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Simulation of Rainfall -Runoff of Kankai River Basin Using SWAT Model: A Case Study of Nepal

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Abstract: The present study is based on SWAT (Soil and Water Assessment Tool) Model which integrates the GIS information with attribute database to estimate the runoff. Soil and Water Assessment Tool (SWAT) is a physically based distributed parameter model which has been developed to predict runoff, erosion, sediment and nutrient transport from agricultural watersheds under different management practices. This model has been used to simulate the rainfall-runoff process in Kankai Basin of Eastern Nepal. The catchment area of the Kankai basin is 1165 square kilometer. In the model Clark unit hydrograph method of rainfall-runoff transformation, deficit constant loss method, constant monthly base flow method, Muskingum method of flow routing, constant monthly evapotranspiration etc. have been selected. The daily rainfall-runoff data of the year 1986-1989 has been used for calibration purpose. The model has been calibrated by adjusting the different parameters (infiltration rate, time of concentration, Muskingum constants) that directly affects the runoff and observing the output of the model (resulting hydrograph) till it best matches with the observed hydrograph at the outlet. The evaluation has been done in terms of various efficiencies such as Nash-Sutcliffe efficiency, percent error in peak estimate and percent error in volume estimate, coefficient of determination. The result for the Calibration period shows that Nash Sutcliffe Efficiency is 0.87 which is within acceptable range though it overestimates the performance during peak flow and under estimates during lean flow. The model is then validated for the period 1990-2011 with the observed daily rainfall and discharge data. The result for the validation period shows that Nash Sutcliffe Efficiency is 0.79 which is within the acceptable limit though it overestimates the performance during peak flow and under estimates during lean flow. The regression statistics shows multiple R value 0.98, R square 0.9, adjusted R square 0.96 of the model. The sensitivity study of the different parameters was also carried out responsible for the stream flow generation. Based on the analysis the surface flow manning's n, average slope length, and available water capacity of the soil layer were found to be the most sensitive parameters .Overall, the performance of the SWAT model in simulating stream flow of Kankai river can be rated as good and the calibrated model could be used for runoff simulation for this agricultural mostly vegetated watershed basin. And the model can be used for water resources planning, development and management within the basin as well as in other basin lying in the same region.
Keywords: Hydrological Model SWAT, Runoff simulation, Calibration and Validation

I. INTRODUCTION

With the changing scenario of the natural climate change and environment change due to artificial activities generated by the human in present years flood occurrence and its hazards are seen every year[1]. The occurrence is so frequent and unprintable in case of poor countries.Urbanizatoin, deforestation and unplanned road construction led to the increased the flood hazard. The vulnerability level is so high due to which the human life loss and physical property loss is unbearable to the nation[2]. The socio-economic conditions are worsening day by day. The developing countries are not able to afford for the well management and development in river projects. As a result the sufficient and reliable flood predictions, proper design of control and precautions measures remain a main challenge everywhere. However this requires the proper understanding, knowledge of hydrological and hydrodynamic process of river and its watershed properties/characteristics. A rainfall runoff modelling anticipates evaluating the runoff from a precipitation in a catchment which gives well information about the possibility of inundations problems in plain region of the river reach. In case of Nepal the condition is completely different where very poor work are done for flood modelling and inundation mapping where most of the rivers are ungauged. This is serious issue in case of middle and small rivers .Even the flood forecasting and models are not in proper use developed for the major basins of Nepal and people are highly suffered from the uncertain flood in the rivers across the countries. The scattered settlements in hilly regions are suffering from landslides and erosion while in plain regions people are suffering from inundations. As all major rivers in Nepal are Himalayan snow melting rivers having good hydro potential and can be a good source of nation income if properly managed.

A. Rainfall Runoff Modeling

Reliable information of catchments is required to help the policy maker and planner of the management and development work on the river systems. In the lack of real information the projects like dam, bridge, and barrage will be unstable and may collapse during monsoon period due to high flood. There are various methods of estimating the peak discharge and its time of occurrence (concentration time) at the out let of river basin. Rational method very applicable in small catchment area[3]. Empirical and statistical techniques to calculate river discharge commonly known as rainfall runoff models .A runoff model helps to visualize the response of water systems to change in the land use and meteorological events. [4].in hilly terrain the seepage flow is the main contributor in river water during dry season[5]. So the type of soil and underground water table development is equally important to consider for river water which can be estimated underground water modeling approach. However the hydrological models(R-R) estimates the flood frequency, its peak discharge when the basin properties are given as input to the model. The simulated output of the model is compared with the observed value. At best parameters value the observed and simulated matches close to each other at which we define the basin properties which is real information required. At present there are various models are developed for simulation. But the most efficient easy for handling and multipurpose models are to be use for simulation. So considering the entire model SWAT is chosen for the present study.

B. Significance of Hydrological Modeling in the context of Nepal

Nepal is a country in the world having second largest water resource potential..[6] Geographically more than two third of the country has been covered with hill and mountains. There are many perennial as well as non-perennial rivers originating from Himalaya to Churia regions[7]. The rainfall distribution of the country is not uniform throughout the year. About 80 percent of total annual rainfall occurs in monsoon season. The importance of hydrological modeling in the country can be explained in the following aspects.

1) *Water Resources Development and Management:* Though, there is large water resource potential available in the country, but the country has utilized only limited a portion of available water resources. Only about 80 percent of total population has excess to safe drinking water. Around two third of irrigable land has been irrigated till now. In terms of hydropower development, around 1500 MW capacity has been developed till now. But most of the hydropower plants are of run of river type and there is much fluctuation in power production throughout the year[8]. Hence the country is presently suffering from the problem of load shedding especially in dry seasons. There is much potential of inland navigation in larger perennial river but navigation has not been practiced till now in any river. To develop the water resources projects to meet the demands in various fields as explained above, starting point is the hydrological analysis. Hydrological analysis to access the availability of water resources in reference to time frame can be done in better way with the use of hydrological modeling. Hydrological analysis with reasonable accuracy can be done in shorter time by different types of modeling approach. Wider use of remote sensing and GIS based data along with observed hydro meteorological data in hydrological modeling provides quick hydrological solution to water resources development. On the other hand, there are many projects (irrigation, hydropower, water supply etc.) developed earlier which are now becoming nonfunctional due to non-availability of water. To access the availability of water before rehabilitating and management of such developed projects and suggesting a proper measure, hydrological analysis with modeling approaches provides quicker solution.
2) *Flood Analysis and Management:* Plain region of Nepal is suffering from tremendous flood due to high monsoon precipitation (natural cause) as well as human encroachment in the flood plain (human induced factor). Flood resulting from the severe monsoon precipitation are significant natural disasters affecting the areas in terms of impact on loss of life, huge damage to property, economic condition etc. Due to uneven distribution of rainfall, sometimes significant percentage of total annual rainfall occurs even in a single day, which generates very high monsoon discharge resulting flooding condition in adjacent areas of river banks. There is also limitation of hydro meteorological station and data in Nepal especially in hilly areas. Using hydrologic modeling techniques, it is possible to better prepare for and respond to flood events. Use of appropriate hydrologic models can mitigate flood damage and provide support to contingency planning and provide warning to people threatened by floods. [2]
3) *Sediment Management:* Due to hilly topography, weak geological condition (in lower Mountain and Churia region), human induced activities (deforestation, development of infrastructure etc.), heavy rainfall during monsoon season; most of the rivers of Nepal carry huge sediments in monsoon season which damages the fertile agricultural land every year. Sediment modeling approach in hydrological modeling will be helpful for the sediment management [9].

II. STUDY AREA

Nepal is a mountainous country with a geographical area of 147181 square kilometer. Geographically Nepal has been divided into three regions namely Mountain (Elevation 3600m-8848m) , Hill (Elevation 600m-3600m) and Terai (Elevation 100m-300m) based on altitude. The area covered by Mountain, Hill and Terai region is about 15%, 68% and 17% respectively. There are many perennial as well as non-perennial rivers originating from Himalaya, Mahavarat and Churiya range. Kankai is one of the perennial rivers originating from the Mahabharata range of Nepal.

A. Kankai Basin

Kankai Basin is located in eastern part of Nepal. The latitude and longitude for the selected study area lies between $26^0$41' to $27^0$07' N and $87^0$44' to $88^0$09' E respectively. Kankai is the major river in the basin originating from the border of Ilam and Panchthar district of Mechi Zone. It is rain fed Perennial River. The catchment area of the Kankai basin is 1165 square kilometer. The elevation of the catchment area varies from 130 m to 3535 m above mean sea Level. The Kankai basin in the map of Nepal has been shown in Figure 1 and the drainage networks in the study area has been shown in Figure 1 Kankai Basin attached together.

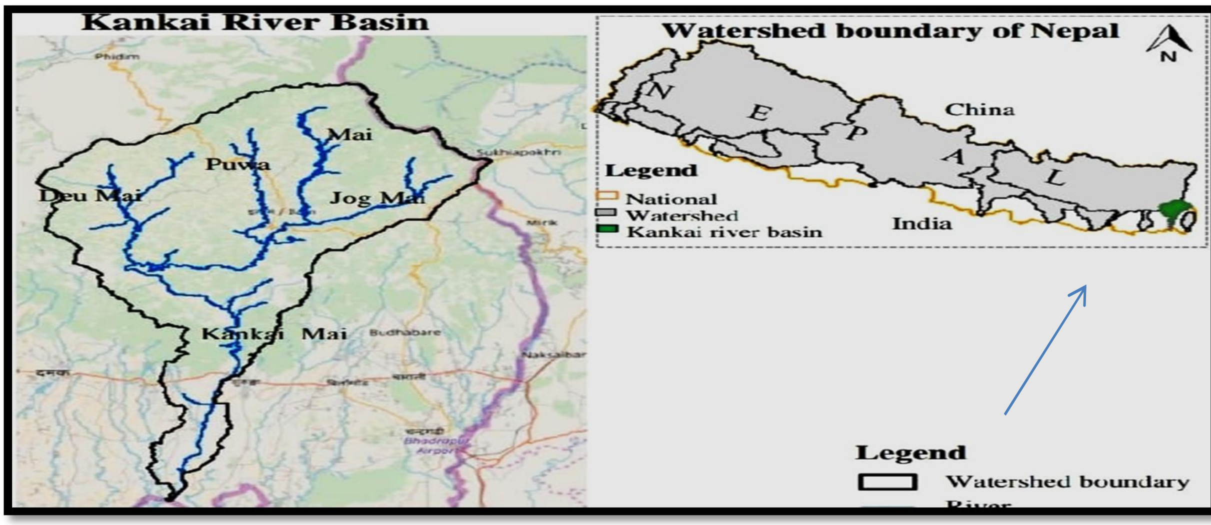

Figure 1: Basins of Nepal on the basis of origin of river and location (Source:Department of Map Nepal)

B. Major Tributaries of Kankai River

The Major tributaries of the Kankai River are Jogmai, Puwa Mai, Deu Mai Rivers which have been shown in Figure 2. All the tributaries are rain fed perennial rivers. The flow in the tributaries in lean season is quite low as compared to rainy season and is mainly due to spring sources. Jogmai river originates from Jogmai VDC, Ilam which lies in the border of Nepal and India. Puwa mai river riginates from Puwamajhuwa VDC, Ilam which lies in the border of Ilam and Panchthar district of Nepal. Deu Mai River originates from the Chamaita VDC of Ilam district which also lies in border of Panchthar and Ilam districts. The river end at the Nepal india Boarder in south. In image the downstream is end at the boundary between two countries. But for the simulation only the upstream from the outlet gauge station is considered.

