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RESEARCH ARTICLE

Assessment of Impact of Climate Change in the Western Ghats Region, India

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Abstract

Objectives: The current research assessed the patterns of precipitation and discharge in the Sagar and Kokkarne catchments in the Western Ghats of Karnataka. **Methods:** Soil and Water Assessment Tool (SWAT) model was used to find the discharge at the outlets of the catchments. The yearly precipitation and discharge patterns of both the catchments were studied using data from observed data (1991 to 2020) and the projected data (2021-2050). Considering the IMD data (1991-2020) as the reference data, the percentage change in precipitation and discharge were calculated. **Findings:** For the Sagar catchment, the maximum percentage change in precipitation and discharge were projected to be 24.79 % and 53.71 %, and the minimum percentage change in precipitation and discharge were projected to be -20.29 % and -41.65 %. For the Kokkarne catchment, the maximum percentage change in precipitation and discharge were projected to be 31.30 % and 42.92 %, and the minimum percentage change in precipitation and discharge were projected to be -18.22 % and -16.98 %. In both the catchments, the increase or decrease in precipitation has led to corresponding changes in the discharge of the catchment. **Novelty:** This present work tries to project and compare the precipitation and discharge patterns in two catchments belonging to two varied river flow regimes in the Western Ghats of Karnataka to establish how the changing climate is affecting the hydrology of the catchments. As the precipitation varies in intensity throughout time and space and Indian agriculture relies heavily on precipitation, the present study can help in formulating water resource management techniques.

Keywords: Western Ghats; Hydrological Cycle; IPCC; SWAT model; Lockdown; Vaccination

1 Introduction

Climate change has an impact on all spatial scales [1,2]. There is strong evidence that the hydrological cycle has already responded to global warming [3], which includes altering precipitation patterns, in recent decades. Changes in precipitation or the melting of snow and ice are affecting hydrological systems thereby water resources in various places[4]. Climate change has impacted water resources globally. Precipitation, evaporation, and discharge of India's major rivers and lakes have all changed to varying degrees. Furthermore, there is evidence that the climate change impacts on the water cycle will likely become even more intense. As a result, investigating the effects of expected climate change on river discharge in India will be a fascinating subject.

Global climate models (GCMs) are important instruments for simulating climatic systems and conducting climate change research, as well as for generating hypothetical future climate scenarios. Most of the climate projection studies in the IPCC AR5 (Intergovernmental Panel on Climate Change, Fifth Assessment

Report) use precipitation and temperature downscaled from different GCMs[5]. Climate change has the potential to have a significant impact on water resources, according to these studies. It emphasises the uncertainty in expected changes in river runoff, which are governed by regional climate estimates. GCMs are generally regarded as the most significant source of uncertainty when it comes to estimating the effects of climate change as demonstrated by past studies which tried to assess the discharge patterns of catchments in various regions[6–10]. But very less research work has been done with respect to the Western Ghats region using Soil and Water Assessment Tool (SWAT) model. Hence present work is taken up in the catchments belonging to the Western Ghats. The results of the study can be helpful in deciding the cropping patterns in the region which can improve the agricultural economy of the country. Given the importance of climatic scenarios in decision-making and the significant uncertainties in climate projections, a better assessment of the uncertainties is necessary to decrease future risks and implement adaptive water management. The major objective of this research is to examine the precipitation and discharge patterns to understand 1) The variability of percentage change associated with precipitation and discharge in Sagar and Kokkarne catchments and 2) The precipitation and discharge trend of the hydrologic cycle using box- plot approach.

2 Methods

2.1 Study area

Varada river (Shimoga district) and Seetha river (Udupi district) belong to the West coast of Karnataka, India. Both the rivers originate in the Western Ghats of India. The Seetha river flows westward joining the Swarna river, and the Varada river flows eastward joining the Tungabhadra river. The delineated Sagar and Kokkarne catchments cover a total area of 81 km^2 and 385 km^2 respectively. Fig 1 shows the map of the study area. The Sagar catchment is located between 14^{0} N and 14.25^{0} N latitudes and the Kokkarne catchment is located between 13.25^{0} N and 13.75^{0} N latitudes. Both catchments are located between 74.75^{0} E and 75.25^{0} E longitudes. According to Koppen-Geiger climate classification, Sagar catchment has Aw type climate and Kokkarne catchment has Am type climate. Metasediments and metavolcanics constituting the Western Ghats is an important morphological feature that serves as a water barrier for the west- flowing and east-flowing rivers of the southwestern Indian peninsula. The Varda River basin is characterized by the Archaean meta-greywacke–argillite suite of rocks, with lateritic rocks covering certain regions of the basin. The younger Greenstone lithoclan is found to be dominating the Seetha River basin region.

2.2 Model input data

The spatial and temporal data used in the development of the Soil and Water Assessment Tool (SWAT) model was acquired from a range of available sources as shown in Table 1 .

