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Impact of Climate Change on Chaliyar Stream Flow

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Abstract- The objective of this thesis is to assess the impact of climate change on Chaliyar stream flow. Statistical Downscaling Model (SDSM) is used to downscale GCM data to finer scale. SDSM promotes the rapid development of multiple, low-cost, single-site scenarios of daily surface weather variables under current and future regional climate. SDSM downscaled climate outputs are used as input to the SWAT model and the stream flows in 2015, 2025, 2035, and 2045 are calculated. The result shows a reduction in Chaliyar stream flow in the next 20 years.

Keywords: - Climate Change, SDSM.

I. INTRODUCTION

Weather is the state of the atmosphere at a given time whilst climate is the average weather over a period of time [11]. Beyond the annual periodicity in weather patterns, the climate of Earth has changed many times in its life. This change in climate has a significant effect on the hydrological cycle, specifically on stream flow. This stream flow, which is one of the forms of surface water, influences human activities and most of the activities of nature. It is extremely important to conduct the study on impacts of climate change on hydrological regimes, so that society can respond the future challenges.

Recently, many new climate models are available for evaluating the impact of climate change. Climate models, particularly Global Climate Models (GCMs) are an important tool to represent the main features of the global distribution of basic climate parameters.

GCMs are based on the physical laws and physical-based empirical relationships and are mathematical representations of the atmosphere, ocean, cryosphere and land surface processes. The current GCMs are available in coarse grid resolution of 10 to 20.

Thus, the GCM outputs cannot be directly used in hydrological models often requires the information on a local scale for impact assessment of climate. In this situation, many researches are undertaken for the development of many downscaling methods to convert the GCM large scale information to local-scale information.

Downscaling, is the technique designed to link the gap between the information that the climate models can currently provide (global scale) and that required by the hydrologist for assessing the possible impact of climate change (local scale) [18].

Taking the information at large scales to make the predictions at local scales as in figure 1.

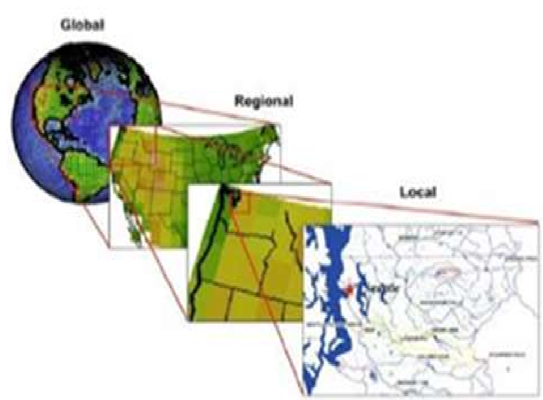

Fig 1. Concept of downscaling.

Downscaling represents the general procedure of There are two species of downscaling, dynamic downscaling and statistical downscaling. Dynamic downscaling involves converting a regional climate model (RCM) into a GCM. A specific location is defined and a high resolution model basically regional climate model (RCM) driven by boundary conditions from a GCM are used to derive finer-spatial scale information [10]

Statistical downscaling assumed that the regional or local climate is determined by two factors: the large – scale climate state and regional/local physiographic features. It consists of two steps. The first is to generate a statistical relationship between local climate variable (predicted) and NCEP variables (predictors). The next step is to correlate the established relationship to the output of GCM to simulate future climate data. The main merit of this technique is that it is computationally cheaper.

II. STUDY AREA

The Chaliyar, known in the lower reaches as Beypore, is the fourth longest river in Kerala with a length of 169 km. The main river starts from the Elambalari hills at an altitude of 2,067m above mean sea level. It is formed by the confluence of numerous streams and rivers.

The major streams are Cheru puzha Iruvahni puzha, Kanjira puzha, Punna puzha, Karim puzha, Chaliyar puzha. Other important tributaries are Kuruman puzha, Pandi puzha, Maradi puzha, Kuthira puzha and Karakkodu puzha.

The river joins the Lakshadweep Sea, south of Kozhikode near Beypore. The basin is bound by latitudes 11º06′′07″N and 11º3′′35″N and longitudes 75º48‟45″E and 76º33‟00″E falling in Survey of India and is shown in fig 2. The river drains a total area of about 2,933sq.kms of which 388 sq.kms lies in Tamilnadu. The basin consists the parts of three districts in Kerala viz. Kozhikode district cover an area of 626 sq.km in the northwest, Wayanad district over an area of 112 sq.km in the north, Malappuram district spreads over an area of 1784 sq.km in the southwest direction.

