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RESEARCH ARTICLE

Assessment of Impacts of Climate Change on Varied River-Flow Regimes of Peninsular India

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Abstract

Objectives: Precipitation is a major component of the hydrological cycle. Precipitation varies in intensity throughout time and space. The discharge at the outlet of the catchment is directly proportional to the precipitation received in the catchment. The current research looks at the precipitation as well as discharge patterns in the Sagar and Kokkarne catchments in the Western Ghats of Karnataka, India. **Methods:** In the present research, the soil water assessment tool (SWAT) has been applied to monitor and quantify the streamflow of the Sagar and Kokkarne catchments. Precipitation and discharge analysis for the period of 2021-2050 for both of the catchments is carried out. The seasonal and yearly discharge patterns of the catchments were studied using the Coordinated Regional Downscaling Experiment-South Asia data for the RCP 4.5 scenario for the period 2021-2050. **Findings:** During the Southwest monsoon and Northeast Monsoon, about 81.44 % and 14.22 % of the precipitation in Sagar catchment and about 87.34 % and 6.93 % of the precipitation in Kokkarne catchment were obtained respectively. The contribution of the Southwest Monsoon in both the catchment is greatest, followed by the Northeast monsoon. During the period 2021-2050, less than 80 % probability of discharge is expected for 23 years and more than 20 % probability of discharge is expected for 4 years. The maximum discharge expected in Sagar and Kokkarne catchments are 16.96 m^3/sec and 213.87 m^3/sec respectively. **Novelty:** The patterns of the precipitation and discharge of two different catchments on each side of the Western Ghats of Karnataka are compared in the current study to understand the impact of climate change on catchment hydrology in these regions.

1 Introduction

Precipitation and temperatures are regarded as fundamental elements in the climate, as both of these parameters govern the climatic condition of a certain place, which influences agricultural output. One of the most important global issues discussed by scientists are global warming and climate change. The varying precipitation patterns and an increase in temperature are two of the effects of climate change that have adverse impacts on monsoon arrival and departure timings, and extreme precipitation occurrences in India[1]. The precipitation quantity and timing are predicted to change as a result of increased evaporation due to global warming, particularly in the tropics[2]. Precipitation patterns and precipitation quantity are among the most critical factors that influence crop production. India is predominantly an agricultural country, where agriculture is

critical for the economy of the country and the survival of its people. Agriculture generates a significant contribution to the GDP of the country[3]. For employment, nearly 53 % of the population of India is dependent on agriculture[4]. Although crop productivity has improved dramatically as a result of the green revolution, crop production, primarily governed by natural precipitation, and agricultural commodities are considered to be the mainstay of the people of India[5], notwithstanding the so-called advancements in industrialization. The southwest monsoon (June–September) is the main source of precipitation in the country, except for the southeast region of peninsular India and parts of Jammu and Kashmir. During the monsoon season alone, most parts of India receive more than 75 % of its annual precipitation[6]. Drought and flood years have a significant impact on the economy of the country as well as the living conditions of residents of the affected regions[7].

The Soil and Water Assessment Tool (SWAT) model has been widely utilised to evaluate basin hydrology under RCP 4.5 global climate change scenarios using CORDEX-SA data in studies like[8–10]. Many studies like[11–13] carried out using the SWAT model to investigate the effects of climate change on rainfall and streamflow indicate that future rainfall patterns are extremely likely to vary but, the direction of change in rainfall is cannot be perfectly predicted as it is dependent on the GCMs/RCMs used as well as the downscaling approach used. To simulate basin hydrology, the SWAT model was examined in the Western Ghats region[14–16] proving the adaptability, dependability, and appropriateness of the SWAT model as a hydrology model to use for planning and management of water resources. Many scholars belonging to different geophysical domains have studied the consequences of climate change. For example, here are some reviews of relevant research in recent times[17–21]. However, none of these research works represented a study on seasonal water availability. Further sufficient research work in the Western Ghats region has also not been reported. And also, appropriate streamflow measurement is critical for agricultural watershed management and its impact on a variety of water balance parameters. Hence the present research work has been done, which gives information on precipitation and discharge patterns and their associated variability in the two different catchments which lie on the east and west side of Western Ghats.

