Assessment of climate change impacts on the hydrological components of Ghataprabha sub-basin in southern India

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Abstract : Over the coming, the changing climate is likely to put pressure on the water resources of Ghataprabha sub-basin in southern India., This is the first attempt to assess the impact of climate change on surface water resources. Soil and Water Assessment Tool (SWAT) was used to carry out this study. Manual calibration and validation of the model was done for the period of 1995-2005 using observed discharge data. R^2 and NSE were used as model evaluation criteria which showed the satisfactory model performance, with R^2 and NSE of 0.69 and 0.60 during calibration and 0.61 and 0.50 during validation. To study the impact of climate change on hydrology of the sub-basin, data from HadRM3 regional climate model under A2 and B2 scenario for the period of 2070-2100 were used. Temperature analysis indicated the warming of the study area. Annual and monthly hydrological components are likely to increase for the selected climate change scenarios compared to the baseline scenario with the higher values corresponding to the A2 scenario.

Key words: *Climate change, Ghataprabha sub-basin, Soil and Water Assessment Tool, Southern India, Water balance components.*

I. INTRODUCTION

Population growth, changes in land use pattern and climate change driven by global warming have threatened the dynamic balance between water supply and water use (Giacomoni et al., 2015). As humans have direct access to the surface water, it has been extensively exploited, degrading its quality and quantity, making it a scarce source. Apart from unmanaged human exploitation, climate change poses threat on the water resources. Though there are uncertainties associated with climate change, they possess severe threat across low latitude and developing countries because of their low capacity to adapt (Gosain et al., 2006; Surinaidu et al., 2013). Furthermore, climate change has direct impact on surface water resources (Gosain et al., 2006). Many researchers across the globe (Frederick et al. 1997; van Dam 1999; Lettenmaier et al. 1999; Gleick 2000; National Assessment Synthesis Team “Climate” 2000; Inter-Government Panel on Climate Change 2001; Arora and Boer 2001) have attempted to study the impact of climate change on water resources on global, regional, and local scale with a common aim of developing strategies to cope with it.

Ghataprabha River has been one of the major sources of water supply in the sub-basin. Increasing population, urbanization and unplanned agricultural activities has degraded water quality of the river lowering the water availability. Over past few years, this sub-basin has been experiencing water shortage for domestic as well as irrigation sectors (GOK, 2008). Further, drying up of most surface water sources during summer, water supply for both domestic and irrigation purposes has been a major problem. In addition, the south-west monsoon in India is capricious further intensifying the uncertainty in ensuring in the right quantity of water at the required time. Climate change could further worsen the water shortage problem in the basin. Various studies were dealt assessing impact of land use change on the water quality (Purandara et al., 2011 and Hiremath et al., 2015). Also, a research report by National Institute of Hydrology, 1997 presents the groundwater modeling in this area. However, no documents are available on the study of climate change on the surface water resources for this area which provides me an opportunity to study the impact of climate change on the surface water dynamics of the sub-basin.

Various watershed models (agricultural non-point source (AGNPS) (Young et al. 1987), Hydrological Simulation Program-Fortran (HSPF), MIKE SHE (Abbott et al. 1986), and Soil and Water Assessment Tool (SWAT)) have been practiced to study the impact of climate change on water resources as an alternative management strategies to address the water resources problems (Shi et al., 2015). These models try to incorporate the spatial heterogeneities of watershed such as topography, land use, soil, and climate to simulate hydrologic process.

SWAT was used to carry out this study. Wibel in his report has illustrated some of many watershed scale models based on the peer- reviewed journal articles in international journals database. His study clearly indicates the SWAT is the most widely adopted model with highest number of peer reviewed journals.

II. STUDY AREA

Ghataprabha, one of the sub-basins of mighty Krishna Basin shown in Figure 1, extend from 15° 45' N and 16° 25' N in latitude and 74° 00' E and 75° 55' E in longitude. The catchment area of this sub-basin accounts for 8829 km2, out of which 6815.988 km2 (77.2%) lies in Karnataka and rest 2013.012 km2 (22.8%) lies in Maharashtra. The annual rainfall in the study area is 650 mm on an average. Southwest monsoon contributes about 65 % of total precipitation, remaining 35% being contributed from northeast monsoon. The climate of sub basin is dominated by hot summer and a mild winter. Summer usually starts in mid of February and ends on May, April being the hottest month with the average daily maximum temperature of 37.5^0 C and minimum of 19.5^0 C. Similarly, the winter commence in November lasting to mid of February with December being the coldest month with mean daily maximum and minimum temperature of 29.3 ^{0}C and 19.3^{0}C respectively. According to National Water Development Agency (NWDA) report, 1991 agriculture covering 63.7% of the basin area tends to be the largest water consumer. Details of land use for the study area are presented in the table 1 below. The dominating soil features in this basin are black soil, blend of black, red soil and lateritic soil.

Table 1: land use pattern of the Ghataprabha sub-basin (source: NWDA report, 1991).