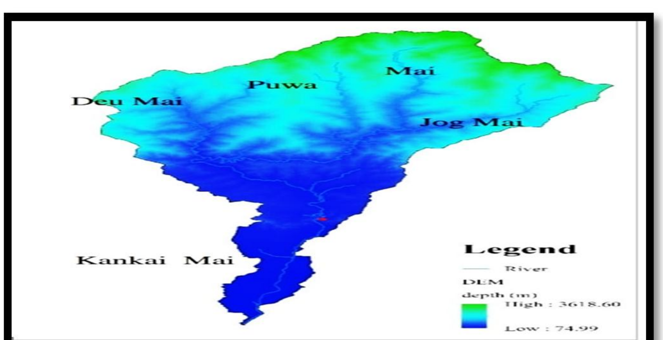

Figure 2**:** Catchment area of Kankai basin showing sub basins and major tributaries up to the Nepal India boarder.

C. Land use Practices in the Catchment

The land use pattern within the catchment can be classified into agricultural land, natural forest, scrub land, urbanized area etc. The agriculture land consists of terrace type land. The crops grown in agricultural lands are paddy, wheat, maize, potato, ginger, millet, cardamom, vegetables etc. The forest and scrub lands are natural and maintained by community as community forests. Beside these, there is considerable percentage of area covered by Tea farming within the catchment area. The percentage of greenery area covered by forest, tea, scrub etc. is around 45 percent. The impervious area within the catchment is around 7.5 percent including market, paved road, residential areas, VDC centers, community developed area, hard rocks in the catchments etc. Figure 3 is the land use map of the basin generated by the Landsat remote sensing ERDAS software in crack version. In figure the basin area is up to the end of river in Nepal India boarder. But for the study only upstream is made consider from the gauge station at outlet of the water shade.

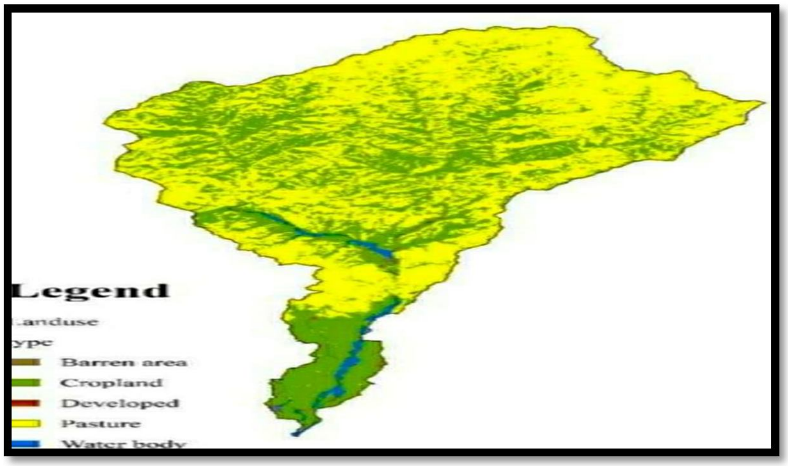

Figure 3: Land use pattern in kankai basin Landsat remote sensing image

D. Rainfall and River Flow

The average annual rainfall of the Ilam district, Nepal is about 1400 mm. Ilam is the second place of Nepal after Pokhara, which receives larger amount of precipitation. About 80-90 percent of the total annual rainfall is received from mid-June to mid-October. The average annual discharge is about 90.2 cumec. The peak flood discharge recorded during extreme rainfall event was about 5680 cumec which was too higher than average discharge. For other period rather than extreme events in rainy season, the discharge varies up to 3 time’s average discharge. For dry season, the flow in the river is quite low as compared to average which is due to ground water flow and spring sources. Fig 4 and fig 5 are the rainfall pattern of 2006 of kankai basin and the location of the gauge station set up within the basin. For the study only upstream from the Mainachuli as shown in figure 6 is considered for simulation of the river basin.

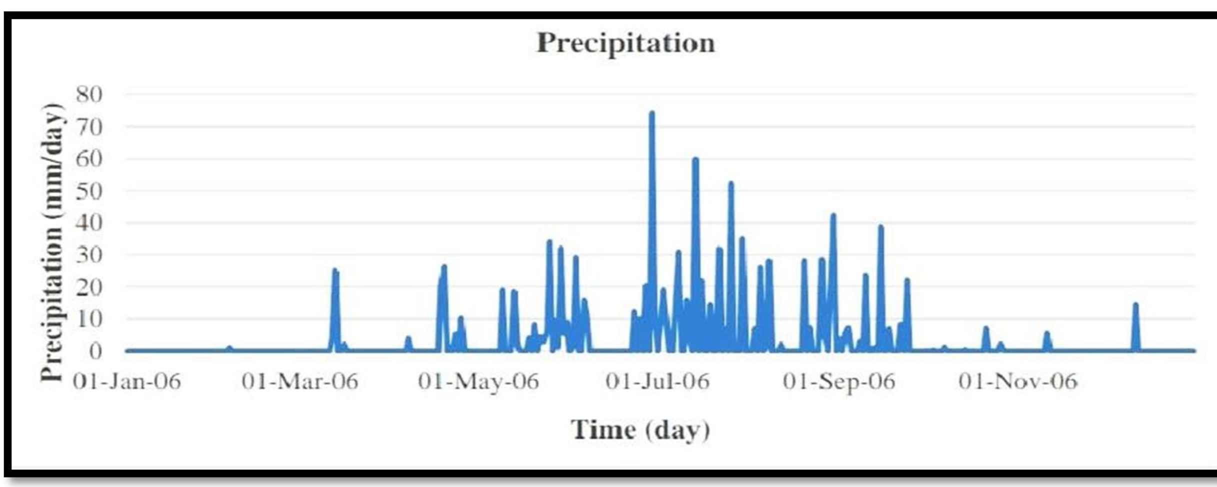

Figure 4: precipitation pattern of kankai basin of year 2006(Source:DHM)

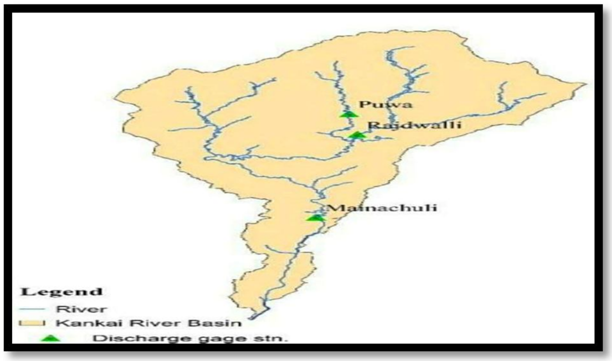

Figure 5: the Discharge gauge station on Kankai Basin (source:DHM)

E. Study drainage Sub Basin Division

The simulation area is considered upstream of the Mainachuli discharge gauge station as shown in figure 6. The digital image of the basin and sub basin area is as shown in figure below.

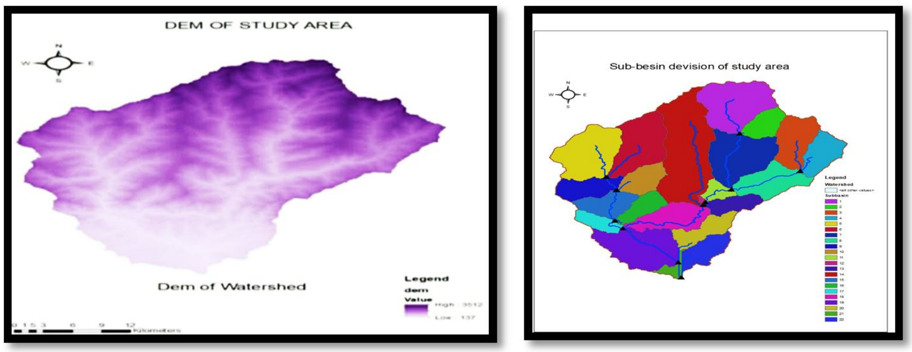

Figure6: DEM and Sub basin division of the study area.(Source:DHM)

F. Geology and Soil Characteristics

Kankai River originates from Mahabharata range and it flows through Siwalik region to Plain area. The elevation at which the river originates is about 3500 m and when the river reaches to terai, the elevation is about 100 m. In terms of geological condition, upper part of the basin comprises of granitic gneiss of Cambro-Ordovician age while in lower part, quaternary rocks are predominant. The river is in boulder stage in upper part. When it flows through Churiya range, it carries gravels, pebbles etc. along with flow and finally when it flows in plain region; it carries a lot of sediment during rainy season. Explaining in terms of geological condition, the upper part of the basin is quite stable while the geological condition of Churiya range is weak as the region is under rock formation age. Sedimentary rocks, limestone, mud stone, sand stones are predominant in Churiya range. The river is the gravelly bed river in which the gravels are formed from gneiss, sedimentary and metamorphic rocks. More than 50% of gravel is from gneiss. The soil type within the catchment area is sandy loam, clay loam, sandy clay etc. The predominant soil type is sandy loam[10].Fig 7 is the Landsat image for soil classification of the kankai basin up to the end of river at Nepal India boarder.