The major goal of this research is to examine the variability and trend of precipitation and discharge in the Sagar and Kokkarne catchments. Following are the objectives of the study, 1) To assess the season-wise distribution of average precipitation (2021-2050) 2) To assess the water availability in the catchments 3) Seasonal Discharge analysis.

2 Data used and Methodology

2.1 Study area

Both Varada and Seetha rivers originate in the Western Ghats of Karnataka, India at an elevation of 610 m and 980 m above mean sea level (MSL). The delineated watershed area of the Sagar catchment (Varada river) is 81 km^2 and the Kokkarne catchment (Seetha river) is 385 km^2. The location map of the study area is shown in Figure 1.

2.2 SWAT Model

The SWAT is a physically-based model. River discharges are simulated by using the Soil and Water Assessment Tool (SWAT model)[22]. The rainfall-runoff model usually works on a daily time scale and accommodates spatial heterogeneities by splitting the delineated watershed into various hydrological response units (HRUs). Each HRU is made up of a unique mix of soil, land cover, and elevation. The model predicts the hydrology of each HRU, taking into account the water balance of daily precipitation, surface runoff, evapotranspiration, percolation into the ground, and return flows. The SWAT model analyses the discharge of each sub-basin and guides the streamflow to the outlet of the watershed. The Arc-SWAT addon for ArcGIS is used in performing the pre-processing and model setup

The SWAT hydrological model for both catchments was calibrated by using gridded data obtained from the Indian meteorological department (IMD), discharge data from the Water Resource Development Organization, and several other data inputs. A sensitivity analysis is a critical factor in understanding how variables influence model behaviour before the calibration method is carried out. In hydrological modelling, sensitivity analysis is a function that investigates how model outputs vary as a result of changes in model parameters. The sensitivity analysis helps to reduce the number of parameters used in calibration. For modelling both the catchments, the SWAT model was calibrated using the Latin hypercube–one factor at a time (LH-OAT) approach[23], which specifies eight critical parameters that regulate the model. During calibration (1991) and validation (1997), a one-year warm-up period was employed. The model's calibration and parameterization for the years 1992-1996 were done manually using a heuristic technique on a monthly time step. Lastly, the validation procedure was carried out on a monthly

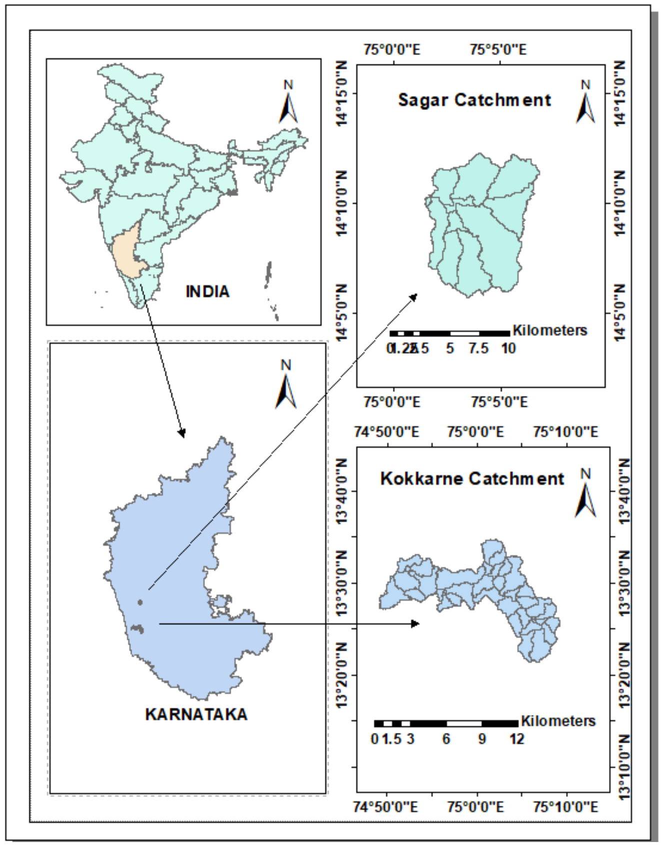

Fig 1. Location map of the study area

time step for the years 1998-2002. For the Sagar catchment, R^2 and NSE were 0.72 and 0.74 during calibration and 0.71 and 0.70 during validation. For the Kokkarne catchment, R^2 and NSE were 0.75 and 0.73 during calibration and 0.72 and 0.71 during validation.