Description	Spatial coverage
Net area sown	63.7
Forest	12.6
Current fallows	8.7
Nonagricultural use	4
Barren land	3.9
Culturable waste land	2.7
Permanent pastures and other grazing land	2.3
Other fallows	1.8
Land under miscellaneous crops and trees	0.3

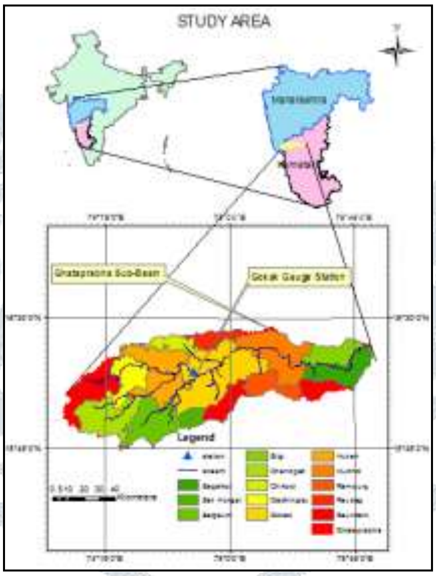

Figure 1: location of study area

III. METHODS AND MATERIALS

3.1 Description of SWAT:

The Soil and Water Assessment Tool (SWAT) was developed by the USDA-ARS (Arnold et al., 1991; Arnold and Fohrer, 2005; Neitsch et al., 2005; Gassman et al., 2007; Neitsch et al., 2011). SWAT is a basin scale, physically based, semi distributed hydrological model that emphasizes on surface processes. Usually, it operates by taking a single watershed, breaking it into multiple sub-basins. These sub-basins are further broken into numerous unique combinations of land use, soil and slope, known as Hydrologic Response Units (HRUs). Flugel 1995 describes HRUs as homogeneous spatial units having similar geomorphic and hydrologic properties.

In SWAT, calculations are carried out for each HRU, which are then extended to sub-basin outlet based on the percentage of HRU area lying within that sub-basin.

Although, SWAT has been developed in US, its use has not been limited to US only; it has been adopted in various hydrological projects worldwide. One example being the European Commission's (EC) Climate Hydrochemistry and Economics of Surface water Systems (CHESS) project (CHESS, 2001). Details on SWAT and its use in modeling can be found on its website (https://www.card.iastate.edu/swat_articles). For the easy use of SWAT, a GUI has been developed for ArcGIS known as Arc-SWAT. It helps in preparing all the necessary input data required for the model to run, such as watershed delineation, land use and soil map over laying to define HRUs, defining weather parameters etc. To carry out this study, Arc-SWAT ver. 2012 was used.

Land use management, soil profile, weather parameters, hydrology, plant growth, nutrients and stream routing are the major model components.

In SWAT, weather generator derives weather data from the station nearest to the centroid of each sub basin. Calculated hydrologic balance components (precipitation, surface runoff, infiltration, evapotranspiration, lateral subsurface flow, and return flow from the shallow aquifer etc.) per HRU are then, routed to the stream and then to outlet of sub -basins. SWAT uses different methods to calculate hydrologic water balance components. Variable storage or Muskingum routing equation is used to simulate channel routing.

Modified soil conservation services (SCS) is used to estimate surface runoff. This method takes into consideration of soil properties, land use and antecedent moisture condition to calculate runoff. Groundwater flow contributing to streams is calculated by routing shallow water storage to stream (Arnold and Allen 1996).

Penman-Monteith (Monteith, 1965), Priestly-Taylor (Priestly and Taylor, 1972), or Hargreaves (Hargreaves et al., 1985) methods are used to calculate evapotranspiration. SWAT also contains a number of subroutines to handle both forest and agricultural areas. The groundwater processes used by SWAT are a simplified lumped-parameter approach.In this study, Hargreaves method was used because of the lack of solar radiation data.

The land phase of the water balance calculated by SWAT per HRU is shown in equation 1 with units in mm of H_2O.

$$SW_t = SW_o + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \qquad (1)$$

Where, SWt =final soil water content (mm H2O); SW0=initial soil water content on day i (mm H2O); t=time (days);Rday=amount of precipitation on day i (mm H2O); Qsurf=amount of surface runoff on day i (mm H2O); Ea=amount of evapotranspiration on day i (mm H2O); wseep =amount of water entering the vadose zone from the soil profile on day i (mm H2O); and Qgw =amount of return flow on day i (mm H_2O).

3.2 Data Products:

Prior to the model setup, necessary data should be in hand.Data requirement for the SWAT can be broadly categorized into spatial and non-spatial data. The spatial input data includes DEM, soil properties, and land use/land cover map. The following data sets for the Ghataprabha sub-basin were prepared for the study: (1) digital elevation model (DEM) with a spatial resolution of 90 m obtained from the Shuttle Radar Topography Mission (SRTM) website (http://srtm.csi.cgiar.org);land-use map of 1km grid resolution for 2005-06 (University of Maryland Global Land Cover Facility, USA, 2005-06)**;**(3) soil map at a scale of 1:5,000,000(FAO, 1995**)**as presented in figure 2 and(4) daily climate data from 1995 to 2005 provided by IMD, Pune (non-spatial data).

