994149
5	455.043617	652.453076
10	629.655844	829.534158
20	797.148085	999.394584
25	850.278856	1053.27658
30	893.502238	1097.1111
40	961.434894	1166.00426
50	1013.94961	1219.26148
60	1056.7667	1262.68397
70	1092.91568	1299.34406
80	1124.19636	1331.06702
90	1151.76575	1359.02621
100	1176.41184	1384.02078
110	1198.69558	1406.61959
120	1219.0305	1427.24203
130	1237.73021	1446.20614
140	1255.03825	1463.7589
150	1271.14749	1480.09591
200	1338.28128	1548.1789
250	1390.31993	1600.95333
500	1551.83727	1764.75437
1000	1713.23782	1928.43698

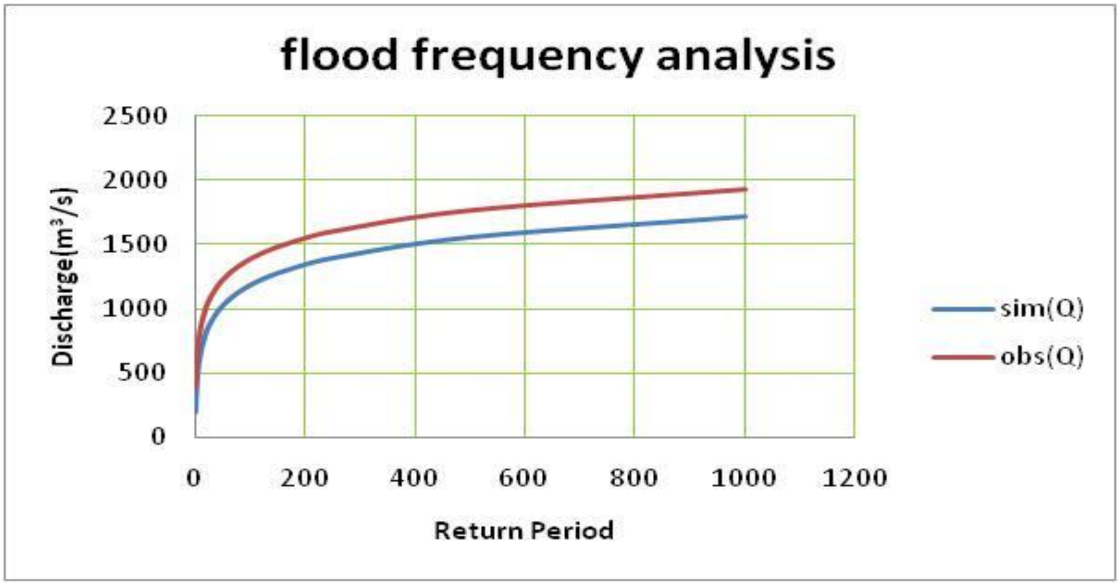

Fig.5.31: Comparison between Gumbel Distribution of annual daily maximum discharge of observed and simulated

The maximum instantaneous flow of 942m3/s was recorded while the lowest flood flow of 103 m3/s was recorded during observation. The 17-year mean instantaneous flood flow is 420.76m3/s with a skewness of 0.98 and Confidence Level (95%) of 126.31.

The maximum instantaneous flow of 820.41 m3/s was recorded while the lowest flood flow of 59.25m3/s was recorded during simulation. The 10-year mean instantaneous flood flow is 221.26m3/s with a skewness of 2.64 and Confidence Level (95%) of 158.08. Measured and predicted flood flows show no significant differences hence, a goodness of fit of the Gumbel distribution (Figure .5.31)

5.2. Discussion

Decrease in water discharge exerts enormous impact in the overall river ecosystem such as damaging the habitat aquatic life, exposing the river banks, channeling of the flow, etc. Discharge record on the basis of (DHM) discharge data for last 10 years(1999-2008) at Khokana station reveals the overall decreasing trend in water discharge (Figure 3.8). During these periods, frequent high discharges have been also noticed at the time of flood in Bagmati river. But the overall trend is decreasing. The water level used to be up to the Ghats and in monsoon it used to go up to the wall in Shakhamul till 2036-2037 according to local aged people in a consultation meeting with local committees.

The tapping of water for drinking and irrigation purpose right from main sources of rivers is one of the root causes of decreasing water discharge. Sundarijal the upstream of Bagmati, Bishnudwar of Bishnumati, Sangla River, Chapagau of Nallu River, Godavari River, Mahadev Khola, Dudh Pokhari (fig. 3.9) are major locations from where huge volume of water has been diverted for drinking and irrigation purpose by NWSC (now KUKL). According to NTNC (1995), everday about 30 million litres of water is tapped from rivers Bagmati, Bishnumati and other small streams originated from Shivapuri area. The river sources outside Shivapuri National Park, such as Manahara River, Nakhu River and Balkhu River are being intensively used for agricultural, tourism related business, recreation activities and many other purposes.