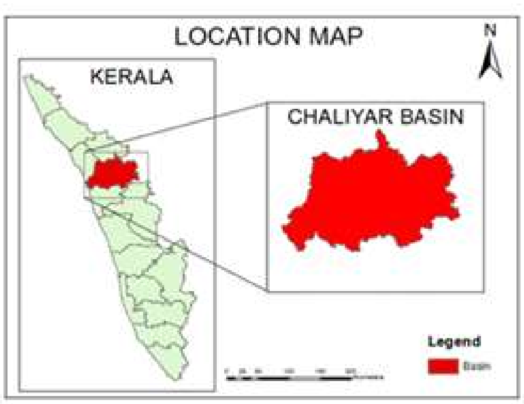

Fig 2. Location map of Chaliyar basin.

III. DATA COLLECTED

In this study we are using two software's named SDSM and SWAT. SDSM is a software for statistical downscaling to produce high resolution daily climate data from coarse-resolution climate models.

1. GCM Output Data:
Global Climate Models (GCM) is the major tools used for future prediction of climate. It is recommended to use multiple GCMs to study the effect on climate change. However, due to time limitation only one model is used in this study, which is the second generation Canadian Earth System Model (CanESM2).

This model is developed by Canadian Center for Climate Modelling and Analysis (CCCma) of Environment Canada. The daily predictor variables available from this model can be directly fed into Statistical downscaling model (SDSM). The CanESM2 outputs are available for three different climate scenarios viz., Representative Concentration Pathway (RCP) 2.6, RCP 4.5 and RCP 6, RCP 8.5.

The scenario used in this study is RCP 4.5. This RCP is developed by Pacific Northwest Laboratory in US. This scenario assumes that the future is consistent with lower energy intensity, strong reforestation programmes, stable methane emissions and CO2 emission increase only slightly before decline commences around 2040.

2. NCEP Reanalysis Data:
Apart from GCM data, we need NCEP data for downscaling. Here 45 years data is used for our station from 1961-2005 on an average.

CCCma also provides NCEP/NCAR predictor variables in addition to the large scale atmospheric variables from CanESM2. All reanalysis data is standardized before downscaling by subtracting the long-term mean and dividing by the standard deviation.

Both the CanESM2 output and NCEP/NCAR reanalysis data is downloaded from Canadian Climate Data and Scenarios website http://ccds-dscc.ec.gc.ca and used in this study.

3. Station Data:
Observed daily data for the meteorological parameters like temperature, precipitation, relative humidity, wind speed, sunshine, and evaporation are

required for the calibration and validation of the downscaling model.

Weather data is collected from the meteorological observatory of the Center for Water Resources Development Commission (CWRDM) at Kottaparambu with latitude 110 17′ 07′′ N and longitude 75 052′ 15′′ E. The summary of collected data is listed in table 1.

Table 1. Weather data.

VARIABLES	YEAR
Precipitation	1979-2005
Temperature	1983-2005
Relative humidity	1983-2005
Wind speed	1987-2005
Sunshine	1987-2005
Evaporation	1986-2005

The input data for SWAT can be broadly classified into spatial data and temporal data. The spatial data include Digital Elevation Model (DEM), land use map and soil map. Whereas temporal daily data include meteorological parameters like precipitation, maximum and minimum temperature, relative humidity, wind speed, sunshine, evaporation.

4. Digital Elevation Model (DEM):

DEM can very well define the topography of the area by representing the elevation of any point. ASTER (Advance Space borne Thermal Emission and Reflection) DEM is used for this study which has a resolution of 30 m. The DEM is downloaded from the site http://earthexplorer.usgs.gov.(site of United States of Geographical Survey) as shown in fig 3. DEM is used by Arc SWAT for watershed and stream network delineation and for slope calculation.

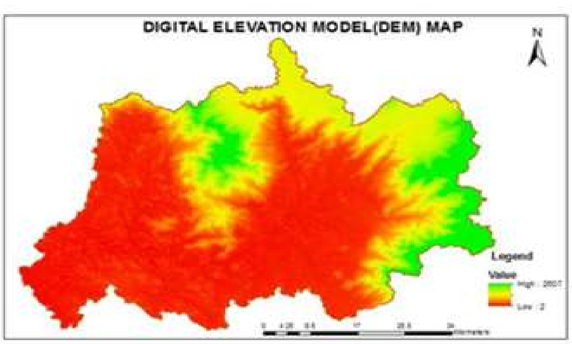

Fig 3. Digital Elevation Model of Chaliyar basin.

