IMPACT ANALYSIS OF CONSERVATION STRUCTURES AND CLIMATE CHANGE ON STREAMFLOW OF THUTHAPUZHA WATERSHED, KERALA

ABSTRACT

Hydrological models are increasingly being used to assess how climate change and watershed management practices affect the hydrological processes.In this research, SWAT model was used to analyse the impactof water conservation structures and climate change of Thuthapuzha watershed, subbasin of Bharathapuzha located in Kerala, India.Major conservation practices in the study area were modelled as ponds and Kanjirapuzha reservoir was modelled as dam. The impact of conservation structures on streamflow was evaluated and found that monthly streamflow increased during summer season (9-17%), during which usually the river has a lean flow. Thus, the conservation structures increase recharging and thereby helps in maintaining a better environmental flow regime.Similarly, the impact of climate change on streamflow was also analysed and the results of the future simulations of streamflow reveal that, river flow increased under all Representative Concentration Pathways (RCP) scenarios with predominant increase in RCP6 scenario (37-60%) followed by RCP4.5 (13-16%) and RCP8.5 (9-16%) from 2021-2070. For all the scenarios used in the study, a significant increase in streamflow was observed near the end periods of simulation.

Keywords: *SWAT, RCP, CMIP5, CORDEX-SA, GFDL-CM3, GCM*

1. INTRODUCTION

The rate of degradation of soil and water resources is increasing day by day across the globe. This influences directly or indirectly all ecological processes on the Earth's surface especially the water bodies and the water quality (Issaka and Ashraf, 2017).In most of the tropical mountain regions, water erosion has become a generalized process (Nyssen *et al*., 2009).It is crucial to have scientific management of natural resources to cope up with climate change and water scarcity.Effective conservation as well as management of natural resources can be accomplished by adopting watershed as a basic unit of development(Suresh, 2016).One of the major issues concerning watershed management is the inequitable benefits for downstream users due to reduction in flow in the downstream reaches (Nune*et al*., 2013).Scientists are now focusing on the impact of these conservation practices on watershed hydrology including runoff, sediment, nutrient loss, quality of water and so on.Modelling approaches are widely used to determine the efficiency of conservation practices onnutrient runoff and sediment (Santhi*et al.,* 2006). Advancements in computer processing technology have indeed made it possible for scientists to use hydrological models to evaluate the conservation practices impact on watershed hydrology.

Over the last few decades, studies related to climate change and its effects on both natural and man-made processes have gained significant attention. Many environmental effects of climate change have already been reported. Its impact on hydrology of watersheds is of great significance among the observed effects. Management and planning of water resources has become a challenging task as a result of climate change uncertainties. It will be difficult to adjust to these impacts in future without a drastic and appropriate plan of action immediately. For simulating projected conditions of climate change, General Circulation Models (GCMs) are a reliable tool which gives us an idea of how the climate is going to change in future. There will be mismatch between regional variables and those simulated by GCMs. It is therefore necessary to downscale GCM output for a specific area of interest in order to regionalize global climate data.Variations may exist within the Regional Climate Model (RCM) derived data as compared to reference period data. Therefore, the bias between the observations and the RCM output need to be eliminated by using bias correction methods prior to impact studies. Bias corrected data are then fed to hydrological models for climate change impact assessment.

Modelling approach will help to simulate the long-term effects without the need for time-consuming and costly experiments. Among the models available, the SWAT (Soil and Water Assessment Tool) model can predict impacts and also evaluate best management practices in agriculture, specifically the soil and water conservation practices adopted in watersheds. Hence, this research work involves assessing the impacts of structural conservation measures and climate change on stream flow of the watershed using a developed SWAT model for the study area

2. MATERIALS AND METHODS

2.1 Study area

Thuthapuzha, a sixth-order subbasin, covers an area of 905 km². It lies between latitudes 10°50' to 11°15'N, and longitudes 76°05' to 76°40' E. Of the total area, 75% falls in Palakkad district and 25% in Malappuram district. Thuthapuzha watershed is located in the north-eastern part of BharathapuzhaRiver and is the main tributary that supplies water to Bharathapuzha, particularly during the summer. The annual average discharge of Thuthapuzha sub basin is about 1750 Million cubic meters (CWC, 2012). Other than the reservoir built across Kanjirapuzha, which serves as a source of water for irrigation, there are no other major structures in the watershed. There are wide spatial variations in precipitation ranging from 2020 mm to over 5000 mm/year, with heavy precipitation in the direction of the Silent Valley Reserve Forest (Manjula and Unnikrishnan Warrier, 2019).The average temperature in the area is 27.3°C (Tejaswini and Sathian, 2018). Variations in general precipitation (Raj and Azeez, 2009) and surface temperature in the region have been observed over the last few years. In recent years, severe water scarcity and drought conditions have also been reported in the river basin. The location map of study area is shown in Figure 1.

