

Climate Change Impact on the Groundwater Resources of Nagavali Basin Using QSWAT Model



M. Jothi Jeya Sri and K. Venkata Reddy

Abstract Groundwater is one of the major freshwater resources, which has been under stress nowadays. The rate depletion of groundwater resources is more than its recharge rate due to the pumping of groundwater for industrial and agricultural use. Global warming causes a change in precipitation and temperature rate. Nagavali basin is a tropical river basin that lies between Mahanadi and the Godavari river basins of South India. It is a major source for agriculture, industrial and domestic purposes. This report assesses the possible future climatic condition and changes in the aquifer recharge with climatic parameters under two Representative Concentration Pathway (RCP) scenarios of 4.5 and 8.5. The hydrological balance was studied with the SWAT model using the climate parameters. The groundwater recharge and evapotranspiration rate with the change of temperature and precipitation for the calibration period 1991–2018 and the future period of 2021–2080 were carried out. The QSWAT model was calibrated for the observed streamflow data. From the calibration, it is clear that the observed and simulated streamflow data have a significant correlation with an R^2 value of 0.85. The future prediction of rainfall and temperature for the period of 2021–2080 shows the pattern of future weather. There is an increase in temperature in the future period of 2% for RCP 4.5 and 4% for RCP8.5 scenarios. In the future period, the amount of recharge is increased compared to the present status. The average aquifer recharge was 9.62 and 11.64 m under RCP 4.5 and 8.5. The average evapotranspiration is decreased in the future period by 16 and 11% under RCP 4.5 and RCP 8.5 scenarios compared to base period. Due to increased percentage of precipitation and decreased evapotranspiration under the RCP 8.5 scenario, there is an increase in recharge. Methodology presented in this paper is useful for groundwater studies of the basins in semi-arid regions under climate change scenarios.

M. Jothi Jeya Sri (✉) · K. Venkata Reddy
Department of Civil Engineering, National Institute of Technology, Warangal, Telangana, India
e-mail: jothi_191856@student.nitw.ac.in

K. Venkata Reddy
e-mail: kvreddy@nitw.ac.in

Keywords Climate change · Climate model · Evapotranspiration · Groundwater recharge · Representative concentration pathway (RCP)

1 Introduction

Groundwater is an integral part of the hydrological cycle. Groundwater is a key resource for human development. On a global scale, one-third of the population depends on groundwater for their drinking water, in urban as well as rural areas. Groundwater also plays a pivotal role in agriculture, and an increasing portion of groundwater is being used for agriculture. Central Ground Water Board mentioned that contribution of groundwater for irrigation was 48.19% in their 2009 report (Kambale et al. 2007). The IPCC (2013) has reported that changes in climatic factors will affect the groundwater availability and quality. Presently in most of the places in India groundwater is being over-exploited. This over-exploitation of water resources may result in future famine. Hence, it is necessary to maintain the groundwater availability for the future period.

The climate parameters temperature, precipitation, wind speed, and solar radiation have major effects on the groundwater recharge capacity. The change in trend pattern of climate variables gives the idea of the change of climate over the region. Many previous assessments had been focused on trend analysis of climate variables and change in groundwater level with climate change. Kumar [14] reviewed coupling of climate data with the specific hydrological model used for the study of water balance components. The spatiotemporal change of climate variables has its impact on the water balance component of the watershed and reported that the highest rainfall accelerated the recharge over the watershed [17]. Marhaento et al. [16] studied the change of hydrological components in response to future landuse change and climate change. With their study, it was concluded that the fraction of changes is more under the climate change scenario, so the impact of land-use change is slower compared to climate change. Mogaji et al. [18] assessed the recharge rate and PET with the empirical relationship equation. The change of climatic conditions concerning economic and environmental development scenarios such as A1B, A2, B1. Alam et al. [1] assessed the groundwater storage of California central valley using distributed variable infiltration capacity model (VIC), where the change in groundwater was assessed for the different cropping patterns and agriculture practice.

Shrestha et al. [30] assessed the change of groundwater level for the period of 2011–2100 using the WETPASS and MODLFW model. They used average precipitation and temperature from five different GCM under two different RCP scenarios of 4.5 and 8.5. In their study, the recharge rate gets decreased mainly during the dry season. Kahsay et al. [12] assessed future groundwater recharge and base flow of Tekeze basin, Ethiopia using the WETSPA model. They concluded that the rate of precipitation has impact on variation of recharge rate. Kambale et al. [13] predicted the climate change impact on the northern part of India for the future period of 2030. The groundwater level variation was studied using the hydrological models

HYDRUS-1D and MODFLOW. They reported that the recharge rate might vary with the number of climate parameters considered for analysis and soil types over the region. Shrestha et al. [30] assessed the climatic factor change for the period of 2006–2100 and its influence on recharge for four Asian cities. The climate parameters from five different RCM were coupled with the model WETSPASS and SWAT model. Based on the size of the area the model was selected and concluded that recharge is mainly due to amount of rainfall and temperature. More decrease in recharge occurs during the summer season due to an increase in temperature. Loukika et al. [15] estimated the groundwater recharge of chintalapudi village, West Godavari for the period of 1990–2000. For the groundwater recharge estimation coupled SWAT-MODFLOW were used, where they calculated the groundwater recharge on monthly basis in wells based on aquifer parameters.