3.3 Climate change scenarios data:

To assess the climate change impact on hydrological components of the sub-basin, data from Hadly Regional climate model (HadRM3) were taken. The characteristics of climate from the model simulations used by the Hadley Centre models are outcomes of a set of emission storylines created by the Intergovernmental Panel on Climate Change (IPCC, 2000). The model design was based on the UK climate impact program, which has been linked to the IPCC story lines.Data from Hadley Regional Model 3 (HadRM3) are of a smaller scale, with grid resolution of 50km by 50km.The daily weather parameters are generated for two extreme periods: baseline (1960-1990) and end century (2070-2100). In this case, IPCC A2 and B2 scenarios were used to assess climate change impact on the surface water hydrology of the basin.

3.4 SWAT set up and execution:

Arc-SWAT processes the Digital Elevation Model (DEM) and automatically delineates the watershed and sub-basins, generates the stream network, outlet and monitoring points for a given threshold value. In this case, 21 sub-basins and 286 HRUs were delineated. Land use, soil and slope map were overlaid to generate HRUs with the threshold value of 10%. General practice is to define a threshold value of 5-10% during HRUs generation to improve the computational efficiency by avoiding smaller HRUs. (Starks and Moriasi 2009).

3.5 Sensitivity analysis:

Sensitivity analysis is an approach to study the effect of rate of change on outputs with respect to change in inputs. Sensitivity analysis is done prior to calibration to identify the sensitive parameters. It is necessary to identify key parameters and the parameter precision required for calibration (Ma et al., 2000). However, in this study, six parameters related to stream flow which have been most widely used in calibration purpose by various researchers (Abbaspour et al. (2007); Ahl et al.(2008); Behera and Panda (2006); Shanti et al. (2002); chin et al. (2009); chu et al. (2004) etc., were considered for calibration propose. Sensitive parameters considered for calibration purpose are presented in Table 2.

3.6 Calibration and validation:

Calibration is a meticulous effort of increasing model performance by reducing uncertainties associated to model prediction by changing the parameters within an allowable range of change. Model calibration should be done carefully, varying input parameters with in their uncertainty range, to match the model predictions with the observed values or field measurements.

The SWAT model was calibrated and validated by using stream flow measured at the Gokak gauge station. The observed data were split into two sets; one for calibration (1986–1995) and other for validation (1996–2005) purposes.

In this study, both the manual and automated calibration processes were carried outwith R^2 and NSE as a model evaluation criteria.The R^2 value ranges from 0 to 1, with 0 indicating no correlation and 1 with perfect correlation. NSE is a measure of how well is the plot of simulated versus observed data fits the 1:1 line. NSE can range between -∞ to 1.

A perfect fit between the simulated and observed data is indicated by an NSE value of 1. NSE values between 0.0 and 1.0 are usually considered as an acceptable values (Moriasi et al. 2007).

NSE is computed using the equation 2.

$$NSE = 1 - [\frac{\sum_{i=1}^{n}(Q_i^{obs} - Q_i^{sim})^2}{\sum_{i=1}^{n}(Q_i^{obs} - Q_i^{mean})^2}] \qquad (2)$$

Where Q_i^{obs} is the i^{th} observation, Q_i^{sim} is the i^{th} simulation value, Q_i^{mean} is the mean of the observed value and n is the total number of observation.

Automated calibration, in this case, was carried out using SUFI-2 (Abbaspour et al., 2004) algorithm through SWAT-CUP program. Similarly, Manual Calibration with the focus on Nash-Shutcliffe efficiency (NSE) and R^2(Coefficient of Determination) to evaluate monthly SWAT output has been addressed by various authors in their literatures (Coffey et al., 2004; Santhi et al., 2001; Cao et al., 2006; Nair et al., 2011 and Moriasi et al. 2007). Table 2 tabulates the list of parameters used in calibration with their initial value, adjusted value and method of adjustment.

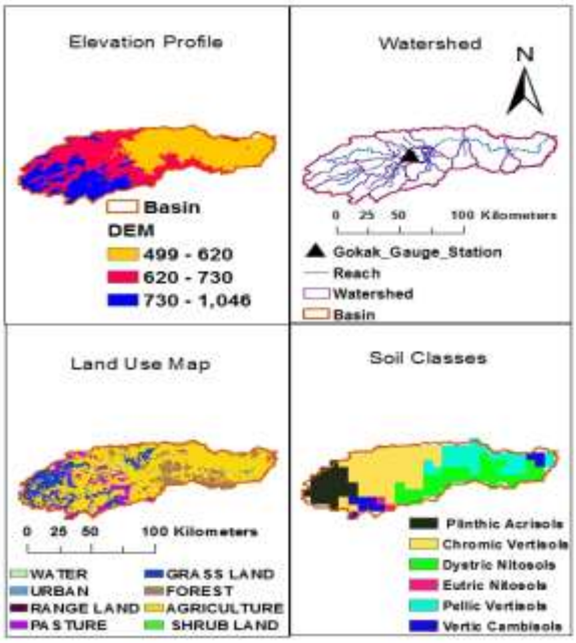

Figure 2: basic spatial and weather data input

Table 2: Parameters used in calibration and their adjustment values

Parameter	**Initial value**	**Adjusted value**	**Specification**
CN_2	Default	-20%	Multiplication/ relative change ( ) ↓
ESCO	0.95	1	Replaced (↑)
SOL_AWC	0.95	1	Replaced (↑)
GW_DELAY	31 days	90 days	Replaced (31 to 90 days) (↑)
ALFA_BF	Default	0.5	Replaced (reduction)

IV. RESULTS OF CALIBRATION AND VALIDATION:

Engel et al., (2007) highlights the absence of absolute criteria to evaluate the model performance till the date. However, for a model to be considered as fit for application on a monthly time scale, NSE and R^2 value should exceed 0.5 (Moriasi et al., 2007; Shanti et al. 2001).