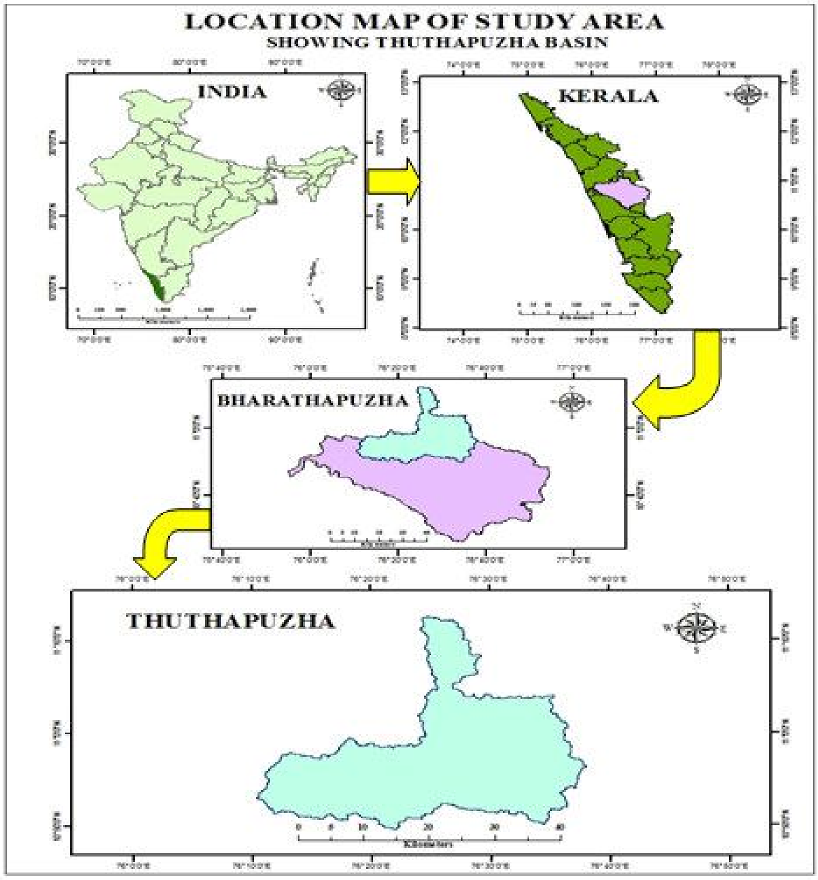

Fig. 1 Location map of study area

2.2 Developed SWAT Model

The Soil and Water Assessment Tool (SWAT) model was selected to model streamflow in the Thuthapuzha watershed in Kerala. For Thuthapuzha watershed, SWAT model was developed by Fousiya and Varughese, 2020. The performance of the model was assessed by Nash-Sutcliffe Efficiency (NSE), coefficient of determination (R^2), and per cent bias (PBIAS). The R^2, NSE and PBIAS values were 0.88, 0.88 and -1.4 for the calibration period and 0.8, 0.8 and 5.4 for the validation period respectively. Overall model statisticshave shown that streamflow simulation could be successfully performed in the Thuthapuzha watershed using thedeveloped model. It was concluded from the study that the developed model can be used for further studies in the same area including climate change and management impact analysis, land use change impact assessment etc.

2.3 Details of conservation practices in the watershed

Details of the water conservation structures and the reservoir within Thuthapuzha watershed is needed to study the impact of conservation practices on watershed hydrology. The necessary details include area, volume, year of construction of the structure, etc. Several conservation structures are present in the study area such as check dam, vented cross bars, brushwood dam etc. Details of the reservoir have been collected from previous literatures and Kerala Engineering Research Institute, Peechi. Details of the conservation practices were collected from the Regional Office, Kerala State Land Use Board, Thrissur.

2.4 Conservation practices impact analysis

The developed SWAT model was run so as to analyse the effect of conservation practices on the hydrological processes happening in the watershed. The SWAT model itself is capable of simulating a number of management practices such as tillage, fertiliser application, crop rotation, dams, ponds, etc.

For this research, the collected details of conservation practices were analysed. Three main conservation practices; Vented Cross Bar (VCB), check dam and brushwood dam in the study area were selected for further analysis. The SWAT model divides the area of simulation into sub watersheds following the river network in a cascade manner. From the literature, it was found that check dams could be modelled as ponds in the SWAT model (Jalowska and Yuan, 2019). Since the conservation practices chosen have a similar function as the check dams, all three have been modelled as ponds.Thus, for each subbasin, the storage area and the volume of all three conservation practices were summed up and given as a single pond at the outlet of subbasins in which it is located. SWAT model already has the option to simulate the reservoir. As a result, the Kanjirapuzha Dam was modelled as a reservoir. Following the modelling of ponds and reservoirs, the SWAT model was run with and without structures to simulate the impact of conservation practices on stream flow.

2.5 Climate change data and analysis

One of the main input sets for modelling future watershed conditions in SWAT is data on climate change.Precipitation, maximum and minimum temperature are the major climatic parameters needed to achieve future climatic conditions.The most basic method of generating climate projections is based on a climate model concept and scenarios for future emissions of greenhouse gases.The Earth System Grid Federation (ESGF) portal provides access to a wide variety of data sets, including the Coupled Model Intercomparison Project Phase 5 (CMIP5) model data that serves as the basis for IPCC AR5. ESGF also have provision for downloading numerous CORDEX RCM simulations produced by a number of modelling groups around the globe, similar to the CMIP5. CORDEX simulation over the South Asian domain (CORDEX-SA) was available in the Centre for Climate Change Research, Indian Institute of Tropical Meteorology (IITM) regional data portal. It was found from literatures that the GFDL-CM3 model provides better simulation of the Indian condition (Varughese and Hajilal, 2016). The GFDL-CM3 model was developed by the National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Laboratory. Climate change data of the GFDL-CM3 model (precipitation, maximum temperature and minimum temperature) was downloaded from the ESGF-CMIP5 dataset and the CORDEX-SA FTP server.

In the CMIP5 download, all four RCP scenarios, namely RCP2.6, RCP4.5, RCP6.0 and RCP8.5, were available for the period 2006-2100, while in the CORDEX-SA GFDL-CM3 download data, only RCP4.5 and RCP8.5 were available for the period 2006-2070. For historical data comparison, the 1989-2005 data was downloaded from both datasets. These data were used to evaluate the GFDL-CM3 GCM data from CMIP5 and the RCM data from the CORDEX-SA. Prior to the evaluation of both CMIP5 and CORDEX-SA data, bias correction was done separately for precipitation, maximum temperature and minimum temperature. The comparison of model output from CMIP5 and CORDEX-SA was made after the bias correction.Historical data from 1989 to 2005 was used for the comparison. The correlation of the data with historical data was assessedusingstatistical parameters (standard deviation, correlation coefficient and coefficient of variation).

