Spatial analysis of rainfall and FDC to assess the effect of climate change in Malaprabha basin

Yogendra B. E[1], Chinmayi B.Y[2]

1) Professor in civil Engineering, Malnad College of Engineering, Hassan - 573201, Karnataka
2) Research scholar, National Institute of Technology Surathkal, Karnataka.

Abstract – Flow characteristics of a stream and spatial analysis of rainfall data for the catchment are very essential for any water resource planning and management. Construction of Flow Duration Curve (FDC) at a section of the stream and spatial variation map of precipitation for the catchment of the stream provide the flow characteristics and spatial vitiation of rainfall data for any water resource project. Hydrologists are required to overcome the challenges posed by the lack of availability of historical rainfall and streamflow data in an ungauged river basin. The present investigation is carried out on Malaprabha river basin to assess the future streamflow and rainfall. Five downscaled General Circulation Models (GCMs) (GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC and NoerESM1-M) for four Representative Concentration Pathway (RCP) emission scenarios (RCP-2.6, RCP-4.5, RCP-6.0 and RCP-8.5) in each of the GCM models are considered for the future projection of the hydrometeorological variables (rainfall, maximum temperature, minimum temperature, solar radiation, humidity and wind speed). Calibrated and validated Soil Water Assessment Tool (SWAT) is used for the future projection of streamflows for the time period 2006-2085. Coefficient of determination (R2) and Nash-Sutcliffe Efficiency (NSE) are used to calibrate and validate the SWAT model for the Malaprabha basin by using observed streamflow data for the period of 1975-2015. FDCs are prepared for the projected streamflow are useful information for the management of water resources and to maintain the low flows during the dry season for the preservation of the ecosystem of the stream.

Keywords: **Flow Duration Curves (FDC), Soil Water Assessment Tool (SWAT), Coefficient of Determination (R^2) and Nash-Sutcliffe Efficiency (NSE).**

I. INTRODUCTION

Global warming and climate change is a critical issue all over the world as it has a negative impact on the ecology and human life. This study is conducted to understand the changes that may happen in surface runoff in future in Malaprabha River which is one of the major tributaries of Krishna River. The FDCs are the tool used to interpret the hydrological behaviour (Booker, 2012). The FDCs are used for the systematic understanding of the occurrence of high flows and low flows in the stream and to assess the probability of exceedance during the time duration of study. The FDCs provide both analytical as well as graphical information to understand the future and past variability in the flow.

Paired catchment data were analysed with consistent methods in a study (Brown et al., 2013) to assess the impact of forest cover change, in afforestation and deforestation experiments, on annual streamflow and FDCs. The results of the study indicate that it takes eight to twenty-five years for the full change in the forest cover to reach a new hydrological equilibrium in a catchment. Effect of forest cover change on high flow, low flow and zero flow was analysed by using FDCs.

Many researchers used FDCs for the study of water resource in various river basins, but there are limited research on the basins in south India. Narsimlu et al., (2013) used FDCs and SWAT in upper Sind River basin to assess the effect of future climate change. Pumo et al., (2013) used FDCs for the study of base flow in basins of southern Italy, Castellarin (2014) made an attempt to develop a relationship between magnitude and frequency of daily streamflows over a number of years for a given basin and modified the same for long-term FDCs. Nruthya and Srinivasa (2015) considered regional FDCs for the prediction of stream flow in an ungauged sub basin of Mahanadi basin. Atieh et al., (2015 and 2017) used artificial neural networks (ANN) and FDCs for the study of ungauged basin in Ontario, Canada; and the model was tested using historical streamflow records. In a study (Requena et al., 2018) functional multiple regression (FMR) is proposed for the construction of FDCs for 109 sites of hydrometric station network in the province of Quebec, Canada.

The specific objectives of the study:

(1) To know the probability of exceedance of low flow and high flow rates in the Malaprabha River basin for the time period 2006-2085. (2) To compare the flow duration curves derived from the various downscaled GCMs and to identify the most suitable FDC constructed for the study area. (3) To quantify the uncertainty in prediction of the future low and high flows. (4) To derive the spatial variability in the stream flow, using slope of the FDCs.

