Journal of Civil Engineering and Environmental Technology
p-ISSN: 2349-8404; e-ISSN: 2349-879X; Volume 6, Issue 5; July-September, 2019, pp. 336-340
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http://www.krishisanskriti.org/Publication.html

Hydrological Modeling for Assessment of Future Run off Potential of upper Dwarakeswar Watershed Amid Changed Climate Scenario

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Abstract—*The main objectives of this study were to perform calibration and validation of SWAT model at upper Dwarakeswar watershed, and assessment of future runoff potential in changed climate scenario. A 90m by 90m grid DEM, land use and soil layers, thirteen years of historical from 1997 to 2009 and future climatic data of 2022,2023,2028 & 2030 and nine years stream flow data were used for the delineation and simulation of the hydrology of the watershed. Sensitivity analysis was done to identify the most sensitive flow parameters. These sensitive model parameters were adjusted within their allowable ranges during auto calibration to optimize model prediction. The model was calibrated using five years of hydrometric measurements, on monthly time steps. Validation of the model was also done with independent observed stream flow data from 01 January 2006 to 31 December 2009. The model performance evaluation statistics during calibration, coefficient of determination (R^2); and Nash–Sutcliffe model efficiency (NSE) were 0.65 and 0.64 and During validation the value obtained for R^2 was 0.69 and NSE value was 0.68 for monthly time steps. Both results obtained are within the acceptable ranges. The model slightly overestimated the flow on most of rainy months. Overall, the model demonstrated good performance in capturing the patterns and trend of the observed flow series, which confirmed the appropriateness of the model for future scenario simulation. Comparative study between historical and projected time steps were analyzed by exerting future climate data through the model, that reveals appreciable alteration of various hydrological and meteorological features. Remarkable deviation in stream flow was also found ahead like 87% rise of maximum peak flow in 2030 compared to historical maximum and also in annual flow volume as average two times greater flow volume was enumerated compared to the historical period.*

Introduction

Water is of paramount importance for sustaining life, development and the environment. The availability of water is the key determinant of economic growth and social prosperity. However, water is a finite resource and its use for one purpose reduces its availability for other purposes. Competing water needs trigger conflicts between disparate water users such as the rich and the poor, or between different sectors and regions, such as domestic and agriculture, agriculture and industry, agriculture and fisheries, upstream and downstream, rural and urban areas, and fisheries and flood control. Increased demand for water stemming from population and economic growth and ecosystem services on the one hand, and the problem of water management in flood control situations on the other, have posed significant challenges for the planning and allocation of its uses among competing demands [1]. Therefore, improvement of techniques to assist in the sustainable management of water resource system of the catchment is a crucial issue as water is a limited resource. Hence, to settle this physical water scarcity, usually attributed to limited access to water resources due to either climatic conditions or unsustainable management of resources, is most often addressed by storage reservoir construction in the specific area. Discharge is an important issue to be monitored because of its significant influence on agricultural systems and on human lives and to develop any water resource development work knowing the stream flow with a greater certainty is a must. Thus, from operational water resources management point of view, hydrological models are developed to guide the formulation of water resource management strategies by understanding spatial and temporal distribution of water resources [2-3]. Hence, the same is applied in this study for upper Dwarakeswar watershed. The Intergovernmental Panel on Climate Change (IPCC) has recently released the fifth assessment report including new carbon emission scenarios for the years of 2010 through 2100. Continuous anthropogenic carbon emissions from the Industrial Revolution post-1850s to the present have influenced climate [4]. In the Northern Hemisphere, the last three decades (1983 to 2012) have been the warmest to date since the 1400s [4]. Warming trends and precipitation regime change are projected to continue. Projected temperature and precipitation shifts from the carbon emission scenarios will impact hydrology at global, national, and regional levels. Hydrology, the interaction, movement, quality, and distribution of water over land, is studied to inform policy, resource planning, and engineering.