3. RESULTS AND DISCUSSION

3.1 Impact of conservation practices on streamflow of Thuthapuzha watershed

The SWAT model defines reservoirs as water bodies which are situatedin the network of streams in the basin and receive loadings from all upstream sub basins(Jalowska and Yuan, 2019). Ponds and wetlands are explained as water bodies located off the stream network, and they do not usually receive loadings from other subbasins (Neitsch*et al.,* 2002).SWAT allows for one reservoir, one pond, and one wetland for each subbasin (Neitsch*et al.,* 2002).If there are ponds, wetlands, and reservoirs in a subbasin, the predicted runoff from each HRU shall be aggregated by first routing the runoff into ponds and wetlands followed by channel reach, and at the end into the reservoir, irrespective of the location of the impoundments in the subbasin.

Here, SWAT was used to model the Kanjirapuzha dam as reservoir component and the remaining structures as ponds. The required input parameters for the pond and reservoir are volume of water and surface area at both the principal spillway and the emergency spillway. The amount of water entering the water body throughout the day is estimated for the ponds as a fraction of the runoff provided by the user from all the HRUs within the subbasin, irrespective of their location in the subbasin. Data needed for the conservation practices simulation was summed up for each subbasin.The location of the structures considered for the study separately for each tributary is shown in Fig.2.

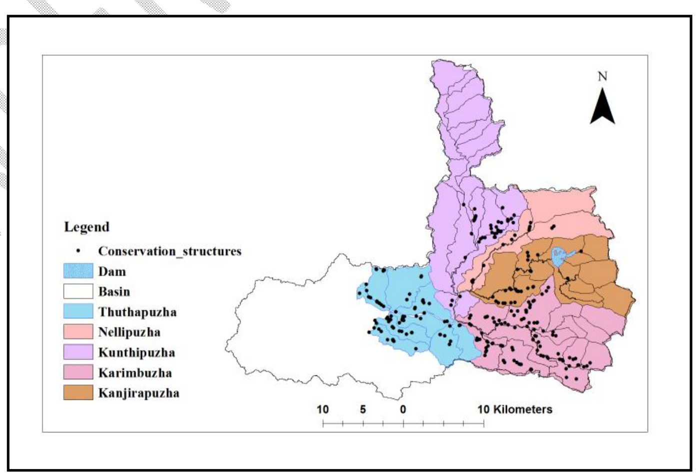

Fig. 2 Map showing location of conservation practices of Thuthapuzha watershed

In the developed SWAT model, the inputs for ponds and reservoir are given and the SWAT model was run. In order to study the impact of conservation practices on streamflow, the annual and monthly streamflow values were compared with the results of SWAT model run without considering conservation practices.Comparison of annual and monthly streamflow simulated with and without structures for the period 1992-2017 is shown in Fig. 3 and Fig. 4 respectively. Predicted annual streamflow simulation is showing an average decrease of 55 Mm³ in streamflow in all the years when conservation practices were added. The annual streamflow is found to be decreasing with the implementation of conservation structures from 1992-2017. Though there is a small decrease in the annual streamflow, the peak flow redistribution to summer months is of great importance.

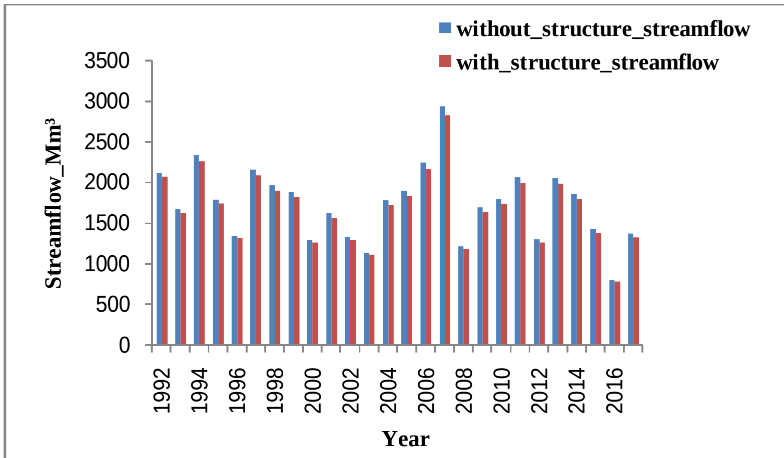

Fig. 3 Predicted annual streamflow simulation with and without conservation structures

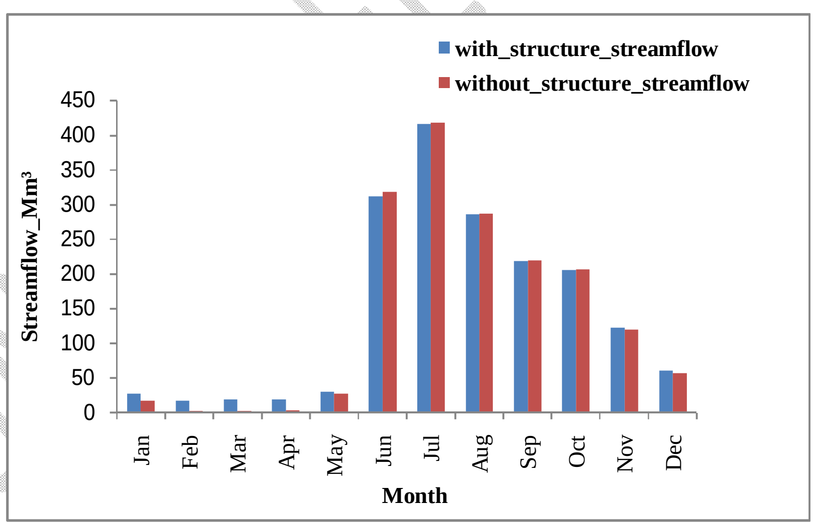

Fig. 4 Predicted monthly streamflow simulation with and without conservation structures

