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# Sensitivity of SWAT simulated reservoir inflow to climate change in a semi arid basin

K. SHIMOLA and M. KRISHNAVENI

*Centre for Water Resources, Anna University, Chennai – 600 025, India*

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**e mail : shimola_jeslin@yahoo.com**

**सार -** पेरियार जलाशय, उत्तरपूर्वी मॉनसून के दौरान अत्यधिक प्रवाह वाली वईप्पर नदी की मुख्य धारा के ऊपरी भाग की प्रमुख धारा में स्थित एक प्रमुख जलाशय है। इस शोध पत्र में मृदा और जल निर्धारण उपकरण (SWAT) निदर्श का उपयोग करते हुए उस जलाशय के अन्तर्वाह पर पड़ने वाले जलवायु परिवर्तन के प्रभाव का विश्लेषण किया गया है। इस निदर्श में वर्षा (10%, 20%, -10% और -20%) के परिवर्तन के संयोजन, तापमान (2° से., 4° से. और 6° से. की वृद्धि) और क्षेत्रीय जलवायु परिवर्तन परिदृश्य (A2 और B2) की सूचनायें दी गई हैं और नदी के बहाव में परिवर्तनों तथा जलाशय अन्तर्वाह का अध्ययन किया गया है। इसमें यह पाया गया है कि जलाशय के अन्तर्वाह (10%, 20%, की वृद्धि के लिए 21.4%, 22.4%) में वृद्धि की तुलना में वर्षा (-10%, -20%, की कमी के लिए -29.1%, -28.9%,) में कमी के लिए अत्यधिक संवेदनशील रहा है। इस अध्ययन में यह भी निर्धारित किया गया है कि तापमान की अपेक्षा वर्षा में परिवर्तन जलाशय अन्तर्वाह को उल्लेखनीय रूप से प्रभावित कर सकते हैं जबकि वर्षा मुख्य रूप से धारा के प्रवाहों को आगे बढ़ाती हैं।

**ABSTRACT.** Periyar reservoir is the major reservoir located in upstream of the main stream of river Vaippar having adequate flow during northeast monsoon. In this paper, the impact of climate change on inflow into that reservoir has been analysed using SWAT (Soil and Water Assessment Tool) model. In the model, a combination of change of precipitation (10%, 20%, -10%, and -20%), temperature (increase of 2°C, 4°C, and 6°C) and regional climate change scenario (A2 and B2) is given as input and the changes in river discharge and reservoir inflow are studied. It is found that the reservoir inflow are very much sensitive to decrease in precipitation (-29.1%, -28.9% for a decrease of -10%, -20%) compared to increase in precipitation (21.4%, 22.4% for an increase of 10%, 20%). Also, it is determined in this study that the changes in precipitation, rather than temperature, would have a significant effect on reservoir inflow since precipitation is the main driving force to stream flows.

**Key words** – Climate change, Reservoir inflows, Sensitivity, Precipitation, Temperature.

## 1. Introduction

Climate change influences water resources significantly by bringing shift in rainfall pattern and hence it has its own effect on reservoirs. Reservoir management requires a comprehensive knowledge about the future reservoir inflow under climate change scenarios. The sensitivity of reservoir inflow under climate change conditions can be examined by percent change inflow and it is attempted in the present study. (Mengistu *et al*., 2012) studied the sensitivity of SWAT simulated streamflow to climatic changes within the Eastern Nile river basin and concluded that the annual streamflow of the Eastern Nile is very sensitive to variations in precipitation and moderately sensitive to temperature changes. (Darren *et al*., 2009) used the Soil and Water Assessment Tool (SWAT) to model the hydrology and impact of climate change in the highly agricultural San Joaquin watershed in California. The study modelled the hydrological responses to variations of atmospheric $CO_2$ (550 and 970 ppm), temperature (+1.1 and +6.4 °C), and precipitation (0%, ±10%, and ±20%) based on Intergovernmental Panel on Climate Change projections. The study determined that water yield decreased with an increase in temperature and that increase of precipitation by ±10% and ±20% generally changed water yield and stream flow proportionally and had negligible effects on predicted evapotranspiration and irrigation water use. The current study examines the sensitivity of flows at Periyar reservoir which will help to develop a decision support system for operating this reservoir that supplies irrigation water to over 7219 acres of existing command area. The runoff from the basin mainly depends on the northeast monsoon precipitation and this reservoir is capable of