Hydrological systems will change from the melting of snow and ice, reduction in snowpack accumulation, changes in precipitation events, and warming temperatures. Quantity and quality of water resources will impact human and natural systems [4]. Climate change is one of the most important global environmental challenges, with implications for food production, water supply, health, energy etc. [5].The associated impact would be particularly severe in the tropical areas which mainly consist of developing countries including India[6]. Projecting the impacts of climate change on water resources at regional scale allows communities to be proactive in planning for the future. Therefore, there is a need to evaluate the impact of climate change on water resources in India at regional and local level. The climate change impact assessment on water resources in a river basin is normally handled through simulation of the hydrological condition that shall prevail under the projected climate condition in the basin. This ,in turn ,requires the development of a hydrological model (depicting hydrological response)for the basin concerned. The projected climate condition is extracted from output of General Circulation Model(GCM), downscaled to basin-scale variables, through statistical relationships or extracted from output of a Regional Climate Mode(RCM) and fed into the aforementioned hydrological model for simulation run [7-8-9]. Finally, climate change impact assessment is made by enumerating the changes in basin hydrology such as evapotranspiration, streamflows, extreme hydrological events viz., floods/droughts due to projected change in climate from those under baseline years. These processes viz., climate projections, downscaling methods and hydrologic simulations involve their own uncertainties [10-11-12] thereby introducing uncertainty in impact analysis. A relatively overlooked aspect of uncertainty in impact analysis is that associated with different methods of estimating potential evapotranspiration PET [13-14-15-16]. Uncertainty in climate projections is addressed by using an ensemble of GCMs and emission scenarios [17-18].Downscaling uncertainties have been explored [19-20-21] also by other researchers. Uncertainty in hydrologic model structures that closely relate to descriptions and approximations of natural hydrologic process is taken care of by using diverse hydrologic models [15].Uncertainty in PET computation methods are directly and indirectly associated with temperature change and is handled by using variety of PET computation methods in impact analysis [15-16].The objective of this study is therefore applying a physically based semi distributed model i.e. Soil and Water Assessment Tool (SWAT), to understand the rainfall runoff relationship in presence of probable uncertainties of the model and future run off projection in changed climate scenario.

Materials and Methods

The hydrologic simulation package ARC-SWAT has been used for the evaluation of hydrologic impact of climatic variability on water resources of Upper Dwarakeswar watershed. ARC-SWAT is interface of GIS tool ARC-GIS and SWAT. Dwarakeswar River is a major river in the western part of West Bengal. It is entirely a rainfed river originating from the dissected uplands of Bagalia (224m) and Tilaboni hill (407m) of Hura block in the district of Purulia in West Bengal. It enters Bankura district near Chhatna. It cuts across the district flowing past the district head quarters and enters the south-eastern tip of Bardhaman District. It then passes through Hooghly District. The Shilabati joins it near Ghatal and the two together is known as Rupnarayan River, which flows into the Hooghly River near Gadiara in Howrah District. The river basin is one of the 26 rivers sub basins of the state and is under the Ganga- Bhagirathi system. The Dwarakeswar river basin looks like an elongated balloon on map and is located between longitudes 86^{o}31’ -87^{o}51’E and latitudes 22^{o}37’-23^{o}33’N. the 220 km long river covering a basin area of about 4673 km^2 passing through three districts namely Puruliya, Bankura and Hugli (I&W,Dte.Govt. of WB).This study is limited up to upper part of the river basin (upto Suknibasa gauging station).

SWAT is a Hydrological model that attempts to describe the various physical processes controlling the transformation of precipitation to runoff, namely Evapotranspiration (ET), surface runoff, infiltration, percolation to shallow and deep aquifers, and channel routing. These processes may vary spatially as well as temporarily and are simulated in four subsystems: surface soil, intermediate zone, shallow and deep aquifers, and open channels. Stream flow in main channel is determined by three sources : surface runoff, lateral flow and base flow from shallow aquifers .The model is efficient in computing terms with the ability to perform the long simulations. In SWAT being a so-called distributed hydrological model, the impacts of spatial variations in topography, land use, soil and other watershed characteristics on the hydrology are considered in subdivisions. There are two level-scales of the latter: (1) a basin is divided into a number of sub- basins based upon drainage areas of the tributaries, and (2) each sub-basin is further divided into a number of hydrological response units (HRUs) defined by section of similar land cover and / or soil type [22-25-26].

To delineate the watershed and sub-basins, stream networks and simulation DEM data (collected from website CGIAR Consortium for Spatial Information (CGIAR-CSI)),River Map (collected from website USGS Hydro Sheds), Land use data (USGS Land Cover Institute),Soil data(website FAO-Geo Network), Historical Weather Data of Daily rainfall, temperature, relative humidity and wind speed (website Global weather Data for Swat for period -1997-2009) are used in the model. For projected weather generation data under A1B scenario of Regional Climate Model PRECIS (Providing Regional Climates for Impact studies) of the Hadley centre ,(the resolution being 0.44^o x 0.44^o Lat./Long. ,giving a grid spacing of 50 km) was collected for 2016-2030 for the study area from Indian Institute of Tropical Meteorology (IITM), GOI, Pune. Daily discharge data of Suknibasa gauging station for the period of 2001-2009 were collected (from Irrigation and Waterways Directorate, Gov. of WB) for calibration of the model. The performance of SWAT was evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. A forecast efficiency criterion is therefore necessary to judge the performance of the model. Assessing performance of a hydrologic model requires objective estimates of the closeness of the simulated behavior of the model to observations [27]. SWAT developers in [23] assumed an acceptable calibration for hydrology at (Coefficient of determination) $R^2 > 0.6$ and (Nash-Sutcliffe simulation efficiency) $E_{NS} > 0.5$ these values were considered in this study as adequate statistical values for acceptable calibration.