With respect to the daily or monthly basis, the results obtained for the Bagmati basin may be said to be very good, for the annual discharges. Throughout the period under consideration, the relative error was found to be quite small and the result obtained may be said to be acceptable. It should be noted that actual daily evaporation data were not totally available for this case as well as some data were missing on discharge and precipitation. This may account for some part of the errors produced by the Tank Model. From the hydrographs, except for the fact that the peaks of daily discharges were underestimated by the Tank Model, the results obtained may be said to be quite satisfactory .As mentioned above, peak discharges are underestimated by the Tank Model. When the computed peak discharges were increased to be of the same range as the observed data, the annual discharges and hydrographs ceased to be close to this historical one. That is, Comparison of observed and the simulated hydro graph showed that the simulated runoff is underestimated than the observed runoff. The low flows (dry season flows) were somewhat well captured. The highest peak flows were underestimated. However, the model has reproduced most parts of the observed hydrograph and simulated well the seasonal and annual variations in runoff. The Tank Model would be very useful for the extension of stream flow records. Having calibrated its parameters using the available data for rainfall, runoff and evaporation, the model can be used to transfer rainfall to runoff when data on the former are available for a longer period. The flow in July 23, 2002 was recorded 814m^3/s, the highest during the study period and which might be due to the continuous rain fall in part of the basin that lies in Nepal as a result of monsoonal effect.

Flood frequency analysis involves the fitting of a probability model to the sample of annual flood peaks recorded over a period of observation, for a catchment of a given region. The model parameters established can then be used to predict the extreme events of large recurrence interval (Pegram and Parak, 2004) Reliable flood frequency estimates are vital for floodplain management; to protect the public, minimize flood related costs to government and private enterprises, for designing and locating hydraulic structures and assessing hazards related to the development of flood plains (Tumbare, 2000). Nevertheless, to determine flood flows at different recurrence intervals for a site or group of sites is a common challenge in hydrology. Although studies have employed several statistical distributions to quantify the likelihood and intensity of floods, none had gained worldwide acceptance and is specific to any country (Law and Tasker, 2003). The Gumbel distribution is particularly convenient for extreme value distribution purposes and has been commonly used for the estimation of discharge peaks. The 17-year mean instantaneous flood flow is 420.76m^3/s with a skewness of 0.98 and Confidence Level (95%) of 126.31.The 10-year mean instantaneous flood flow is 221.26m^3/s with a skewness of 2.64 and Confidence Level (95%) of 158.08. Measured and predicted flood flows show no significant differences hence, a goodness of fit of the Gumbel distribution (Figure .5.31).

6. Conclusion and Recommendations

6.1. Conclusion

The model was run for a total of ten years data, eight years during calibration and two years during validation, using calibrated parameters in Table 5.3 to predict the discharge at the outlet of the watershed. That is, Model parameters developed from previous studies were calibrated to fit the characteristics of the area. Running the simulation of the model for ten years, the model was calibrated from1999 to 2006 while the model was validated for 2007 and 2008. The scattered diagrams for measured and predicted river flows of different time steps are presented in Figures 5.1-5.30. Figures 5.22-5.30 compares the daily time step of measured and simulated discharges during calibration and validation, respectively. The graph clearly shows that the model, despite its simplicity and the watershed's high rainfall variability and distribution, simulates discharge with reasonable agreement during both calibration and validation. Furthermore calibration and validation resulted in a similar accuracy, suggesting that the model performs in a consistent manner in the study area. Judging by the coefficient of correlation and Nash efficiency, it can be concluded that the model simulated stream flows with a reasonable accuracy, and more importantly, the processes simulated in the model were in agreement with experimental data within the watershed.

Flood frequency analysis had been carried out for Bagmati River using 17 years of observed peak flow and 10 years of simulated data. The outcome of the analysis clearly reveals the good capability of the Gumbel distribution function to predict river flood magnitudes (Figure 5.31). There were no significant differences between the predicted and measured flow magnitudes. Hence, the model can be reliably applied to predict the occurrence of Bagmati River floods of Kathmandu valley at Khokana.

6.2. RECOMMENDATION

Data set used in this study is only of few years (i.e. 1999-2008), nine rainfall stations and one evaporation station. To build a good rainfall-runoff modeling using tank model more rainfall gauge stations data are required in order to represent the whole watershed and provide better result. Further, more than one year data with good quality is also necessary. In this study, the initial water level in each tanks are decided before the optimization process started. For the future study, it is better to optimize the initial condition of the tank model (set the water level in each tank as the parameters that should be determined), so it can give the best result of parameters although it will need more time to calibrate it.

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