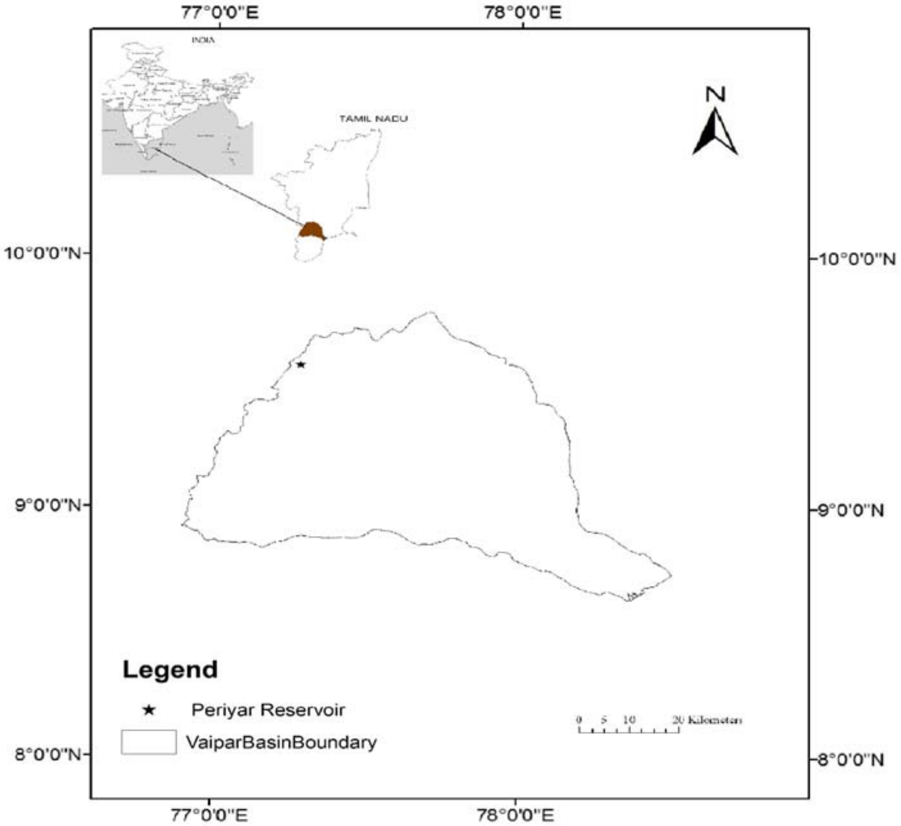

**Fig. 1.** Map showing the study area

storing one third of river's annual runoff. The water delivery from the reservoir system is highly sensitive to even small variations in reservoir inflows under climate perturbations.

## 2. Study area

Vaippar basin is one of the semi-arid basins located in the southern part of Tamil Nadu facing various claims in water resource management associated with water supply and irrigation practices. The basin lies between latitudes 8º59' and 9º49 N' and between longitudes 77º15' E and 78º23' E, which is bounded in the west by the western ghats, in the east by the Gulf of Mannar (Bay of Bengal), on the south of Tambaraparani and north by Gundar basin. The river Vaippar originates from the Echamalai Mottai hill ranges of Western Ghats at an elevation of 1500 m amsl near Sivagiri in Thirunelveli district. The river flows generally in the southeasterly direction for a length of 140 km and joins the Bay of Bengal. The total geographical area of Vaippar is 5423 km$^2$ having tropical climate. The total average monthly reservoir inflows are estimated as 514.12 Mcft. Due to high seasonal variability in rainfall patterns the seasonal variations of flow is large with maximum inflow volume in October which is around 242 times greater than its minimum in the month of June. The average annual rainfall ranges from 900 mm to 800 mm in upper part, 800 mm to 725 mm in middle part and 650 mm to 500 mm in lower part of the basin. The basin gets maximum rainfall during north east monsoon and lesser amount during south west monsoon. There are totally eight reservoirs located in the basin, of this Periyar and Kovilar are the main reservoirs which are located in the upstream of Arjunanadhi. Fig. 1 shows the study area in detail.

