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Original Article

Evaluating the Impacts of Climate Change on Thunga River Basin Karnataka

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Abstract *- Climate change affects the environment and natural resources. Rainfall, Temperature and Evapo-Transpiration are major parameters affected by climate change in the environment. This study uses SWAT model for estimation of water flow in future for Thunga river basin of 2413sq-km. Spatial and metrological data was used as input for the model to calculate the runoff at watershed outlet. The calibration and validation was carried out by using manual calibration method, performance of model is evaluated using correlation coefficient and Nash–Sutcliffe efficiency coefficient technique. The future river runoff is estimated using GCM outputs of precipitation and temperature data for RCP4.5 and RCP8.5 scenarios. The runoff for 79 years period (2020-2099) is estimated. The maximum daily discharge for RCP4.5 is lesser than the RCP8.5scenario. Decade mean discharge for RCP4.5 shows almost constant trend line up to mid-century; increasing trend line from 2060. However, in RCP8.5 initially trend line decreases up to mid-century and increases again draws down from 2050 to 2070. It has increased again up to end of century. Dependable observed discharge is less than the dependable flow of future period for both the scenarios at50%, 75% and 90% probability of exceedance. After analyzing results we can conclude that the water availability in future years will be more than the 21% of present water availability, so there is a requirement of proper watershed management plans and further developmental activities in Thunga river basin.*

Keywords — *SWAT, RCP4.5 and RCP8.5 Scenarios, Probability of Exceedance.*

I. INTRODUCTION

The climate changes may lead to droughts and floods in the southern India river basins, which are one of the India's largest supplies of freshwater. Hydrological models have been used as a main assessment tool in river basin to simulate present and predict future water resources including the impacts of climate change. Statistically downscaled GCM precipitation data for Krishna Basin indicates more rainfall and discharge nearer to Western Ghats and droughts at Deccan plateau region. High intensity and frequency of extreme discharge are likely to occur for Lower Krishna Basin, including Thunga, Badra and Varada rivers in 21st century (Byakod et al. 2016). Climate change affects the function and operation of existing water infrastructure – including hydropower, structural flood defenses, drainage and irrigation systems. Adverse effects of climate change on freshwater systems aggravate the mpacts of other stresses, such as population growth, changing economic activity, land-use change and urbanization.

The Inter-Governmental Panel on Climate Change (IPCC) was forecasted that, the south India will be facing erratic rainfall pattern as per IPCC report, 2014.

The Thunga river basin is functioned by monsoonal type of rainfall; it varies spatially and temporally over the entire basin. Any change in the rainfall may affect the runoff decreases in the basin. Government of Karnataka is planning for new irrigation project Upper Thunga and Upper Badra projects to supply the drinking and irrigation water to Chitradurga, Davanagere and Thumkur district. These projects withdraw the water mainly from Thunga reservoir. Apart from this, the IPCC has projected erratic rainfall pattern over the peninsular India by considering the effect of climate change. In view of this, it is essential to understand how these changes would effect on the water availability in the river basin. Keeping it in mind, a comprehensive scientific study is carried out by framing the objective to estimate the effects of climate changes related to water availability in the selected area.

Globally, water demand will increases in the coming decades, mainly because of population growth and expanding abundance; locally, extensive changes in water system water request because of environmental change are normal.

SWAT model is used for conducting the rainfall-runoff simulation in Thunga River basin, in Karnataka. Various parameters like- DEM, land use land cover, soil and climate datawere used as input for the model to calculate the runoff at watershed outlet. The model is calibrated and validated using manual method. Further, the impacts of climate change on Thunga river basin is assessed under two climate change scenarios namely RCP4.5 and RCP8.5. These data were simulated by two COordinated Regional climate Downscaling EXperiment (CORDEX) from the World Climate Research Program (WCRP). The precipitation and temperature data extracted using GCM data over-estimates the values when compared with observed values. Hence the values obtained by GCM are to be suitably reduced by multiplying factor which is estimated by linear scale bias correction method to estimate water availability. Study is mainly focused to estimate the river water flows for future period from 2020 to 2099 using RCP4.5 and RCP8.5 scenario data.