Results and Discussions

After the sensitive parameters identification, calibration followed by validation was executed for the significant parameters The calibration of the model was executed to evaluate the performance of the model and measure the fit between the simulated and observed outputs by automatic calibration tools embedded in SWAT-CUP. Flow calibration was performed for a period of five years from January 1st, 2001 to December 31st, 2005 for monthly peak surface runoff using the sensitive parameters identified. However, flow was simulated for 9 years from January 1st, 1997 to December 31st, 2005, as the first four years were considered as a warm up periods. The flow was calibrated using automatic calibration method by using the observed flow gauged at the Suknibasa outlet of the watershed. The calibration results is demonstrated by the coefficient of Determination (R^2=0.65) and the Nash-Suttcliffe (1970) simulation efficiency (E_{NS}=0.64) values for the whole watershed.

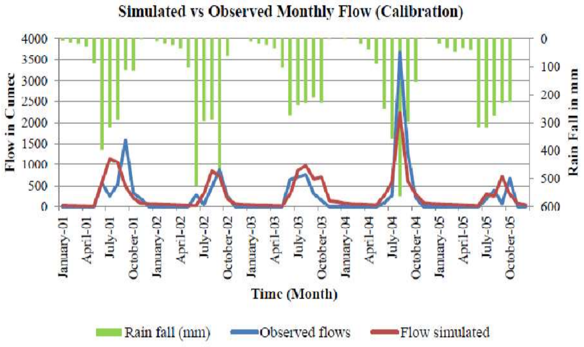

Fig. 1: Simulated vs Observed Monthly Flow (Calibration Period 2001-2005)

After Calibration and Validation of the model Projected climate data was fed into the model without changing other parameters and validation was performed for four years period from January 1st, 2006 to December 31st, 2009. The performance test result of the validation value lies under good performance (R^2=0.69, E_{NS} =0.68) [24].

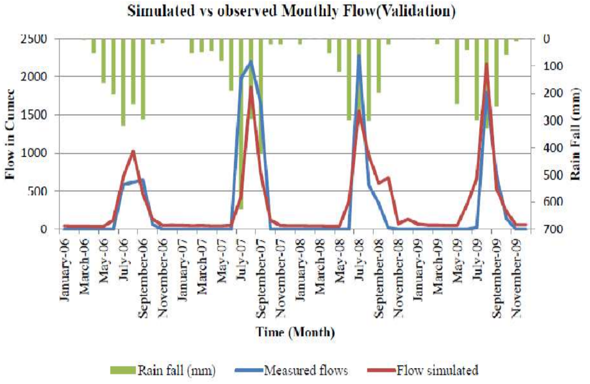

Fig. 2: Simulated vs Observed Monthly Flow (Validation Period 2006-2009)

Various hydrological parameters were compared in projected climate scenario with the historical data. From the historical observed data it was found monthly rainfall of July was highest for the basin followed by August and September. At future climatic projection in the year 2022 highest monthly rainfall was projected to occur in the month of June, in 2023 it was in the month of May ,in 2028 in the month of June, and in the year 2030 it was in the month of May. So in the projected climate scenario it was observed tendency of highest monthly rainfall shifted towards the month of May instead of Historical average July. An increase in quantum of annual 24h maximum rainfall over corresponding historical value (187mm) of the basin was found to occur in both the projected years 2023 and 2030. A very high 24 hour maximum rainfall (of 319 mm) was projected for the second week of May and second and third highest rainfall for the year and also among the projected years were projected in the same month in very large scale (267 mm and 229mm respectively).