Monthly streamflow simulated with and without structures was also compared. It was found that the streamflow value increased during summer season (January to May) with the effect of conservation structures whereas it decreased slightly during rainy months.Large increase in the streamflow value with the implementation of conservation structures helps in maintaining a better environmental flow regime. Percent increase in monthly streamflow with the addition of conservation practices was calculated and is shown in Fig. 5. From the graph, it is clear that percent increase in streamflow is high in the range of 9 to 17 percent from January to April and a small decrease of about 0.5 to 7 percent in flow was observed from June to October. This redistribution of peak flow to summer months helps in increasing the groundwater recharge. During summer season, generally very lean river flow occurs in the watershed which results in water scarcity especially for the downstream water users. Such a situation can be avoided with the implementation of conservation practices. Moreover, the conservation practices will delay or reduce the surface runoff thereby recharge to groundwater also increases.

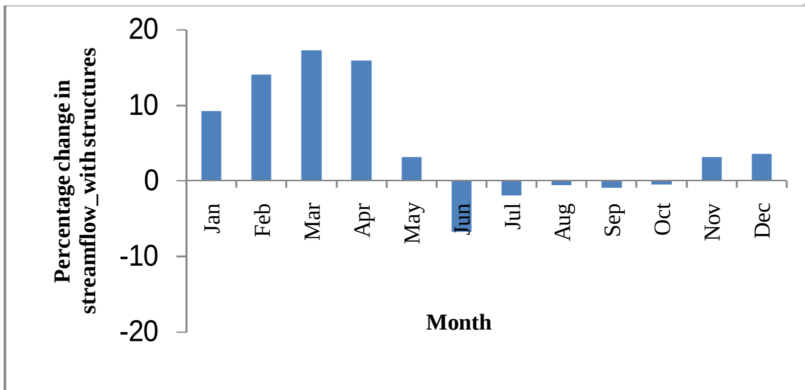

Fig. 5 Percentage change in streamflow with and without structure

3.2 Impact of climate Change on streamflow of Thuthapuzha watershed

Based on literature review, GFDL-CM3 model was selected for projecting climate change data of Thuthapuzha river basin (Varughese and Hajilal, 2016).In order to make choice between CMIP5 and CORDEX-SA datasets, the bias corrected outputs of both the datasets were compared and found that both the datasets showgood correlation with the observed. CMIP5 datasets provides the global climate data whereas CORDEX-SA datasets are specifically for South Asian domain and provides regional data.The lack of regional information makes the GCMoutput unsuitable for a number of impact studies requiring regional information.A strong conclusion cannot be drawn for selecting bias corrected GCM and RCM due to the different ways of controlling the atmospheric circulation in the RCM and the GCM simulations.Thus, by considering the above aspects, CORDEX-SA dataset was selected. CORDEX- SA is providing data for two RCP scenarios, RCP4.5 and RCP8.5 which represents low and high scenario respectively. A medium scenario related study is not possible using CORDEX-SA datasets.Since CMIP5 datasets provides medium scenario datasets, RCP6.0 data from CMIP5 dataset was also taken for the study purpose. In general, RCP4.5 (low) and RCP8.5 (high) scenarios from CORDEX-SA bias corrected dataset and RCP6.0 (medium) scenarios from CMIP5 bias corrected dataset from 2021-2070 were taken for further impact analysis.

<u>3.2.1 Predicted future precipitation and temperature for different scenarios</u>

Monthly variation of the bias corrected data including precipitation and temperature data for different scenario selected (RCP4.5, RCP6.0 and RCP8.5) from 2021-70 were compared with the observed data from 1989-2017. Precipitation data variation under different scenarios for two time periods, 2021-40 and 2041-70 with the observed data is shown in Fig.6. There is a significant decrease in precipitation during June to December for RCP 4.5 and increase in precipitation from January to May except February for 2021-40. During 2041-70 for RCP 4.5, increase in precipitation was found for all months except June, July, September and October. Significant increase in precipitation was observed for RCP6.0 for almost all months except February, July and October during 2021-40 whereas from 2041-70, increase in precipitation was observed for all months except February and October. For RCP 8.5, decrease in precipitation was found for all the months except January, March and December from 2021-40 whereas from 2041-70 decrease is precipitation is found for the months of June, July, September, October and November.

While comparing between scenarios, it is seen that precipitation is increasing for RCP6.0 whereas it decreases for both RCP8.5 and RCP4.5. Chong-Hai and Ying (2012) projected precipitation over China under RCP Scenarios using a CMIP5 multi-model ensemble and found that precipitation will tend to decrease especially under RCP8.5 (Rajczak and Schar, 2017) projected precipitation and its extremes over the European continent using EURO-CORDEX Regional Climate Models (RCMs) under RCP4.5 and RCP8.5 and found that precipitation decreases under both RCP scenarios but predicted extreme rainfalls.

The percent change in monthly rainfall from the observed monthly values is plotted in Fig.7.The percent decrease in precipitation is found to be higher for RCP8.5 followed by RCP4.5 whereas percent increase in precipitation is higher for RCP6.0. In RCP4.5, emissions are starting to decline by around 2045 to reach approximately half of the 2050 levels by 2100. Emissions continue to rise in RCP8.5 throughout the 21st century (Riahi*et al.,* 2011). Based on the annual average precipitation predicted for the entire period (2021-70), a decrease of about 13 and 16 percent was found for RCP4.5 and RCP8.5 respectively and an increase of 33 percent was observed for RCP6.0 from the observed annual average precipitation.