II. DESCRIPTION OF STUDY AREA

Malaprabha River is one of the major tributary of river Krishna. The basin lies between 14°58'48" - 16°14'13" latitudes and 74°12'25" - 76°6'28" longitudes. The river originates at Chorla Ghats of 792 m elevation and total length of Malaprabha River is about 306 km before confluences in river Krishna at Kapila Sangam of 488 m elevation in Bijapur District. The total catchment area of the Malaprabha basin is 11,549 km^2. The dam was constructed across the Malaprabha River near Munavalli, Saundatti taluk of Belagavi District and formed the Renukasagar reservoir, it is providing irritation water for 1,96,130 hectare of land. The soils of the basin found be red loamy soil and medium dark soil. The average yearly precipitation is around 2262 mm. The annual average of daily minimum and maximum observed temperature are 19.30 ^{0}C and 29.50 ^{0}C respectively. The annual average discharge at Khanapur gauge is 8989.45 m^3/sec.

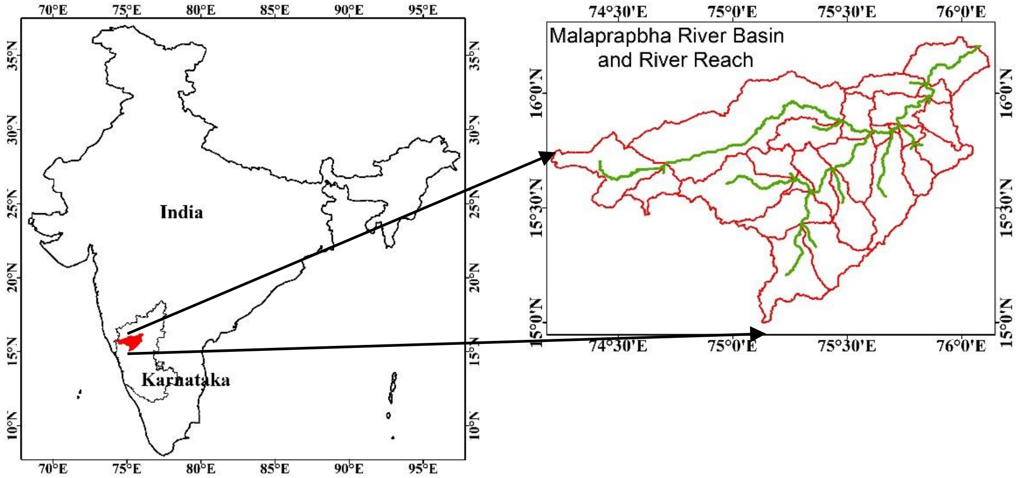


Figure-1. Malaprabha River basin in Karnataka, India

III. METHODOLOGY AND DATA USED

A DATA USED:

GCMs from Atmosphere Ocean (AO) are currently available at 0.50^0 grid for maximum-minimum temperature and precipitation. Downscaled future projected hydrometeorological data from the GCM models shown in Table-1, are used to generate the future discharge in the Malaprabha River using calibrated and validated SWAT of description given in Mengistu and Sorteberg (2011) in their study on sensitivity of streamflow to temperature.

Sl. No	Models	Name of the contributing Institute
1	GFDL-ESM2M	NOAA/Geophysical Fluid Dynamics Laboratory
2	HadGEM2-ES	Met Office Hadley Centre
3	IPSL-CM5A-LR	L'Institute Pierre-Simon Laplace.
4	MIROC	AORI, NIES and JAMSTEC
5	NoerESM1-M	Norwegian Climate Center

Table 1: List of GCMs mode considered in the present study

In the present study; five different downscaled GCM models used are given in Table-1. The future projected data for the time period 2006-2085 is used to construct the flow duration curves. The projected data has been divided into 4-time slices namely 2006-2025, 2026-2045, 2046-2065 and 2066-2085. Each time slices are consisting of four RCP emission scenarios (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5) are used for projecting the future hydrometeorological data based on the severity of the Greenhouse Gas (GHG) emissions due to both anthropogenic and natural causes.