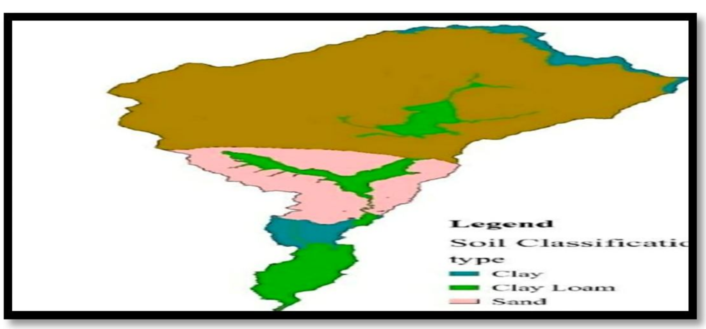

Figure7: Soil classification by Landsat remote sensing of kankai Basin

G. Climatic Condition

The lower part of the catchment has tropical climatic condition while the upper part has sub-tropical and temperate climatic condition. Humidity within the catchment is higher for the months July to September and low for the months March to April. The temperature in the lower Kankai basin is lowest in the month of December-January with an average minimum value within 8-10 ^{o}C and maximum of 24-25 ^{o} C. The minimum temperature in the hottest month April-June is 23-25 ^{o}C and maximum is 32-35 ^{o} C. Fig 8 and fig 9 are the weather station location and temperature pattern of the kankai basin of the year 2006 as reported by Hydro Metrological Development(DHM) Nepal.

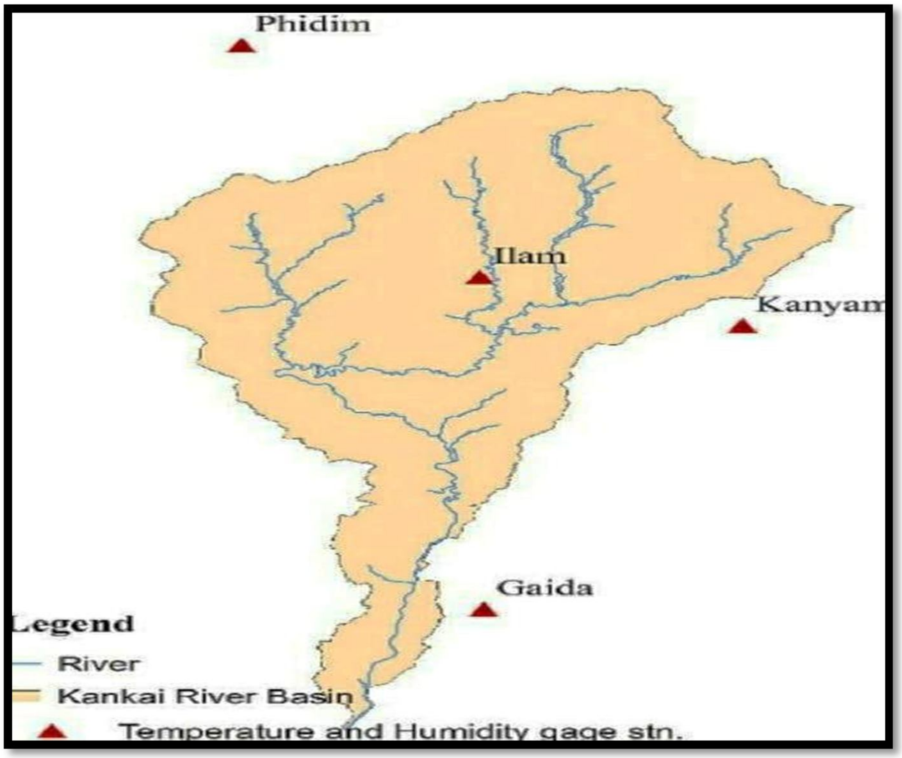

Figure 8 temperature and Humidity measuring station on kankai basin (source: DHM)

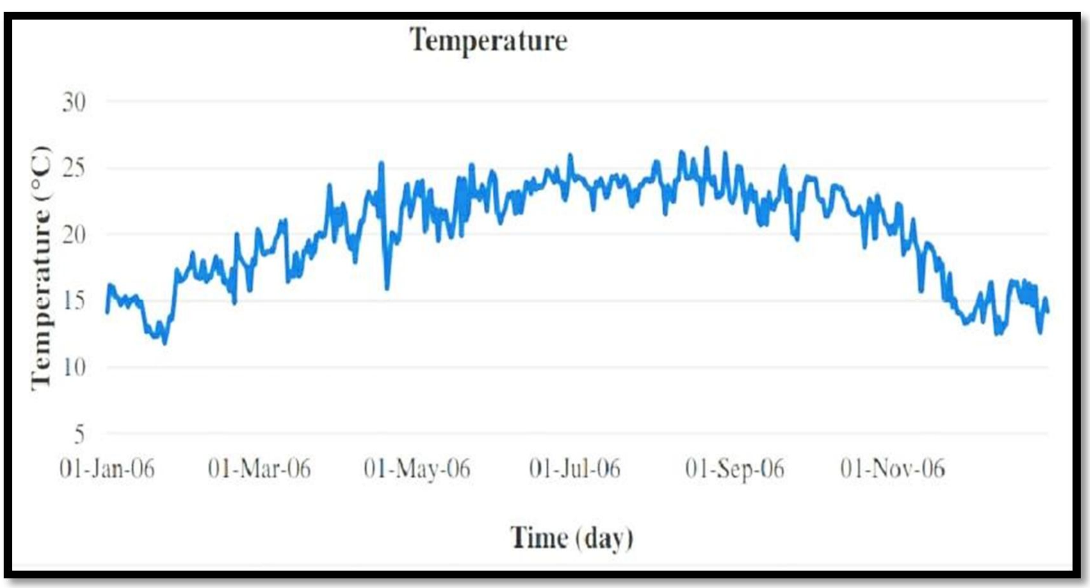

Figure 9: temperature variation pattern in kankai basin for the year 2006 (Source:DHM)

III. LITERATURE AND THEOREY

A. General

Presently hydrological modeling technique has become a quite popular tool to plan, assess, and manage water resources as well as water resource projects all over the world. Use of remote sensing data and GIS techniques have made the hydrological modeling quite easier and faster. Various hydrological modeling techniques are in use depending upon the extent of problems and availability of hydro-meteorological data. [11]

B. Development of Hydrological Models

1) *From Empirical to Physically Meaningful Models:* Development and application of hydrological models for the study of water resources has longer histor. Few remarkable dates in hydrological model developments are; In the 19th century: In the middle of 19th century, rainfall runoff modeling has started in broad sense to solve the problem of urban drainage, land reclamation and spillway design. Design discharge estimation was the major for the above mentioned problems. The concept of rational method for peak discharge was proposed by Mulvancy, an Irish Engineer in 1850 for application in land drainage. Later, Kuichiling uses the formula in sewer design in 1889 in USA. The start point of hydrological modeling may be taken as the rational method proposed by Mulvancy (1850). In this method time of concentration and maximum runoff are inter related. This method estimates the peak runoff from watershed not the volume of runoff. This method can be effectively used in small impervious watershed where the flow is kinematic process. In literature, use of rational method in the design of sewerage system can be found by the end of 19th century. In the 1930s: A major achievement on hydrological modeling was achieved in 1932 by Sherman, an American engineer. He had introduced the concept of unit hydrograph based on the principle of superposition for hydrological analysis. The superposition method based on many assumptions such as causative catchment, linear time invariant etc. The unit hydrograph concept would be able to calculate the runoff volume of particular rainfall event. Various statistical analysis techniques were used to improve the concept of unit hydrograph and its subsequent results during 1940s. In the 1950s: Use of system engineering approaches in the analysis of complex dynamic systems had been realized by the different hydrologists after 1950. They noticed that concept of unit hydrograph was only the solution of a causative, linear time invariant system. They introduced various mathematical techniques such as Laplace transform, Fourier transform, Z transform etc. to develop responsive function from input output data. During this period, conceptualized hydrological model concept had been started. Discretized form of unit hydrograph with sample data was still a big problem due to nonlinear behavior of the system. To solve this problem, hydrologists use the solution of simplified differential equation to determine the shape of hydrographs. With the application of the above solutions to hydrological problems, the unit hydrographs could be expressed in terms of parameters like catchment characteristics or by statistical procedures such as moments, regression etc. Solutions like linear channel and reservoirs, nonlinear reservoirs, cascade of linear reservoirs etc. are the outcomes of the above concepts. From the 1960s: From 1960 onwards, different hydrological models were developed representing the response of particular sub system in which components of hydrologic cycle were represented by interconnected conceptual elements. Some conceptual model developed during this periods are; Dawdy and O'Donnell (1965), Stanford Model IV (Crawford and Linsley, 1966), HBV Model (Bergstrom and Forsman, 1973), Sacramento Model (Burnash et al., 1973) etc. When these models were developed they were the best based on the current data and computation methods but above models were based on trial and error approaches. Further improvement on hydrological modeling showed that the optimizations of the model parameters were introduced. In 1970s: Real time forecasting models were introduced to solve the various hydrological problems such as flood forecasting and management. One of the popular model was TOP Model (Beven and Kirkby, 1979) based on assumption that topography have prominent role on flow routingAt the end of 1970: Variable contributing area models were introduced based on the assumption that rainfall runoff process was based on dynamics of saturated areas. Runoff only begins after the saturation of the upper soil layer which can be represented by models (Todoni, 2007). Models developed during these periods Xianjiang (Zhao, 1997), probability distribution models (Moore and Clarke, 1981) etc. were characterized by some significant parameters but were poor in the context of conservation of mass. The further step towards model development was the combination of variable area contributing model and probability distribution model to a Synthesized Constraint Linear System Models (SCLS) (Juemou et al, 1987). Under the above concept ARNO model was developed with modification over Xianjing model (Todoni, 2002 a). Wood et al. (1992) developed VIC model with modification of ARNO model considering soil layer concept. On the above models, total volume of water stored in saturated layer and the extent of saturation areas can be represented as a function in a physical meaningful manner but still the empirical method was used to estimate of parameters like drainage, ground water flow, percolation etc. from the observed data. To address the above issues, Beven and Kirkby (1979) developed the TOP