Unlike temperature, there exist large uncertainties in the precipitation obtained from GCM than RCM. Since RCP6 scenario data was collected from CMIP5 GCM datasets, precipitation data is showing an increase in trend than the observed period of time. Moreover, in RCP6 scenarios, emission peaks around mid-century (2080s) and then stabilises by 2100. Since the time period taken for the study purpose is from 2021-2070 where peak emission occurs, it may result in the increased precipitation. This change in precipitation pattern may affect the streamflow of the Thuthapuzha watershed in future, thus proper planning and conservation of soil and water should be taken in advance.

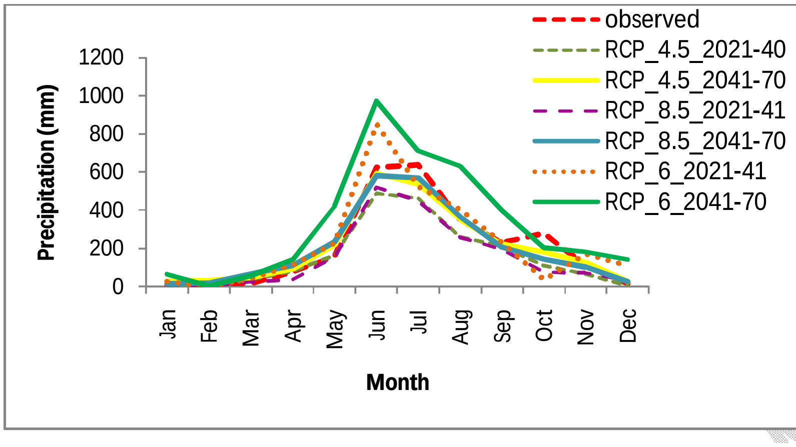

Fig. 6 Comparison of observed and bias corrected monthly precipitation under different scenarios

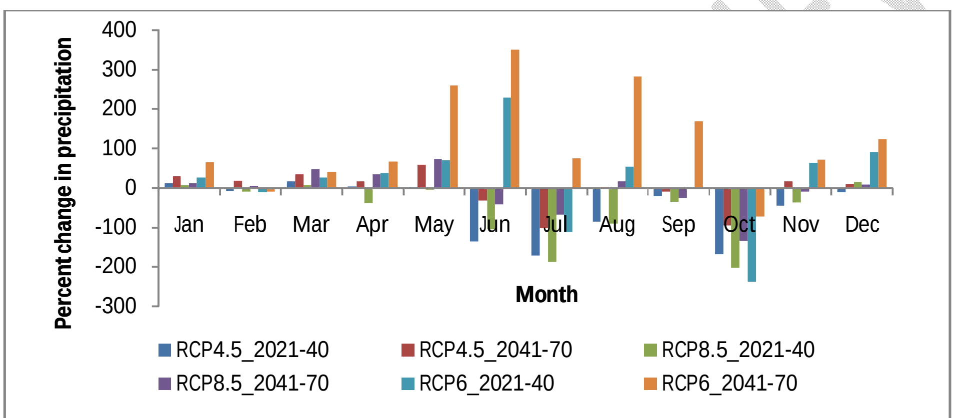

Fig. 7 Percent change in monthly rainfall from observed data under different scenarios

Monthly variation of bias corrected maximum and minimum temperature data for different RCP scenarios from 2021-70 in comparison with observed maximum and minimum temperature is shown in Fig.8 and Fig.9 respectively. Maximum temperature shows an increase in the trend for all months in the RCP4.5 and RCP8.5 scenarios compared to the observed data, while the RCP6.0 scenario shows a decrease in the trend for January, February and December. Maximum temperature projected forentire India showed an increase within the range 2.5°C to 4.4°C by end of the century (Bal *et al.,* 2016). While comparing minimum temperature data, it is found that minimum temperature is almost in the same range as that of the observed minimum temperature for RCP4.5 and RCP8.5 scenarios. A similar increasing trend in minimum temperature was also noted in case of RCP6.0 scenario. These results were used for studying the climate change impact using SWAT model.

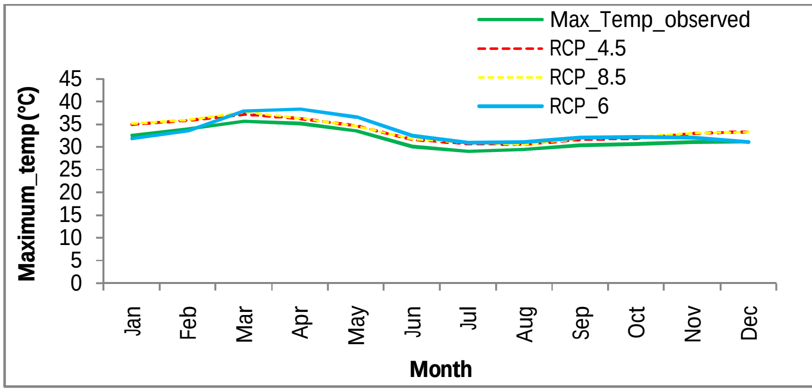

Fig. 8 Comparison of observed and bias corrected monthly maximum temperature under different scenarios

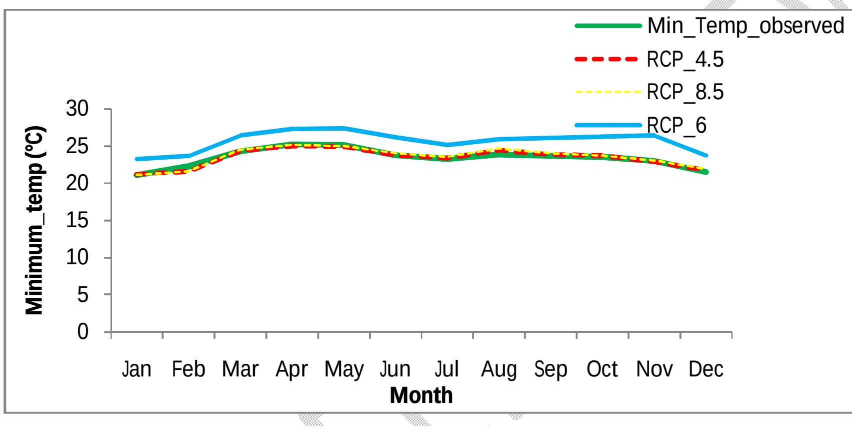

Fig. 9 Comparison of observed and bias corrected monthly minimum temperature under different scenarios

3.2.2 Impact of climate change on streamflow under different scenarios

For convenience of the study, the entire projected period of simulation was divided into two time periods; 2021-2040 and 2041-2070. The bias corrected precipitation and temperature data were given as weather inputs to the developed SWAT model.The streamflow simulated by the projected data was compared with the observed flow to analyse the trend of streamflow in future periods.