B SWAT MODEL DISCRIPTION:

In this study, SWAT has been used to simulate hydrological processes of the study area for predicting daily streamflow. The SWAT model is basically a physical semi-distributed model that is capable of simulating streamflow, sediment and water quality parameters (e.g., nutrients, and pesticides), at various temporal (daily, monthly, and annual) scales in complex watersheds with varying soil, land use management and topographic conditions (Arnold and Fohrer, 2005; Neitsch et al., 2011). The model partitions a watershed into multiple subwatersheds, which are further subdivided into Hydraulic Response Units (HRUs) that are homogeneous in land cover, soil and management conditions. Runoff is predicted separately for each HRUs and routed to obtain the total runoff for the subwatershed, ensuring overall water balance. Simulation of hydrological processes of a watershed by SWAT is considered in two major divisions: (i) land phase of the hydrologic cycle, which controls the amount of water, sediment, nutrient and pesticide loadings to the main channel from each subwatershed, and (ii) water or routing phase of the hydrologic cycle which controls the movement of water, sediment and other pollutants through the channel network to watershed outlet. Gassman et al., (2007) provide an overview of SWAT development history, and summary of research findings in the literature based on the model, its key strengths and weaknesses. Further details on SWAT may be found from Neitsch et al. (2011).

SWAT model was calibrated and validated by considering land use land cover (LULC) data from national remote sensing centre (NRSC) of government of India, soil map from food and agriculture organisation (FAO), digital elevation model (DEM) of shuttle radar topography mission (SRTM) from United States Geological Survey (USGS), daily hydrometeorological data from Indian meteorological department (available at 0.50 grid) and monthly mean streamflow data from Water Resources Development Organisation (WRDO) of government of Karnataka.

IV. RESULT AND DISCUSSION

A Construction of flow duration curves.

Calibrated and validated SWAT model is used to estimate the projected stream flow of Malaprabha River basin by giving hydrometeorological data downscaled and projected from five GCMs model (rainfall, maximum temperature, minimum temperature, solar radiation, wind speed and humidity) as input into the SWAT model by keeping all other input data same. In the present study five GCMs model (GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC and NoerESM1-M) which are presented in the Table-1, and four RCP emission scenarios (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5) for each of the GCMs model are considered as separate input into the SWAT model. FDCs for the entire Malaprabha River basin for RCP 2.6 presented in Figure-2, for RCP 4.5 presented in Figure-3, for RCP 6.0 presented in Figure-4 and for RCP 8.5 presented in Figure-5 are corresponding to data of all five GCMs (GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC and NoerESM1-M) and for the time period 2006-2085. In the FDCs Y-axis indicates the projected stream outflow in m^3/s and X-axis gives the percentage of exceedance. Steep slopes in the curve indicate that there is a sudden variation in the stream flow due to the high intensity and short duration rainfall in the study area. Large change in the streamflow is observed in the study corresponding to the low and high percentage of exceedance, less variation in the discharge is observed corresponding to the moderate percentage of exceedance.

The FDCs of Malaprabha River basin, presented for RCP 2.6 in Figure-2, indicates that GCM models HadGEM2-ES and IPSL-CM5A-LR slightly over predicts high flows and remaining three GCM models give similar projections. The average simulated high flow is 376 m^3/s. Observed highest stream flow rate in the study area is 650 m^3/s corresponding to the 10% exceedance for the entire projected time period (2006-2085) for GCM HadGEM2-ES. Observed low flow rate is 30-50 m^3/s with 70% exceedance in the basin for the period 2006-2085. The details are presented in the Table-2.