## 3. Data and methodology

SWAT is a physically based continuous time step hydrological model developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time (Neitsch *et al*., 2002). The model has been tested in different tropical watersheds and reported to be able to well explain hydrological processes (Abraham *et al*., 2007). The model is tested here because of the occurrence of tropical climate, its free accessibility

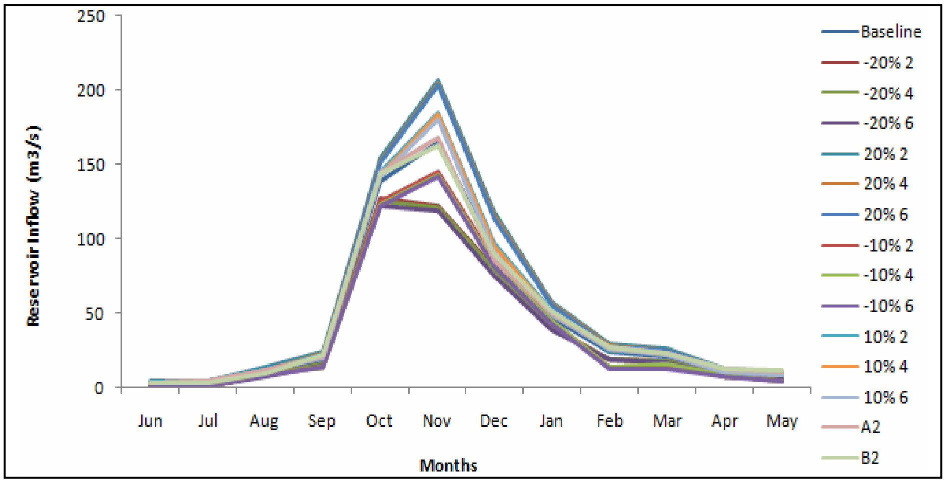

**Fig. 2.** Variation of inflows to reservoir ($m^3/s$) due to hypothetical changes and regional climate scenarios

and good modelling capability. The hydrological processes included in the model are evapotranspiration (ET), surface runoff, infiltration, percolation, shallow and deep aquifers flow, and channel routing (Arnold *et al.*, 1998). The aim of this study is to apply Soil and Water Assessment Tool (SWAT) over Vaippar basin to assess the potential impacts of climate change on reservoir inflows using 12 hypothetical perturbations by the combination of precipitation and temperature change and regional climate change scenarios (A2 and B2). The simulated reservoir inflows are compared with the observed inflows and the flow duration curves are also derived to assess the uncertainty in future streamflow changes. The physiographic data needed for SWAT modelling are digital elevation model, land use, soil data and meteorological data.

### 3.1. *Digital elevation model (DEM)*

A DEM is created using elevation data of resolution 90m × 90m obtained from SRTM (Shuttle Radar Topography Mission) Source: http://srtm.csi.cgiar.org/. It is used to delineate the drainage pattern and watershed boundary. The basin characteristics such as flow accumulation, flow direction, stream order are also derived from DEM by hydrological tool in ARCGIS environment.

### 3.2. *Land use*

Land use is an important input as it controls the hydrological process in the watershed such as evaporation and runoff. The land use map of the study area is obtained from Institute for Water Studies, Chennai. The major land uses in the basin are Hill area, sparsely irrigated area, intensively irrigated area, barren land and river region.