2.3 Data

The various sources of data are utilized in the creation of the Soil Water Assessment Tool (SWAT) model. The Daily rainfall and temperature data for 1991-2020 is obtained from India Meteorological Department (IMD). The Daily discharge data is obtained from Water Resources Development Organisation (WRDO). Bangalore. Digital Elevation Model (DEM) is downloaded from Shuttle Radar Topography Mission (SRTM). Soil map and Land-use/land-cover maps (LULC) are obtained from Food and Agricultural Organization (FAO) and Water Base Worldwide Dataset respectively. The RCP 4.5 data of future climate variables from ACCESS1-0, GFDL-CM3, CNRM-CM5, MPI-ESM-LR, NorESM1-M downscaled to the South Asian region was acquired from the Indian Institute of Tropical Meteorology, Pune (Table 1). The ensemble mean of bias-corrected temperature and precipitation data is given as an input to run the SWAT model[24]. The SWAT model is employed in the present study to understand the impact of climate change on catchment hydrology[13].

Table 1. List of CMIP5 GCMs CORDEX-SA data for RCP 4.5 Scenario

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

2.4 Methodology

The steps followed in this research are as given below:

1) SWAT model is used to simulate both the catchments, with the required data inputs. The discharge output of the developed SWAT model is employed in the analysis of the current study.

2) The season-wise distribution of average precipitation in both the catchments is analyzed.

3) The water availability in both the catchments during the future period 2021-2050 is assessed

4) The seasonal discharge analysis is carried out to calculate the average discharge during monsoon, post-monsoon, winter, and summer seasons of the future period 2021-2050.

5) The seasonal discharge analysis is also carried out to find out which years are projected to receive a discharge with more than 20 % and less than 80 % probability level.

3 Results and Discussions

3.1 Season-wise Distribution of Average Precipitation (2021-2050)

The seasonal distribution of precipitation exhibited significant fluctuations during the monsoon, post-monsoon, pre-monsoon, and winter seasons for both the catchments is shown in (Table 2) (Figure 2). In the Sagar

catchment, for the rainy season, the southwest monsoon is expected to deliver around 81.44 % of the annual precipitation or about 1484.28 mm, while the effective precipitation was 648.43 mm. Post-monsoon and winter seasons each provide around 14.23 % and 0.62 %. Further, the pre-monsoon precipitation contributes 3.71 % of annual precipitation, with an average of 67.53 mm and effective precipitation of 63.73 mm. On the other hand, in the Kokkarne Catchment, monsoon, post-monsoon, winter and summer seasons each provide rainfall with an average of 3554.32 mm, 282.39 mm, 9.92 mm, and 222.76 mm with contributions of 87.34 %, 6.94%, 0.24 %, and 5.47 % of annual precipitation and effective precipitation of 855.43 mm, 203.89 mm, 9.76 mm, and 182.95 mm respectively. The monsoon season is the main source of rain in both the catchments with the highest rainfall contribution as reported by other studies[25,26]. Post-monsoon rainfall delivers the second-highest contribution and winter rainfall delivers the least contribution towards the annual rainfall in both the catchments as reported by studies like[27].

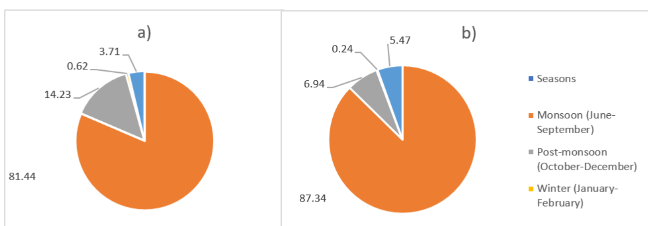

Fig 2. Precipitation distribution in different seasons in a) Sagar b) Kokkarne catchment based on 30-years long-term precipitation (2021-2050)

$$P_{eff} = \frac{P\,(125-0.2P)}{125}\ for\ P < 250 \quad (1)$$

$$P_{eff} = 125 + 0.1P\ for\ P \geq 250mm \quad (2)$$

Where-P_{eff} is monthly effective rainfall (mm) and P is the monthly total rainfall