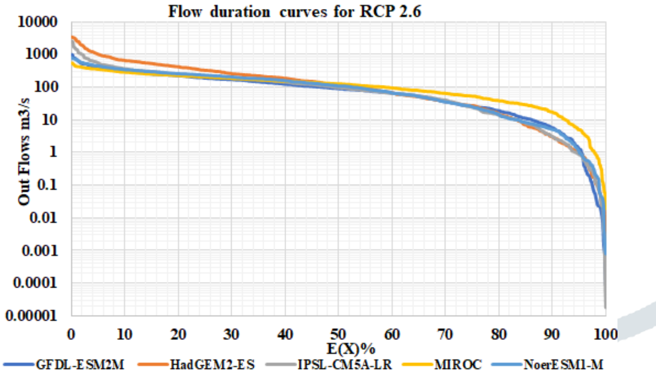


Fig. 2. Flow duration curve for RCP 2.6 for year 2006-2085

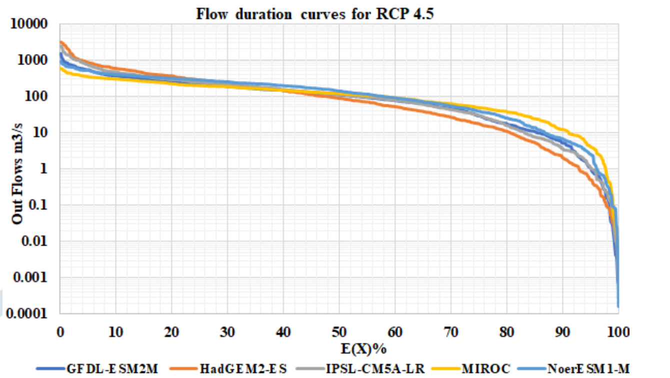


Fig. 3. Flow duration curve for RCP 4.5 for year 2006-2085

The FDC Malaprabha basin is presented for RCP 4.5 in Figure-3 infer that HadGEM2-ES are slightly over predicted for high flows and remaining four GCM models are projected similar result. The average simulated high flow could be 432m^3/s. Observed highest stream flow rate in the study area is 600 m^3/s corresponding to the 10% percentage of exceedance for the entire projected time period (2006-2085) for GCM HadGEM2-ES. Observed low flow rate is 100 m^3/s with 70% percentage of exceedance in the Malaprabha sub basin for the period 2006-2085 are presented in the Table-3.

Table 2: Percentage of exceedance for RCP 2.6

GCM Models	Percentage exceedance (%) for RCP 2.6				
	10%	30%	50%	70%	
GFDL-ESM2M	300	150	100	50	Outflows in m^3/s
HadGEM2-ES	650	280	110	50	
IPSL-CM5A-LR	350	175	100	50	
MIROC	280	150	100	50	
NoerESM1-M	300	175	90	30	

Table 3: Percentage of exceedance for RCP 4.5

GCM Models	Percentage exceedance (%) for RCP 4.5				
	10%	30%	50%	70%	
GFDL-ESM2M	380	180	180	100	Outflows in m^3/s
HadGEM2-ES	600	230	120	100	
IPSL-CM5A-LR	480	230	150	100	
MIROC	300	180	150	100	
NoerESM1-M	400	260	150	100	

The FDCs for the basin for RCP 6.0 presented in Figure-4 shows that HadGEM2-ES and IPSL-CM5A-LR slightly over predicts high flows and the remaining four GCM models projected similar result. The average simulated high flow is 448 m^3/s. Observed highest stream flow rate in the study area is 600 m^3/s corresponding to the 10% exceedance for the entire projected time period (2006-2085) for GCM HadGEM2-ES. Observed low flow rate is 75 m^3/s with 70% exceedance for the period 2006-2085. The details are presented in Table-4.

The FDCs for the basin for RCP 8.5 is presented in Figure-5 shows that MIROC slightly over predicts for high flows and remaining four GCM models projected similar result. The average simulated high flow is 444 m^3/s. Observed highest stream flow rate in the study area is 680 m^3/s corresponding to 10% exceedance for the entire projected time period (2006-2085) for GCM HadGEM2-ES. Observed low flow rate is 40 m^3/s with 70% exceedance for the period 2006-2085. The details are shown in Table-5.

