Original Research Article

Trends in streamflow in relation to water retention structures: A case study in Bharathpuzha river basin, India

ABSTRACT

Lack of availability of land, water and other natural resources along with climate change has caused a major threat for increasing the agricultural production on par with the increasing population. Bharathapuzha river, considered as the cradle of civilization in Kerala is flowing through Kerala as well as Tamil Nadu, the two southern states of India. The river flow is highly affected by increased water use and reduced recharge caused due to increasing population, urbanization and unscientific management practices. Watershed development activities in river basins help in conserving water in the upstream areas for agricultural, domestic and other uses. The effect of the conservation measures on the flow regime in the lower reaches was studied.

The calibrated and validated SWAT model was applied to Bharathapuzha river basin for studying the impact of watershed interventions on the water balance of the area. The simulated monthly streamflow was analysed during 2007 to 2011 after addition of Water Retention Structures (WRS) @ 0.05%, 0.1% and 0.2% of the land area. The results indicated that even though the total annual flow decreased, the flow during the summer months (baseflow) increased due to the addition of the conservation structures. The increase in river flow was highest during the period January to April when the river had lean flow. The conservation structures help to store water in the upper reaches for irrigation and domestic purpose, and at the same time it helps in increasing the summer flow. This helps to maintain a better environmental flow regime.

Key words: SWAT, Bharathapuzha, water retention structure, climate change, RCP

1. INTRODUCTION

Land and water are precious natural resources which are becoming scarce and need to be conserved. The availability of fresh water of acceptable quality is becoming scarce (Ahmadi *et al,* 2020;

Boretti and Rosa, 2019) and at the same time it is urgent to conserve the fresh water resources which are utilized at alarmingly increasing rates and is polluted by the increasing population. Global water demand is mainly influenced by population growth, urbanization, socio-economic development and the consequent increase in consumption by different stake holders (Wang *et al*, 2021). This ever-increasing demand has made water resource planning and management a complex and challenging task. Climate change has a key role on the water cycle as well as on the water availability for agricultural production (Gornall et al., 2010). Water conservation, especially on a watershed basis is the need of the hour since the fresh water resource availability is only 2.5% of the global water availability (Okello *et. al.* 2015).

Kerala, one of the southern states of India is facing severe drought in the recent years and many of the rivers are having very lean flow during the summer months. Bharathapuzha river flowing through Kerala and Tamil Nadu (Magesh *et al*., 2013) is one typical example of this situation. One of the major social issues leading to environmental consequences in the region is sand mining. Very lean flows, low levels of water tables on either side, acute shortage of water in summer season, salinity intrusion in the coastal regions and unsustainable exploitation of natural resources are other problems encountered in the region. The lean flow in the river also causes saline water back flow into the river channel. Apart from the dams constructed across the river in 1970's and 80's, a number of check dams have been constructed across its tributaries for retaining water for irrigation and drinking purpose. From the climate studies done in the basin, it is seen that the temperature in the area is having an increasing trend (Raj and Azeez, 2010) and at the same time the precipitation is decreasing (Raj and Azeez, 2010; Jagadeesh and Anupama, 2013) in major part of the basin.

Different conservation measures are used for conserving water in the upper reaches. The impact of these structures on the components of river flow depends on many factors such as watershed characteristics, climate of the region and soil characteristics. Studies in this regard is essential in the Bharathapuzha river basin since the river channel has been dammed at several locations and a large number of check dams and other water conservation structures are coming up within the catchment area day by day for water conservation in the tributaries.

Due to the above explicated reasons, it was felt that the impact of watershed development activities as well as future climate change on the hydrology of Bharathapuzha river basin need to be assessed. Soil and Water Assessment Tool (SWAT) hydrologic model was used to simulate the transport of water through the river basin.

2. MATERIALS AND METHODOLOGY

Bharathapuzha river basin lies between 10°25' to 11°25' N and 75°50' to 76°55'E (Bijukumar *et al*., 2013) and has a total basin area of 6186 km^2 (Raj and Azeez, 2012). The river is the major source of water for three districts in Kerala and two districts in Tamil Nadu. Even though the catchment area is blessed with an average annual rainfall of 2924.4 mm, the area experiences water shortage during the summer season (Magesh et al, 2013).

The study was conducted utilizing the different models, softwares and tools available for effective analysis of data and prediction of trends and impact analysis. ArcGIS 10.3 was used for setting projection for all the SWAT inputs such as DEM, landuse and soil map. Preparation of land use map of the study area was done using ERDAS IMAGINE 2015 software.

A physically based continuous time semi distributed hydrologic model SWAT was used for modelling the flow in the basin. SWAT was used to study the impact of watershed interventions on the hydrologic response of the area. SWAT operates on a daily/ sub daily time step and works based on the water balance. The SCS curve number method was used to determine surface runoff and this is a function of landuse, antecedent soil moisture conditions and soil permeability. Four subbasin outlets were added at Mankara, Cheruthuruthy, Pulamanthole and Kumbidi where river gauging stations are available.

2.1 Data preparation

The details of land use, soil, topography and hydrometeorological data required by SWAT were collected/prepared. Shuttle Radar Topographic Mission (SRTM) DEM with spatial resolution of 30m was downloaded from the U.S. Geological Survey (USGS) Earth Explorer website. Land use map of Bharathapuzha (Kerala region) was prepared through supervised classification using ERDAS Imagine 2015. The morphological characteristics of the soil and soil map needed for the SWAT model were collected from the Directorate of Soil Survey & Soil Conservation of Kerala State. The soil properties which were not available from the data collected from soil survey were computed using SPAW software. Observed rainfall data was collected from IMD, Water Resources Department, Government of Kerala and Kerala Agricultural University. Other climatic data including daily maximum and minimum air temperature, wind speed, solar radiation and relative humidity were collected from Regional Agricultural Research Station (RARS) Pattambi under Kerala Agricultural University. Streamflow data of different gauging stations in the area were collected from the Central Water Commission (CWC).