The precipitation distribution in different seasons for both catchments is shown in Table 2. The effective precipitation, which has a substantial impact on the optimal allocation of irrigation water resources, was taken into consideration to help in planning objectives. The rice-wheat farming strategy can be used to take advantage of the effective precipitation distribution in the research area. The effective rainfall can be calculated using the formula 1 and 2. As the monsoon season precipitation is maximum among all other seasons, it is better to find a potential method for storing excess precipitation in an on-farm reservoir, which would otherwise get wasted to be runoff or evaporation. Using this excess precipitation during the monsoon season, a guideline for groundwater recharge might also be developed. A good balance of groundwater can be maintained, with limited extraction during the monsoon period and the adoption of the groundwater recharging method. Growing high-value post-monsoon crops without extra irrigation facilities would be problematic since post-monsoon precipitation is found to be more unpredictable and variable than monsoon precipitation.

Table 2. Precipitation distribution in different seasons in a) Sagar b) Kokkarne catchment based on 30-years long-term precipitation (2021-2050)

	Sagar catchment			Kokkarne catchment		
Seasons	Average rainfall (mm)	Effective rainfall (mm)	% of annual rainfall	Average rainfall (mm)	Effective rainfall (mm)	% of annual rainfall
Monsoon (June- September)	1484.28	648.43	81.44	3554.32	855.43	87.34
Post-monsoon (October-December)	259.32	190.76	14.23	282.39	203.89	6.94
Winter (January- February)	11.33	11.13	0.62	9.92	9.76	0.24
Pre-monsoon (March- May)	67.53	63.73	3.71	222.76	182.95	5.47
Annual	1822.47	914.05	100.00	4069.39	1252.03	100.00

3.2 Water Availability

The average annual discharge in Sagar and Kokkarne catchments is projected to be16.96 m^3/sec and 213.87 m^3/sec. Annual discharge with 20 % and 80 % probability levels for a) Sagar catchment and b) Kokkarne catchment is shown in Figure 3. The orange line indicates a 20 % probability level and the grey line indicates an 80 % probability level of seasonal discharge in the graph. In both the catchments from 2021 to 2050, for nearly 04 years, the discharge was more than 20 % probability level and for nearly 06 years, the discharge was less than 80 % probability level. The years which are projected to receive discharge more than 20 % probability level during this time period are 2023 (23.60 m^3/sec), 2024 (24.58 m^3/sec), 2031 (21.65 m^3/sec), 2038 (23.21 m^3/sec) and 2041(23.53 m^3/sec) in Sagar catchment and 2025 (250.78 m^3/sec), 2031 (251.91 m^3/sec), 2041 (276.48 m^3/sec), 2043 (245.52 m^3/sec) and 2046 (248.63 m^3/sec) in Kokkarne catchment. The years which are projected to receive discharge less than 80 % probability level during this time period are 2026 (10.34 m^3/sec), 2032 (11.08 m^3/sec), 2037 (11.51 m^3/sec) , 2040 (12.50 m^3/sec), 2049 (9.33 m^3/sec) and 2050 (12.00 m^3/sec) in Sagar catchment and 2026 (167.70 m^3/sec), 2028 (188.61 m3/sec), 2032 (161.24 m^3/sec), 2037 (172.95 m^3/sec), 2040 (188.51 m^3/sec) and 2049 (160.58 m^3/sec) in Kokkarne catchment. The highest discharge of 24.57 m^3/sec in the year 2024 and 276.48 m^3/sec is projected for the year 2041, while the lowest discharge of 9.32 m^3/sec in the year 2049 and 160.58 m^3/sec is projected for the year 2049 for Sagar and Kokkarne catchments respectively. In both, the catchments, an increase in the discharge is evident with an increase in the rainfall received in the catchment as reported by studies[28–30].