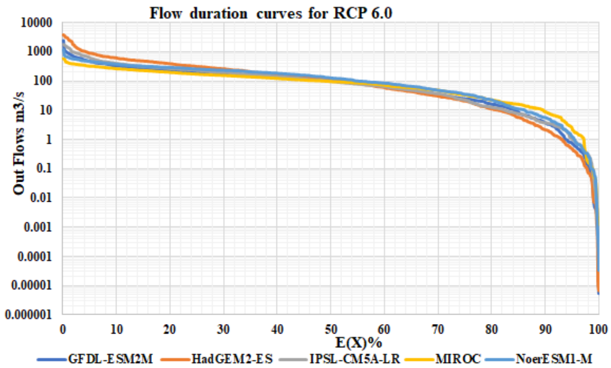


Fig. 4. Flow duration curve for RCP 6.0 for year 2006-2085

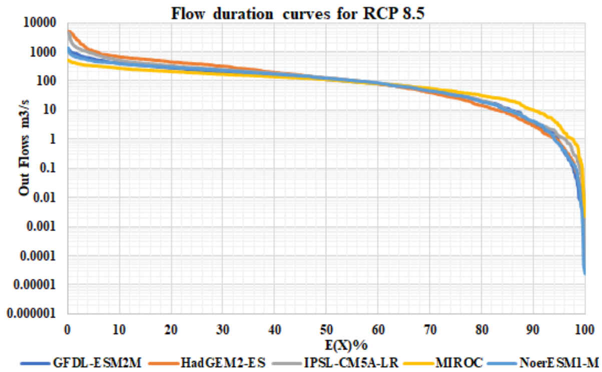


Fig. 5. Flow duration curve for RCP 8.5 for year 2006-2085

Table 4: Percentage of exceedance for RCP 6.0

GCM Models	Percentage exceedance (%) for RCP 2.6				
	10%	30%	50%	70%	
GFDL-ESM2M	300	150	100	75	Outflows in m^3/s
HadGEM2-ES	600	290	100	75	
IPSL-CM5A-LR	400	150	100	75	
MIROC	230	120	100	75	
NoerESM1-M	300	150	120	75	

Table 5: Percentage of exceedance for RCP 8.5

GCM Models	Percentage exceedance (%) for RCP 4.5				
	10%	30%	50%	70%	
GFDL-ESM2M	410	210	110	40	Outflows in m^3/s
HadGEM2-ES	680	350	110	40	
IPSL-CM5A-LR	500	200	110	40	
MIROC	230	150	100	40	
NoerESM1-M	400	200	110	40	

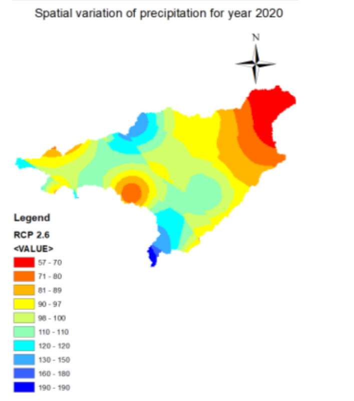
B. Spatial variation maps of precipitation:

The special variation of the annual intensity of the precipitation for the downscaled and future projected for the years 2020, 2040, 2060 and 2080 for all four scenarios (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5) of the GFDL-ESM2M GCM model of 0.5^0 grid resolution data are prepared as a sample for the whole study area of Malaprabha basin by considering Inverse Distance Weighting (IDW) method are presented in the Figure-6(a) to Figure-6(p). The spatial distribution map of rainfall is useful for the visually distinguish between the high, moderate and low rainfall intensity in the study area regions for the purpose of future systematic water resource management for the irrigation and other water supply management.

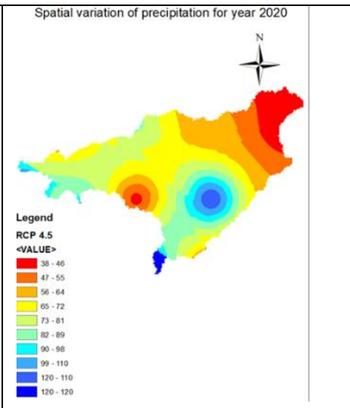
For the future projected year 2020 for RCP 2.6 is between 57-190 mm/day is presented in Figure-6 (a), for RCP 4.5 is between 38-120 mm/day is presented in Figure-6 (b), for RCP 6.0 is between 71-240 mm/day is presented in Figure-6 (c), for RCP 8.5 is between 75-290 mm/day is presented in Figure-6(d). For the future projected year 2040 for RCP 2.6 is between 66-210 mm/day is presented in Figure-6(e), for RCP 4.5 is between 58-180 mm/day is presented in Figure-6(f), for RCP 6.0 is between 58-180 mm/day is presented in Figure-6(g), for RCP 8.5 is between 74-300 mm/day is presented in Figure-6 (h). For the future projected year 2060 for RCP 2.6 is between 89-280 mm/day is presented in Figure-6(i), for RCP 4.5 is between 80-250 mm/day is presented in Figure-6(j), for RCP 6.0 is between 80-250 mm/day is presented in Figure-6(k), for RCP 8.5 is between 77-300 mm/day is presented in Figure-6(l), For the future projected year 2080 for RCP 2.6 is between 97-300 mm/day is presented in Figure-6(m), for RCP 4.5 is between 83-270 mm/day is presented in Figure-6(n), for RCP 6.0 is between 83-270 mm/day is presented in Figure-6(o), for RCP 8.5 is between 84-280 mm/day is presented in Figure-6(p).