Table 1. Model input data sources

Component	Source
Precipitation (Daily)	India Meteorological Department
Temperature (Daily)	India Meteorological Department
Discharge (Daily)	Water Resources Development Organisation
Digital Elevation Model (DEM)	Shuttle Radar Topography Mission
Soil map	Food and Agricultural Organization
Land-use/land-cover maps (LULC)	Water Base Worldwide Dataset

The data collected for RCP 4.5 for future climate variables (precipitation, Tmax and Tmin) was acquired from the Indian Institute of Tropical Meteorology, Pune. The five global climate models (GCM) used in the study are downscaled for the South Asian region are shown in Table 2. The ensemble mean of bias- corrected climate variables is obtained in order to run the SWAT

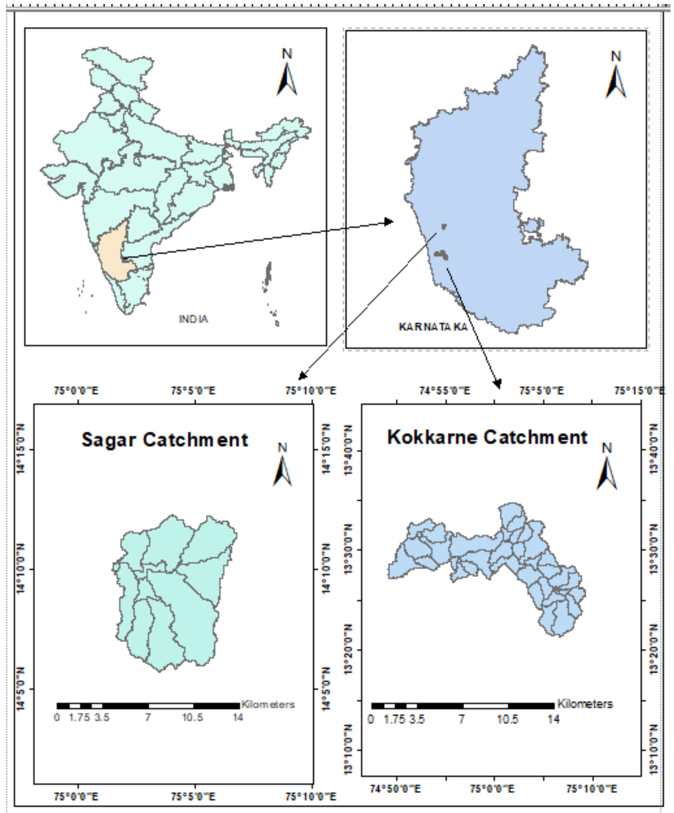

Fig 1. Study areas (Sagar and Kokkarne catchments)

model[11].

Table 2. List of CMIP5 GCMs for RCP 4.5 data.

GCMs	ACCESS1.0	CNRM-CM5	GFDL-CM3	MPI-ESM-LR	NorESM1-M
Horizontal grid spacing (lon x lat)	1.875^0 x 1.25^0	1.4^0 x 1.4^0	2.5^0 x 2.0^0	1.9^0 x 1.9^0	2.5^0 x 1.9^0

2.3 Description of SWAT model

The SWAT model is a comprehensive, time-continuous, semi-distributed, process-based model developed by the Agricultural Research Service of the United States Department of Agriculture[12]. SWAT is capable of modelling changes in the hydrologic response of the catchment, water quality, and erosion, as well as evaluating the impacts of land-use changes and climate variability on a catchment[13]. The SWAT model first divides the catchment into a number of sub-basins, which are then divided into Hydrologic Response Units (HRUs). The varied combinations of land use, soil, and slope are used to define these subdivisions. The governing equations that the model employs to simulate processes within a watershed are described in the Soil and Water Assessment Tool User's Manual[14]. A hydrological cycle based on the water balance technique is used in the development of the model[15]. The quantity of streamflow is influenced by climate variables including precipitation, as well as soil erosion. It is necessary to simulate the hydrological cycle of the catchment in order to suggest appropriate management methods to improve the water yield of the catchment[16].

2.4 Model set-up and processes

The steps followed in the current study are:

1) The SWAT hydrological model for both the catchments were calibrated using the Indian meteorological department (IMD) gridded data on daily rainfall and temperature and discharge data from Water Resource Development Organization

along with various other data inputs as shown in Table 1. Before the calibration procedure is performed, a sensitivity analysis is a crucial step toward understanding how factors impact model behaviour. It also helps to reduce the number of parameters. The sensitivity analysis used in hydrological modelling is a function that explores the change in model outputs as a result of changes in their parameters. The SWAT model was calibrated based on 8 sensitive parameters which govern the model, as specified by the Latin hypercube–one factor at a time (LH-OAT) method[17]. A one-year warm-up time was used during calibration (1991) and validation (1997). The calibration of the model (1992-1996) and the parameterization were manually performed using the heuristic approach. Finally, the validation process (1998-2002) was conducted. R^2 and NSE of 0.72 and 0.74 during calibration and 0.71 and 0.70 during validation for Sagar catchment were obtained. R^2 and NSE of 0.75 and 0.73 during calibration and 0.72 and 0.71 during validation for Kokkarne catchment were obtained.