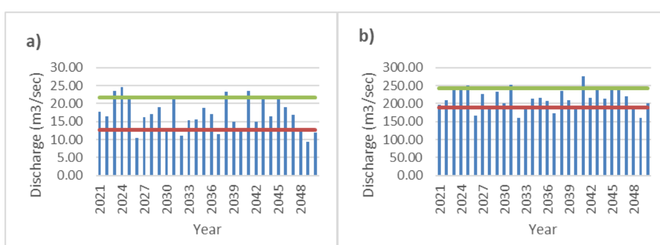

Fig 3. Annual discharge with 20 % and 80 % probability levels for a) Sagar catchment b) Kokkarne catchment

3.3 Seasonal Discharge

The years which are projected to receive discharge more than 20 % probability level and less than 80 % probability level during monsoon, post-monsoon, winter, and summer seasons of the time period under consideration have been plotted as graphs as shown in Figure 4 and Figure 5 corresponding to Sagar and Kokkarne catchments respectively. The years 2026, 2049, and 2050 are projected to have discharge less than 80 % probability during all the seasons in the case of the Sagar catchment. The seasonal discharge is highest in monsoon and lowest in the summer season for both the catchments. However, the quantity of discharge in all four seasons is higher in the Kokkarne catchment as compared to the Sagar catchment. This is because- the delineated area and rainfall received in the Kokkarne catchment are higher than in the Sagar catchment.

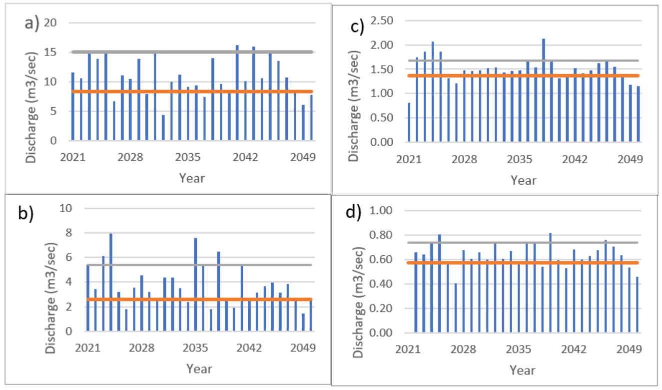

Fig 4. Season-wise discharge for Sagar catchment a) Monsoon season b) Post monsoon season c) Winter season d) Summer season

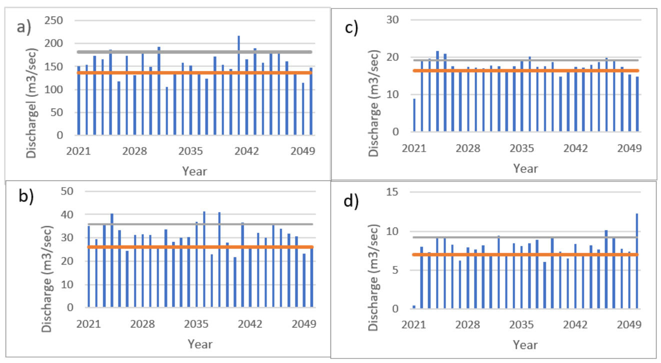

Fig 5. Season-wise discharge for Kokkarne catchment a) Monsoon season b) Post monsoon season c) Winter season d) Summer season

The average discharge for SWM, NEM, Winter, and summer seasons are 10.99, 3.83, 1.51, and 0.61 m^3/sec for Sagar catchment and 157.08, 31.30, 17.59, and 7.88 m^3/sec for Kokkarne catchment. The number of years in each season which are projected to receive discharge more than and less than the seasonal average discharge is shown in Table 3. Except for the summer season, the number of years with more than seasonal mean discharge is lesser than the number of years with less than seasonal mean discharge is higher in the Sagar catchment. The seasonal rainfall analysis of the present study can be helpful in assessing food grain yields in the future as the variations in monsoon season rainfall have a direct impact on total food grain yield[31,32]. The increases or decreases in rainfall are usually accompanied by an increase or decrease in food grain yield. There is no evidence of a similar correlation during the winter season food grain production. Variations in post-monsoon precipitation do not have a direct impact on the Rabi crop. in many parts of our country, the summer season rainfall affects the Rabi crop through water and soil moisture availability[33]. The Rabi crops usually being produced on residual soil moisture[34], and the droughts can affect crop productivity in the region. Though a drop-in rainfall amount during the monsoon season reduces crop yields, the occurrence of continuous rainfall breaks has a negative impact on crop growth, resulting in lower crop yields.