MODEL considering the concept topography index distribution function. During the application of the model, this concept became valid for small hill slope catchment areas (Franchini et al. 1996). Further to represent rainfall and runoff process physically, Kinematic models had been used by different modelers for the study of small urban basins. After this, concept of mathematical model was started based on distributed physical knowledge of surface as well as subsurface phenomena (Freeze and Harlan, 1969). For the development of models, partial differential equation with boundary conditions were used describe flow (surface as well as subsurface). With the use of this concept SHE (Systeme Hydrologique Europeen), a physically based distributed catchment modeling, was developed by the Danish Hydraulic Institute, British institute of hydrology and SOGRAEAH (France) with the assistance of European Union countries (Abott et al., 1986 a, b). Since then SHE has developed many physically based hydrological models. MIKE-SHE (Refsgaard and Strom, 1995), SHETRAN (Ewen et al., 2000) etc. were some of the developed models. The data about topography, soil properties, vegetation can be incorporated in catchment models. The limitation is the large volume of data requirement as well as computation time and hence its use has been limited to small catchment.[12] More recently: Due to wider availability of data related to catchment area properties (Such as soil type, land use and land cover etc.), use of remote sensing and GIS in hydrological study, use of satellite and radar rainfall data in hydrological modeling, use of mathematical computerized program in hydrological analysis etc. have facilitated the development of physically meaningful hydrological models. Presently, different types of hydrological models have been used in different field of hydrological analysis. Some of the presently used models in hydrological analysis are WATFLOOD, DHSVM, TOPKAPI, LISFLOOD, TOPKAPI, HEC RAS, HEC HMS, SWAT etc.[13]

2) *Data Driven Models:* The unit hydrograph concept proposed by Sherman in 1932 is the start point of data driven models. The unit hydrograph concept was expressed in discrete forms with the relation between the transfer function and Auto Regressive with exogenous variable models (ARX) (Box and Jenkins, 1970). An Auto-Regressive Moving average with exogenous variable models (ARMAX) had been used in flood forecasting with the concept of linearization of nonlinear hydrological process (Todoni, 1978). Afterwards, system engineering approaches had been used in hydrological modeling by different researchers. Artificial Neural Network (ANN) approaches had been started with the concept of nonlinear transform. The result of ANN was satisfactory in experimental scale but not satisfactory in larger real field events (Cameron et. al., 2002, Gaume and Gosset, 2003). Later, Data Based Mechanistic (DBM) techniques had been started in hydrological modeling (Young, 2002). In DBM concept, system engineering approaches had been used with the data input and output concept rather than black box concept to represent linear as well as nonlinear hydrological model structures (Young 2001, 2002). The DBM model had been developed from observations and realizes the importance of hydrological elements in the model but did not consider the contribution of past researches to define hydrological phenomena such as floods.
3) *Commonly used Hydrological Models*
a) *SWAT Model (Soil and Water Assessment Tool):* SWAT model is the successor of the 'Simulator for Water Resources in Rural Basins SWRRB). This model has been developed in early 1990. SWAT Model is continuous in its development process with the passage of time to address the various emerging issues in hydrological modeling. During the course of the development of the models, various tools such as; multiple hydrological response units, auto irrigation and fertilization options, snow melt routine, nutrition cycling routine, Bacteria transport routine etc. have been added to the model. This model is used to for long term hydrological simulation works for un-gauged basins. With the use of this model, water as well as sediment circulation and can be tested and forecasted. Similarly agriculture productions with chemical inputs can be forecasted. This model can be used to estimate runoff in urban catchments. For the application of the models in real scenario, the entire catchment area has been divided into sub-catchment. The sub catchments are further divided into small Hydrological Response Units (HRU) in similarity of land use and land cover, soil and management practices. The hydrology of the basin can be divided into two phase namely land phase and routing phase. In land phase the inflow of water, sediment, pesticides etc. to the channel can be defined while in the routing phase the movement of water, sediments etc. from the basin through the drainage networks of the basin can be defined. Inputs for the SWAT model are daily rainfall, temperature, solar radiation, humidity, wind speed etc. To estimate evapotranspiration, various methods such as Priestly-Taylor, Penman Monteith etc. are used in the models. For obtaining the better estimation and forecasting of water, sediment circulation etc. from the basin, simulation of hydrological cycle integrating overall water circulation within the basin is essential. [14]
b) *MIKE SHE Model (System Hydrologique European):* MIKE SHE is a physically based model developed under the name System Hydrologique European in 1982 with the joint effort of Danish hydraulic institute, British institute of hydrology and French company SOGREAH. This model was developed to address the emerging issues on hydrology due to rapid change in land use pattern resulted from Intensive agriculture development and deforestation. The model can be used to simulate surface

as well as ground water movements, interactions of both surface and ground water, sediment, nutrient and pesticides transport in the study area, water quality issues etc. There is no limitation of size of the catchment area for the application of this model. Major hydrological process in the basin including initial losses after rainfall, resulting surface runoff, snowmelt, evapotranspiration, channel flow, saturated and unsaturated sub-surface flow etc. can be simulated using the MIKE-SHE Model. The model can be used to simulate water quality problems arising due to different developmental and agricultural activities. For the application of model, the entire study area has been divided into polygon based on land use, rainfall and soil type and identification number has assigned to divided polygons. Model data preparation and model set up can be done using GIS software. Full description of model code, preparation and application has been provided in the user's manual of MIKE SHE. In terms of limitation of the model, it requires large number of data and parameters to execute the model which may not be available in many cases of study making difficult to apply the model.

c) *HBV Model (Hydrologiska Byrans Vattenavdelning Model):* It is semi disturbed conceptual model (Bergstrom, 1976). This model can be used to analyze the river discharge and water qualities issues. In application of this model, the catchment area under the study has been divided into sub catchments. Sub catchments are further divided into small units based on the elevation and land use practices. The main components of the HBV models can be taken as; subroutine for snow accumulation and melt, soil moisture accounting, response and river routing. Many free parameters values in the model are found by calibration of the models keeping mostly the constant basin and climate related parameters during calibration. Simulation time step may be daily or monthly. Input data required for the model are precipitation, snow covered area, air temperature, evapotranspiration data etc. To calculate snow accumulation in the model, temperature data are used. Presently different version of models is available in different countries to suit their specific climate. To simulate snow accumulation and snow melt related hydrologic issues, Degree day method is used. The hydrological processes such as; Ground water recharge, surface runoff, evapotranspiration etc.; are simulated as a function of water storage. In warm-up period, HBV-light model may be used. [15]

d) *TOP Model:* It is a two dimensional semi disturbed conceptual rainfall runoff model applicable to watershed and landscape scale. For the generation of runoff, topographical information can be incorporated in the model. Top model may be considered as physical based model implying that model parameters can be measured theoretically and may be stated that it is a variable area contributing conceptual Model (Beven and Kirby, 1979, Beven et. al, 1986). The dynamics of surface as well as sub surface flow can be estimated based on the simple steady flow theory in down slope saturated areas. The model can be applied in single as well as multiple catchments with gridded elevation data to predict the hydrological behavior. Hydrological inputs for the models are time series data of rainfall, measured discharge and potential evaporation. Topography of the area and transmissibility of the soil are the main components in the model. Computation of storage deficit or water table depth at any point is the main purpose of the model application. The storage deficit can be expressed as a function of topographic index ($a/\tan\beta$), where 'a' is drainage area per unit contour length and $\tan\beta$ is the ground surface slope (Beven, 1986). Representative values of the index based on topography can be found by model and result may be interpreted into real field with the pattern of index derived from topography. Estimation of runoff in the model can be done using exponential Green-Ampt Method. The output of the model may be in the forms of simulated hydrographs and area map. In terms of limitation, the model can be applicable in the area having shallow soil depth with moderate topography [16]

e) *VIC Model (Variable Infiltration Capacity Model):* VIC model may be taken as macro scale semi disturbed grid based hydrological model originally developed by Xu liang (Lieng et.al., 1994) with the capability of solving water and energy balance. The model is in continuous development process to address the new emerging issues in watershed hydrology. For the application of the model, entire watershed is divided into grids having large cells (>>1 km). The model grids may have different land cover and elevation. Meteorological inputs are precipitation, temperature, humidity, wind speed etc. The model grid may have different land use cover and elevation. Simulation of water and energy balance may be done in daily basis. To estimate surface runoff, base flow, infiltration etc., empirical relations are used. Surface runoff may be generated by means of infiltration excess runoff and saturation excess runoff. Saturation excess runoff can be simulated considering the soil layers and rainfall. The entire soil has been divided into three layers. Top layer is responsible for quick evaporation, middle layer for dynamic response of soil to rainfall event and the last layer for representation of soil moisture. Improved VIC model accounts the infiltration excess runoff and saturation excess runoff as well as the effect of soil heterogeneity on runoff characteristics. Study of surface and ground water interaction, prediction of ground water table, snow modeling etc. can be done using the model. Presently the model has been used in different regions of the world with different climatic condition to address the issues on climate change and land use[17].

f) HEC-RAS Model: HEC-RAS is hydrological modeling software developed by Hydrologic Engineering Centre (HEC) USA. HEC-RAS model is used to simulate one and two dimensional steady as well as unsteady flows for the networks of artificial as well as natural channels. The major hydraulic components of HEC-RAS may be taken as water profile surface mapping, one and two dimensional unsteady flow simulation, and sediment transport analysis and water quality assessment. The model can be used to study flood plain management and regulation works, to facilitate the design of hydraulic structures, bridges, reservoirs etc. The Model can be used in wide range of geographic areas to solve different emerged hydrological problems. Recently GIS interface to the model has been developed known as HEC-Geo RAS, instead of previously developed Arc-View extension making the model more users friendly. The model has fully functional modeling environment so as to address the all type of problems related to river networks. With the more capabilities of this model, we can say that it is basic hydrological modeling[18].

g) HEC-HMS Model: HEC-HMS (Hydraulic Engineering Center-Hydrological Modeling System) was developed by US Army Corps of Engineers. The model is generally used to simulate many hydrologic processes in dendritic watershed systems. This model can be used in wide range of geographic areas to solve wide ranges of hydrological problems such as flood, water supply, reservoir sedimentation, rainfall runoff response etc. Hydrograph produced by the programs are used directly or in conjunction with other software for the studies of water availability, urban drainage, flood forecasting, future urbanization impact, reservoir spillway design, floodplain regulation etc. It mainly includes the basin model, meteorological model and control specification. HEC-HMS comes with an Arc-View extension which automates the construction of the model input and especially the averaging of soil type and land cover properties, topography and local drainage delineation, through the full exploitation of GIS hydrographic delineation capabilities[4].