Thrissur district land use map was obtained from Kerala Forest Research Institute (KFRI). The land use map of Chaliyar basin was created by clipping the Chaliyar watershed shape file on Thrissur district land use map and is shown in fig 3.3. The land use classes include agricultural land, waste land, built-up land, forest, water bodies and wet lands. The land use map, which is in the shape file format, is required for Hydrologic Response Unit (HRU) creation.

5. Land use Map:

Thrissur district land use map was obtained from Kerala Forest Research Institute (KFRI). The land use map of Chaliyar basin was created by clipping the Chaliyar watershed shape file on Thrissur district land use map and is shown in fig 4.The land use classes include agricultural land, waste land, built-up land, forest, water bodies and wet lands. The land use map, which is in the shape file format, is required for Hydrologic Response Unit (HRU) creation.

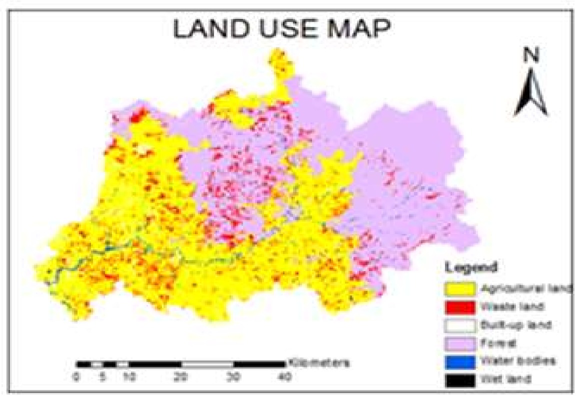

Fig 4. Land use Map of Chaliyar basin.

6. Soil Map:

The soil map of Kerala was obtained from Forest Research Institute (KFRI). The clipped soil map of

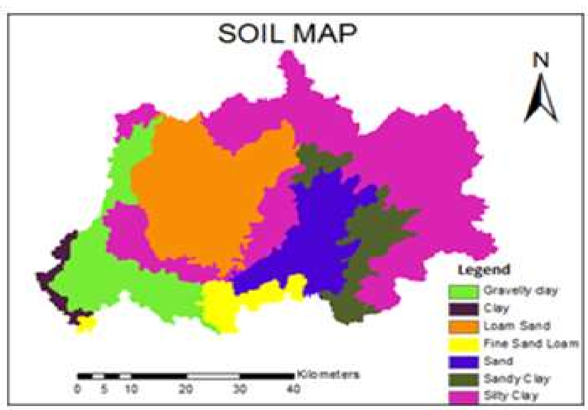

Fig 5. Soil map of Chaliyar Basin.

Chaliyar basin was created and is shown in the fig 5. The soil map is used for the HRU creation.

7. Meteorological Data:

Daily meteorological data is required for the hydrologic modelling of a river. It includes;

- Precipitation (mm)
- Maximum and minimum temperature (oC)
- Relative humidity (%)
- Solar radiation (MJ/m2/day)
- Average wind speed (km/hr)

IV. METHODOLOGY

The main steps that are involved in the study on the impact of climate change on hydrology are:

- Forecasting the climate variables for future years (2006-2100) using the Statistical Downscaling Model (SDSM) 4.2.9.
- Hydrologic modeling of the Chaliyar basin using SWAT.
- Stream flow calculation using observed and forecasted climate.
- Impact analysis is carried out to find the impact of climate change on stream flow.

1. SDSM:

Two software's are used in this study viz., SDSM 4.2.9 and SWAT. The first one is used for forecasting the climate variables whereas the second for stream flow calculation. The SDSM performs the task of statistical downscaling of daily weather data using five steps. The following steps were taken from Wilby and Dawson (2004) that describes the procedure of SDSM.

Quality control and data transformation;

- Screening the predictors
- Calibration of the model
- Generation of current weather data using observed data for validation
- Statistical analysis of the result
- Graphical representation of outputs
- Generation of future weather using GCM and derived predictors.

2. SWAT

The overall methodology of SWAT can be described by the following four main steps:

- Watershed Delineation
- Hydrologic Response Unit (HRU) Analysis
- Weather Data Definition
- SWAT simulation including sensitivity analysis and calibration.