II. STUDY AREA

Thunga River is a sub tributary of the river Tungabhadra, which is one of the biggest wests flowing River in South India. The Thunga river watershed lies between the longitude 75˚4'30.006" E and latitude 13˚ 17' 35.826"N. Thunga River originates in Western Ghats hill known as Varahaparvath place called Gangamoola in Karnataka State, India. The river initially flows towards east, passing through Chikmagalur District and Shimoga District changing way to North and joins Badra at Kudli, a small town near Shimoga city. Tungabhadra River flowing through Karnataka and some part of Andhrapradesha finally joins river Krishna. The study area has a geographical area of 2413 sq-km. The climate of the Thunga river basin is characterized by a heavy rainfall, and the maximum and minimum temperature varies from 33°c to 22°c respectively. The normal yearly precipitation of the catchment is 2498.5 mm.[25][26]

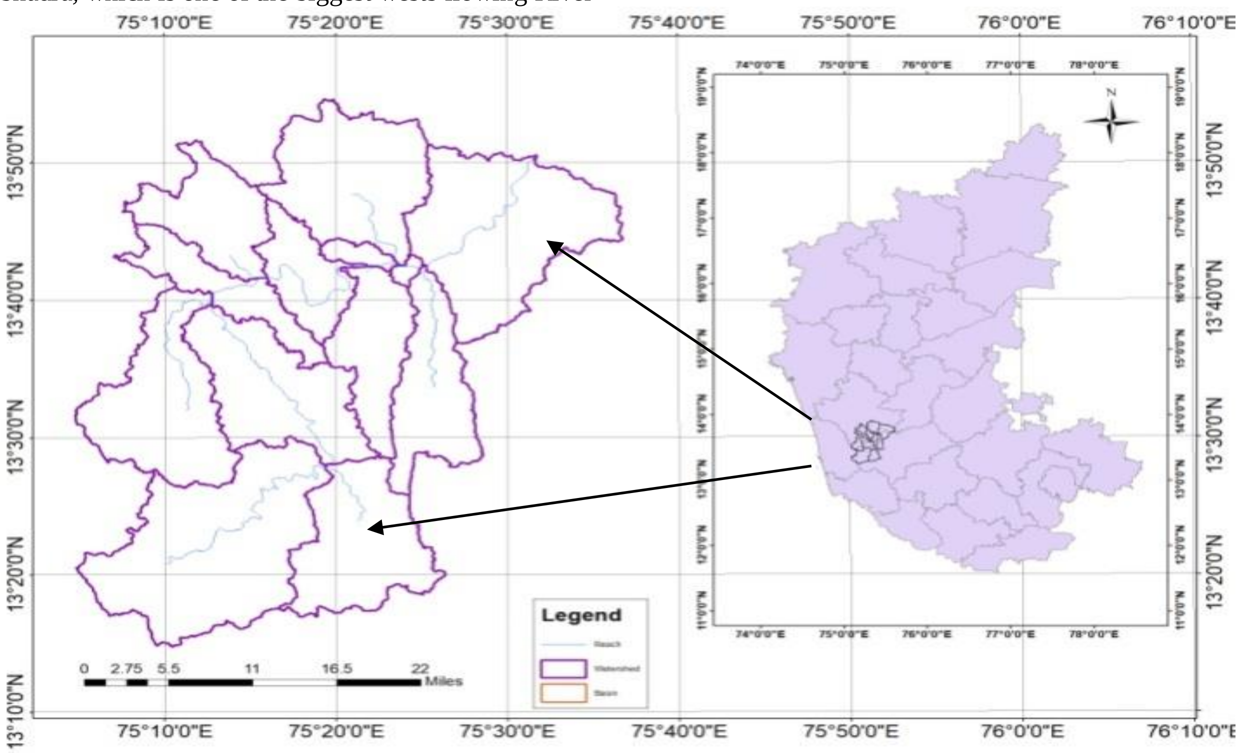

Figure 1: Map of Thunga river basin

III. DATA USED:

Digital elevation model (DEM) of the study area having 32m resolution is been used. The spatial meteorological data i.e. daily rainfall data of 30 years (1985-2015) was collected from Directorate of Economic and Statistics, Government of Karnataka Bangalore. as given in Figure 2. The temperature data for the period 1985 to 2015, collected from Indian Meteorological Department was used for the simulation of rainfall and runoff. Daily observed discharge for the Thunga river (Gajanur discharge gage Station), was collected from Upper Thunga Project Zone, Water Resource Department of Karnataka for the year 1997-2015. Further, the Land use and Land cover map has been downloaded and from SWAT official website and extracted for the study area using Arc GIS 10.1. Soil is classified into known categories using the data extracted from Food and Agricultural Organization, USA.