2) After the successful calibration and validation process, both the catchments were simulated with the help of the SWAT model, and the discharge output of the SWAT model has been used for the analysis in the present study.

3) The percentage departure of annual precipitation and annual discharge (2021-2050) with respect to observed data for the period (1991-2020) is calculated for both the catchments.

4) The box plot analysis has been used to assess the characteristics of percentage change in annual precipitation and annual discharge for the period (2021-2050) with respect to the observed data for the period (1991-2020) of both the catchments.

3 Results and Discussions

3.1 Percentage departure of annual precipitation and discharge

The percentage departure of annual precipitation/discharge from the normal annual precipitation/discharge in the catchment was calculated. The category of departures from the normal annual precipitation/discharge with the ranges as specified in Table 3 was carried out for 30 years period (2021-2050).

Table 3. Category of departures from normal

Code	**Departure from normal**
Large Excess	60 % or more
Excess	20 to 59 %
Normal	-19 to +19 %
Deficient	-20 to -59 %
Large deficient	-60 to -99 %

The difference between the observed annual precipitation and the expected value of normal annual precipitation was divided by the projected normal annual precipitation value to compute the percentage deviation precipitation and discharge. The percentage deviations in precipitation and discharge are classed as large excess, excess, normal, deficient, and large deficient with respective upper and lower limits[18]. The annual precipitation/discharge falls into the category of Large Excess if the percentage deviations from normal values are greater than 60 %, and it falls into the category of Excess if the percentage deviations are between 20 % and 59 %. If the percentage deviations range from -19 % to 19 %, it falls into the Normal category, -20 % to -59 % falls into the Deficient category, and less than -60 % falls into the Large Excess category.

For the Sagar catchment, out of 30 years, no year is projected to be under the large excess and large deficient category for both precipitation and discharge. 2 years, 26 years, 2 years under the Excess category, Normal category and Deficient category respectively for annual precipitation (Figure 2a). 10 years, 13 years and 7 years under the Excess category, the Normal category and the Deficient category for annual discharge (Figure 3a).

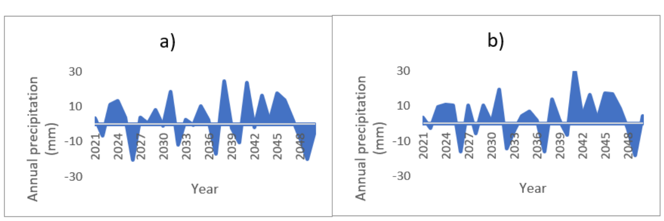

Fig 2. Percentage change in precipitation of Sagar and Kokkarne catchment

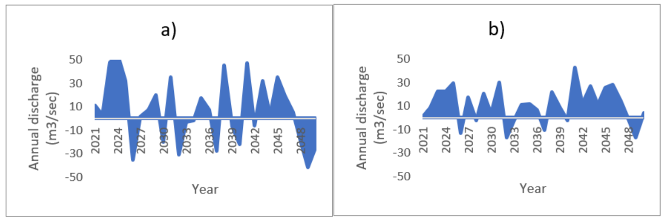

Fig 3. Percentage change in discharge of Sagar and Kokkarne catchment

For the Kokkarne catchment, out of 30 years, no year is projected to be under the large excess, deficient and large deficient category for both precipitation and discharge. 2 years and 28 years under the Excess category and the Normal category for annual precipitation (Figure 2b). 10 years and 20 years under the Excess category and the Normal category for annual discharge (Figure 3b).

As per composite analysis during dry years, Sagar catchment was projected to receive below-normal precipitation during dry years ranging from –0.71 to –20.29 percentage departure, while during the same years the wet season may receive more seasonal precipitation and departures ranging from +0.35 to +24.79% (Figure 2a). Similarly, the Kokkarne catchment is projected to receive below-normal precipitation during dry years ranging from –2.55 to –18.20 percentage departure, while during the same years the wet season may receive more seasonal precipitation and departures ranging from +0.54 to +31.30 % (Figure 2b). The results of the study confirm that the changing climate is affecting the hydrology of both the catchments.