Hence, the R^2 and NSE value of 0.691 and 0.60 during manual calibration and 0.61 and 0.50 during manual validation describes the satisfactory performance of the model. However, automated calibration did not result satisfactory calibration as presented in Table 3.

Table 3: Results illustrating values for objective functions during the period of calibration and validation

Objective Function	Manual		Automatic	
	Calibration	Validation	Calibration	Validation
R^2	0.691	0.61	0.58	-
NSE	0.60	0.50	0.42	-

Figure 3 and 4 shows the plot of observed versus simulated discharge for the virgin model run (prior to calibration). It can be seen that the discharge is overestimated by the model, indicating the need of calibration.

Figure 5 graphically displays the plot of observed versus simulated discharge data during the period of manual calibration (1995-2000) and validation (2001-2005).

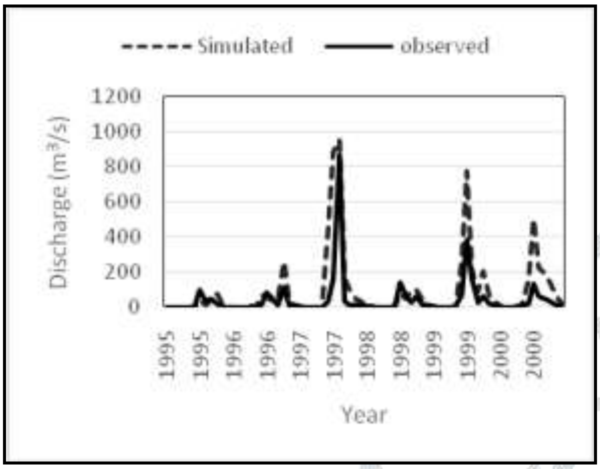

Figure 3: comparison of observed and simulated discharge data before calibration

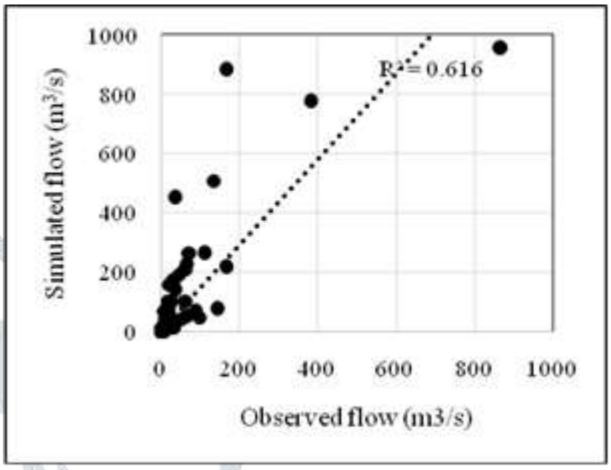

Figure 4: Scatter plot of simulated vs. observed discharge

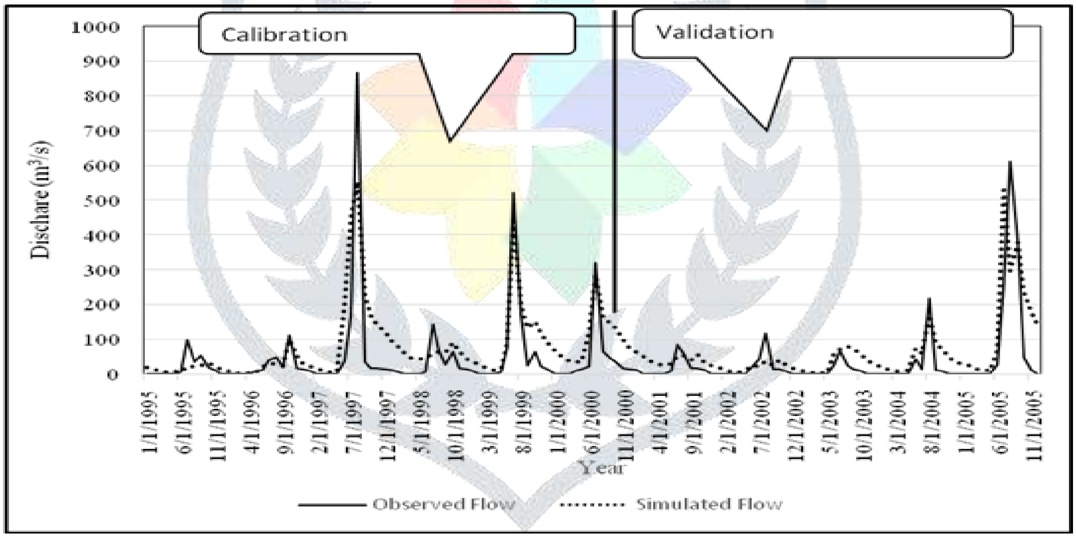

Figure 5: Observed versus simulated flow during the period of calibration and validation