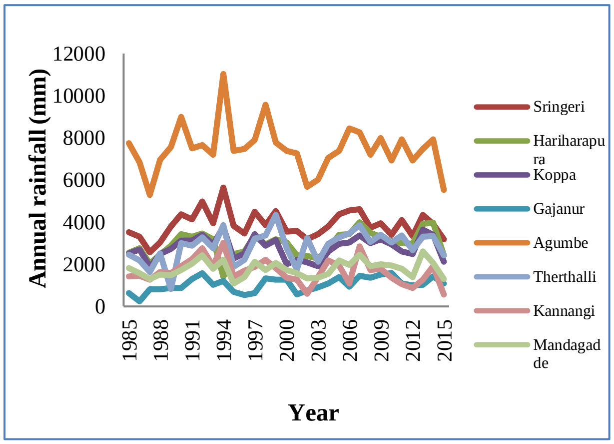

Figure 2: Annual Rainfall Variation in Thunga River Basin

IV.METHODOLOGY USED

A. Hydrological Model Description:

SWAT model is a spatial distributed parameter model having the capability to estimate long term yields. SWAT model involves different input components including hydrology, meteorological conditions, soil temperature, crop growth, nutrients, pesticides, sediment yield, and agricultural management practices. SWAT model is best suitable model for assessment of impact of climate change on hydrological process, surface runoff, groundwater stream, evapotranspiration, irrigation return flow, crop development, sediment yield, nitrate, sulfate, phosphate content and its requirement etc. The model gives the results in various time series like daily, monthly and yearly. Basically the hydrological components involved in SWAT display depend on the water balance equation as mentioned below.

$SW_t = SW_o + \Sigma\,(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$................(1)

Where

SW_i = Soil water content at time t;

SW_o = Initial soil water content;

T =Time in days

R_{day}= Amount of precipitation on day i,

Q_{surf}= Amount of surface runoff on day i,

E_o= Amount of evapotranspiration on day i,

W_{seep}= Water percolation to the bottom of the soil profile on day i

Q_{gw}= Amount of water returning to the groundwater on day i,

SWAT provides two methods for estimating surface runoff, which are the Soil Conservation Service (SCS) Curve Number (CN) and the Green–Ampt infiltration method.

$Q=\frac{(R-0.2S)^2}{R+0.8S}$, R>0.2S.............…………………….(2)

Where,

Q = Daily surface runoff in mm

R= Daily precipitation in mm

S = Retention parameter, the maximum potential difference between rainfall and runoff in mm starting at the time the storm begins.

The second equation related to retention parameter in curve number is shown in below.

$S=25.4\left[\frac{1000}{CN}-10\right]$……………………..…………..(3)

Where,

CN=Curve number, ranging from 0≤CN≤100.

B. SWAT Model Setup and Execution:

ARCSWAT model was used to simulate stream runoff in the thunga river basin. During delineation the entire water shed was divided into 13 sub-basins and were further sub-divided into 57 HRUs which are based on land use/cover, soil and slope attributes. The daily surface runoff volume is simulated for the period of 1997-2015. SWAT model was calibrated for the entire basin during the period 1997–2010 based on daily stream runoff at the Gajanuru discharge gage station. Then, the SWAT model was further validated over the period 2011-2015. The most sensitive parameters were identified for manual calibration. We choose the 11 sensitive parameters based on the ranking of sensitivity analysis are shown in Table 1. The Statistical determination coefficient such as correlation coefficient (R^2) and The Nash–Sutcliffe efficiency coefficient (NSC) were used to assess the efficiency of SWAT in this study.

C. Climate Change Impact Analysis By Using Global Circulation Model:

. The next part of this study involves analyzing the impact of climate change on future runoff pattern. GCM outputs (CORDEX) of precipitation and temperature data for RCP 4.5 and RCP8.5 scenarios prepared by world Climate Research Program (WCRP) are downloaded from Indian Institute of Tropical Meteorology (IITM) and then extracted for the co-ordinates of study area using ARC GIS. The location of GCM station near IMD rain gage stations are depicted in Figure 4. To make accuracy in the extracted data, bias corrections are done by using linear scale method. The correction is made by taking the correlation factors from observed data of IMD rain gage station. The Figure shown below gives the frame work used for the estimation of runoff flow in future climate change period.