2.2 Sensitivity analysis and Calibration of the model

SWAT-CUP is a calibration/uncertainty or sensitivity program interface for SWAT. SWAT-CUP 2012 version 5.1.6 was used for the sensitivity analysis and calibration in the study. Sensitivity analysis was done to identify the response of various model parameters to different processes in the basin. Thus, the number of parameters were reduced and the model was made ready for calibration. The parameters for sensitivity analysis were selected on the basis of characteristics of the study area and previous literatures (Chu and Shirmohammadi 2004, Gosain *et al.*, 2006). After doing a one at a time analysis, thirteen parameters were selected initially for the global sensitivity analysis. The SUFI-2 method in SWAT-CUP was selected for the analysis.

For doing calibration of the model, the data available with monthly stream flow records were divided into two. The first 12-year period from 1989 to 2000 was used for calibration and the later 9-year period from 2001 to 2009 was used for validation. Many researchers have divided the available meteorological data sets to two subdatasets (Thampi *et al*., 2010; Musau *et al*., 2015; Fukunga *et al*., 2015) for doing hydrologic modeling studies. The model performance was evaluated using the efficiency criterias Nash-Suchliffe efficiency, coefficient of determination, percent bias (PBIAS) etc on the basis of the recommended statistics (Moraisi, 2007).

2.3 Impact of Watershed Development

To understand the impact of watershed interventions on the hydrology, the change in the water storage in the basin during the period 2005-2011 was taken into consideration. This period was chosen for the change analysis because major watershed development activities including construction of check dams, percolation ponds and pits, Vented Cross Bars (VCB's) etc. have come up in the area during this period. The change in the area under water bodies, especially, reservoirs, lakes and ponds during the period was studied from the Landuse/ land cover classes prepared and published in the NRSC website. These thematic maps were prepared as a part of the project on "National Land Use/ Land Cover Mapping on 1:50,000 scale using temporal Resourcesat-1 Linear Imaging Selfscanning Sensor (LISS) -III data" by National Remote Sensing Centre (NRSC), ISRO. Based on the per cent change in the water bodies during the period under consideration, further analysis was done. Details of watershed interventions in selected part of the study area were collected from different government departments.

The watershed interventions that have come up in the area in terms of the hydrologic structures is represented in the SWAT model by combining them into a reservoir. SWAT accommodates a single reservoir at the outlet of each subbasin. Under each subbasin, the hydrologic structures or water storage structures were accumulated into a single structure and the storage area was calculated by adding the area of the individual structures. The total storage volume was also estimated on the basis of the data collected from the field survey.

The impact of watershed interventions on streamflow was analyzed by simulating the calibrated model with and without the conservation structures and making a comparison of the outputs in both cases. The percent increase in storage volume due to the structures was assumed constant during this simulation period.

3. RESULTS AND DISCUSSION

Observed data of Bharathapuzha river basin on precipitation and temperature for the period 1989 to 2005 was compared with the historical data from the 5 regional climate models on the basis of graphical representation and statistical comparison. The GFDL-CM3 model was found to be the best since it showed close correlation with the observed data. Jena *et al*., 2016 have reported that GFDL-CM3 is one of the best models in the CMIP5 dataset which can capture the pattern of Indian rainfall.

The model GFDL-CM3 simulated the present climate over the basin to a good extent. Even then, the presence of uncertainties on the future climate because of systematic bias existed which need to be corrected. The bias correction method reported by Leander and Buishand (2007) was used for correcting the future climate data. The future projection simulations forced with specified concentrations (RCPs), consistent with a high emissions scenario (RCP8.5) and a midrange mitigation emissions scenario (RCP4.5) was selected for the study. The monthly variation of the bias corrected data of precipitation for the two emission scenarios RCP4.5 and RCP8.5 for the periods 2041-70 and 2071-99 is shown in Fig.1. There is a consistent decrease in rainfall during majority of the months except May, August, September, November and December for the two emission scenarios and for both future periods. After analysing the rainfall during the southwest monsoon, it was observed that the rainfall during June-July showed a decrease, whereas an increase in rainfall was observed during August-September. A seasonal shift in the rainfall pattern was observed with a significant decrease in southwest monsoon (June to September) rainfall and an increase in rainfall during the northeast (October to November) monsoon period.

Based on the predictions, there may be a decrease of 4 per cent and 11 per cent in average annual rainfall in the basin during 2041-70 under RCP4.5 and RCP8.5 respectively. A decrease of up to 8 per cent and 15 per cent in annual rainfall during 2071-99 is also predicted for RCP4.5 and RCP8.5 respectively along with the seasonal shift.