Annual and monthly streamflow under different scenarios (RCP4.5, RCP6.0, and RCP8.5) was studied. The total streamflow at Pulamanthole gauging station is based on the combined features of all the upstream sub basins of Thuthapuzha watershed. The annual observed streamflow of Pulamanthole gauging station was compared with the simulated future annual streamflow values. Predicted annual streamflow under different scenarios in comparison with observed streamflow for time period 2021-40 and 2041-70 is shown inFig. 10 and Fig. 11respectively. From the figure, it is found that the annual river flow under all the scenarios selected for the projected period is higher than the present annual river flow. While comparing between scenarios, increase in annual streamflow is found to be higher in RCP6 scenario (37-60%) followed by RCP4.5 (13-16%) and RCP8.5 (9-16%) during the entire period of simulation. Sathya and Thampi (2020) studied the impact of projected climate change on streamflow of the Chaliyar river basin of Kerala and reported that the annual streamflow is likely to increase by about 27.27% under RCP 4.5 and 42.44% under RCP 8.5. The increase in streamflow may be due to the changes in the projected precipitation pattern. Githui*et al.,* 2009 reported an increase in streamflow due to increased rainfall in western Kenya.

Anthropogenic activities have already changed the river flow patterns in several river basins.Moreover, there are chances of increased population, land use changes, increased demand for irrigation can also add to this streamflow change. Decrease in streamflow is also observed in some years between 2021-40 and 2041-70 due to increase in temperature during the predicted period. Overall annual average streamflow for the entire simulation is showing an increase in streamflow under all RCP scenarios. Predominant increase in streamflow was found in RCP6 scenario may be due to changes in the precipitation patterns observed from the projected CMIP5 datasets. The simulated streamflow using projected dataset from CORDEX-SA for RCP4.5 and RCP8.5 shows that annual average streamflow under RCP8.5 is less than that of RCP4.5. In both the periods from 2021-40 and 2041-70, it is observed that the increase in streamflow is more significant at the end periods of the simulation.

Predicted monthly streamflow under different scenarios in comparison with observed streamflow for the time period 2021-40 and 2041-70 is shown in Fig.12 and Fig.13 respectively.For almost all the months in both the periods and all the scenarios, the streamflow was observed to be higher thanobserved data. In case of rainfall also, an increase in rainfall is found during almost all months. This has caused increased streamflow for the predicted periods. Predicted monthly streamflow under different scenario in comparison with observed from 2021-70 is shown in Fig. 14.During 2021-70, the streamflow in RCP4.5 showed almost similar trend in variation as that of observed with a slight increase in streamflow for all the months except July and October during 2041-70. Under RCP8.5 from 2021-70, the streamflow is found to be increasing from January to July and decreasing afterwards. But the peak flow is found to be higher than that of RCP4.5 during June to August. Thus, in RCP8.5 it is found that during peak flows the climate will become wetter than that of current scenario. Moreover, during 2021-70 in RCP6 scenario, increase in streamflow is observed in all months except during December in the period from 2021-40. The observed and simulated data is showing similar trend in variation except in case of RCP6 scenario during the months of June and July, where there is peak flow in the catchment. Scientists have reported this uncertainty in predicting the peak flows when using SWAT model. The streamflow increase is found to be significant during the end period of simulation for all the scenarios taken for the study purpose. Thus, necessary steps should be taken to mitigate the extreme events due to streamflow increase during future periods.