The model can be run for a specified time period, in which the initial and final days of simulation are set to the first and last day of measured weather data in the window. For calibration, 1987 and 1988 year data are used, whereas for validation 2004 year data is used.

There are three approaches for calibration, such as manual calibration, automatic calibration and the combination of two. Even though, manual calibration is tedious and time consuming, it is the most widely used method. Automatic calibration involves the use of a search algorithm to determine the best-fit parameters. Here, manual calibration is performed by changing the values of model parameters which affects the stream flow. The parameter values are adjusted till the acceptable values of R2 is obtained.

In order to make use of the calibrated model for finding the effectiveness of future prediction, the model is tested against a set of independent values. This is referred as validation. If the model gives reasonable value of R2 for both calibration and validation, then the model can be used for future prediction. Thus the stream flow for the years 2015, 2025, 2035 and 2045 are calculated and compared with the stream flow for the years 1987 and 2004.

3. Statistical Evaluation of the model:

The performance of the SWAT is evaluated using statistical measures to determine the quality and reliability of predictions when compared with observed values. Coefficient of determination (R2), chi-square test and mean absolute percentage error (MAPE) are used to evaluate model performance.

V. RESULTS AND DISCUSSION

The outputs obtained during the model runs are illustrated here. The first section discusses the outputs obtained from SDSM and the following section discusses the outputs from SWAT. The last section gives the result of impact analysis.

1. Results from SDSM:

1.1 Performance Evaluation of SDSM:

The calibration is carried out up to 2000 for all variables and the validation from 2001-2005. For all

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variables except precipitation, the model develops a better multiple regression equation parameters. This is because of the conditional nature of precipitation. R2 values of all variables for calibration is presented in table 2.

Table 2. R2 values for calibration of SDSM.

PARAMETERS	R^2
Maximum Temperature	0.632
Minimum Temperature	0.402
Evaporation	0.432
Sunshine	0.410
Relative Humidity	0.534
Wind speed	0.537
Rainfall	0.201

The R2 value of precipitation is very low when compared with the other variables. This shows that, all other variables except precipitation can replicate the future very well. The low value of precipitation is because of the highly varying character of the rainfall in space. So the relatively coarse spatial resolution of the current generation of climate model is not adequate to fully capture that variability.

1.2 Prediction of Future Climate:
CanESM2 predictors from 1961-2099 are used to downscale the present and future climate variables. 1961-2005 year data is used for calibration and validation and the data from 2006- 2100 is used for forecasting.

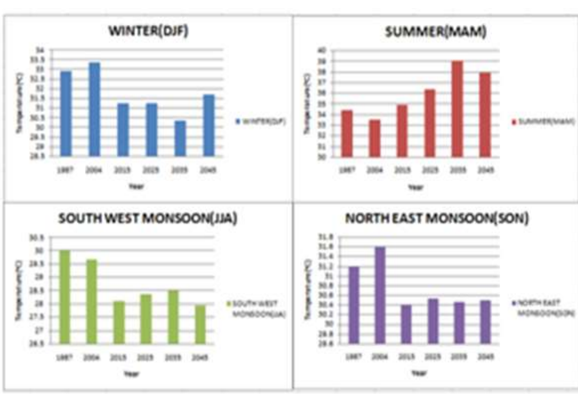

Fig 6. Seasonal comparison of Maximum temperature.

Using the calibrated model the future climate is forecasted, which is the mean of the 20 ensembles produced by the scenario generator. For the ease of simplicity, the generated scenarios are individually analyzed for each predict and seasonally for the years 2015, 2025, 2035, 2045 and are compared with the observed data of 1987 and 2004.

The months December (D), January (J) and February (F) are considered as winter season, whereas March (M), April (A) and May (M) are summer months. The south west monsoon season includes June (J), July (J) and August (A) and north east monsoon season consists of September, October and November months.

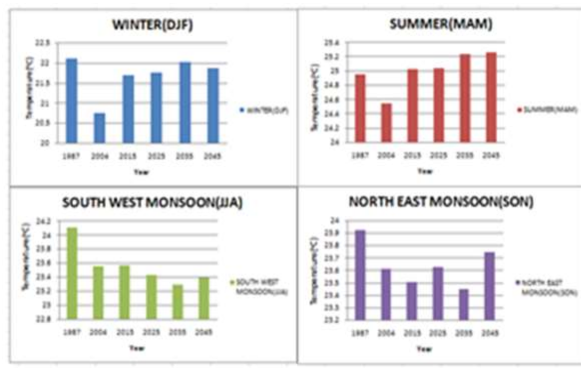

Fig 7. Seasonal comparison of Minimum temperature.