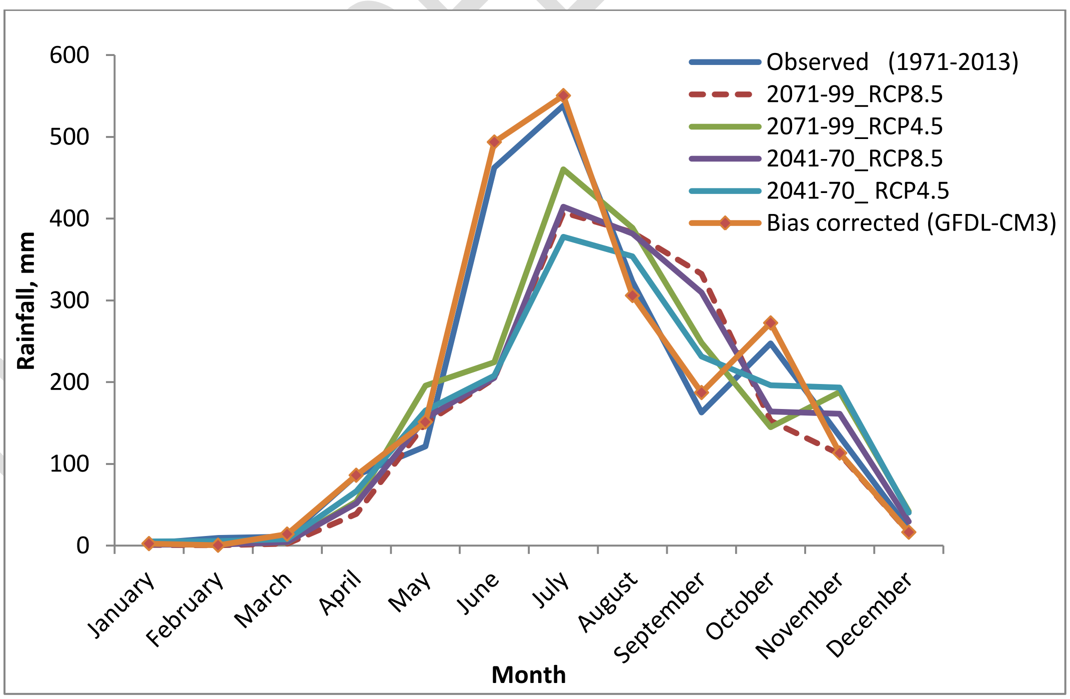

Fig.1. **Comparison of present and bias corrected future precipitation**

Rainfall decline is more predominant in June and July, but it is increasing in August and September. This decreasing trend in southwest monsoon rainfall in Kerala has been reported by other researchers (Guhathakurta and Rajeevan, 2007; Raneesh and Thampi, 2013; Patwardhan *et al*., 2014).

SWAT model setup was done for the basin. The entire catchment was divided into 33 subcatchments (subbasins) based on the Digital Elevation Model (DEM) and the drainage network. The watershed was again divided into 401 Hydrologic Response Units (HRU's). The t-stat gives a measure of the sensitivity of a parameter, and the p-value, indicates the significance of the sensitivity of the parameter. These measures were used to rank the various parameters that influence streamflow, and the top ranked and most sensitive seven parameters were used for calibrating the model (Table 1). It is observed that the calibration effort can be very much reduced when the optimum parameter selection is limited to the parameters suggested in the sensitivity analysis. These parameters are highly responsible for model calibration and changes in the rest of the parameters had no significant effect on streamflow simulations.

Table 1. Sensitive parameters and ranking for Bharathapuzha watershed

Sensitivity rank	Parameter	Description	t-value	p-value
1	CN2.mgt	SCS runoff curve number	**32.48**	**0.00**
2	GW_DELAY.gw	Groundwater delay time (days)	**-21.79**	**0.00**
3	ALPHA_BNK.rte	Baseflow alpha factor for bank storage (days)	**3.69**	**0.00**
4	ESCO.hru	Soil evaporation compensation factor	**3.02**	**0.003**
5	CH_K2.rte	Effective hydraulic conductivity of main channel	**1.24**	**0.22**
6	GW_QMN.gw	Threshold depth of water in the shallow aquifer	**1.06**	**0.29**
7	SOL_AWC.sol	Available water holding capacity of soil	**-0.65**	**0.53**

From the similar studies reviewed, it is seen that the selected parameters were sensitive to streamflow (Schuol *et al*., 2008; Raneesh and Thampi, 2011; Faramarzi *et al*., 2009). The model parameters were adjusted on the basis of statistical indicators as well as on the characteristics of the study area. In SWAT model, the soil water content, surface runoff, crop growth parameters, nutrient movement, and management practices are all simulated for each HRU, and the results are aggregated for the sub basin by weighted average.

The calibrated SWAT model was applied to Bharathapuzha river basin for analysing the impact of climate change on water balance components. The climate change impacts on the hydrological regime of various catchments across the world was assessed using the SWAT model (Devkota and gyawali, 2015; Lubini and Adamowski, 2013; Raneesh and Thampi, 2011).

3.1 Impact of watershed interventions on river hydrology

Watershed development programs are implemented in India and in the state of Kerala for augmenting surface and groundwater resources mainly through rainwater harvesting. The hydrological impacts of large-scale implementation of watershed interventions can be significant. Therefore, the impacts of such changes on the hydrology need to be analyzed using a modelling framework. Along with climate change, this can also play an important role in the hydrology of the river basin.

Data on watershed development activities in the study area, mainly the construction of Water Retention Structures (WRS), was collected from different government departments. The field level study was restricted to selected watersheds in the Kunthipuzha subbasin which has a gauging station at Pulamanthole and joins the main river at Kudallur near Thrithala. This information was later scaled up to the entire Bharathapuzha river basin for use in the hydrologic model.

3.2 Land use Land cover Classes of the Area

Using temporal Resourcesat-1 Linear Imaging Self scanning Sensor (LISS)-III data, National Remote Sensing Centre (NRSC) under Natural Resources Census (NRC) Project has prepared Land Use Land Cover (LULC) data for Kerala state. LULC data is regrouped for use with emphasis on land cover classes and is published in the Bhuvan website. The details of LULC classes of the three districts through which the river is flowing in Kerala was taken from the site for analysis.