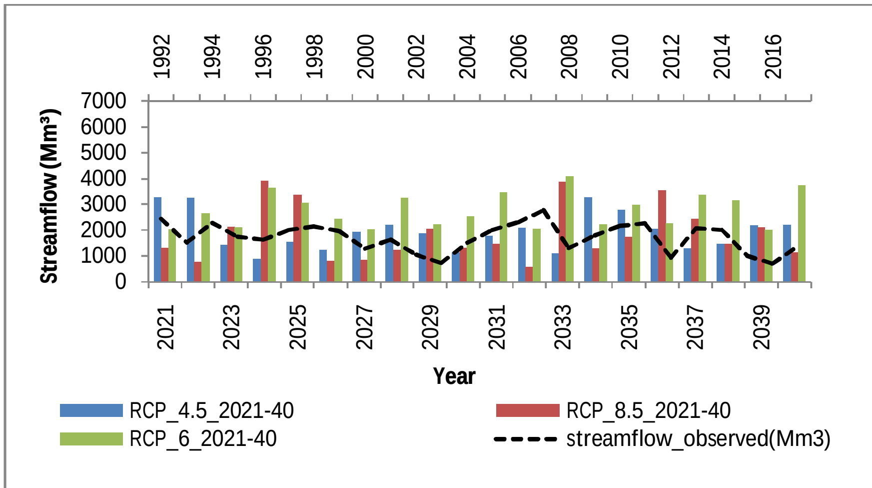

Fig. 10 Predicted annual streamflow under different scenario from 2021-40

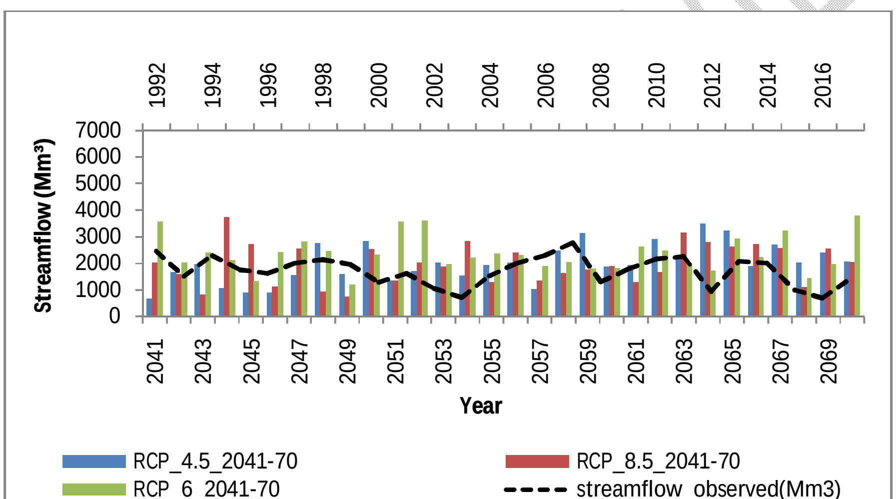

Fig. 11 Predicted annual streamflow under different scenario from 2041-70

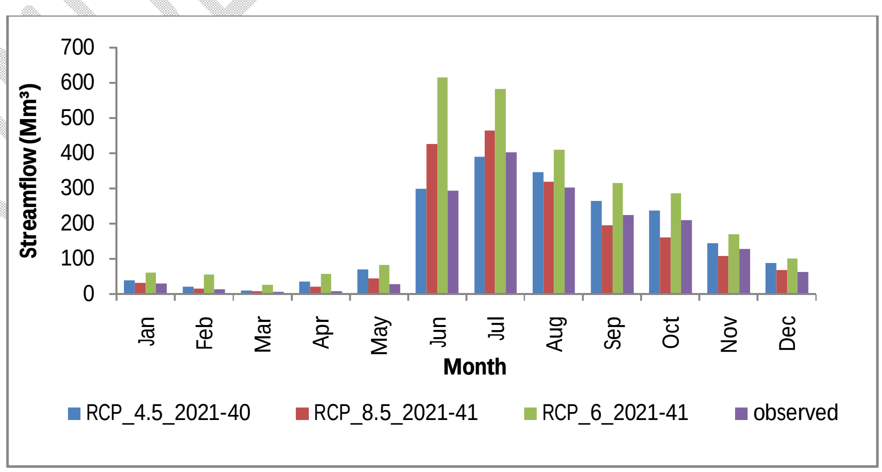

Fig. 12 Predicted monthly streamflow under different scenario from 2021-40

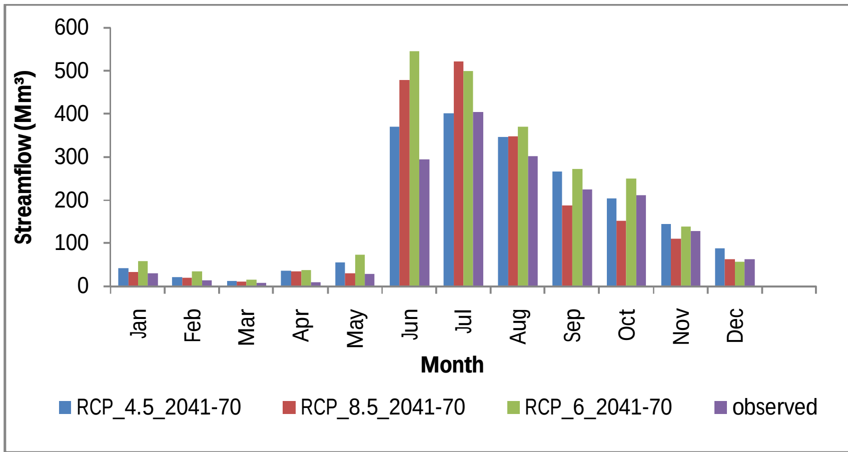

Fig. 13 Predicted monthly streamflow under different scenario from 2041-70

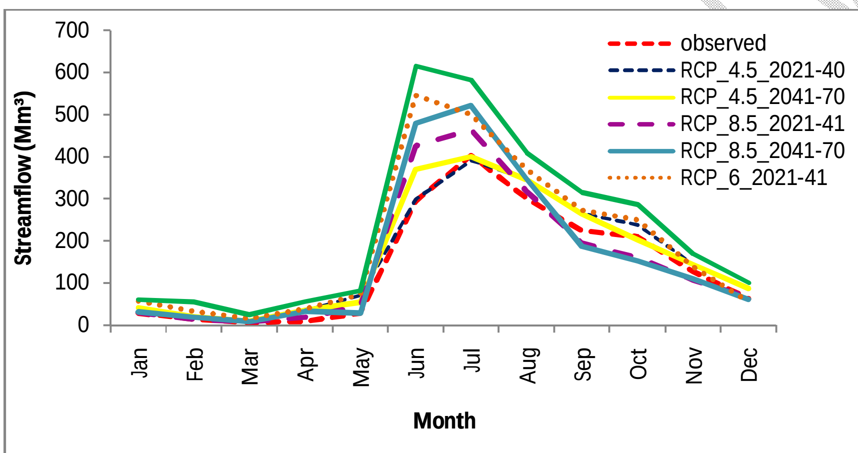

Fig. 14 Predicted monthly streamflow under different scenario in comparison with observed from 2021-70

4. SUMMARY AND CONCLUSIONS

Bharathapuzha, the second longest river in the state of Kerala is now facing significant threats to its survival due to many natural and man-made reasons. Climate change effects have modified the river flow pattern resulting in extreme rainfall during monsoon and severe drought in late monsoon. Conservation measures can also modify the hydrological regime by altering the runoff pathways, as well as the temporal and spatial distribution of water availability. To analyse the reasons for this river flow pattern and to understand the impacts of climate change and conservation practices, a detailed study was carried out in the Thuthapuzha subbasin of Bharathapuzha river using the SWAT hydrological model.