4.1 Hydrological components:

It is of utmost importance to analyze and quantify different elements of hydrological processes occurring in the study area in order to deal with water management issues. After model calibration, various hydrological components: actual evapotranspiration, groundwater recharge, stream flow and water yield were analyzed for the sub-basin. Annual hydrological components are tabulated and displayed in a graphical forms. Table 4 tabulates the average annual hydrological components for the area during the simulation period (1995-2005) and figure 6 represents them graphically. Model yielded evapotranspiration ranging between 395 to 500mm per year for both dry and wet spell of precipitation. For the dry spell (low average annual precipitation), about 50 to 75% of average annual precipitation contributed for the evapotranspiration. In contrast, during the wet spell, only 20-50% of average annual rainfall accounted for the evapotranspiration. Water yield and groundwater recharge showed increasing and decreasing trend in relation to the nature of precipitation. During the simulation period, 7 to 31% of average annual rainfall contributed to the groundwater recharge which is in agreement with the 12–37% of average annual precipitation mentioned by Varalakshmi et al. 2014 in their paper for this region.

Monthly hydrological components is tabulated in table 5 and graphically represented in figure 7. Monthly hydrological components seem to be following a seasonal trend with the higher values during monsoon season (June to October). However, groundwater recharge didn’t show the direct fluctuation with precipitation. As shown in figure 7, though the highest rainfall has occurred in the month of July, with an average value of 279.12 mm, groundwater recharge attained a maximum valueof 19.47 mm in the month of October, showing a delay in groundwater recharge. Groundwater recharge is the amount of water that passes unsaturated zone to contribute to saturated zone. As basin aquifer is overlaid by low permeable soil, aquifer showed a delayed response to the precipitation in gaining peak recharge. Other hydrological components, ET and water yield showed direct fluctuation with the rainfall.

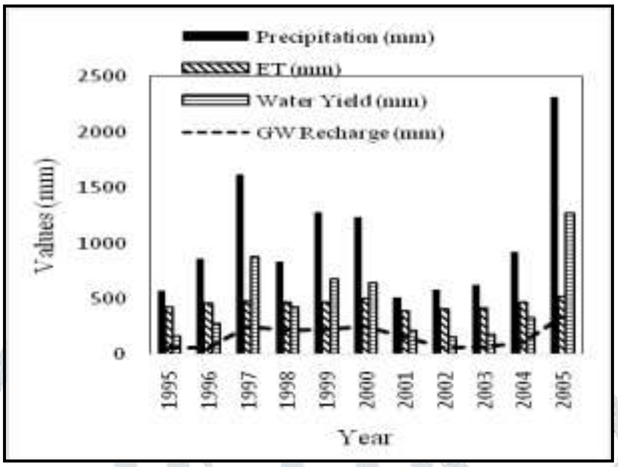

Figure 6: Average annual values of hydrological components for the Ghataprabha sub-basin during the period of calibration and validation (1995 -2005)

Table 4: Average annual values of hydrological components for the Ghataprabha sub-basin for the period of 1995 -2005

Year	Precipitation (mm)	ET (mm)	Water Yield (mm)	GW Recharge (mm)	ET (% of precipitation)	GW Recharge(% of precipitation)
1995	575.02	429.18	163.57	59.36	74.63	10.32
1996	859.29	461.07	280.98	59.47	53.65	6.92
1997	1616.76	484.37	876.63	253.24	29.95	15.66
1998	837.95	476.07	425.21	213.94	56.81	25.53
1999	1281.90	471.31	677.94	226.21	36.76	17.64
2000	1238.37	504.06	644.57	249.66	40.70	20.16
2001	515.291	396.36	223.45	154.64	76.92	30.01
2002	580.72	414.90	162.42	62.80	71.44	10.81
2003	630.36	417.19	183.33	67.63	66.18	10.72
2004	919.61	474.33	333.80	100.47	51.58	10.92
2005	2316.59	522.78	1275.94	337.24	22.56	14.55

Table 5: Average monthly hydrological components for the Ghataprabha sub-basin during the period 1995 -2005

Month	Precipitation (mm)	ET (mm)	Water Yield (mm)	Gw Recharge (mm)
Jan	0.85	9.37	12.13	12.36
Feb	1.46	15.46	7.85	10.01
Mar	3.30	71.70	5.83	9.77
Apr	21.63	34.23	6.17	8.37
May	51.69	32.08	10.18	7.65
Jun	183.73	47.59	35.58	6.98
Jul	279.12	54.30	103.78	11.34
Aug	191.23	52.84	91.67	18.05
Sep	146.75	46.91	69.45	19.01
Oct	136.67	54.95	74.08	21.32
Nov	14.09	26.48	37.36	19.47
Dec	3.190	13.26	22.93	17.86

4.2 Climate change scenario analysis:

Table 6 represents the long term average precipitation for BL, B2 and A2 scenarios. Long term average annual precipitation indicates increased precipitation for both A2 and B2 scenarios with respect to BL. Thirty years average annual precipitation shows an increase of 201.27 mm for A2 scenario compared to 169.02 mm for B2 scenario.Average increment in precipitation is 21.92 percent and 19.02 percent for A2 and B2 Scenario respectively.