The land use land cover classes comprise among water bodies, reservoirs, lakes and ponds which represent areas with surface water in the form of ponds, reservoirs, check dams, VCB's and other water storage structures. The increase in area under this category was taken into consideration to account for the change in surface area of the water storage structures that have come up in the area during the period. The average per cent change in surface area of waterbodies with respect to the total geographical area was calculated. The per cent increase in area of waterbodies with respect to the total area of the district ranges from 0.01 per cent in Malappuram district to 0.23 per cent in Palakkad district.

3.3 Ground Water Level

The monthly groundwater levels of three open wells in the upper regions of Kuntipuzha subbasin were collected from the State Groundwater Department. The groundwater level during different seasons was analysed and are shown in Fig. 2 to 4.

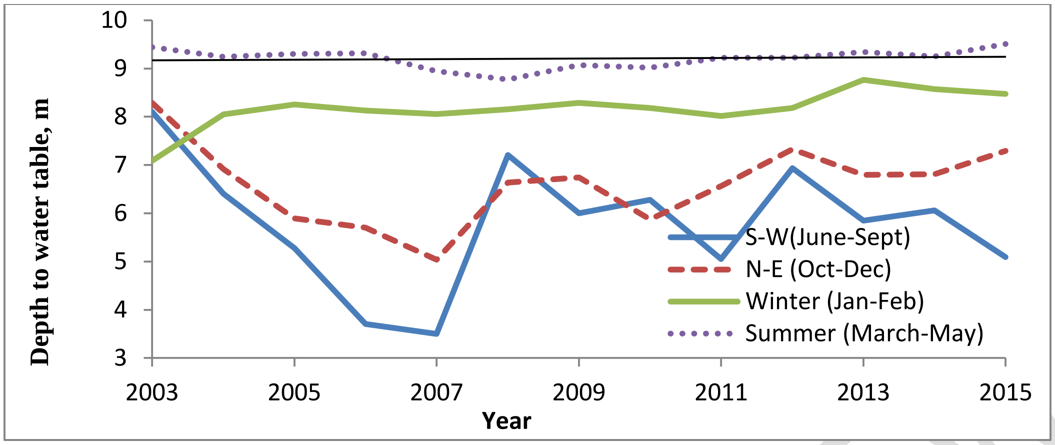

Fig.2. Seasonal variations in depth to water table in open well 1

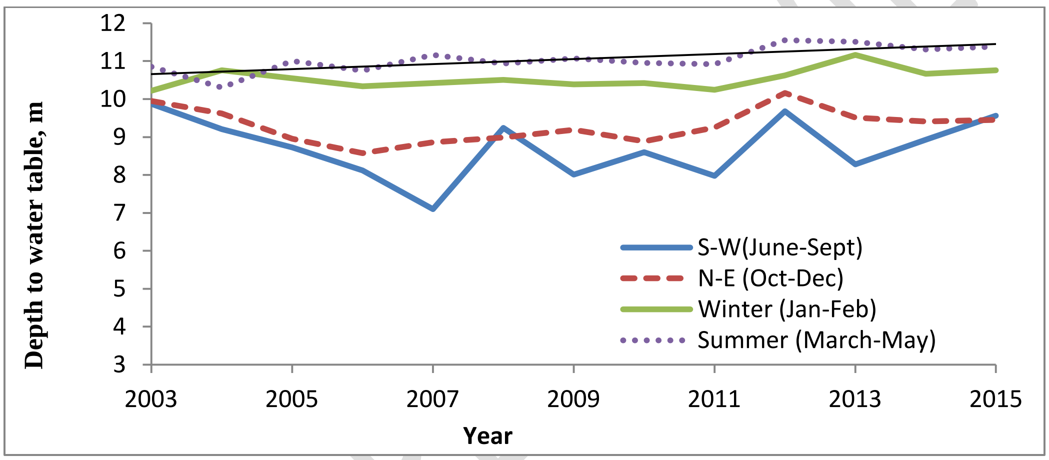

Fig. 3. Seasonal variations in depth to water table in open well 2

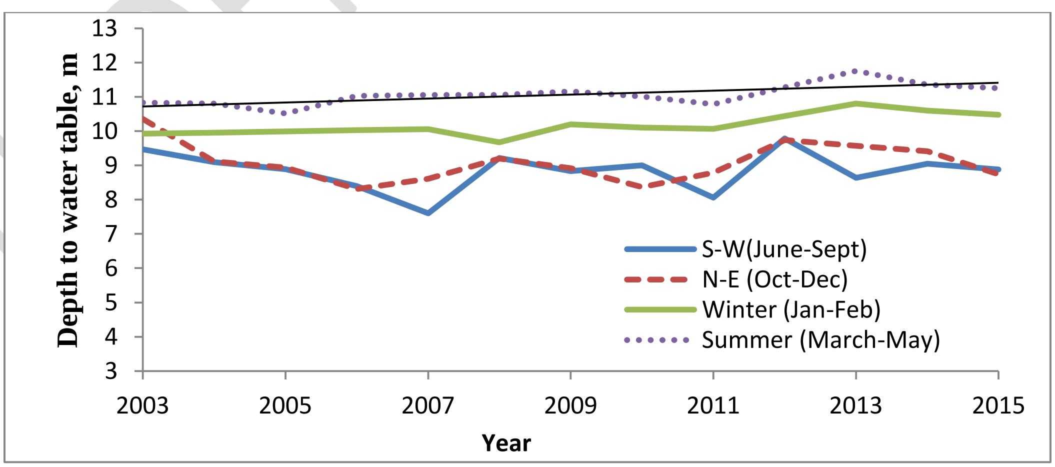

Fig. 4. Seasonal variations in depth to water table in open well 3

During summer, the depth to water table is having an increasing trend, which indicates lowering of water table. The decline in water table during the recent years may be due to decrease in natural recharge and increase in withdrawal for domestic and irrigation needs.