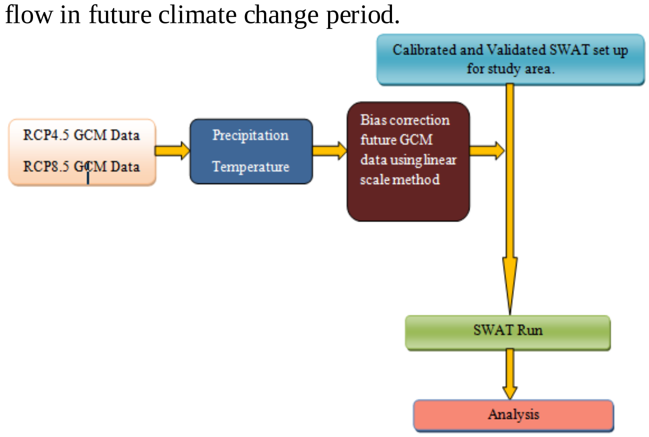

Figure 3: Methodology Used For Future Runoff Prediction

The linear-scaling methodology operates with monthly correction values based on the differences between present-day simulated and observed values. By definition, corrected RCM simulations will perfectly agree in their monthly mean values with the observations. Precipitation is corrected with a factor based on the ratio of long-term monthly mean observed and control run data.

$$P^{*}_{contr}(d) = P_{contr}(d)\frac{\mu_m(p_{obs}(d))}{\mu_m(p_{contr}(d))}$$

$$P^{*}_{scen}(d) = P_{scen}(d)\frac{\mu_m(p_{obs}(d))}{\mu_m(p_{contr}(d))}$$

$$T^{*}_{contr}(d) = T_{contr}(d) + \mu_m(T_{obs}(d)) - \mu_m(T_{contr}(d))$$

$$T^{*}_{scen}(d) = T_{scen}(d) + \mu_m(T_{obs}(d)) - \mu_m(T_{contr}(d))$$

Where,

μ_m =Mean (location parameter of Gaussian distribution).

* =Final bias-corrected.

(d)= dialy data.

P_{contr} =RCM simulated rainfall data in the year 1985–2005.

T_{contr} = RCM simulated temperature in the year 1985–2005.

p_{obs} = Observed rain fall data.

T_{obs} = Observed temperature data.

P_{scen}= RCM-simulated rainfall data in the year 2020–2099.

T_{scen}= RCM-simulated temperature in the year 2020–2099.

Temperature is corrected with help of an additive term based on the difference of long-term monthly mean observed and control run data.

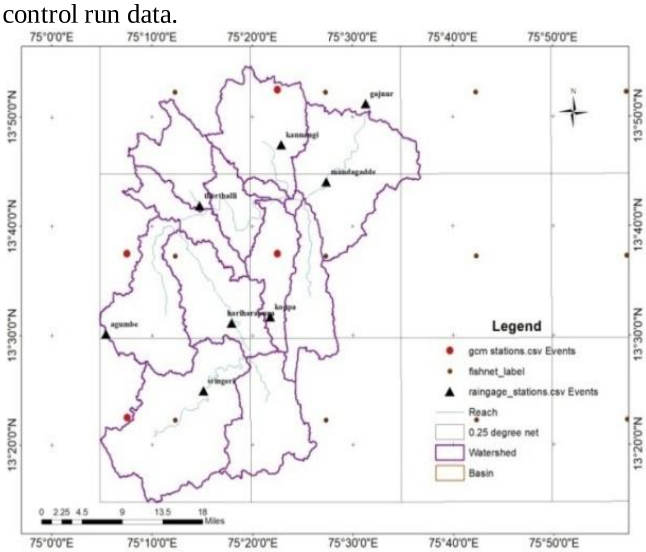

Figure 4: River basin map showing GCM 0.25^0 x 0.25^0 grid rain gage stations and rain gauging stations of metrological department

V. RESULTS AND DISCUSSIONS

A. Data Preparation

As discussed in section-4 above, the study area is delineated using the DEM of Thunga basin as shown in Figure 5. The Land use is dominated by forest which possessed 97.75 percent of the watershed and a small area is covered by Savanna grass land i.e.0.008 percent as shown in Figure 6. The detail of the soil map is shown in Figure 7, which indicates majority of soil is clay loam with 82.71 percent present in the study area.