The study shows that the change in the annual runoff would be largely variable. The runoff during the period 2021-2050 is projected to be more different than 1991-2020. River flow fluctuations over the projected period of 2021-2050 will seem to be minor compared to year-to-year variability, but they will be noticeable on a decade-by-decade basis. However, due to disparities in climate change predictions, there is considerable uncertainty in the magnitude of percentage change in precipitation and discharge in the catchments. Climate change-related projections can be used as scenarios to assess the susceptibility of various environmental and socio-economic systems to climatic change due to the lack of consistency inherent among different GCMs. The SWAT model offers a discharge-precipitation-temperature correlation based on the input data, which is valuable for quantifying the implications of climate change on regional hydrological regimes.

During the deficient precipitation period, it is required to make plans for conjunctive use of groundwater, as the groundwater storage provides a variety of options for increasing storage and improving the overall water supply for irrigation and domestic uses. Sustainable groundwater management will necessitate adherence to a few well-known economic principles to conserve groundwater. An attempt to create awareness about groundwater has to be done to reduce the persisting overdraft which can deplete the resource completely. The significance of groundwater will rise as its shortage worsens, necessitating appropriate groundwater management. As the groundwater management plans that are designed for local regions will be most beneficial such plans should be taken up to regulate the extractions and/or recharge.

3.2 Box Plot Analysis

The box plot method has the advantage of allowing the researcher to examine numerous datasets side by side, as shown in Figure 4. With this method, the central tendency, dispersion, and extremes of each dataset are all relatively easy to comprehend and depict [19,20]. The average percentage change in annual precipitation and annual discharge for the Sagar catchment was estimated to be 3.92 % and 6.06 %. The average percentage change in annual precipitation and annual discharge for the Kokkarne catchment was estimated to be 2.51 % and 10.56 % (Figure 4). It was observed that, for both the catchments, there is an increase in the discharge with a corresponding increase in the precipitation of the catchment in the same duration as reported by studies [21–25]. The approach in the present study can capture the overall relationship between precipitation and streamflow, but it cannot express the complicated interaction between streamflow and precipitation. The study helps in the assessment of the sensitivity of yearly streamflow to precipitation fluctuations. The application of this method to two basins shows that precipitation is a major factor affecting regional runoff generation and that the response of streamflow to precipitation is linear.

The results of the analysis can help in designing the much-needed advancements in irrigation technologies of this era to help in the identification of irrigation scheduling techniques that reduce water demand while having the least influence on crop yields and yield quality of crops, resulting in increased food security of the country. The specifics of crop water and irrigation water requirements, as well as the most recent irrigation scheduling theories and strategies, can be developed keeping in view the projected discharge component of this study.

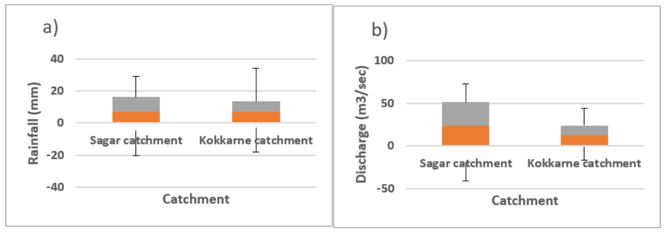

Fig 4. Box plot for percentage change in a) precipitation b) discharge of Sagar and Kokkarne catchment

4 Conclusions

An attempt has been made in this work to understand the possible influence of changing climate on the hydrology of Sagar and Kokkarne catchments, using the SWAT model. In the future, both catchments have the potential to be a significant source of water for the rapidly expanding communities surrounding them for irrigation and domestic uses. The percentage departure of annual precipitation and annual discharge

analysis was used to assess the trend of precipitation and discharge in order to have an overall understanding of the impact of climate change on water resources in the catchments. The present research has helped to bring about the following conclusions:

1. The percentage departure of annual precipitation and annual discharge of the Sagar catchment is falling under the categories of excess, normal, and deficient categories.
2. The percentage departure of annual precipitation and annual discharge of the Kokkarne catchment is falling under the categories of excess and normal categories.
3. Kokkarne catchment receives more precipitation as compared to the Sagar catchment by 55.91 %.
4. The discharge in the Kokkarne catchment is more as compared to the Sagar catchment by 74.03 %.
5. The discharge at the outlet of the catchment is directly proportional to the precipitation received in the catchment.

The widespread pandemic related lockdown restrictions imposed in recent times before the introduction of vaccination caused a drastic reduction in men and material transportation and industrial production. This resulted in substantial reductions in greenhouse gas emissions with significant regional and global impacts on air quality and climate. This effect of the reductions in greenhouse gases and aerosol particles on the precipitation via associated changes in the atmospheric energy balance and dynamics through radiative effects has not been considered in the present analysis and is a limitation of the study.

Overall, based on the present precipitation analyses, a precipitation dependent agricultural system might be built to maximise the use of precipitation while reducing indiscriminate usage of groundwater. It can be concluded that sustainable agriculture in the region can be achieved with better management of soil, water and crops.

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