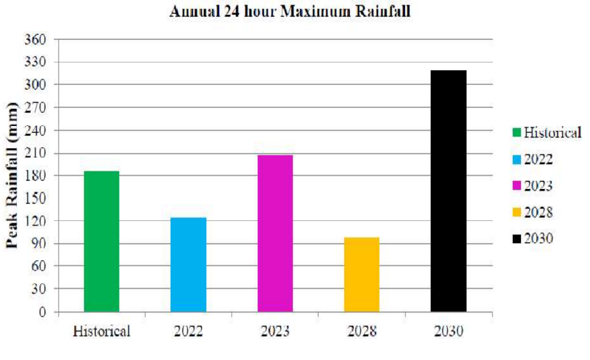

Fig. 3: Comparism of Annual 24 hour Maximum Rainfall in historical and Projected Years.

Annual daily average maximum and minimum temperature changes in projected climate as ascending manner. In 2022 temperature increased 0.84 degree Celsius from historical observed (2000), in 2023 it was 1.65^{o}C, in 2028 it was 1.84^{o}C and in 2030 it was 1.97^{o}C. Also as compared to historical(2000) average daily minimum temperature too increased to the range of 1.3°C upto the year 2030 gradually.

Potential Evapotranspiration was calculated using Pennman-Monteith equation as per projected climate data. Overall it was predicted that annual PET value in the projected years differed some amount compared to the historical as in 2022 it was estimated 3.5% greater value than the historical, in 2023 it was 2% greater, in 2028 it was 4.9% and ultimately in 2030 it was 5.9% greater than the historical. So the PET value in Projected years had a trend of increase in quantum though their trends towards monthly distribution matched with the historical monthly.

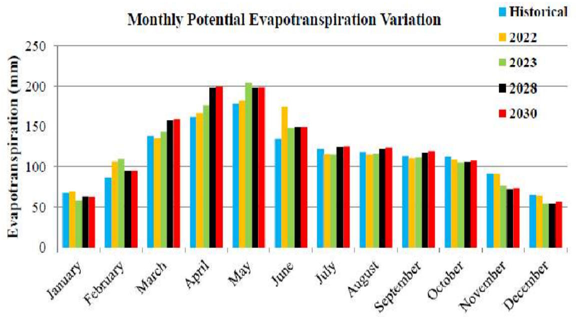

Fig. 4: Monthly Variation of Potential Evapotranspiration in Historical and Projected Years.

It was observed in case of highest annual peak flow among the projected years of the basin was around two times greater than the historical highest annual flow. Generally monthly flow was found maximum in August for historical years, whereas in the projected years flow pattern found erratic and no similarity of flow pattern recorded with each other. The maximum monthly flow (Yr-2030) was found likely six times greater than the historical maximum monthly flow. Annual flow volume was found greater in all the projected years than the historical average .

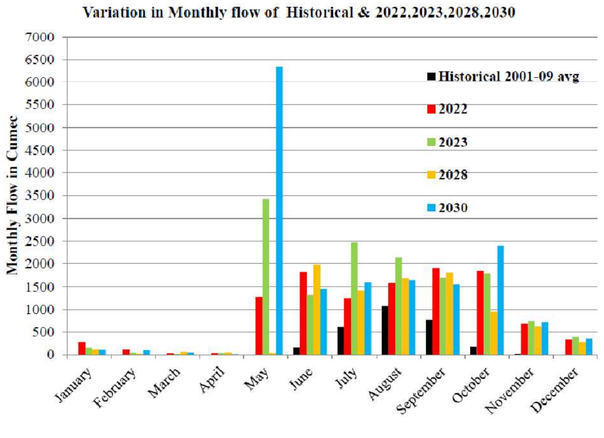

Fig. 5: Monthly Flow Variation of Historical and Projected Years.

1. CONCLUSION

SWAT model was found to produce a reliable estimate of monthly runoff for upper Dwarakeswar watershed. Model was biased to slightly over estimation of annual flow volume and some high flood events though within acceptable ranges, overall the simulated and measured discharge followed similar patterns and trend, thus, SWAT model can be used for hydrologic simulation of the watershed with similar characteristics to Dwarakeswar river watershed. However, for a more accurate modeling of hydrology, a large effort will be required to improve the quality of available input data. The emergence of appreciable quantum of flow during pre-monsoon and post monsoon season in projected years and subsequently reduction of monsoonal flow compared to non monsoon months in the projected years, significant increase in peak flow in the stream flow hydrographs and a general increase in the annual stream flow volume in projected scenario have been observed. An unforeseen high flow in the stream flow hydrograph in May-2030 may be attributed to 3-day heavy rainfall back to back in the basin. The monthly PET values for projected years follow the trend of the monthly PET of the historical years but with slight increase in the range is most probably due to the rise of the global atmospheric temperature.

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