3.4 Details of Water Storage Structures

Details of the major water storage structures constructed in the Kunthipuzha subbasin during 2005-2015 were collected from the state irrigation department and through field survey. On the basis of the data collected during field survey, the average depth area volume relationship of the water storage structures in the area was derived (Table 2).

Table 2. Details of water storage structures in the basin

	Average Area (m^2)	Average depth (m)	Average volume (m^3)
Check dams	800x15	1.2	14400
Percolation ponds	40x40	1.8	2880
Water harvesting pits	1.5x1.5	1.0	2.25
Vented cross bars	900x12	1.5	16200

Analysing the depth area volume relationships of all water harvesting structures constructed through watershed management, it is seen that retention structures in the form of check dams and VCB's are more in number and percolation ponds are only a very few in number. The average depth of water stored in the retention structures helped to determine the area volume relationship. Hence, the average depth of the WRS was taken as 1.2 for arriving at the volume of water retained in the structure.

3.5 Criteria for Analysing the Impact of Watershed Interventions

The total storage capacity of Water Retention Structures (WRS) was then estimated based on the change in land use under the category of water bodies and on the average depth area volume relationships obtained from field. The increase in area in each subbasin was calculated separately based on the per cent changes considered. The increase in area under water bodies in the individual subbasins corresponding to 0.05, 0.1 and 0.2 per cent were calculated.

In SWAT, all the water retention structures in a subbasin are pooled together as a single reservoir. For analyzing the impact of the water retention structures coming up in the area, three levels; level 1, level 2 and level 3 with 0.05, 0.1 and 0.2 per cent of the subbasin area additionally coming under the land use water bodies were selected. The corresponding increase in storage volume was also calculated and this increase in storage was given as input to SWAT in the form of reservoir input.

3.6 Impact of Watershed Interventions on Monthly Streamflow

Monthly streamflow simulated for the period 2007 to 2011 without adding the WRS and after adding the WRS (0.05 per cent increase in surface area) are given in Table 3. The simulated monthly streamflow after adding WRS @ 0.1 per cent and 0.2 per cent increase in surface area are given in Table 4.

Table 3. Simulated monthly streamflow during 2007-2011 with (0.05 per cent increase in surface area) WRS and without WRS

	Simulated streamflow without WRS					Simulated streamflow with WRS (0.05%)				
	2007	**2008**	**2009**	**2010**	**2011**	**2007**	**2008**	**2009**	**2010**	**2011**
January	39.1	39.4	12.8	53.6	97.6	43.2	43.1	16.0	55.9	99.4
February	5.1	10.6	2.8	10.9	34.7	5.6	10.7	2.6	12.1	43.4
March	2.0	19.5	8.2	2.9	8.1	1.4	29.6	8.1	2.6	8.4
April	5.2	5.9	6.1	9.8	30.9	11.9	7.3	5.6	16.2	28.3
May	17.8	14.5	7.7	35.5	17.3	19.0	20.9	10.6	29.3	13.4
June	744.9	292.6	114.5	477.9	534.5	711.5	266.1	102.7	413.2	504.
July	1286.0	373.5	953.2	550.9	410.6	1263.0	359.2	903.0	521.2	401.
August	670.5	271.0	337.0	370.6	612.4	659.0	267.6	329.0	367.3	605.
September	782.0	317.1	354.3	370.3	585.5	783.1	315.5	346.1	363.5	587.
October	446.7	364.9	278.7	445.4	451.5	449.5	351.8	272.7	434.9	448.
November	249.3	128.2	324.7	332.2	416.0	257.9	131.3	318.6	333.2	421.
December	131.2	68.2	111.4	173.7	155.9	133.7	71.64	113.1	177.8	162.

Table 4. Simulated streamflow with 0.1 and 0.2 per cent increase in surface area of WRS

	Streamflow with WRS (0.1%)					Streamflow with WRS (0.2%)				
	2007	**2008**	**2009**	**2010**	**2011**	**2007**	**2008**	**2009**	**2010**	**2011**
Jan	66.7	69.4	31.8	65.4	110.7	84.0	86.5	50.7	84.7	123.6
Feb	20.8	24.4	9.8	24.1	52.8	33.7	35.4	20.6	31.8	47.3
Mar	8.3	26.9	7.8	7.1	16.2	15.1	21.2	9.3	15.29	26.0
Apr	10.3	11.9	12.3	10.8	18.7	16.2	11.6	11.8	10.8	14.3
May	13.8	17.0	16.7	22.1	9.9	8.3	9.5	4.9	19.5	11.2
Jun	613.7	196.7	72.7	282.5	359.6	394.7	112.9	32.5	249.2	281.8

Jul	1160.0	300.3	724.0	416.8	342.7	979.2	264.2	594.0	381.5	339.7
Aug	681.1	264.3	376.7	349.4	566.2	664.7	278.0	395.1	389.8	515.7
Sep	780.7	308.4	338.4	333.7	575.6	698.9	289.1	372.7	365.3	565.2
Oct	498.4	301.2	255.3	340.2	411.6	511.1	303.6	284.4	370.6	432.1
Nov	311.0	144.9	274.4	309.4	424.1	333.2	173.9	277.4	339.7	412.4
Dec	166.1	82.82	124.3	195.0	195.9	181.6	106.5	150.3	233.0	220.2