From the visual interpretation of the annual average intensity of rainfall over the river basin, it is observed that the highest rainfall is observed in the south west side of the Malaprabha River basin located upstream of river basin near the watershed boundary. In all the cases of spatial variation of rainfall presented, low rainfall was observed in the downstream part of the river basin near the confluence of Malaprabha River with the river Krishna. These patterns of rainfall in the river basin cause delayed and low flood situation in the river. Pattern of spatial variation of rainfall is similar in all the cases presented. Comparison between spatial variation for year 2020 for RCP 8.5 (Figure 6(d)) and for year 2040 for RCP 8.5 (Figure 6(h)) would bear this out. The maximum difference in the spatial variation in the river basin could be observed between the plot for the year 2060 for RCP 2.6 (Figure 6(i)) and for the year 2020 for RCP 8.5 (Figure 6(d)).

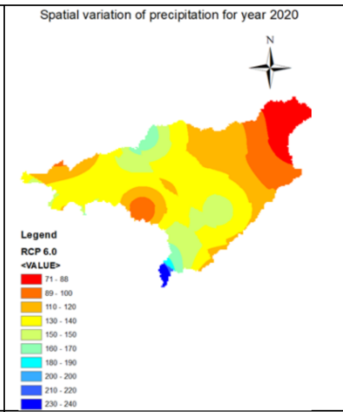
Even high intensity of rainfall in the upstream side of the river basin could cause the low flow in the down stream side of the river basin. Pattern of the rainfall in the river basin have the effect on the FDC for a river basin. FDCs given in Fig.2 to Fig.5 are indicate low flows with percentage of exceedance nearly 100%



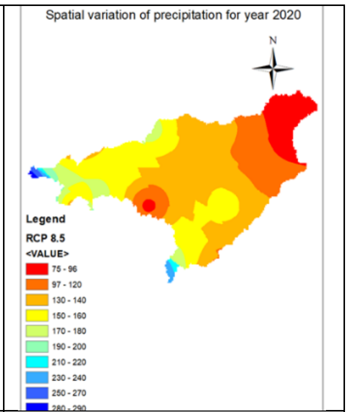
a) Spatial variation for year 2020 for RCP 2.6



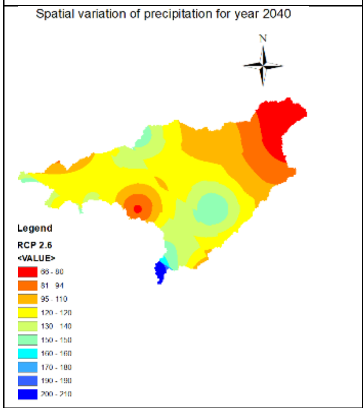
b) Spatial variation for year 2020 for RCP 4.5



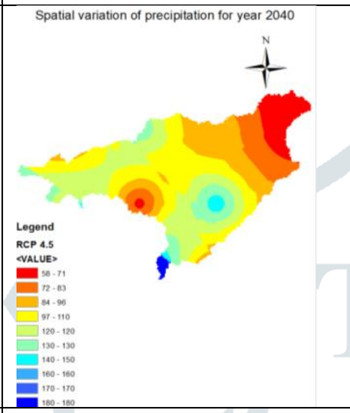
c) Spatial variation for year 2020 for RCP 6.0



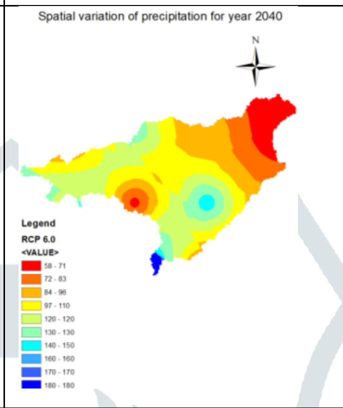
d) Spatial variation for year 2020 for RCP 8.5



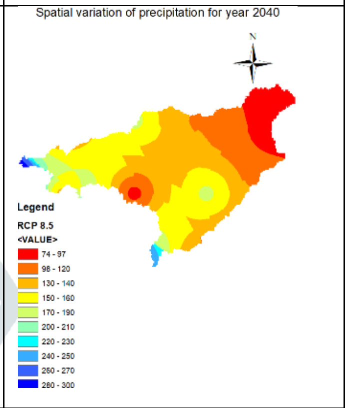
e) Spatial variation for year 2040 for RCP 2.6