Table 3. The number of years with discharge more than and less than the season-wise average discharge for Sagar and Kokkarne catchments.

		Monsoon	Post monsoon	Winter	Summer	Annual
Sagar catchment	More than mean	13	12	14	17	14
	Less than mean	17	18	16	13	16
Kokkarne catchment	More than mean	15	14	15	16	16
	Less than mean	15	16	15	14	14

This analysis can be used to decide the cropping pattern. For long-term sustainability, alternate cropping systems such as maize-lentil, soybean-chickpea, soybean-lentil, and maize-chickpea, which have lesser water requirements in addition to precipitation can be recommended. As a result of this, irrigation requirements can be reduced. If rice is to be planted, then short-duration and moisture stress-tolerant cultivars should be preferred over long-duration cultivars. To help reduce the amount of water required for puddling, techniques such as the aerobic method or direct dry-seeding should be used. Soil and crop management practices such as broad-bed and furrow planting, crop residue retention, and conservation tillage could be used to conserve soil moisture.

4 Conclusions

The present study has been conducted to analyse the rainfall and discharge patterns in different catchments. This study can be very helpful in the process of planning the agricultural operations like cropping patterns and preparation of land for sowing ahead of time which can improve crop yield and bring about economic benefits Following are some of the conclusions of the present study

- Both the catchments received the most precipitation during the southwest monsoon and Northeast monsoon seasons.
- For the Sagar catchment, the average SWM precipitation was 1484.28 mm, which is 5.72 times more than the average NEM precipitation.
- For the Kokkarne catchment, the average SWM precipitation was 3554.32 mm, which is 12.58 times more than the average NEM precipitation.
- Sagar catchment is projected to receive 81.44 %, 14.23 %, 0.62 %, and 3.71 % out of total annual precipitation, during SWM, NEM, winter, and summer, seasons respectively.
- Kokkarne catchment is projected to receive 87.34 %, 6.94 %, 0.24 %, and 5.47 % out of total annual precipitation, during SWM, NEM, winter, and summer, seasons respectively.

However, the limitation of the current study is that the impact on the hydrological cycle due to reduced greenhouse gas emissions caused by the recent pandemic-related lockdown restrictions has not been considered. The analysis in the present study helps the farmers to take up necessary contingency preparations as and when needed. The present research about seasonal precipitation distribution and discharge of the catchments can be of great help in formulating the guidelines for appropriate crop planning and soil water conservation in Sagar and Kokkarne catchments.

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References

1) Shukla R, Agarwal A, Sachdeva K, Kurths J, Joshi PK. Climate change perception: an analysis of climate change and risk perceptions among farmer types of Indian Western Himalayas. *Climatic Change*. 2019;152(1):103–119. Available from: https://doi.org/10.1007/s10584-018-2314-z.
2) Dai A, Rasmussen RM, Liu C, Ikeda K, Prein AF. A new mechanism for warm-season precipitation response to global warming based on convection-permitting simulations. *Climate Dynamics*. 2020;55(1-2):343–368. Available from: https://doi.org/10.1007/s00382-017-3787-6.
3) Bisht IS, Rana JC, Ahlawat SP. The Future of Smallholder Farming in India: Some Sustainability Considerations. *Sustainability*. 2020;12(9):3751–3751. Available from: https://doi.org/10.3390/su12093751.
4) Kour VP, Arora S. Recent Developments of the Internet of Things in Agriculture: A Survey. *IEEE Access*. 2020;8:129924–129957. Available from: https://doi.org/10.1109/ACCESS.2020.3009298.
5) Panda A, Sahu N. Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir and Koraput districts of Odisha, India. *Atmospheric Science Letters*. 2019;20(10):1–10. Available from: https://doi.org/10.1002/asl.932.
6) Maharana P, Agnihotri R, Dimri AP. Changing Indian monsoon rainfall patterns under the recent warming period 2001–2018. *Climate Dynamics*. 2021;57(9-10):2581–2593. Available from: https://doi.org/10.1007/s00382-021-05823-8.
7) Amarasinghe U, Amarnath G, Alahacoon N, Ghosh S. How Do Floods and Drought Impact Economic Growth and Human Development at the Sub-National Level in India? *Climate*. 2020;8(11):123–123. Available from: https://doi.org/10.3390/cli8110123.
8) Khan AJ, Koch M, Tahir AA. Impacts of Climate Change on the Water Availability, Seasonality and Extremes in the Upper Indus Basin (UIB). *Sustainability*. 2020;12(4):1283–1283. Available from: https://doi.org/10.3390/su12041283.
9) Kuntiyawichai K, Sri-Amporn W, Wongsasri S, Chindaprasirt P. Anticipating of Potential Climate and Land Use Change Impacts on Floods: A Case Study of the Lower Nam Phong River Basin. *Water*. 2020;12(4):1158–1158. Available from: https://doi.org/10.3390/w12041158.
10) Dhaubanjar S, Pandey VP, Bharati L. Climate futures for Western Nepal based on regional climate models in the CORDEX-SA. *International Journal of Climatology*. 2020;40(4):2201–2225. Available from: https://doi.org/10.1002/joc.6327.