The percent change in streamflow after adding the WRS (with 0.05, 0.1 and 0.2 per cent increase in surface area of water bodies) with respect to the simulated flow before adding the retention structures was calculated and is depicted in Fig. 5, 6 and 7 respectively. From these graphs it is clear that the river flow during the base flow had substantial increase due to the addition of water retention structures. The higher per cent increase was noticed during the January to April when there was very lean flow in the river. This is highly beneficial in maintaining a better environmental flow in the river. Now a days, during summer when the river is having a very lean flow, sufficient water is not available even to support the critical ecosystems. In such a situation, adding WRS can increase the summer flow and it will be helpful for supporting the environmental flows.

Impact of Watershed Interventions on Annual Streamflow

The impact of adding WRS in the basin was also studied on the basis of the annual streamflow. The annual streamflow was simulated for different conditions and as the percentage of water stored on the water storage structures increased, the flow in the river decreased (Fig. 5).

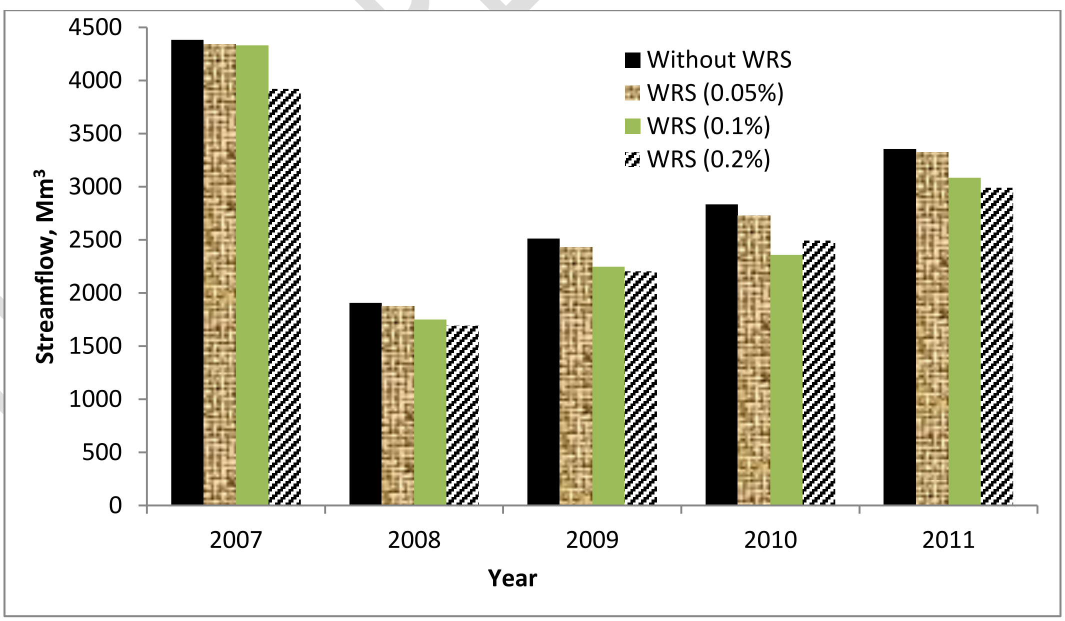

Fig. 5. Annual streamflow under different levels of WRS

Though the decrease in annual streamflow is less (1 to 6 per cent), since the peak floe is redistributed to the summer months the conservation is of great importance. This redistribution may also help in increasing the groundwater storage also, which need to be studied in detail with the help of groundwater flow models which can be associated to SWAT.

3.7 Impact of Watershed Interventions on Future Streamflow

A scenario assessment that includes the combined effects of climate change and watershed interventions would be of great interest for water resource planners and hence, the impact of both aspects together was also studied. The streamflow prediction was done for 2041-2069 only, since it was not justifiable to extrapolate the increase in WRS in the basin to a long term to get the data for the period 2071-2099. Prediction for the period 2041-2069 under the two scenarios RCP4.5 and RCP8.5 was done with the assumption that the WRS were added by 2030 which increases the surface area of the WRS by 0.1 per cent. The monthly streamflow with added WRS under climate change was compared with that of no WRS under the same climate change scenario. The monthly streamflow with and without WRS (0.1 per cent increase in surface area of WRS) during 2041-2070 are shown in Fig.6 and 8 respectively. The per cent change in streamflow after adding the WRS under RCP4.5 and RCP8.5 during the same period is shown in Fig.7 and 9 respectively.