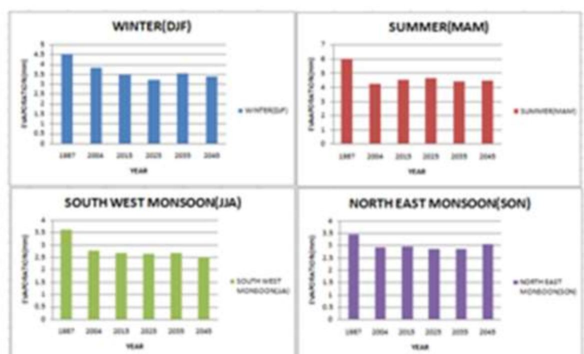

Fig 8. Seasonal comparison of Evaporation.

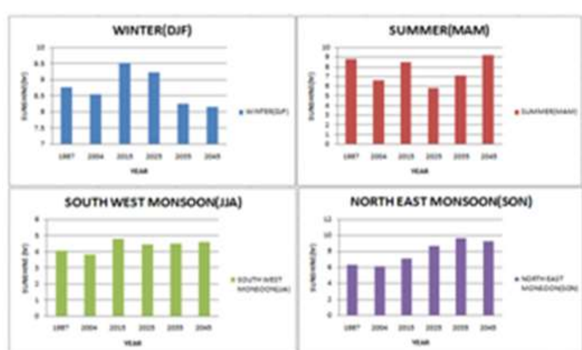

Fig 9. Seasonal comparison of Sunshine.

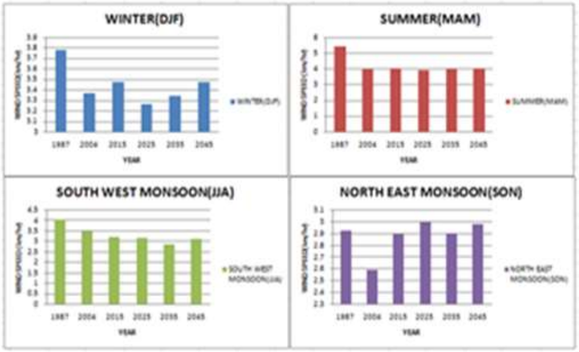

Fig 10. Seasonal comparison of Wind speed.

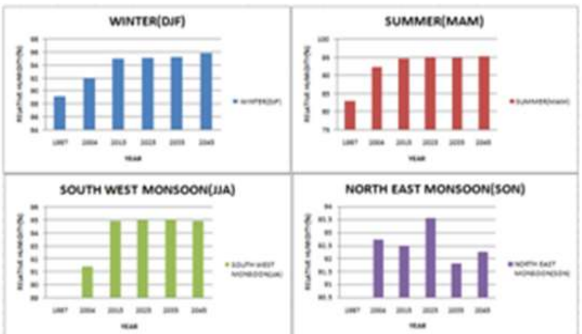

Fig 11. Seasonal comparison of Relative Humidity.

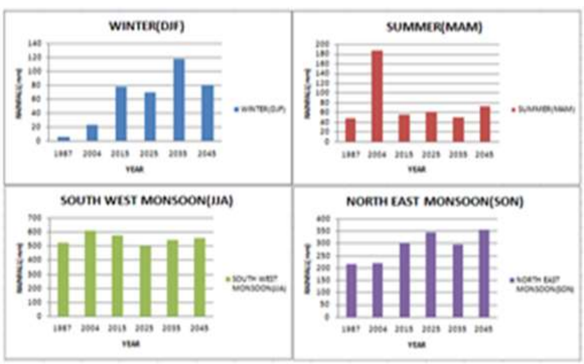

Fig 12. Seasonal comparison of Rainfall.

2. Results from SWAT:

2.1 Model Calibration:

The simulated discharges are compared with the observed discharge on monthly basis. The model is calibrated for the years 1987 and 1988 and the performance of the model is evaluated using R2, chi-square value and Mean Absolute Percentage Error (MAPE).