Table 6: Long term average precipitation value for different climate change scenarios

Scenarios	Long term average Precipitation values (mm)
BL	1014.571
A2	1215.846
B2	1183.557

Figure 8 shows average monthly precipitation variation for BL and GHG scenario. Long term average monthly precipitation shows a seasonal variation in precipitation. Higher values of precipitation is expected during monsoon season (June to September), July receiving the highest precipitation for both A2 (301.57 mm) and B2 (307.59 mm) scenarios compared to base line scenario (258.44 mm).

Based on data analysis, it is expected to rise mean annual average, maximum and minimum temperature for B2 scenario by 2.26 ^{0}C, 2.31^{0}C and 1.76^{0}C (10.50 %, 8.12% and 14.15 %) respectively, in respect to the BL scenario. Similarly, for A2 scenario, it is expected to rise average annual average, maximum and minimum temperature by 3.66 ^{0}C, 3.33 ^{0}C and 4.02 ^{0}C (14.48%, 11.16% and 19.55%) respectively, with respect to the BL scenario. Figure 9, 10 and 11 graphically represents the average, maximum and minimum temperature for the GHGs scenarios respectively.

Figure 12 shows the graphical representation of long term mean monthly average temperature for BL, B2 and A2 scenarios, which clearly indicates the seasonal variation in the temperature, high during summer (February to May), moderate during rainy season (June – September) and low during winter season (October to January).

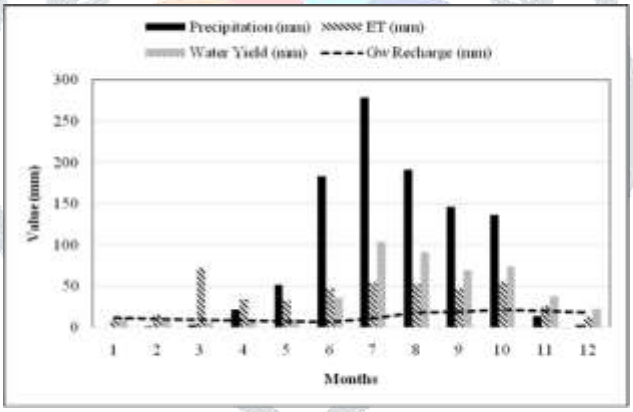

Figure 7: Average monthly hydrological components for the Ghataprabha sub-basin during the period of calibration and validation (1995 -2005)

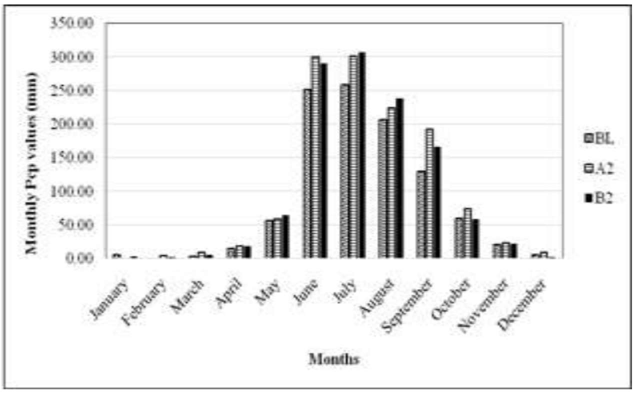

Figure 8: Long term average monthly precipitation for Base line and GHG scenarios

Thirty years annual average values of hydrological components are tabulated in table 7 which imparts the picture of increase in values for hydrological components.