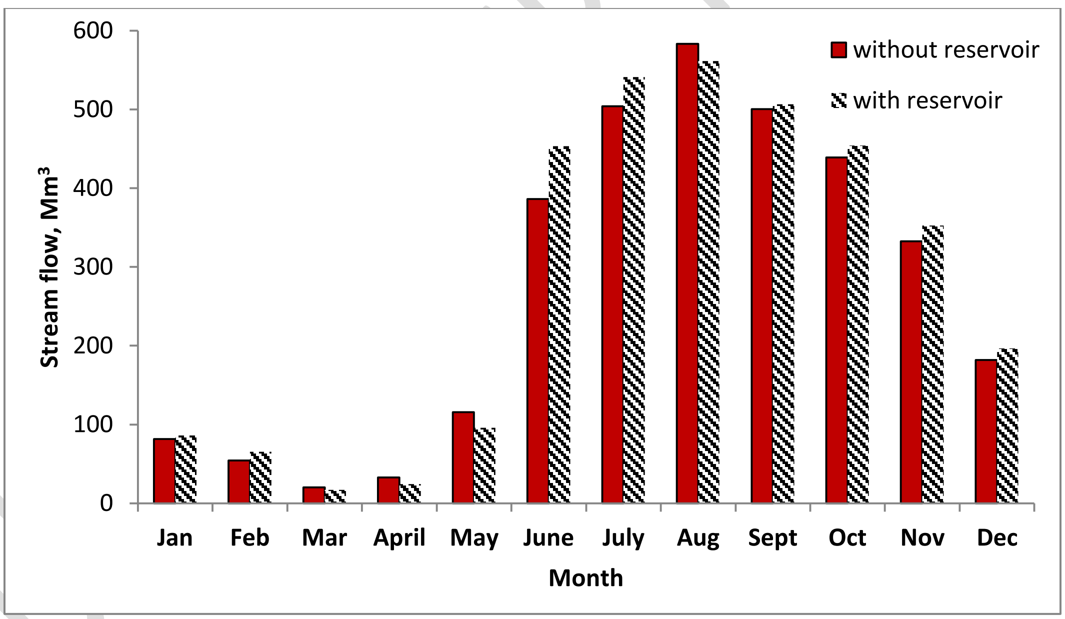

Fig.6 Monthly streamflow with and without reservoirs (0.1% increase in area of waterbodies) during 2041-2070 under RCP4.5

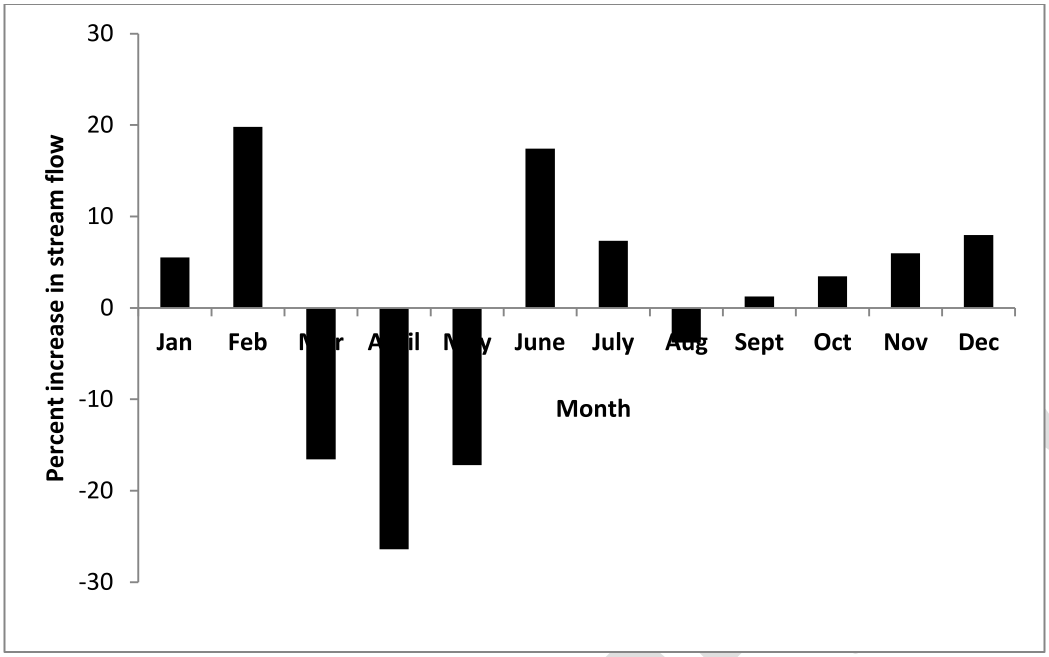

Fig.7 Percent change in stream flow after adding reservoirs to the subbasins (0.1% increase in area of waterbodies) during 2041-2070 RCP4.5

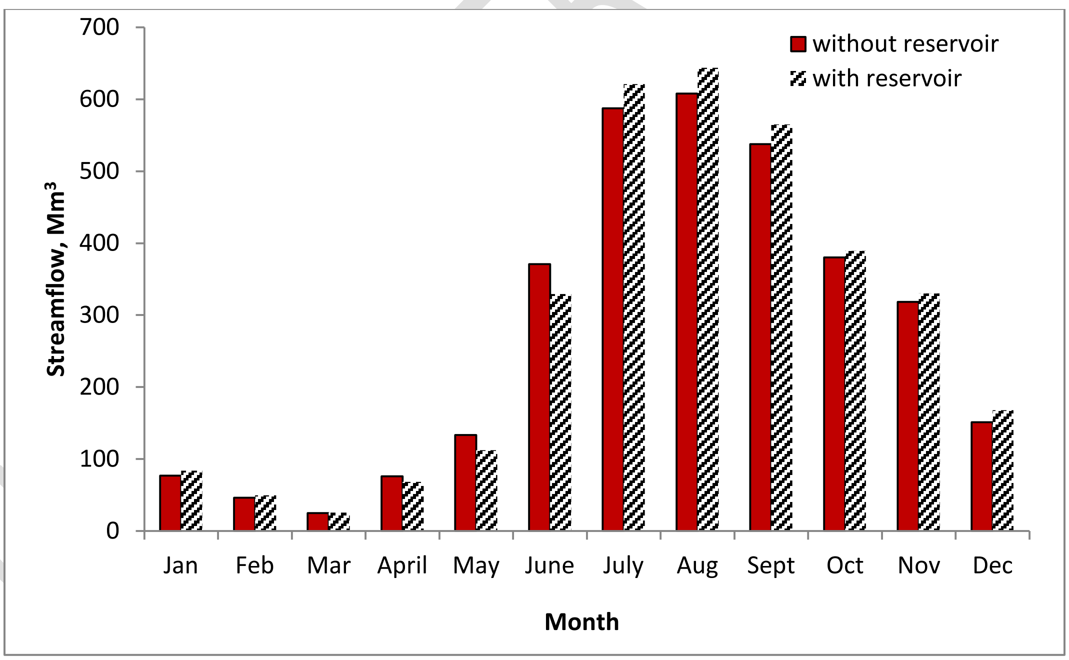

Fig.8 Monthly streamflow with and without reservoirs (0.1% increase in area of waterbodies) during 2041-2070 under RCP8.5