C. Application of SWAT Model

The Soil and Water Assessment Tool (SWAT) model has emerged as one of the most widely used water quality watershed- and river basin-scale models worldwide, applied extensively for a broad range of hydrologic and/or environmental problems. The international use of SWAT can be attributed to its flexibility in addressing water resource problems, extensive networking via dozens of training workshops and the several international conferences that have been held during the past decade, comprehensive online documentation and supporting software, and an open source code that can be adapted by model users for specific application needs. The catalyst for this special collection of papers was the 2011 International SWAT Conference & Workshops held in Toledo, Spain, which featured over 160 scientific presentations representing SWAT applications in 37 countries. This special collection presents 22 specific SWAT-related studies, most of which were presented at the 2011 SWAT Conference; it represents SWAT applications on five different continents, with the majority of studies being conducted in Europe and North America. The papers cover a variety of topics, including hydrologic testing at a wide range of watershed scales, transport of pollutants in northern European lowland watersheds, data input and routing method effects on sediment transport, development and testing of potential new model algorithms, and description and testing of supporting software. In this introduction to the special section, we provide a synthesis of these studies within four main categories: (i) hydrologic foundations, (ii) sediment transport and routing analyses, (iii) nutrient and pesticide transport, and (iv) scenario analyses. We conclude with a brief summary of key SWAT research and development needs.

IV. DESCRIPTION OF MODEL AND METHODS

A. Introduction to SWAT

SWAT model is the successor of the 'Simulator for Water Resources in Rural Basins SWRRB). This model has been developed in early 1990. SWAT Model is continuous in its development process with the passage of time to address the various emerging issues in hydrological modeling[12]. During the course of the development of the models, various tools such as; multiple hydrological response units, auto irrigation and fertilization options, snow melt routine, nutrition cycling routine, Bacteria transport routine etc. have been added to the model. This model is used to for long term hydrological simulation works for un-gauged basins[19]. With the use of this model, water as well as sediment circulation and can be tested and forecasted. Similarly agriculture productions with chemical inputs can be forecasted. This model can be used to estimate runoff in urban catchments. For the application of the models in real scenario, the entire catchment area has been divided into sub-catchment. The sub catchments are further divided into small Hydrological Response Units (HRU) in similarity of land use and land cover, soil and management practices[20]. The hydrology of the basin can be divided into two phase namely land phase and routing phase. In land phase the inflow of water, sediment, pesticides etc. to the channel can be defined while in the routing phase the movement of water, sediments etc. from the basin through the drainage networks of the basin can be defined. Inputs for the SWAT model are daily rainfall, temperature, solar radiation, humidity, wind speed etc. To estimate evapotranspiration, various methods such as Priestly-Taylor, Penman Monteith etc. are used in the models. For obtaining the better estimation and forecasting of water, sediment circulation etc. from the basin, simulation of hydrological cycle integrating overall water circulation within the basin is essential. [14]

1) *An overview of SWAT:* SWAT is an extension in Arc GIS to process geospatial data in GIS environment and creating SWAT model input files. It consists of integrated data management and graphical user interface (GUI). Analyzing of terrain information, delineation of sub basin and drainage networks, hydrologic input file preparation can be done through the use of GUI. SWAT is the means for transferring spatial information of the watershed into SWAT model files. Overview of the SWAT can be described by the following components.[21]

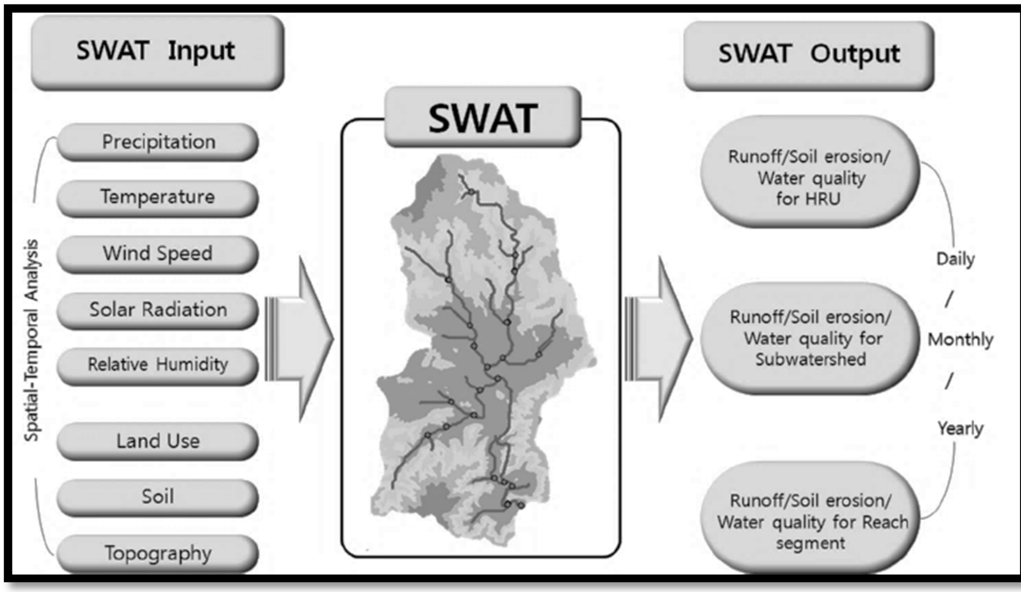

Fig10 GIS and SWAT Relation

B. Evaluation of the SWAT model

Model performance evaluation can be done to fulfill the following objectives i) quantitative aspects; determining the model ability in representing the historical as well future watershed behavior ii) to suggest the improvement in modeling approach with the consideration of various factors such as adjustment of modal parameters, use of additional information, modeling structure modification, consideration of important spatial and temporal characteristics of watershed etc. iii) comparison with the past modeling practices/approaches with the current approach.

After simulation run of SWAT model, the model parameters are optimized so as to match the observed hydrograph and simulated hydrograph at the outlet. Optimization is done to minimize a scalar quantity known as objective function. The objective function can be defined by the different methods.

Different approaches have been used to evaluate the performance of model. Most two approach of performance evaluation used are as:

1) *Nash-Sutcliffe efficiency (NSE):* The efficiency for evaluating the performances of hydrological models as proposed by Nash and Sutcliffe (1970) has been defined by the following relation;

$$NSE = 1.0 - \frac{\sum_{i=1}^{n}(oi^{obs} - Pi^{sim})^2}{\sum_{i=1}^{n}(Oi^{obs} - Oi\text{^}sim)\text{^}2} \qquad (1)$$

Where,

E = coefficient of efficiencies

O = Observed values

P = predicted values

Ō = Mean observed value

n = no of values

The efficiency E proposed by the above equation varies from 1 to -∞. Negative value of the efficiency means that mean value of the observed time series data would be better predictor than the model. Major deficiency in the above method is that differences between observed and predicted values are calculated on the square basis that results larger value are overestimated and smaller values neglected. Due to this effect, it leads to overestimation of model performance during peak flow and underestimation during lean flow. This model efficiency is not more sensitive for systematic model over or under predictions during lean periods.

2) *Coefficient of Determination (r2):* The value of r2 ranges from 0 to 1 explaining the observed dispersion from the simulated values. A value of 0 means there is no correlation and a value of 1 means there is perfect correlation between observed and predicted values. Major drawback of this method for defining model efficiency is that it only quantifies the dispersion. A model with that systematically over or under predicts all the time may have good correlation even the predictions are wrong. To overcome the above effect, additional information intercept ‘a’ and slope ‘b’ of the regression on which r2 is based can be combined with coefficient of regression while interpreting the result. For good prediction, the intercept ‘a’ should have near to zero while slope ‘b’ near to 1.
3) *Standard Deviation Ratio (RSR):* The value of standard deviation ration for the model is given by the Equation below

$$RSR = \frac{\sum_{i=1}^{n}(oi^{obs} - Pi^{sim})^2}{\sum_{i=1}^{n}(oi^{obs} - pi^{mean})^2} \quad (2)$$

O = Observed values
P = predicted and simulated values
n = no of values
The table below shows the statistical parameters of performance rating of the model[22]

Table1 Statistical Parameter performance rating of SWAT Model

Performance Rating	RSR	NSE
Very good	0<RSR<0.5	0.75<NSE<1
Good	0.5<RSR	0.65<NSE<0.75
Satisfactory	0.6<RSR<0.7	0.5<NSE<0.65
Unsatisfactory	RSR>0.7	NSE<0.5

V. METHODOLOGY

A. *Data Collection*

Daily discharge data of last twenty eight years’ time series (1983 to 2011) at the outlet of the study area have been collected from Department of Hydrology and Meteorology, Nepal. Similarly, average daily Meteorological data (precipitation, humidity, temperature, wind pressure, sunshine hours etc.) of the station within the catchment area as well as in the vicinity for the same period (1983 to 2011) have been collected from the Department of Hydrology and Meteorology, Nepal. The other related data have also been collected from various departments of government. Precipitation and daily observed discharge at the outlet for the study period have been shown in Figure 11 and 12.