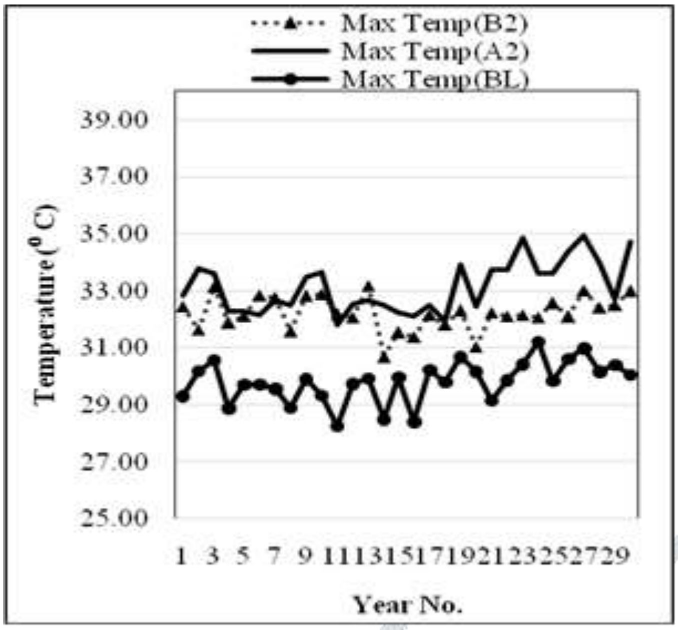

Figure 9: Annual Maximum Temperature for A2, B2 and BL scenarios

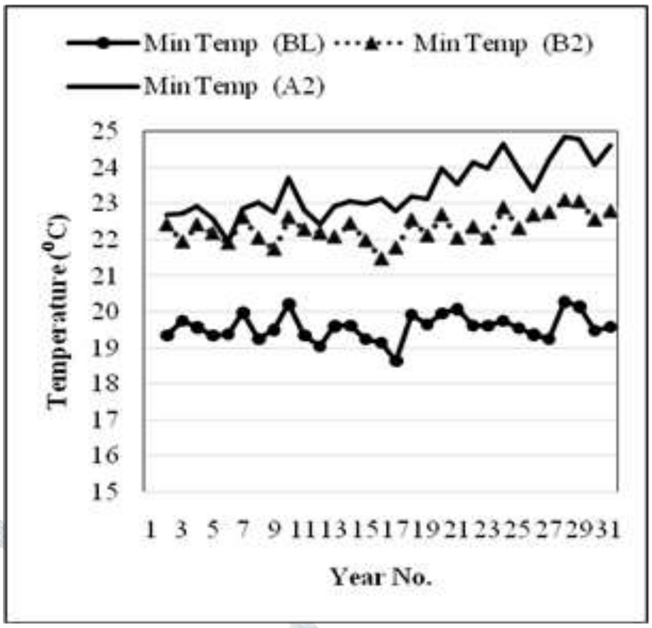

Figure 11: Annual Minimum Temperature for A2, B2 and BL scenarios

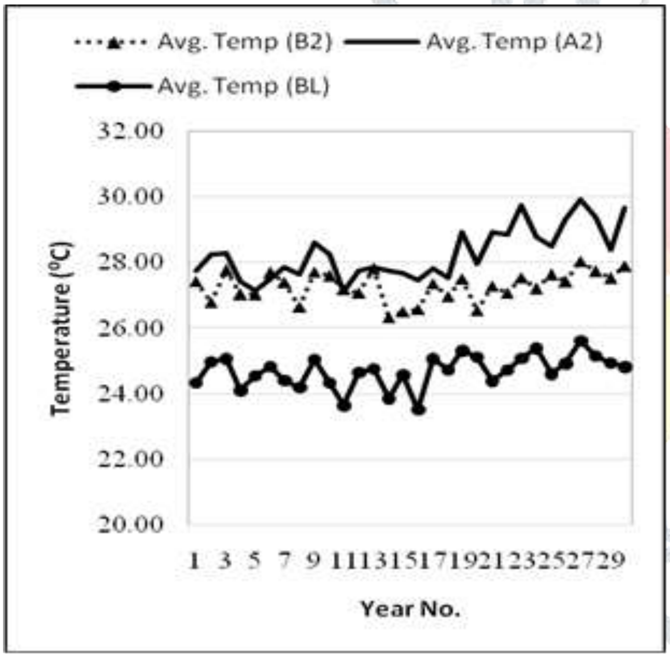

Figure 10: Annual Average Temperature for A2, B2 and BL scenario

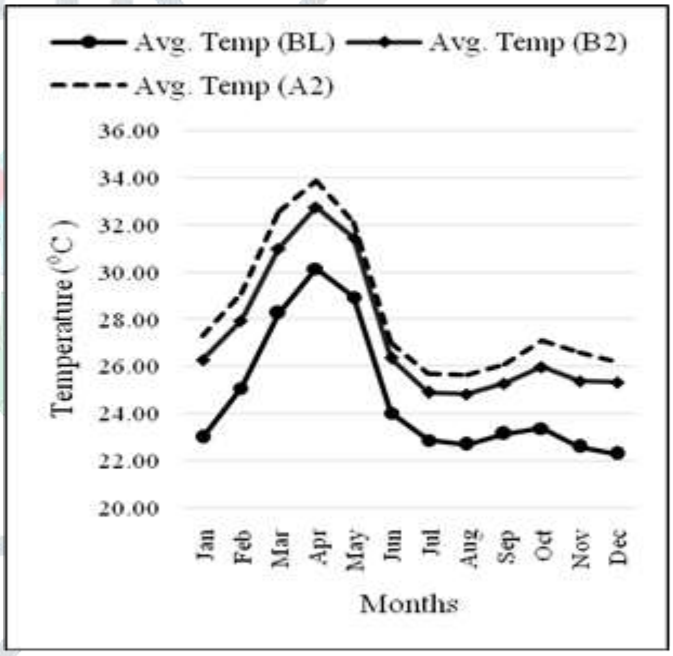

Figure 12: Long term mean monthly average, maximum and minimum temperature for BL, B2 and A2 scenario

Table 7: Values for long term average hydrological components values for BL, B2 and A2 scenario

Scenarios	Precipitation (mm)	ET (mm)	Water Yield (mm)	Gw Recharge(mm)
BL	1014.57	531.07	439.02	451.72
A2	1215.84	549.58	565.54	543.14
B2	1183.55	531.07	558.82	533.99

Figure 13 graphically represents the average long term annual hydrological components for BL, A2 and B2 scenarios, clearly indicating the increase in hydrological components