### 3.3. *Soil*

The soil map is obtained from Tamil Nadu Agricultural Department, Coimbatore. The soil properties such as percentages of clay, sand, silt, and rock, available water content (AWC), hydraulic conductivity, bulk density, soil erodibility factor, electrical conductivity etc., are incorporated in the SWAT model as user defined inputs. The major soil types in the basin are Inceptisols, Alfisols, Vertisols, Entisols.

### 3.4. *Meteorological data*

The meteorological data for the period of 1990-2009 are obtained from Institute for Water Studies. Totally there are eleven raingauge stations and five climate stations in the basin. The missing data are filled using weather generator using Markov chain model.

### 3.5. *River discharge*

The discharge data are obtained from Institute for Water Studies to assess the uncertainty while using the model.

## 4. Swat modeling under climate change scenarios

These necessary data are given as input to the SWAT model and the entire basin is divided into 17 sub-basins and further into 493 hydrologic response units (HRUs) that possess unique land use and soil combination. Land use, soil properties and slopes having a threshold limit above 5% of the sub-basin are used for HRU definition. The land use and soil parameters used in the model are assumed to remain constant and valid under climate change conditions. The surface runoff is estimated using

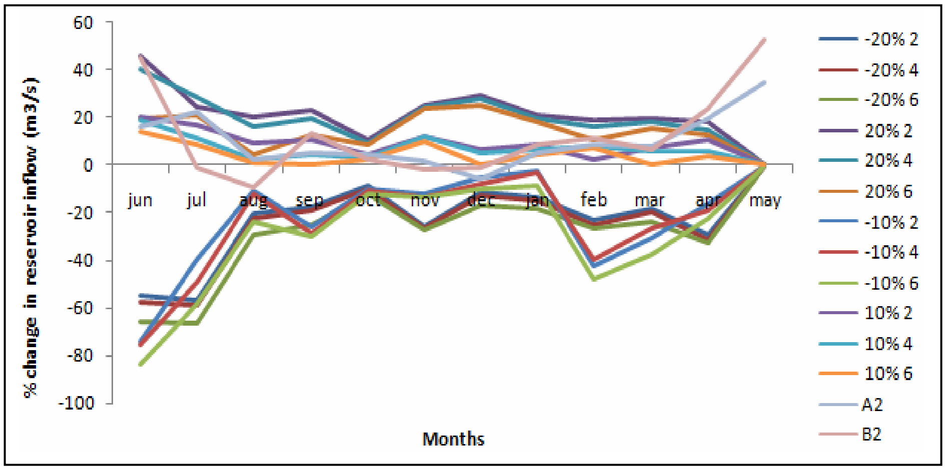

**Fig. 3.** Per cent change in reservoir inflow (m$^3$/s) to hypothetical and regional climate change scenarios

the modified SCS curve number method and reservoir routing by Muskingum method. The surface runoff is predicted separately for each HRU and routed spatially throughout the watershed to obtain the total runoff of the basin. The model used climate perturbations such as 2 °C + 20%, 4 °C + 20%, 6 °C + 20%, 2 °C - 20%, 4 °C - 20%, 6 °C - 20%, 2 °C + 10%, 4 °C + 10%, 6 °C + 10%, 2 °C - 10%, 4 °C - 10% and 6 °C - 10% to examine the reservoir inflows under climate change scenarios. Regional climate change scenario (A2 and B2) which are statistically downscaled from HadCM3 GCM are also given as input to SWAT to stimulate the projected flows. Weather and $CO_2$ adjustments are made using edit option in sub-basin parameters. The remaining climate data such as solar radiation relative humidity required for SWAT simulation is generated by WXGEN weather generator (Sherpley and Williams, 1990) included in SWAT. The generated relative humidity values are adjusted for wet and dry conditions based on the wet and dry days in a month. Totally eight reservoirs are considered as impoundments located along the main channel. The reservoir inflow series are analysed under climate change scenarios by applying combined changes in precipitation and temperature. The percentage of change in precipitation is multiplied by a given factor while the temperature perturbation is applied by adding a change factor to the baseline scenario. The $CO_2$ emission is kept as 660 ppm, 990 ppm as $CO_2$ is a hindrance factor to global warming and climate change.