The obtained value of coefficient of determination, R2 is 0.876. The chi- square value is obtained as 18.124, which is less than 19.68 (for degree of freedom 11 and level of significance 0.05) is within the limit. The MAPE value obtained as 8.744, which is also within the limit of 10. The graphical comparison of simulated and observed discharge for calibration is illustrated in figure 13. The visual inspection of the graph indicates that peak of observed data is over than that of simulated for the second year of calibration.

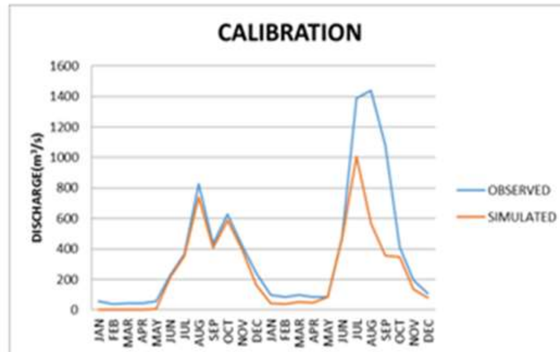

Fig 13. Comparison of observed and simulated stream flow after calibration.

2.2 Model Validation:

The model validation is carried out for the year 2004. In the validation step also, the performance of the model is evaluated using R2, chi-square and MAPE value. For validation, the R2 value is obtained as 0.978 which is within the limit of 0 to1. The chi-square value is 8.634 which is less than 19.68 (for degrees of freedom 11 and level of significance 0.05). The MAPE value is obtained as 2.05, which is less than 10. The graphical representation of the comparison of observed and simulated discharge is illustrated in figure 14.

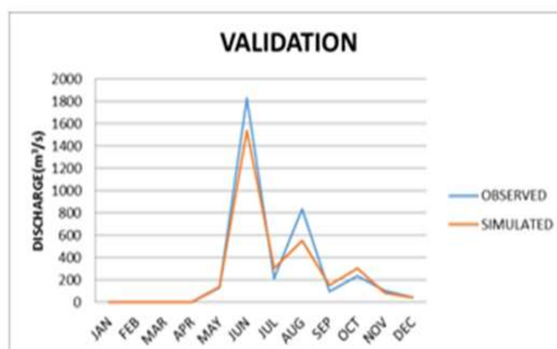

Fig 14. Comparison of observed and simulated stream flow for validation.

To check the model performance with forecasted climate variables, one more validation step is done. For that, the forecasted data of precipitation, temperature, wind speed, relative humidity, sunshine, evaporation for the year 2006 is given as input to SWAT and calculated the stream flow. This obtained stream flow of 2006 is compared with the observed stream flow values for the same year 2006. Fig 15 shows the comparison graph of observed and simulated stream flow for 2006 with R2 equal to 0.8.

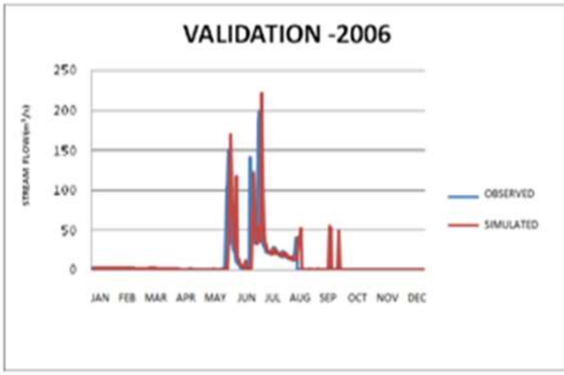

Fig 15. Comparison of observed and simulated stream flow for 2006.

2.3 Stream Flow Prediction:

From the calibration and validation results, it is clear that the model can represent the stream flow characteristics of the watershed and hence it can be used for further analysis. Thus the stream flow is calculated for the years 2015, 2025, 2035 and 2045 and compared with the observed values of 1987 and 2004 as illustrated in figure 16.

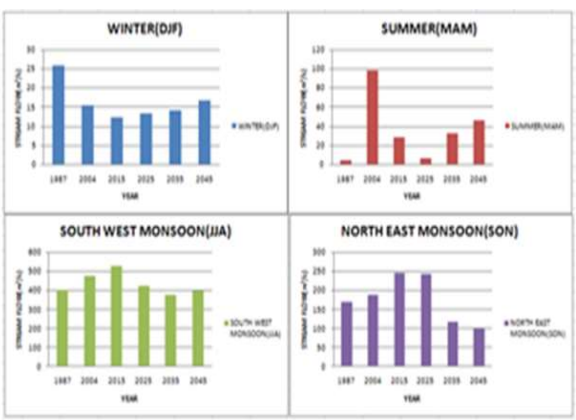

Fig 16. Seasonal comparison of stream flow.