11) Oo HT, Zin WW, Kyi CCT. Analysis of Streamflow Response to Changing Climate Conditions Using SWAT Model. *Civil Engineering Journal*. 2020;6(2):194–209. Available from: https://doi.org/10.28991/cej-2020-03091464.
12) Aawar T, Khare D. Assessment of climate change impacts on streamflow through hydrological model using SWAT model: a case study of Afghanistan. *Modeling Earth Systems and Environment*. 2020;6(3):1427–1437. Available from: https://doi.org/10.1007/s40808-020-00759-0.
13) Bhatta B, Shrestha S, Shrestha PK, Talchabhadel R. Evaluation and application of a SWAT model to assess the climate change impact on the hydrology of the Himalayan River Basin. *CATENA*. 2019;181:104082–104082. Available from: https://doi.org/10.1016/j.catena.2019.104082.
14) Sinha RK, Eldho TI, Subimal G. Assessing the impacts of land use/land cover and climate change on surface runoff of a humid tropical river basin in Western Ghats, India. *International Journal of River Basin Management*. 2020;p. 1–12. Available from: https://doi.org/10.1080/15715124.2020.1809434.
15) Anshuman A, Kunnath-Poovakka A, Eldho TI. Towards the use of conceptual models for water resource assessment in Indian tropical watersheds under monsoon-driven climatic conditions. *Environmental Earth Sciences*. 2019;78(9):1–15. Available from: https://doi.org/10.1007/s12665-019-8281-5.
16) Samal DR, Gedam S. Assessing the impacts of land use and land cover change on water resources in the Upper Bhima river basin, India. *Environmental Challenges*. 2021;5:100251–100251. Available from: https://doi.org/10.1016/j.envc.2021.100251.
17) Marahatta S, Aryal D, Devkota LP, Bhattarai U, Shrestha D. Application of SWAT in Hydrological Simulation of Complex Mountainous River Basin (Part II: Climate Change Impact Assessment). *Water*. 2021;13(11):1548–1548. Available from: https://doi.org/10.3390/w13111548.
18) Mandal U, Sena DR, Dhar A, Panda SN, Adhikary PP, Mishra PK. Assessment of climate change and its impact on hydrological regimes and biomass yield of a tropical river basin. *Ecological Indicators*. 2021;126:107646–107646. Available from: https://doi.org/10.1016/j.ecolind.2021.107646.
19) Sharafati A, Pezeshki E. A strategy to assess the uncertainty of a climate change impact on extreme hydrological events in the semi-arid Dehbar catchment in Iran. *Theoretical and Applied Climatology*. 2020;139(1-2):389–402. Available from: https://doi.org/10.1007/s00704-019-02979-6.
20) Li C, Fang H. Assessment of climate change impacts on the streamflow for the Mun River in the Mekong Basin, Southeast Asia: Using SWAT model. *CATENA*. 2021;201:105199–105199. Available from: https://doi.org/10.1016/j.catena.2021.105199.
21) Padhiary J, Patra KC, Dash SS, Kumar AU. Climate change impact assessment on hydrological fluxes based on ensemble GCM outputs: a case study in eastern Indian River Basin. *Journal of Water and Climate Change*. 2020;11(4):1676–1694. Available from: https://doi.org/10.2166/wcc.2019.080.
22) Neitsch SL, Arnold JG, Kiniry JR, Williams JR. Soil and water assessment tool theoretical documentation version. 2009. Available from: https://oaktrust.library.tamu.edu/bitstream/handle/1969.1/128050/TR-406_SoilandWaterAssessmentToolTheoreticalDocumentation.pdf?sequence=1.