## 5. Results and discussion

Combined effects of precipitation and temperature changes to hypothetical and regional climate change scenarios on reservoir inflow are illustrated in Fig. 2.

### 5.1. *Sensitivity to the combined effect of temperature and precipitation (20%)*

The average reservoir inflows for the baseline, -20% + 2 °C, -20% + 4 °C and -20% + 6 °C are calculated to be 45.33, 37.46, 36.88 and 35.54 m$^3$/s respectively. The results show that an increase in temperature up to 6 °C has a maximum decline in reservoir inflow up to 9.79 m$^3$/s from the baseline scenario. The average reservoir inflows for +20% + 2 °C, +20% + 4 °C, +20% + 6 °C are 54.95, 54.15 and 53.19 m$^3$/s. The result shows that the reduction in precipitation (20%) brings only less change compared to increase in precipitation. The combination of 20% and 2 °C change in precipitation and temperature respectively brings a change up to 9.62 m$^3$/s in reservoir inflow from the baseline scenario which is considered as the maximum change in reservoir inflows. The reservoir inflows show a linear trend with a reduction (+20%), rather than decrease (-20%), in precipitation.

### 5.2. *Sensitivity to the combined effect of temperature and precipitation (10%)*

The sensitivity analysis for the response of reservoir inflows to the combined effect of temperature and precipitation (10% change) is also illustrated in the Fig. 2. The average reservoir inflows for the baseline -10% + 2 °C, -10% + 4 °C, -10% + 6 °C are 39.44, 38.87, 37.7 m$^3$/s respectively. The results show that with the reduction (-10%) and temperature change (6 °C) brings a maximum change up to 7.63 m$^3$/s. The average reservoir inflows for the baseline, +10% + 2 °C, 10% + 4 °C, and 10% + 6 °C are 49.09, 48.42 and 47.28 m$^3$/s respectively. The changes in reservoir inflow with the combination of (+10% and 2 °C, 4 °C, 6 °C) precipitation and temperature is higher than the changes in that with the combination of (-10% and 2 °C, 4 °C, 6 °C) precipitation and temperature.

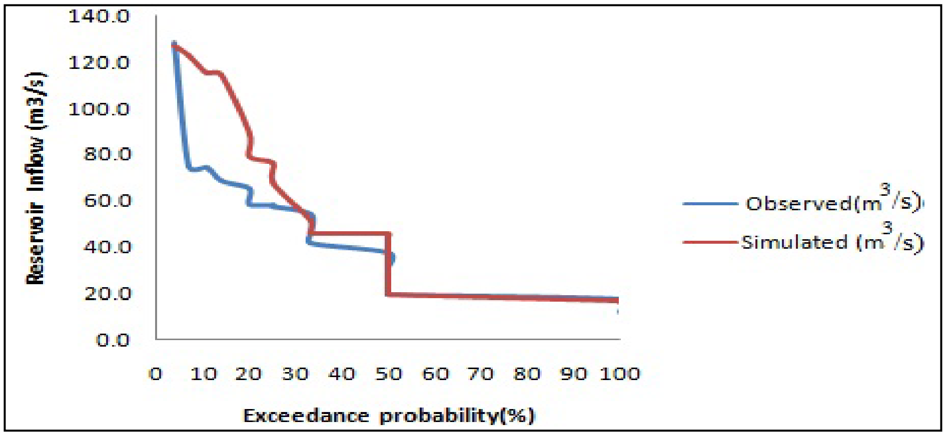

**Fig. 4.** Comparison of flow duration curve between observed and simulated for the period 1982-2005

The change are up to 5.8, 6.4, 7.6 $m^3$/s for the combination of (-10% and 2 °C, -10% and 4 °C, -10% and 6 °C) in precipitation and temperature from baseline. It is also noted that there is no much change between the increase of 2 °C and 4 °C increase in temperature in all the combinations of precipitation and temperature. Hence the overall results show that the combination of -20% precipitation and 6 °C brings a maximum change in the reservoir inflow up to 9.79 $m^3$/s comparing to the baseline.