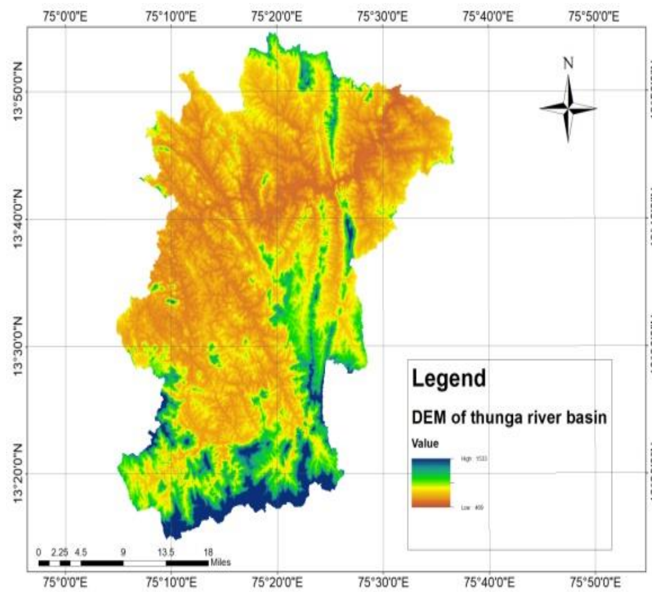

Figure 5: Digital Elevation Model of Study Area (DEM).

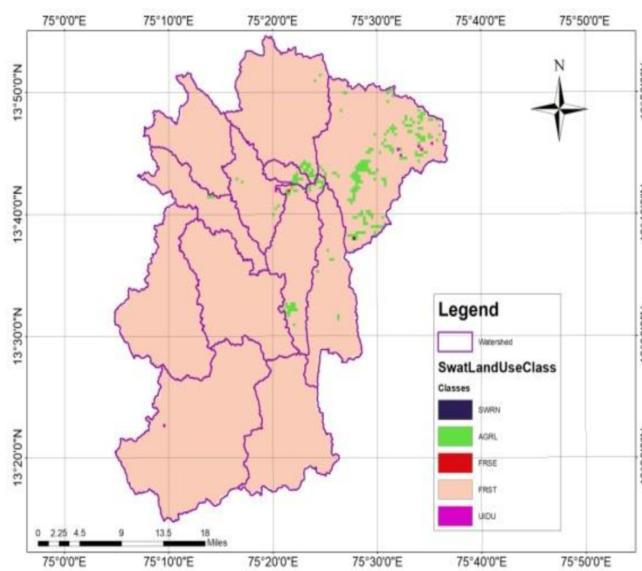

Figure 6: Land use and Land cover map of Thunga river basin.

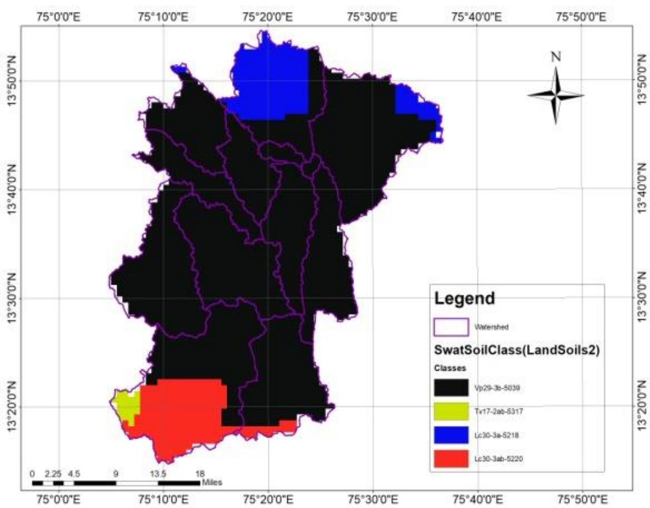

Figure 7: Soil map of Thunga river basin.

B. Calibration and Validation of The Model

Based on the input data, SWAT model was simulated for 13 year period starting from 1997 to 2010 period of time. The obtained correlation co-efficient R^2 and NSE results, indicate that the calibration process is required to correlate the simulated data with that of observed discharge data, Hence the calibration was carried out from 1997 to 2010 by using manual method for the following sensible model parameters shown in Table 1.The performance evaluation of calibrated model using R^2 and NSE are above 0.87 and found satisfactory. Further the validation of the results was done for the period 2011-2015 and the values of R^2 and NSE was found to be greater than 0.80 indicating good correlation with observed data.