23) Van Griensven A, Meixner T, Grunwald S, Bishop T, Diluzio M, Srinivasan R. A global sensitivity analysis tool for the parameters of multi-variable catchment models. *Journal of Hydrology*. 2006;324(1-4):10–23. Available from: https://doi.org/10.1016/j.jhydrol.2005.09.008.
24) Busico G, Colombani N, Fronzi D, Pellegrini M, Tazioli A, Mastrocicco M. Evaluating SWAT model performance, considering different soils data input, to quantify actual and future runoff susceptibility in a highly urbanized basin. *Journal of Environmental Management*. 2020;266:110625–110625. Available from: https://doi.org/10.1016/j.jenvman.2020.110625.
25) Saikranthi K, Radhakrishna B, Thota NR, Satheesh SK. Differences in the association of sea surface temperature—precipitating systems over the Bay of Bengal and the Arabian Sea during southwest monsoon season. *International Journal of Climatology*. 2019;39(11):4305–4312. Available from: https://doi.org/10.1002/joc.6074.
26) Jain S, Salunke P, Mishra SK, Sahany S. Performance of CMIP5 models in the simulation of Indian summer monsoon. *Theoretical and Applied Climatology*. 2019;137(1-2):1429–1447. Available from: https://doi.org/10.1007/s00704-018-2674-3.
27) Saini A, Sahu N, Kumar P, Nayak S, Duan W, Avtar R, et al. Advanced Rainfall Trend Analysis of 117 Years over West Coast Plain and Hill Agro-Climatic Region of India. *Atmosphere*. 2020;11(11):1225–1225. Available from: https://doi.org/10.3390/atmos11111225.
28) Fraga I, Cea L, Puertas J. Effect of rainfall uncertainty on the performance of physically based rainfall-runoff models. *Hydrological Processes*. 2019;33(1):160–173. Available from: https://doi.org/10.1002/hyp.13319.
29) Williams MR, King KW. Changing rainfall patterns over the Western Lake Erie Basin. *Effects on tributary discharge and phosphorus load*. 1975;56. Available from: https://doi.org/10.1029/2019WR025985.
30) Sebastian A, Gori A, Blessing RB, Van Der Wiel K, Bass B. Disentangling the impacts of human and environmental change on catchment response during Hurricane Harvey. *Environmental Research Letters*. 2019;14(12):124023–124023. Available from: https://doi.org/10.1088/1748-9326/ab5234.
31) Mishra V, Thirumalai K, Singh D, Aadhar S. Future exacerbation of hot and dry summer monsoon extremes in India. *Npj Climate and Atmospheric Science*. 2020;3:1–9. Available from: https://doi.org/10.1038/s41612-020-0113-5.
32) Bhatla R, Varma P, Verma S, Ghosh S. El Nino/La Nina impact on crop production over different agro-climatic zones of Indo-Gangetic Plain of India. *Theoretical and Applied Climatology*. 2020;142(1-2):151–163. Available from: https://doi.org/10.1007/s00704-020-03284-3.
33) Pradhan A, Chandrakar T, Nag S, Dixit A, Mukherjee S. Crop planning based on rainfall variability for Bastar region of Chhattisgarh, India. . *Journal of Agrometeorology*. 2020;22(4):509–517. Available from: https://doi.org/10.54386/jam.v22i4.477.
34) Pattanayak S, Rath BS, Pasupalak S, Mohapatra AKB, Baliarsingh A, Nanda A, et al. Characterisation of rice fallow period for increasing cropping intensity in Khordha district of Odisha. *Journal of Agrometeorology*. 2019;21(3):344–351. Available from: https://doi.org/10.54386/jam.v21i3.258.