2.4 Impact analysis of climate change on stream flow:

The impact of climate change on stream flow is analyzed for the years 2015, 2025, 2035 and 2045. All the variables such as precipitation, temperature, relative humidity, wind speed, sunshine, and evaporation are considered for the impact assessment. The bar chart of each variable is illustrated in figures 17 and 18.

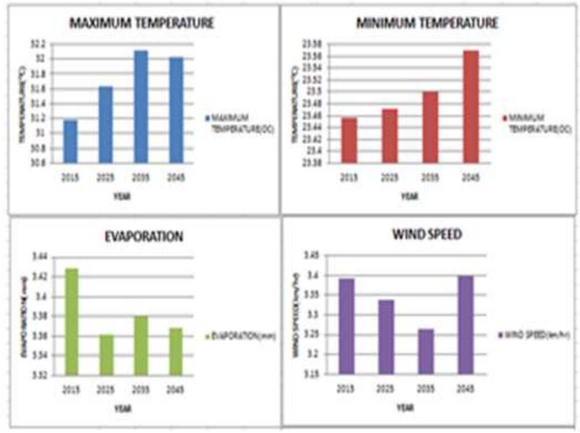

Fig 17. Bar chart for maximum temperature, minimum temperature, evaporation and wind speed.

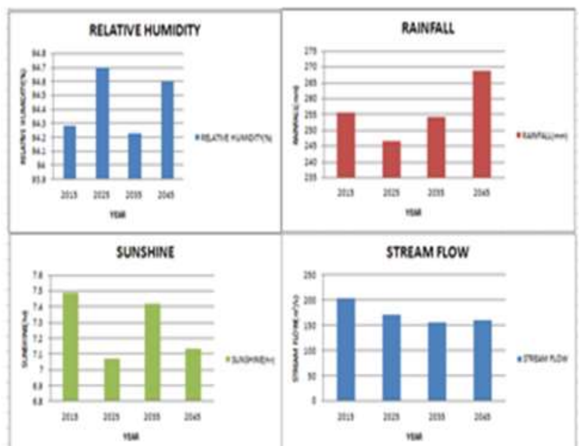

Fig 18. Bar chart for relative humidity, rainfall, sunshine and stream flow.

Maximum temperature is increased till the year 2035 and a small decrease is observed in 2045.Whereas, the minimum temperature shows an increasing trend till 2045. Evaporation shows a small decreasing trend and reaches to a lowest value of 3.36 mm in 2025. Wind speed also shows a decreasing trend in 2035 and an increase in 2045.

The relative humidity shows an alternative increasing and decreasing trend. In the case of rainfall, a reduction is observed in 2025 and then increases till 2045. Like relative humidity, sunshine also shows an alternative increasing and decreasing trend.

Variations in all these variables have great impact on stream flow and it shows a decreasing trend from

2015 to 2035, then a small increase in 2045. The summary of these variations are listed in table 3.

Table 3. Impact Analysis.

PARAMETERS	2015-2025	2025-2035	2035-2045
Rainfall	-11%	3.3%	15%
Maximum temperature	1.5%	1.5%	-0.3%
Minimum temperature	0.06%	0.127%	0.298%
Evaporation	-1.9%	0.53%	-0.3%
Relative humidity	0.5%	-0.49%	0.38%
Sunshine	-5.6%	4.49%	-3.8%
Wind speed	-1.7%	-2.23%	4.1%
Stream flow	-15.7%	-9.81%	3.55%

The results from SWAT shows a decreasing trend of 15.7% stream flow in the period 2015-2025 and then a decrease of 9.88% for next 10 years. But for the period 2035-2045 a small increase of 3.55 % is identified.

VI. CONCLUSIONS

The primary objective of this study was to assess the impact of climate change on stream flow. For that future climate is forecasted using SDSM 4.2.9 model and this projected climate was then used to simulate possible likely changes in stream flow in Chaliyar basin.

It was difficult to get high quality input data for modelling, however every single effort was exerted to produce good output. A set of models was used in this study and the results are really satisfactory.

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