Table 1: The Model Parameters As Ranked By The Sensitivity Analysis.

Sl. No	Parameter	Initial value	Final vale
1	ESCO	5	0.95
2	EPCO	1	1
3	SURLAG	0.33	2
4	CN2	77	87
5	ALPH_BF	0.58	0.048
6	GW_DELAY	30	31
7	RCHRG_DP	0.5	0.05
8	GW-REVAD	0.028	0.02
9	REVAP_MN	752	750
10	SOIL AWC	0.11	0.076
11	SOIL K	20	4.89

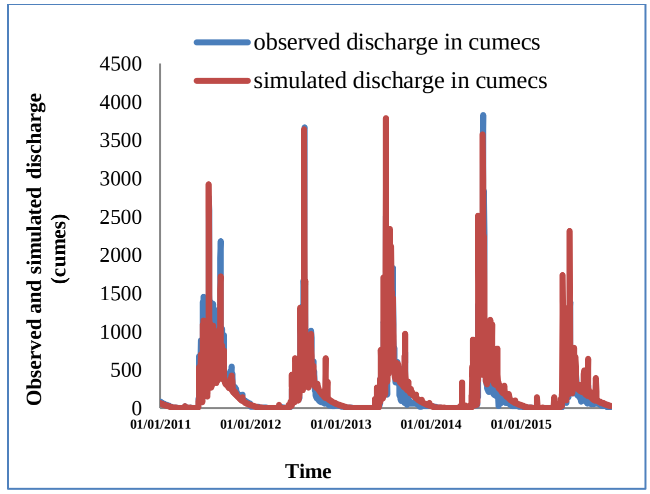

Figure 8: Variation of observed and simulated discharge with validation period

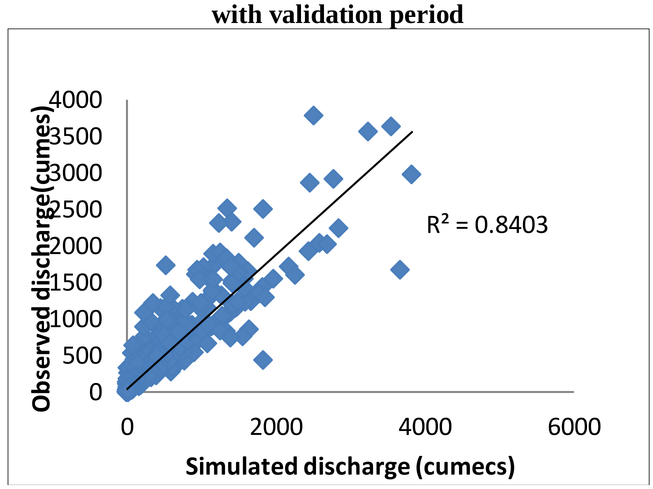

Figure 9: Scattered plot of observed and simulated discharge after calibration.

C. Global Circulation Model Analysis Results

a) Statistical evaluation of liner scaling bias correction bias correction procedures

As discussed in section 4, corrections factors are calculated for each rain gage station nearer to the grid are used for analysis. Correction factors were then applied for the future data of both scenarios for the period of 2019-2099. The Table 2 shows the results of bias correction for the GCM- 0.25 x 0.25 grid nearer to Kannangi rain gage station. The corrected future precipitation data were used for estimation of water availability in the river basin by using SWAT model.

Along with the observed data the forecasted data was used for understanding the temporal variation. To assess temporal variability of mean rainfall during the forecasted period the graph of annual average rainfalls and temperature of all four GCM stations are plotted for both the scenarios during the period 2019 to 2099 shown in Figure 10 and Figure 11.