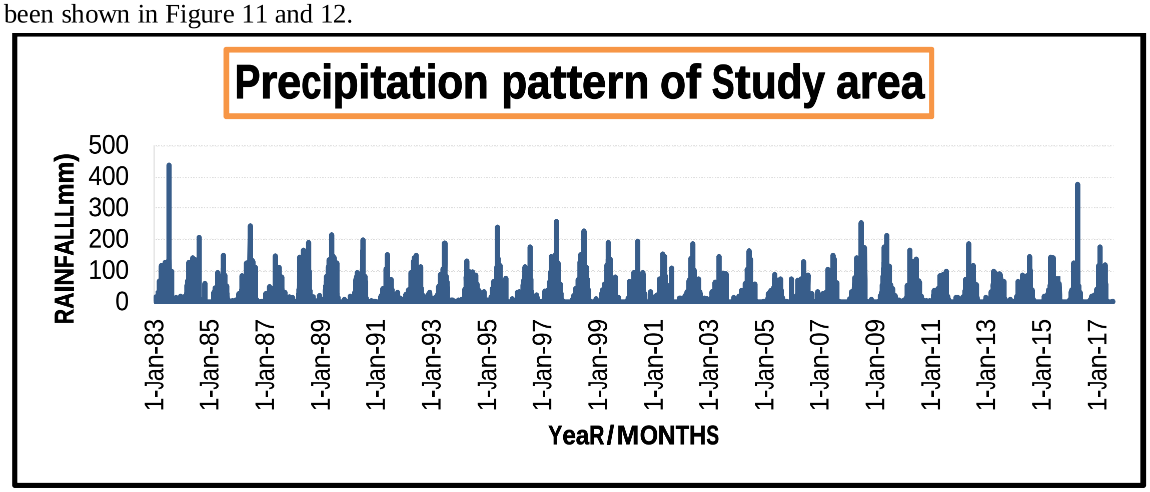

Figure 11: precipitation pattern in the kankai basin from the year 1983 to 2011 time series

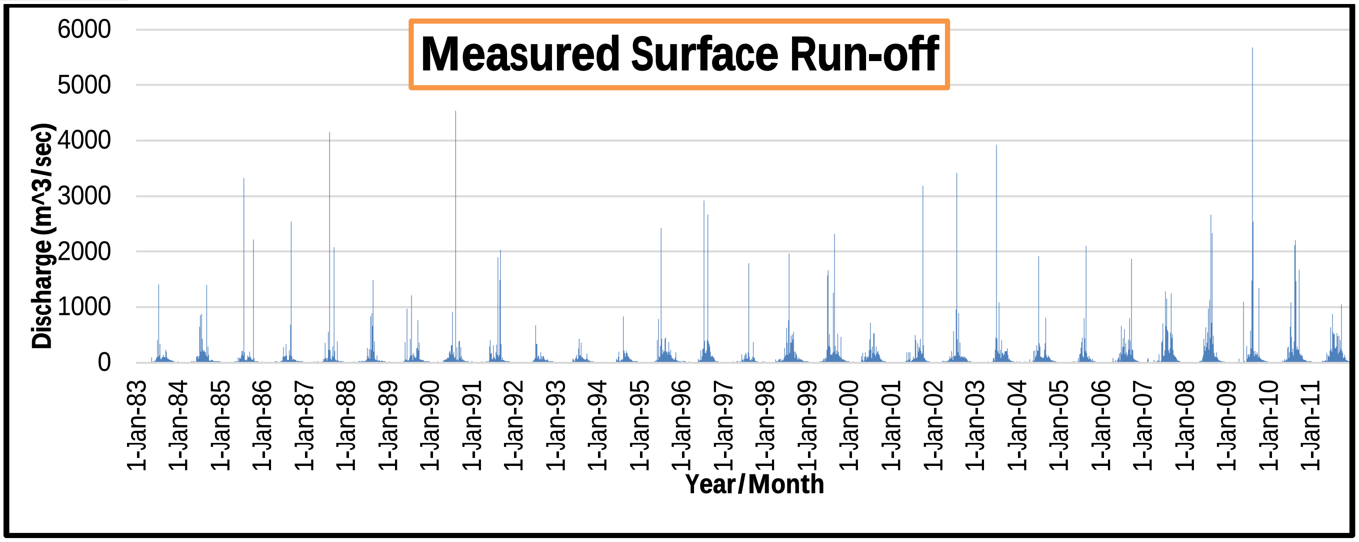

Figure 12: Hydrograph of measured discharge of Kankai river basin of 1983 to 2011 time series

B. Data base Creation/Preparation

30 m x 30 m resolution DEM of the study area has been downloaded from the website of U.S. Geological Survey (htpp://gdex.cr.usgs.gov/gdex/). SWAT software has been used to prepare the hydrological model. GIS based SWAT input files of the study area; namely background map file, meteorological model files and basin model files have been prepared using DEM terrain data with the help of SWAT software. Basin model file contains stream networks and their connectivity within the basin, sub basin and their boundaries. Further basin and terrain processing have been done in an Arc GIS environment. River networks and the catchments of the study area have been incorporated in the basin model and the hydrologic elements are linked.

The time of concentration for each sub basin has been found using TR55 method which utilizes the terrain information derived from DEM processing and maximum rainfall data from observed records of precipitation data. DEM of the study area, sub basin and drainage line in the study area, SWAT schematic map, SWAT basin model map are shown in Figures13 and 14 respectively.

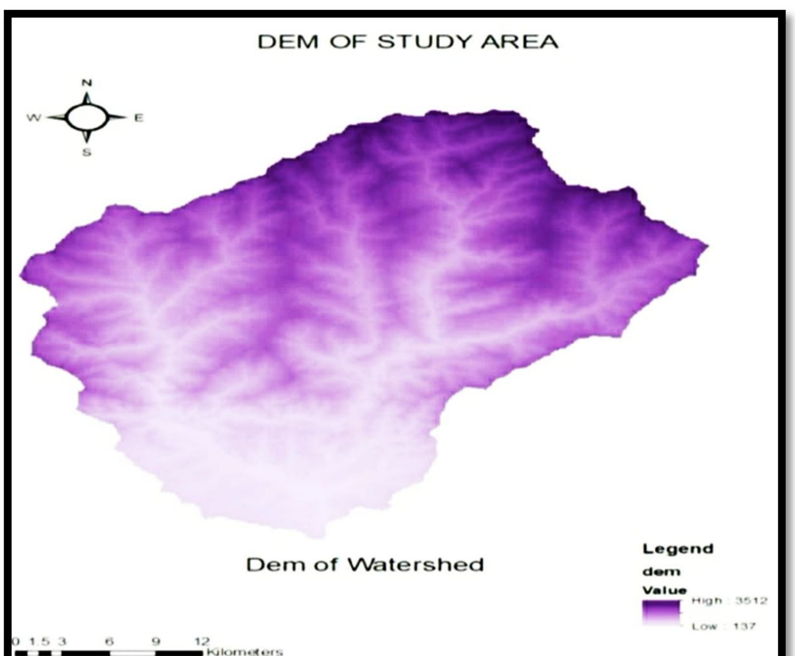

Figure 13: DEM of the Kankai Basin

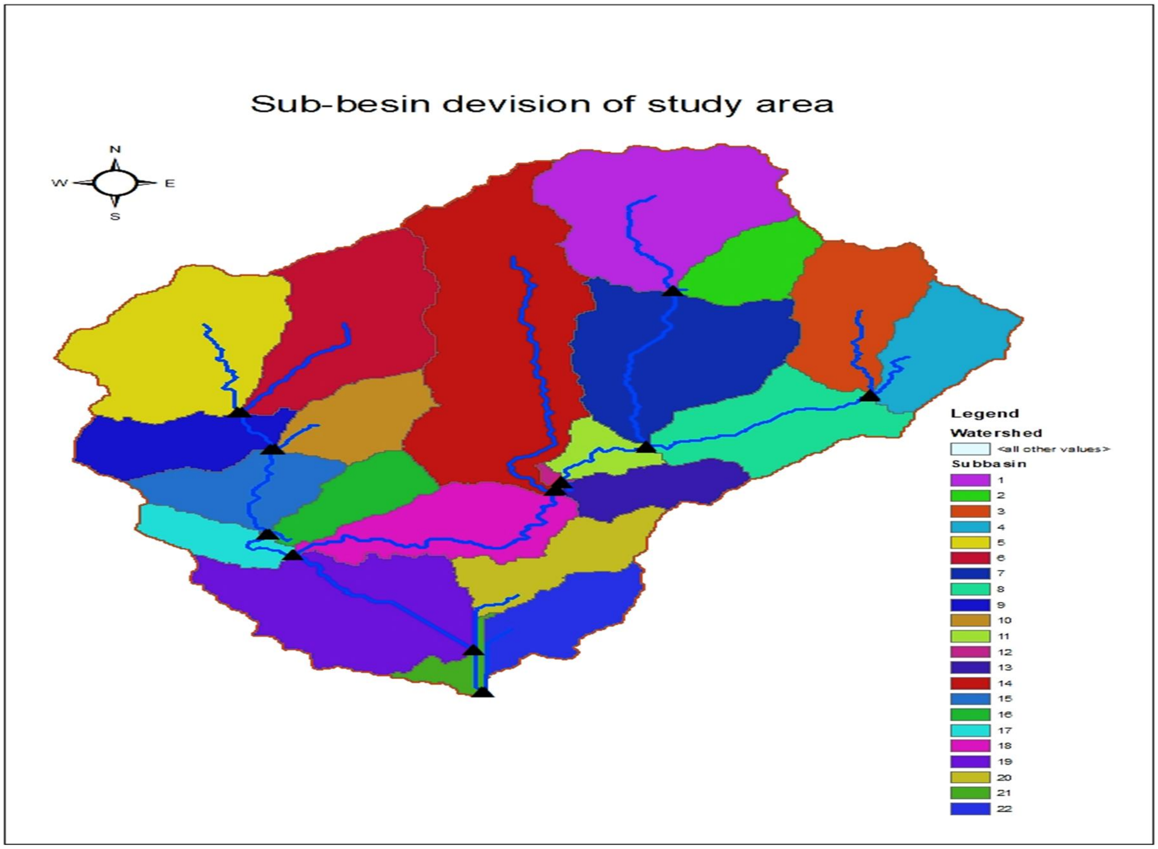

Figure 14 :Sub basin of the Kankai Basin for the simulation study

C. *Model Calibration*

The applications of the SWAT model on the large-scale and long-term series simulations are Concentrated mainly on the monthly scale and most hydrological models have simulated monthly runoff. This study simulated daily runoff and evaluated on the basis of daily scale, and the hydrological process was analyzed from the daily simulation results. The SWAT simulation results can be compared with similar hydrological models in this study area. The model was calibrated for the period from January 1986 to December 1989 and validated for the period from January 1990 to December 2011; the period from January 1983 to December 1986 was regarded as the warm-up period.

The hydrologic calibration followed multi-temporal, multi-variable, multi-site principles and used the observed data, hydrological characteristics, and expert knowledge of the basin to improve the accuracy of the runoff simulation. Parameter sensitivity was analyzed by SWAT-CUP. The 12 most sensitive parameters in the three sub-regions were manually calibrated and validated on the basis of expert knowledge. Table 5.31 shows the most sensitive parameters and their fitted values. The SWAT model used the observed and simulated daily runoff statistics at one hydrological station (Mainachuli). One goodness-of-fit measure, namely, R2 and Nash–Sutcliffe efficiencies (NS), were used. The runoff simulated by the SWAT model was compared with the observed runoff at the three hydrological stations. Statistical analyses of the calibration and validation periods show that the R2 values range from 0-6 to 0.83, indicating that the simulation exhibits a strong correlation with the observation findings. The NS values range from 0.56 to 0.84, exhibiting the high credibility of the simulation. In general, the model performance in the validation period is better than the model performance in the calibration period.