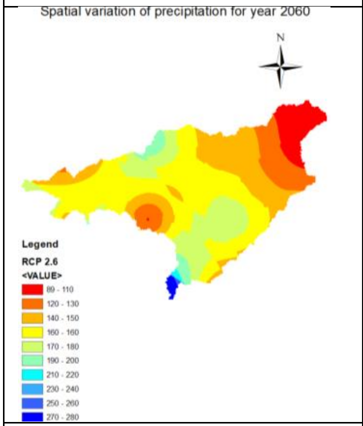
f) Spatial variation for year 2040 for RCP 4.5



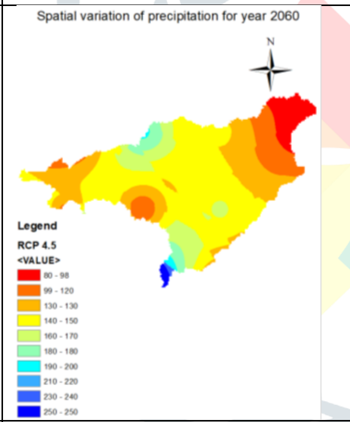
g) Spatial variation for year 2040 for RCP 6.0



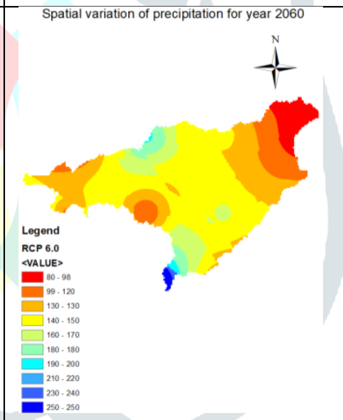
h) Spatial variation for year 2040 for RCP 8.5



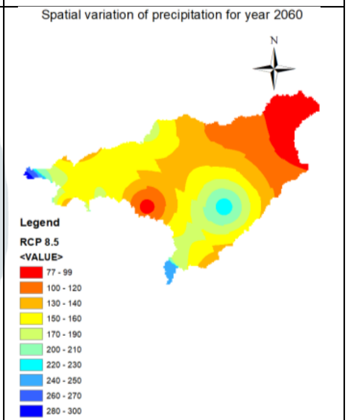
i) Spatial variation for year 2060 for RCP 2.6



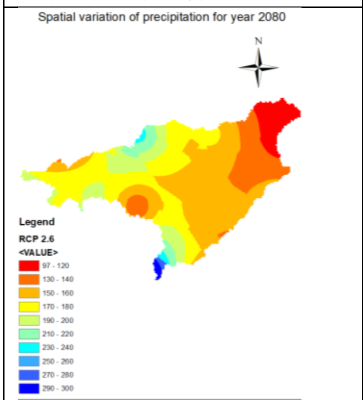
j) Spatial variation for year 2060 for RCP 4.5



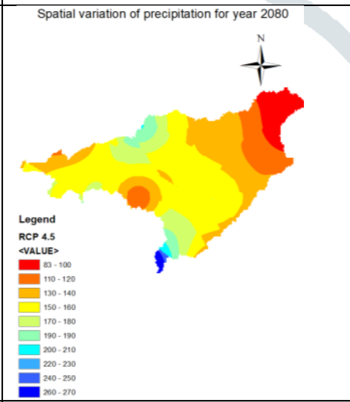
k) Spatial variation for year 2060 for RCP 6.0



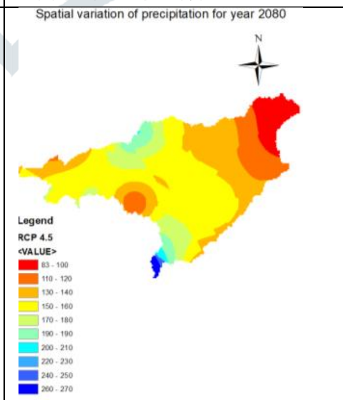
l) Spatial variation for year 2060 for RCP 8.5



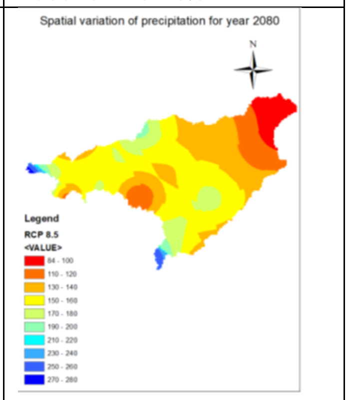
m) Spatial variation for year 2080 for RCP 2.6



n) Spatial variation for year 2080 for RCP 4.5



o) Spatial variation for year 2080 for RCP 6.0



p) Spatial variation for year 2080 for RCP 8.5

Figure-6. Spatial variation in annual intensity of rainfall.