Table 2: Evaluation of bias correction method for Kannangi rain gage station grid for RCP 4.5 scenario

Year	Observed annual rainfall (mm)	Annual rainfall before bias correction	Annual rain fall after bias correction
1988	808.2	995.5	411.5
1989	656.2	1373.4	355.8
1990	684.6	1642.7	1001.5
1991	609.2	1304.3	473.7
1992	486.9	1597.7	842.6
1993	729.5	1166.8	1007.8
1994	641.8	1510.2	503.5
1995	721.2	1677.5	742.7
1996	860.2	1626.3	486.1
1997	570	1128.5	566.1
1998	932.8	1108.7	638.4
1999	583.9	1090.5	1088.6
2000	707	1956.7	515.3
2001	561	875.4	592.8
2002	512.6	1054.6	646.6
2003	232.6	1322.7	625.1
2004	686.3	1286.4	427.0
2005	606.6	1283.1	664.6
Grand Total	11590.6	29128.0	11590.6

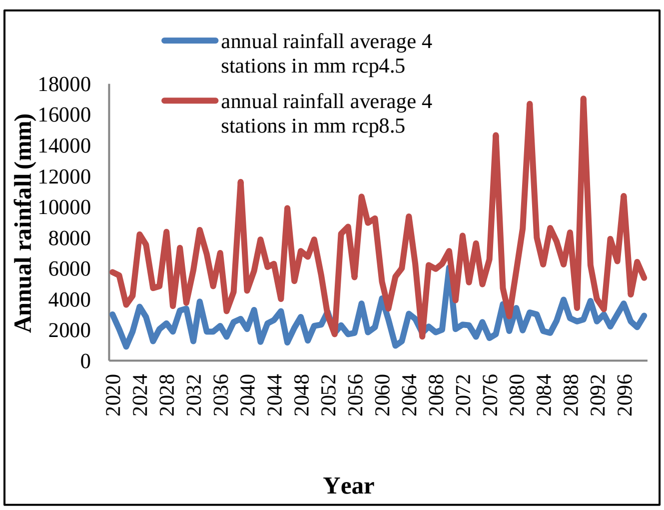

Figure 10: Annual rainfall average 4 stations for RCP 4.5 and RCP 8.5 scenarios.

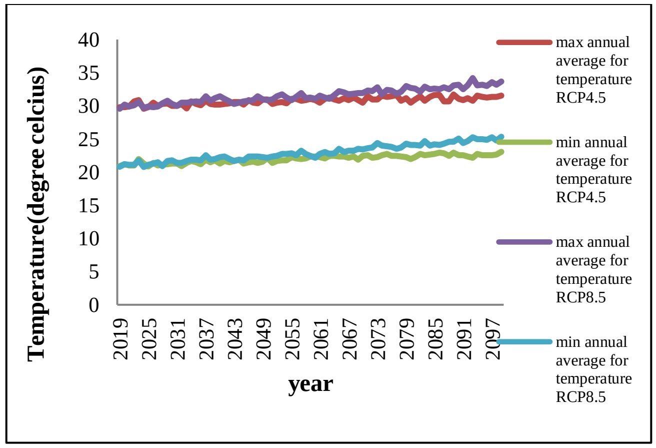

Figure 11: GCM output average annual temperature of Thunga basin.

b) Response of stream flow to climate change

Using bias corrected rainfall data for both RCP 4.5 and RCP 8.5 scenario the prediction of water flow in catchment area has been estimated. For simulating the future discharge calibrated SWAT model has been used. Figure 12 shows the variation of annual discharge for both RCP4.5 and RCP8.5 scenario.

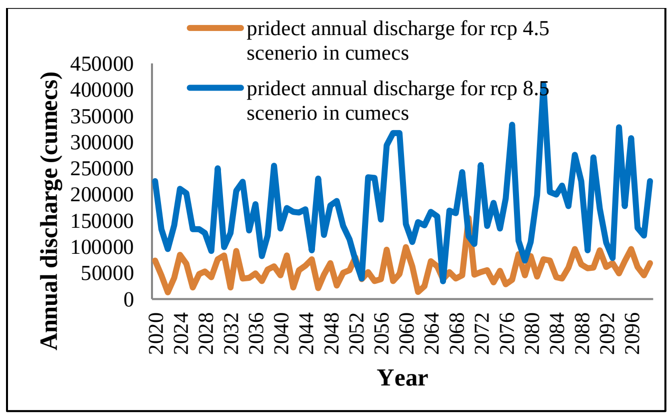

Figure 12: Variation of annual discharge for RCP 4.5 and RCP 8.5.