In summary, the simulation results exhibit good and very good performance that satisfies the accuracy and reliability requirements of the SWAT model. The simulation with the SWAT model used high-resolution gridded precipitation and comprised building virtual stations and calculating lapse rates to optimize the precipitation input parameters and improve the hydrological simulation. After using high-resolution gridded precipitation, the model can simulate accurate and detailed spatial distribution of water balance components, thereby improving the understanding of the regional hydrological processes.

D. Validation of the Model

The developed model with the calibrated parameters has been run to validate the model with observedd hydrological and meteorological data for the years 1990-2011. During the validation process the model performance has been evaluated in terms of various efficiencies as mentioned below table.

Table2: validation parameters for the model

Parameter	Descripting	Bound Upper	Bound Upper	Calibration Results	
				Fitting value	Method
CN2.mgt	Initial SCS CNII value	-25	25	1.0(Forest, Cultivated, Rangeland, Barren	Multiply
Sol Awc.sol	Available water capacity (mm$H_2$0/mm soil)	-25	25	0.75	Multiply
Canmx.hru	Maximum Canopy Storage, (mm H_2 0)	0	10	2.5 (Forest), 1(Cultivation)	Replace
Gw Delay.gw	Groundwater Delay (days)	0	500	8	Replaced
Ch K2.rte	Hydraulic conductivity in main channel, mm/hr	0	150	55	Replaced
CH N.rte	Manning's Roughness in main canal	0	1	0.35	Replaced
SURLAG.bsn	Surface runoff lag time (days)	1	24	1	Replaced
SFTMP.bsn	Snowfall temperature, ˚ C	5	5	1.5	Replaced
SFTMP.bsn	Snowmelt base temperature, ˚ C	5	5	3	Replaced
SMFMX.bsn	Melt factor for snow on June 21 (mm H_2 0/˚ C/day)	0	10	5.6	Replaced
SMFMN.bsn	Melt factor for snow on December 21 (mm H_2 0/˚ C/day)	0	10	1.5	Replaced
TIMP.bsn	Snowpack temperature lag factor	0	1	0.51	Replaced

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VI. RESULTS AND DISCUSSION

A. Calibration and Validation Results

From the available daily records of precipitation and discharge data, year 1986-1989 was selected for calibration period. The optimization was done manually by changing the parameters (infiltration rate, maximum storage, canopy parameters etc.) value used initially in the model that affects the runoff directly and observing the output of the model whether it matches to recorded hydrograph at the outlet or not. The optimization has been done in such a manner that resultant output i.e. the hydrograph at the outlet closely matches the recorded hydrograph. The evaluation of the calibrated & validation model in terms of various NS efficiencies and R^2 value has been presented presented in the Figures 15, 16, 17 ,18 and 19.

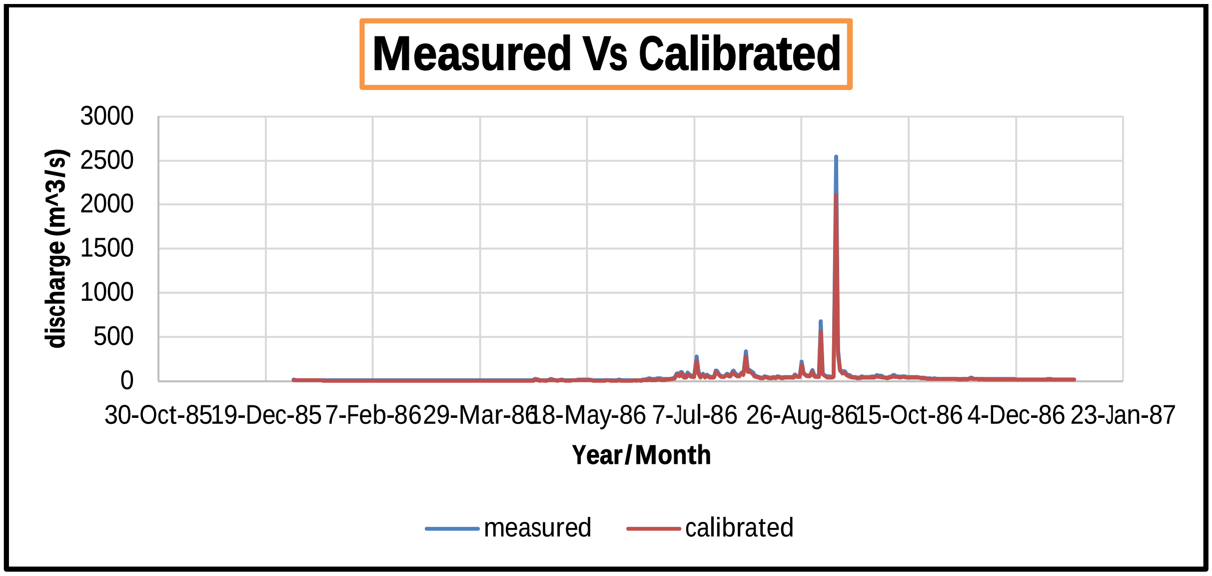

Fig 15:- Calibrated hydrograph of time series (1986-1987)

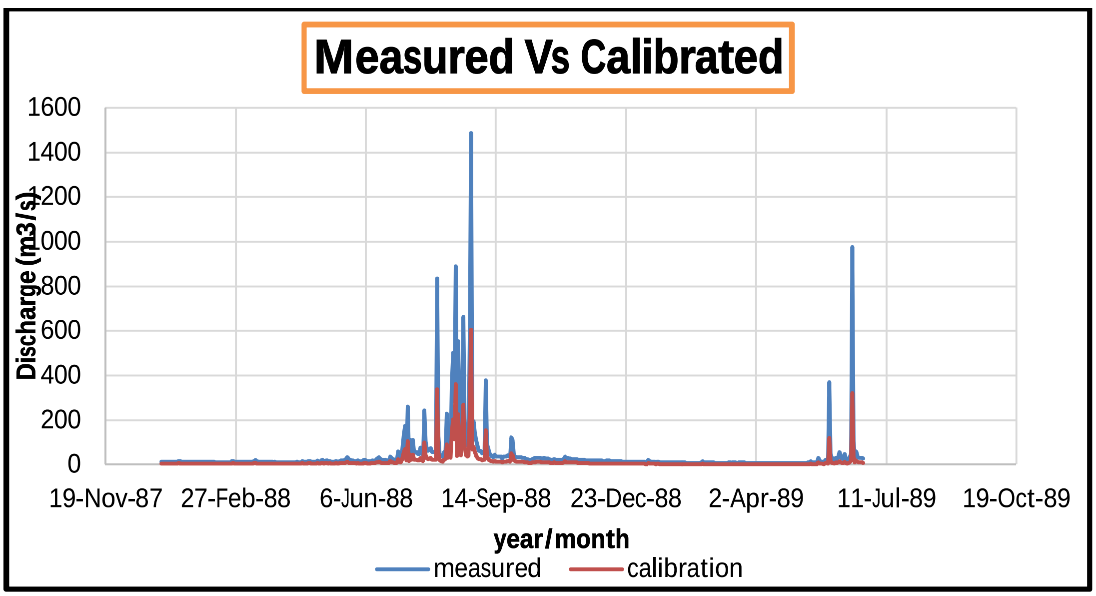

Fig 16:- Calibrated hydrograph of time series (1987-1989)

The result for the Calibration period shows that Nash Sutcliffe Efficiency is 0.87 which is within the acceptable limit though it overestimates the performance during peak flow and under estimates during lean flow. The R^2 value for the validation period is found 0.79 which is satisfactory.

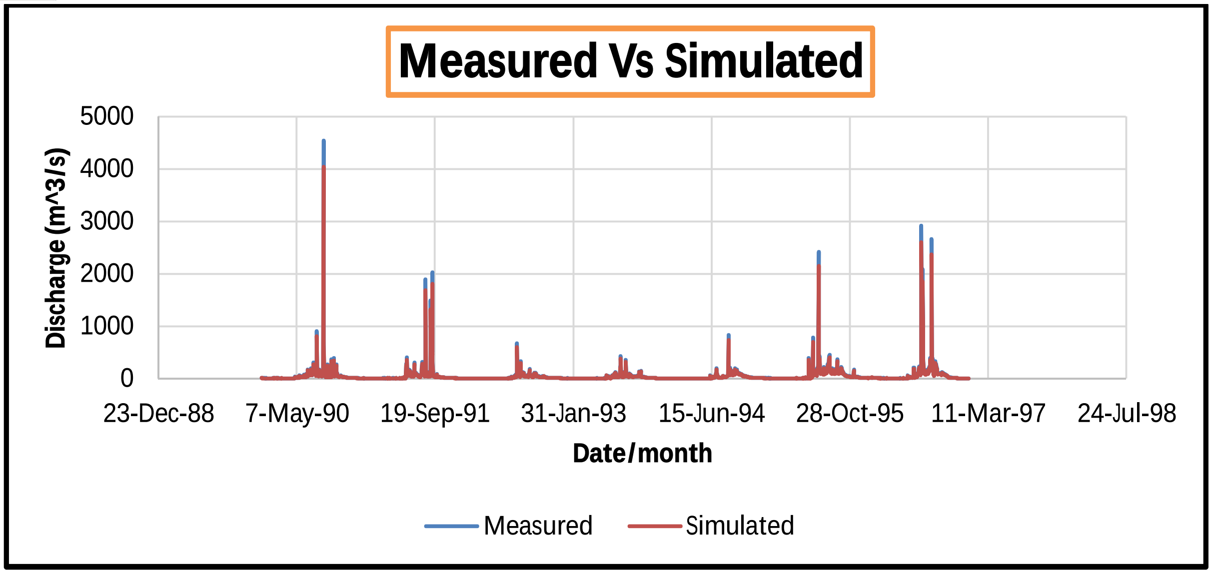

Fig 17:- Simulated hydrograph of time series (1990-97)