V. CONCLUSION

There are several methods and strategies to develop FDCs at ungauged sites. In this work an attempt is made to find the percentage of exceedance for high and low flow rates using five different downscaled GCM models given in Table-1 for the years 2006 to 2085 for Malaprabha River basin, a tributary of river Krishna, Karnataka, India. The analysis of the FDCs indicates that there is a reduction in the number of low flows along with less number of high flows with the increasing order of RCP emission scenarios. In majority of the cases; it is observed that the low flow is more affected and the low flow rate is less than 75 m^3/s. The highest flow rate is found to be 650-680 m^3/s for the GCM model HadGEM2-ES which is often seen to be over predicts but otherwise the highest flow rate is found to be 480-500 m^3/s. It is seen that, RCP emission scenario wise projected average high flow for RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 are 376 m^3/s, 432 m^3/s, 366 m^3/s and 444 m^3/s respectively. Steep slopes in the curve indicate that there is a sudden variation in the stream flow due to the high intensity and short duration rainfall in the study area. The increase in projected outflows justifies that the short duration and high intensity rainfall occurring in the study area and the catchment characteristics leading to the varying projected discharge. Increase in the low flow is also due to the maximum rainfall is concentrated at the upstream part of the watershed.

The analysis of the average annual precipitation rate is done with help the of spatial distribution maps generated by Inverse Distance Weighing (IDW) method which can be utilized in the designing and construction of the water structures in the Sub-basin, watershed management programs, adoption of alternate crop patterns.

ACKNOWLEDGMENT

I would like to express my kind gratitude to WRDO for providing streamflow data for Malaprabha River, IMD for providing meteorological data, NRSC for providing LULC data, FAO for soil map and USGS for providing DEM data for use in SWAT model for the calibration and validation.

REFERENCES

[1] Atieh, M. Bahram G and Ramesh R. 2015. “Entropy-Based Neural Networks Model for Flow Duration Curves at Ungauged Sites.” Journal of Hydrology 529:1007–20.
[2] Atieh, M. Graham T. Ahmed, M. A. S. and Bahram G. 2017. “Prediction of Flow Duration Curves for Ungauged Basins.” Journal of Hydrology 545:383–94.
[3] Booker, D. J. and T. H. Snelder. 2012. “Comparing Methods for Estimating Flow Duration Curves at Ungauged Sites.” Journal of Hydrology 434–435:78–94.
[4] Brown, A. E., Andrew, W. Western, Thomas A. M. and Lu Z. 2013. “Impact of Forest Cover Changes on Annual Streamflow and Flow Duration Curves.” Journal of Hydrology 483:39–50. Retrieved September 1, 2013
[5] Castellarin, Attilio. 2014. “Regional Prediction of Flow-Duration Curves Using a Three-Dimensional Kriging.” Journal of Hydrology 513:179–91.
[6] Mengistu, D. T. and Sorteberg, A 2011. “Validation of SWAT Simulated Streamflow in the Eastern Nile and Sensitivity to Climate Change.” Hydrology and Earth System Sciences Discussions 8(5):9005–62. Retrieved May 19, 2013
[7] Narsimlu, B. Ashvin, K. G and Baghu R. C. 2013. “Assessment of Future Climate Change Impacts on Water Resources of Upper Sind River Basin , India Using SWAT Model.” Water Resour Manage 27:3647–62.
[8] Nruthya, K. and Srinivas, V. V 2015. “Evaluating Methods to Predict Streamflow at Ungauged Sites Using Regional Flow Duration Curves : A Case Study.” Aquatic Procedia 4(Icwrcoe):641–48.
[9] Pumo, D. Leonardo, V. N. and Francesco, V. 2013. “Advances in Water Resources Ecohydrological Modelling of Flow Duration Curve in Mediterranean River Basins.” Advances in Water Resources 52:314–27.
[10] Requena, A. I., Fateh C and Taha B. M. J. O. 2018. “Advances in Water Resources A Functional Framework for Flow-Duration-Curve and Daily Streamflow Estimation at Ungauged Sites.” Advances in Water Resources 113:328–40.