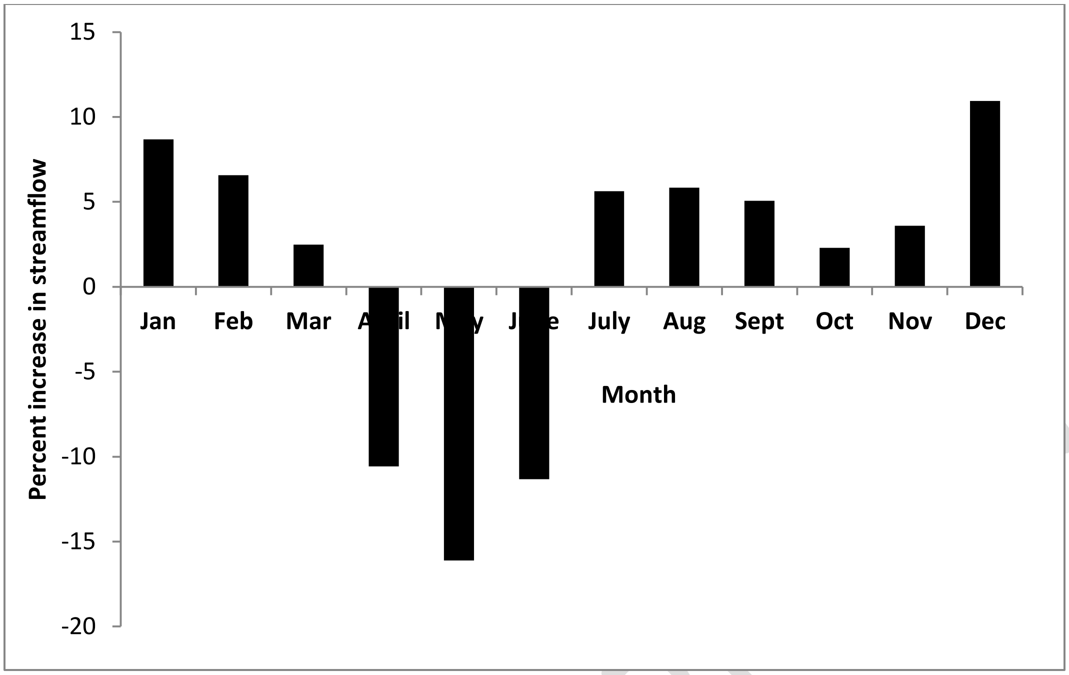

Fig.9. Percent change in streamflow after adding reservoirs to the subbasins (0.1% increase in area of waterbodies) during 2041-2070 RCP8.5

4. CONCLUSION

With the use of properly calibrated hydrological model SWAT, it was able to predict the streamflow in the Bharathapuzha river basin on a monthly basis. The results obtained from the model demonstrate how the changes in the climatic parameters such as rainfall and temperature can significantly affect the streamflow. The overall statistics shows that the SWAT model can very well be used for predicting the impact of climate change and watershed interventions in a watershed in the tropical region. The climate change effects, especially the seasonal shifts in rainfall increases the complexity and uncertainty of agricultural management. The simulated results imply that modifications are needed in the cultivation practices, mainly in those cases which are highly seasonal and are in the marginal limits of the seasons. The vulnerability of agriculture to climate change is highly dependent on the methods adopted by the people to cope up with the changes.

Effective strategies which will promote sustainable agriculture need to be adopted for the benefit of agricultural adaptation planning. Scientific understanding of the response of different crops to climate change (change in carbon dioxide, temperature and other factors) is also needed for the planning. A drastic increase in urban areas, deforestation and changes in natural vegetation may be the reason for an increase in temperature and decrease in rainfall. The results of this research may be an insight to the hydrologists and planners for implementing solutions which can bring down the adverse effects of temperature variability and climate change.

The comparison of the results obtained after including the watershed interventions showed that there was increase in base flow even though there was decrease in average annual streamflow. Due to the addition of the WRS, the summer flow is increased which will help to maintain the river flow, water quality and the fish and other habitats in the river during the lean period. If more water can be made available in the rivers during the summer, it will help in maintaining the irrigation systems and thereby increasing irrigated agriculture of the area.

Predictions on soil loss in the current scenario as well for the climate change scenario were also done. This will also be helpful for the management of the soil and water conservation measures and for planning proper mitigation measures in the area.

This research work is an indicative example of how well the hydrologic model SWAT and GIS tools can be effectively utilized for proper planning in the tropical river basins of India. Limitation in data availability on a fine spatial scale was the major limitation during the study. Under the constantly warming climate of the region, it is expected that the results of the study may arouse serious concern about water resource availability in the region, especially among the water resource planners and managers. Further detailed studies are needed in this regard with more accurate climate models along with hydrological and meteorological data having high spatial resolution.

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