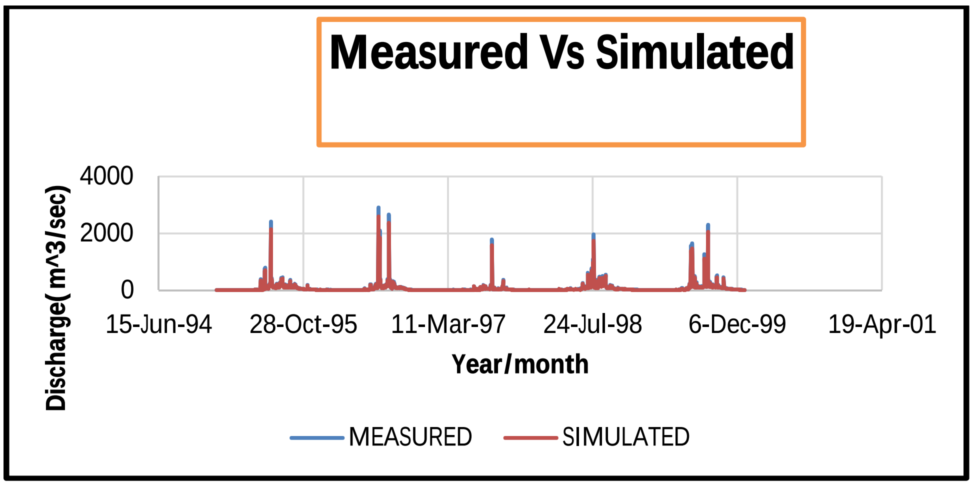

Fig 18: Simulated hydrograph of time series (1994 -2000)

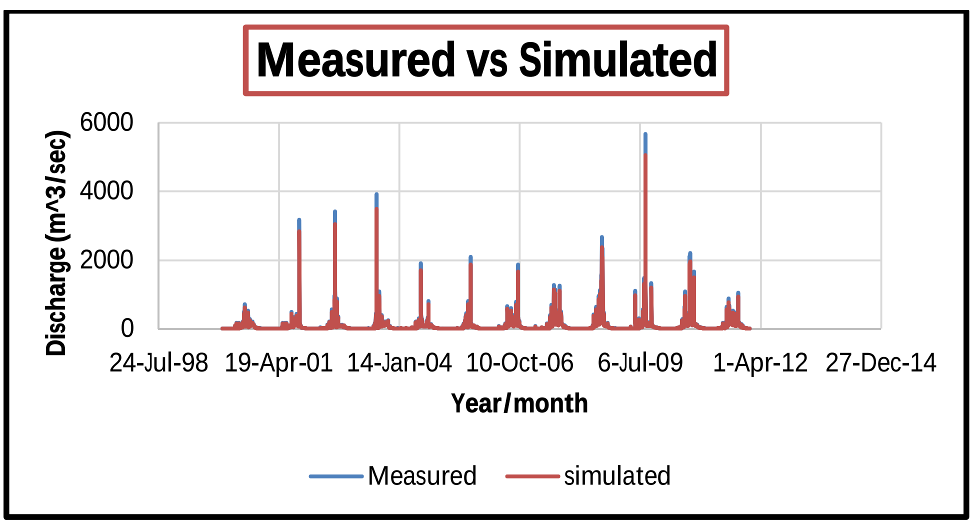

Fig 19:- Simulated hydrograph of time series (2000-2011)

The result for the validation period shows that Nash Sutcliffe Efficiency is 0.79 which is within the acceptable limit though it overestimates the performance during peak flow and under estimates during lean flow. The R^2 value for the validation period is found 0.967 which is satisfactory.

Table3 Regression Statistics of the Model SWAT

Regression Statistics	
Multiple R	0.98337408
R Square	0.96702457
Adjusted R Square	0.96701325
Standard Error	36.7799244
Observations	2914

This study shows the structure of the SWAT-based model used in modeling of the Rainfall Runoff process. SWAT simulation is done for monthly and yearly basis. Average runoff for average yearly rainfall is shown in Figures 17, 18 and 19 from which it can be seen that the maximum runoff occurred in the year 2006 at which observed value was recorded 5680 cumec. The rainfall runoff correlation has also been done for 30 years data and a good correlation is found with R^2 value 0.967 SWAT also gives daily Runoff for corresponding daily Rainfall value throughout the year. Here the graphical representation of daily maximum Rainfall-Runoff values for each year for 20 years period has been shown in Figures 17, 18 and 19.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

SWAT model developed for continuous simulation of rainfall runoff process for Kankai Basin, Nepal is found satisfactory in terms of model efficiencies. The simulated and observed discharge curves are similar in nature. There are a lot of uncertainties in input variables in the model such as missing hydro-meteorological and climatic data, spatial distribution of rainfall event within the catchment, loss method selection, representation of base flow, selection of rainfall-runoff transformation method etc. The hydrological model itself has some limitations such as not consideration of evapotranspiration during rainfall though precipitation is negligible. Overall, the result obtained from modeling is satisfactory. Some conclusions that are drawn from the above study can be listed as;

1) Nash Sutcliffe Efficiency for the calibration period is 0.87 and 0.79 for the validation period which is within the acceptable limit and the model is representing hydrological process in the catchment.
2) The coefficient of determination (R^2) for the calibration period is 0.79 and for the validation period is 0.69, both the values are satisfactory.

In general the performance of continuous simulation of rainfall-runoff process using SWAT model for the Kankai basin, Nepal is found satisfactory.

B. Recommendations

The above study is limited to rainfall runoff simulation works of Kankai basin, Nepal with the help of available recorded hydrological and meteorological data of the stations within the catchments and nearby. Clark unit hydrograph method has been used for rainfall runoff transformation. The loss method used in the above study is initial deficit and constant loss method, simple surface has been assumed. The results of the above study are satisfactory. This model approach can be used in similar catchments of Nepal for the accessing, development and management of water resources. Due to less number of hydrological and meteorological stations within the catchment, the actual spatial distribution of rainfall, temperature, humidity etc. has not been truly represented in the model as a result of which the simulated hydrograph is deviating from observed hydrograph in quantity as well as time.

It is recommended that the future work should incorporate the use of satellite based precipitation data, use of higher resolution DEM, use of satellite images of higher resolutions for land use and land cover classifications, adoption of soil moisture accounting loss method, use of accurate method for base flow representation, use of different methods of rainfall runoff transformations, consideration of effects of climate change if it is significant etc. The modeling of the basin should be done in grid level which represents the rainfall runoff response in the basin more accurately and the output of the model can be used for the development and management of water resource projects within the basin without appreciable errors.

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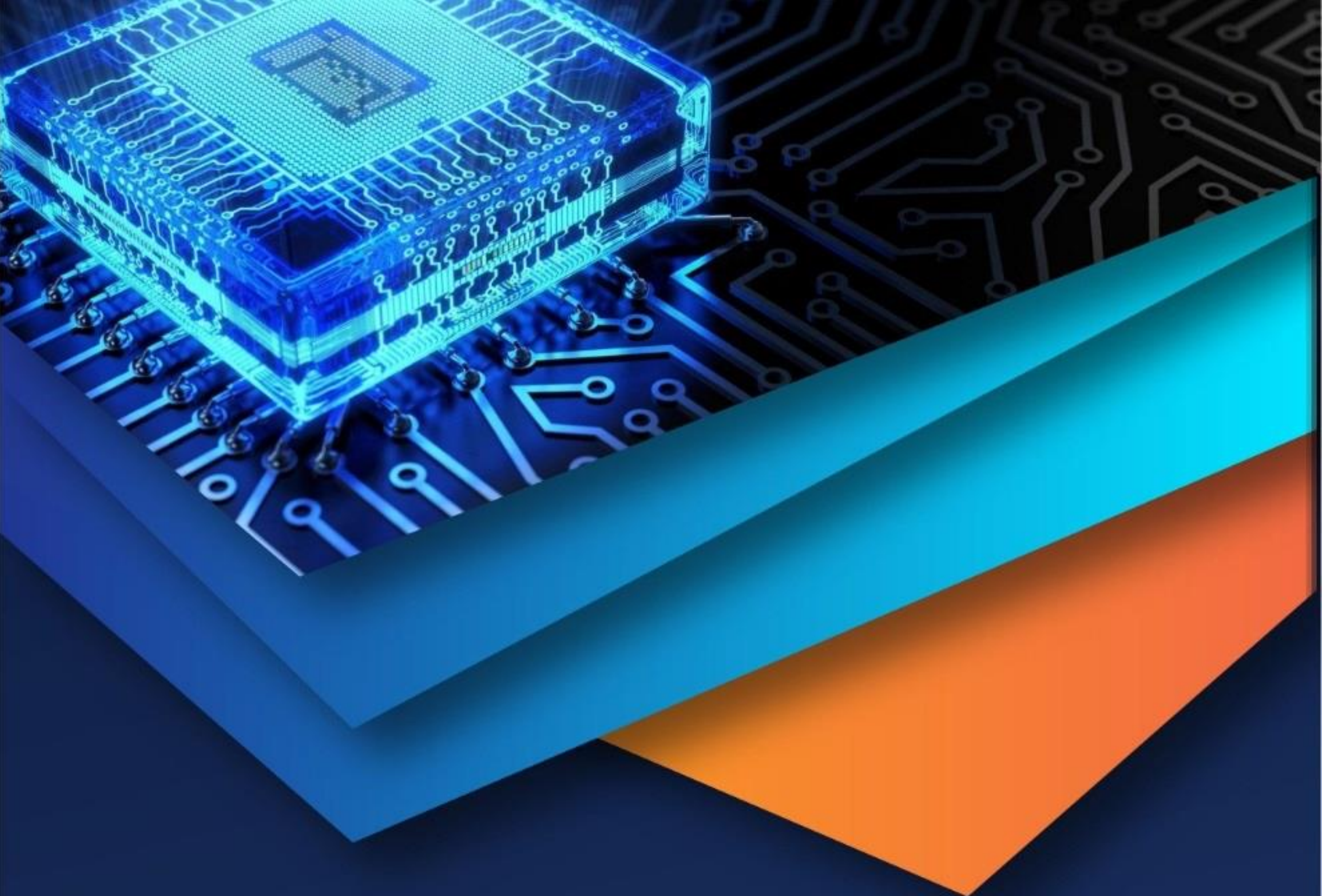

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