Figure 12, indicates the variations in annual runoff values for both RCPs. The maximum annual discharge for RCP 4.5 is 154738.19 m^3/sec in the year 2070 and minimum annual discharge is 12871.76 m^3/sec in the year 2022. The maximum discharge for RCP 8.5 is 409141.13 m^3/sec in the year 2082 and minimum discharge is 34045.94 m^3/sec in the year 2066. The estimated maximum daily discharge for RCP4.5 is lesser than the maximum daily discharge estimated RCP 8.5. In RCP 4.5 situation, the decade mean discharge for the RCP 4.5 scenario shows almost constant trend line up to mid-century, increasing trend line from 2060 (Figure 13). However in RCP 8.5 scenario initially that trend line decreases up to mid-century and from 2050 to 2070 increases and again draw down. It has increased then again up to end of century (Figure 14). So we can conclude that observing these trends variation in stream runoff may occur in coming future. Hence proper water shed management plans and further developmental activities is essential in Thunga river basin.

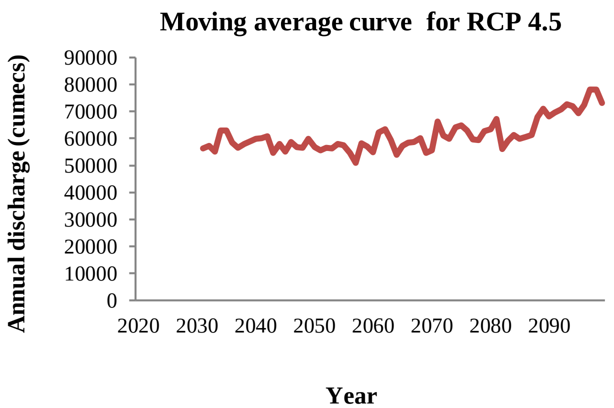

Figure 13: Moving average curve for RCP 4.5.

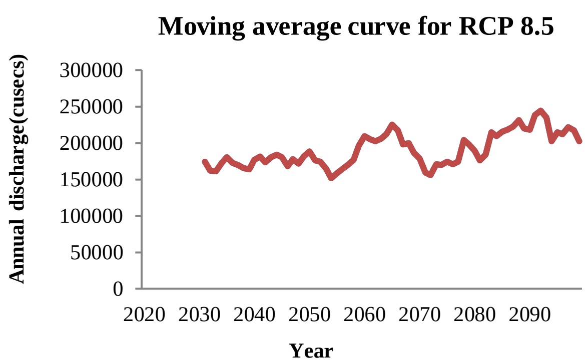

Figure 14: Moving average curve for RCP 8.5.

VI. CONCLUSION

A calibrated Soil and Water Analysis Tools –SWAT model (ARC-SWAT) was applied for analyze the hydrological variations under climate change scenarios in the Thunga river basin. The river discharge is heavily impacted by changing in the precipitation pattern. The changes in precipitation, temperature and river runoff in Thunga river basin in the early century future (2020-2050) and the late century future (2050- 2099) were investigated in the project study.

The results shows that the precipitation imbalance (1.0 to 2.5 m/yr) is about 21 % of total runoff in Thunga River basin up to Gajanur discharge gage station at present (1997-2015). By considering the Climate change effects, the temperature will increase by 0.95 °C for RCP4.5 and 2 °C for RCP8.5 for the early future (2020-2050), and increase 1.8 °C (RCP4.5) and 3.7°C (RCP8.5) at the late future (2050-2099), while the precipitation will increase 18.03 % (RCP4.5) and 54.28 % (RCP8.5) for the early future, and increase by 8.84 % (RCP4.5) and 59.03% (RCP8.5) for the late future over the Thunga river basin.

The Thunga river discharge is increases about 30.56 % for RCP4.5 scenario and 20.77% for RCP8.5 scenario at the early future and 53.30 % for RCP4.5 scenario and 59.22 % under RCP8.5 scenario at the late century. In general for the period 2020 to 2099 The runoff was predicted for RCP 4.5 using SWAT model indicate the % increase in runoff is 24.56.The runoff was predicted for RCP 8.5 using SWAT model indicate the % increase in runoff is 57.11.

The results revels that runoff is going to increase in study area in near future, thus indicating the essential need to focus on extreme events like floods to avoid the negative hydrological effect (such as property loss, increases the salinity of soil etc.,) on the downstream side of the Thunga river basin. Hence appropriate proper watershed and water resource management plans are required.

VII. ACKNOWLEDGEMENT

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