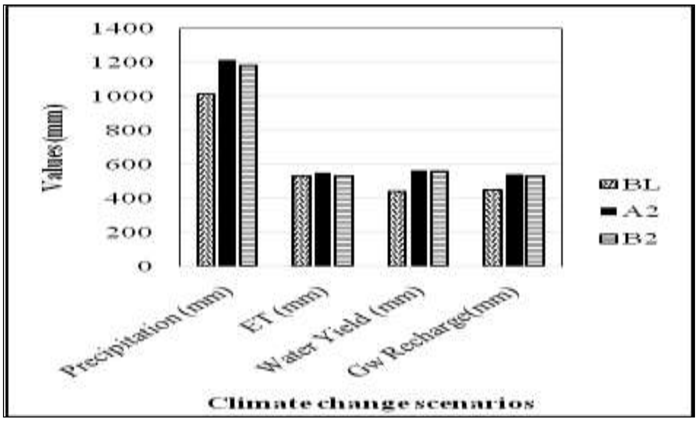

Figure 13: Average long term hydrological components for BL, B2 and A2 scenario

Percentage change in hydrological components for A2 and B2 scenarios with respect to BL scenarios are displayed in forms of graphs in figure 14. The input (precipitation) and the 30 years model output,the long term average ET, water yield and groundwater recharge for the A2 scenario are likely to increase by 21.94%, 10.49 %, 32.09% and 23.85% respectively. Similarly, for B2 scenario, average long term precipitation, ET, water yield and groundwater recharge are likely to increase by 19.20 %, 6.78%, 30.86% and 22.34 % respectively.

Some years are expected to show extreme highs and lows for the hydrological components. For A2 scenario, extremes of precipitation, ET, water yield and groundwater recharge can be expected to increase by 88.45 %, 34.17%, 124.78 % and 91.3 % respectively. Similarly, percentage increase in the extremes of precipitation, ET, water yield and groundwater recharge are 68.21 %, 26.39 %, 94.90 % and 75.73% respectively.

These increase in hydrological components in future compared to present is highly uncertain. These increase may be due to rise in temperature which in turn intensifies hydrological cycle. In simple word, expected hydrological changes in the basin are linked to changing climate. Similarly, it is likely to decrease the hydrological components in some years. Percentage decrease in precipitation, ET, water yield and groundwater recharge for A2 scenario are -21.32,-10.61, -19.46 and -26.21 respectively and -32.18, -13.58, -32.67 and -40.36 respectively for B2 scenario.

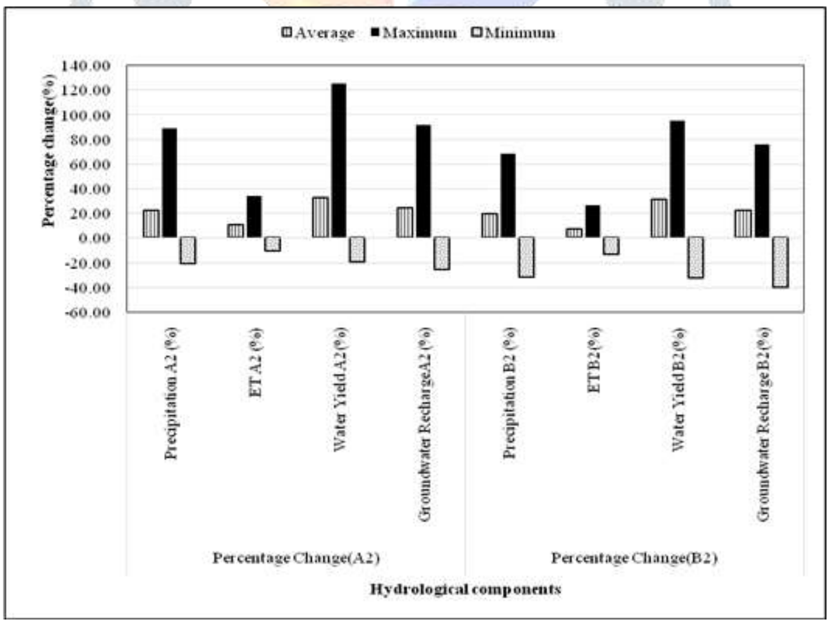

Figure 14: Long term percentage change in hydrological components for A2 and B2 scenarios with respect to BL scenario.

V. CONCLUSION:

Ghataprabha sub-basin is mainly dominated by the agriculture activities accounting for 63.7%. Ghataprabha River is the source of water supply in this sub-basin. Sustainable water resource management plays a vital role in maintaining the agriculture yield under the threat of climate change. Use of watershed models has increase to address the wide spectrum of water resource problems.In this case, the SWAT model was used to study the impacts of climate change on the hydrological components of the basin under IPCC scenarios A2 and B2. Prior to climate change scenario analysis, model was calibrated (1995-2000) and validated (2000-2005) using observed discharge data. Calibration and validation result indicates the good performance of the model.

Model run for climate change scenarios (A2 and B2) indicated the increased long term average ofhydrological components with higher increase corresponding to A2 scenario. Long term monthly hydrological components analysis also indicates the increased precipitation, evapotranspiration, water yield and groundwater recharge following a seasonal trend. Monsoon season (June to September) showed the higher increase in hydrological components.Based on this study, the basin is likely to experience the increased water in the future in contrast ot the present water deficiency. Incorporating the results of the present study in the long term water resource planning and developing adaptation strategies would be advantageous.

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