### 5.3. *Percent changes in reservoir inflows*

The sensitivity of reservoir inflow to climate perturbations and regional climate change scenario indicated through % of change are discussed in Fig. 3.

The percentage change for a -20% with the combination of 2 °C, 4 °C and 6 °C compared to the baseline are -23.23, -24.80 and -28.96%. The percentage change for a 20% with the combination of 2 °C, 4 °C and 6 °C compared to the baseline are 21.47, 19.33 and 14.15%. The percentage change for a -10% with the combination of 2 °C, 4 °C and 6 °C compared to the baseline are -22.46, -23.78 and -29.07%. The percentage change for a 10% with the combination of 2 °C, 4 °C and 6 °C compared to the baseline are 9.20, 6.7 and 4.13%. As shown clearly, the percentage of change increases considerably for the combination 20% decrease in precipitation compared to 10%. The results also show that the highest percentage of change is noted in the north east monsoon months with the maximum percentage of change up to 29.2% with 20% decrease in precipitation. The analysis also shows that there is a strong seasonal variation since there is a high monthly fluctuation in reservoir inflow.

### 5.4. *Sensitivity and percentage change to regional climate change scenario*

The scenarios A2 and B2 are regionally oriented which represents the heterogeneous world. A2 is characterized by economic development and B2 is with local environmental sustainability. The sensitivity analysis for the response of reservoir inflows to regional scenario is also illustrated in Fig. 2. The average reservoir inflows for A2 and B2 scenario are 46.71 and 46.82 $m^3$/s. The results show that like hypothetical scenario, northeast monsoon gets its maximum inflows comparing to other monsoons. The average percentage change for A2 and B2 climate change scenario are 10% and 12% respectively. Percentage change for southwest monsoon is higher for A2 scenario compared to B2. Thus, A2 and B2 scenarios bring projected flows from GCM model to satisfy the regional needs.

### 5.5. *Flow duration curves*

The basin is characterized by no flow or low flow during summer monsoon while its discharge varies from 150-300 $m^3$/s during northeast monsoon season. To understand the changes in inflow volumes into the reservoir, flow duration curves are constructed (Fig. 4).

Comparison of flow duration curve between observed and simulated for the period 1982-2005 shows that, $Q_{90}$ and $Q_{95}$ (low flows) occurs when the average annual flow is upto 20 $m^3$/s while the maximum annual flows $Q_{10}$ (high flows) of 140 $m^3$/s with the exceedance probability of 5-10%. It is also noted that, low flows are exceeded majority of the time, while high flows, are exceeded infrequently.

## 6. Conclusion

The study made by conducting 12 hypothetical climate sensitivity and regional climate change scenarios shows that the inflow to the Periyar reservoir is sensitive to projected variations in precipitation and moderately sensitive to temperature changes. The reservoir inflow is more sensitive to +20% decrease in precipitation than 20% increase in precipitation while they are less sensitive to 10% increase or decrease in precipitation. Since, the reservoir is located in the Western Ghats in the upstream of the basin most of the region is dominated by deep to gentle slope where stream flow change are very sensitive. Therefore, with the decrease in precipitation the response of the basin generating direct streamflow will be smaller since more water infiltrates down to recharge the groundwater though the reservoir is located near by the river origin. Thus the study concludes that the sensitivity of reservoir inflow to precipitation is also due to the topography and channel characteristics. The results also show that increase up to 2 °C to 4 °C brings only less change in the reservoir inflows whereas it is moderately sensitive to 6 °C increase in temperature. The study has its limitations such as SWAT model uses only a hypothetical scenario and regional climate change scenarios.

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