The water conservation measures established in the form of impoundments helps to store the water in the catchment area during the rainy season, which helps to improve the flow during the summer season to the extent of 9 to 17%. The predictions of rainfall for the future gives an indication of increased rainfall during future periods, especially in the RCP6.0 scenario. Based on the result of the study, small conservation measures like VCB's, check dams, temporary brush wood check dams etc., canhelp in reducing the floods and at the same time improve the summer flow regime of the river.

Climate change impact results were based on only one model. The results can be more accurately obtained with multiple models using multiple ensembles. Thus, the studies should be done in a site-specific manner following the same procedures and appropriate mitigation measures and management practices need to be taken. The developed model can be used in the same area for further studies including management impact analysis, land use change impact assessment etc. The capability of a well calibrated SWAT model in simulating conservation practices was also analysed and concluded that SWAT model can be used effectively in conservation practices impact related studies. The results of the entire research work will give an insight to the hydrologists in arriving solutions for problems regarding climate change as well as watershed development activities specifically in the adoption of more conservation structures in the area.

5. REFERENCES

Bal PK, Ramachandran A, Palanivelu K, Perumal T, Rajadurai G, Bhaskaran, B. Climate change projections over India by a downscaling approach using PRECIS. Asia-Pac. J. Atmos. Sciences. 2016; 52: 353-369.

Chong-Hai X, Ying X. The Projection of Temperature and Precipitation over China under RCP Scenarios using a CMIP5 Multi-Model Ensemble. Atmos. Ocean. Sci.Letters. 2012; 5(6): 527-533.

CWC. Integrated hydrological data book (Non classified river basins), Central WaterCommission. 2012; p 675.

Fousiya, Varughese A. Modelling streamflow using SWAT model: a case study of Thuthapuzha river basin, Kerala. Int. J. Farm Sci. 2020; 10(2): 86-95, doi: 10.5958/2250-0499.2020.00040.3

Githui F, Gitau W, Mutua F, Bauwens W. Climate Change Impact on SWAT Simulated Streamflow in Western Kenya. Int. J. Climatol. 2009; 29: 1823 - 1834.

Issaka S, Ashraf MA. Impact of soil erosion and degradation on water quality: a review. Geol. ecol. landsc. 2017; 1:111, DOI: 10.1080/24749508.2017.1301053

Jalowska AM, Yuan Y. Evaluation of SWAT Impoundment Modeling Methods in Water and Sediment Simulations. J. Am. Water Resour. Assoc. 2019; 55 (1): 209–227. doi:https://doi.org/10.1111/1752-1688.12715.

Manjula P Unnikrishnan Warrier C. Evaluation of water quality of ThuthapuzhaSub-basin of Bharathapuzha, Kerala, India. Appl. Water Sci. 2019; 9:70.

Neitsch SL, Arnold JG, Kiniry JR, Srinivasan R, Williams JR. Soil and Water Assessment Tool User's Manual, Version, 2000. College Station, TX: Texas Water Resources Institute. 2002.

Nune R, George B, Malano H, Nawarathna B, Davidson B, Ryu D. An Assessment of Climate Change Impacts on Streamflows in the Musi Catchment, India. 20th International Congress on Modelling and Simulation, Adelaide, Australia, 1–6 December 2013; 2380-2386.www.mssanz.org.au/modsim2013.

Nyssen J, Poesen J, Deckers J. Land degradation and soil and water conservation in tropical highlands. Soil and Tillage Research. 2009; 103(2):197-202. https://doi.org/10.1016/j.still.2008.08.002.

Raj NPP, Azeez PA. Historical Analysis of the First Rain Event and the Number of Rain Days in the Western Part of Palakkad Gap, South India, Climate Change: Global Risks, Challenges and Decisions. IOP Conf. Ser. Earth Environ. Sci. 2009; 6 (7).

Rajczak J, Schar C. Projections of future precipitation extremes over Europe: A multimodel assessment of climate simulations. J. Geophys. Res. :Atmospheres. 2017; 122(10): 773–800.

Riahi K, Rao S, Krey V, Cho C, Chirkov V, Fischer G, Kindermann G, Nakicenovic N, Rafaj P. RCP 8.5—A scenario of comparatively high greenhouse gasemissions. Climatic Change. 2011;109: 33-57.

Santhi C, Srinivasan R, Arnold JG, Williams JR. A modelling approach to evaluate the impacts of water quality management plans implemented in a watershed inTexas. Environ. Modelling Software. 2006; 21(8):1141-1157.

Sathya A, Thampi SG. Impact of Projected Climate Change on Streamflow and Sediment Yield – A Case Study of the Chaliyar River Basin, Kerala. In: *Roorkee Water Conclave;* 26-28, February, 2020. Indian Institute of Technology Roorkee and National Institute of Hydrology, Roorkee.

Suresh KJ. Utilization of remote sensing and gis for mapping of natural resource-on water resource action plan and prioritization for yagachi watershed hassan district. ATMECE. 2016.

Tejaswini V, Sathian KK. Calibration and Validation of Swat Model for Kunthipuzha Basin Using SUFI-2 Algorithm. Int. J. Curr. Microbiol. App. Sci. 2018; 7(01): 2162-2172. doi: https://doi.org/10.20546/ijcmas.2018.701.260.

Varughese A, Hajilal MS. Assessing Long-Term Climate Trends of Bharathapuzha Basin, Kerala, India. Int. J. Ecol. Environ. Sci. 2016; 42: 119-124.