In this paper, groundwater recharge variation for Nagavali basin is studied under climate change scenarios over 60 years from 2021 to 2080. The monthly groundwater recharge has been estimated using the SWAT model. The climate models namely ACCESS, CNRM, and MPI have been used for the climate data retrieved, and the groundwater recharge has been estimated using a model. The seasonal and annual variation of climate variables and groundwater recharge has been studied over the entire study basin.

2 Study Area

The study area was the Nagavali river basin shown in Fig. 1 is an imperative basin among the east-flowing river. An independent and interstate river lies in between the Mahanadi and Godavari basins. The Nagavali originates near the Lakhbahal in the Kalahandi district of Odisha at an elevation of about 1300 m (source: <http://www.dowrodisha.gov.in/BasinMaps/IndexofBasins.htm>). It drains parts of the districts of Odisha and Andhra Pradesh State. Basin lies on the geographical coordinates of 18° 17' to 19° 44' latitude and 82° 53' to 83° 54' longitude. The total basin area is 9510 Sq. Km. This river plays a major role in supporting irrigation demand and water supply demand for the district of Koraput, Rayagada, Vizianagaram, and Srikakulam. The total population of the basin as per census 2011 was 6, 76, 678. The top region of basin was covered with forest so that the lower portion of 5559Sq. Km was analyzed in the study.

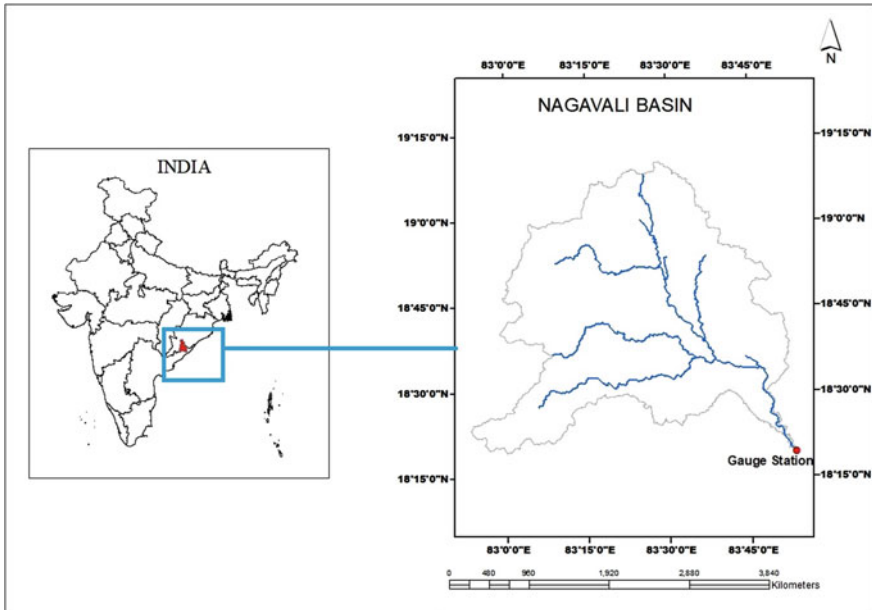


Fig. 1 Location map of Nagavali river basin

3 Data and Methods

3.1 Data

For calculation of recharge of aquifer using SWAT model, the SWAT model requires weather parameters (precipitation and temperature), streamflow data, the digital elevation model, landuse and landcover, and soil properties.

The climate parameters (rainfall and temperature) for the historic period were downloaded from the Indian Meteorological Department (IMD), Pune. The rainfall data is available with the resolution of $0.25^\circ \times 0.25^\circ$. For the analysis, eight grid points data within the basin were downloaded for the period of 1990–2018. The temperature of $1^\circ \times 1^\circ$ grid was also collected for the period of 1990–2018. For the future rainfall and temperature, three climate models were selected data has been downloaded and bias-corrected for the future period of 2021–2080.

An Aster DEM of $30\text{ m} \times 30\text{ m}$ shown in Fig. 2 was used to delineate watershed and stream network generation. The landuse/landcover (LULC) data and soil map of the study area was clipped from SWAT Indian datasets. LULC shown in Fig. 3 is useful for the generation of hydrological response units (HRUs). The soil map shown in Fig. 4 shows that the entire area has three types of soil namely loam, sandy loam, and sandy clay loam. The majority of the upstream portion is covered with sandy

Fig. 2 Digital elevation model

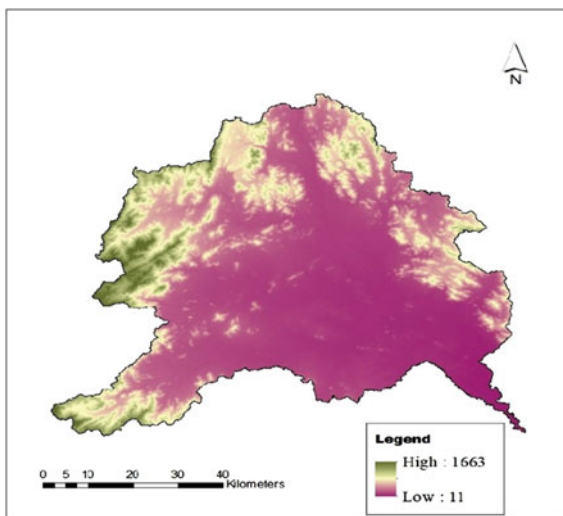


Fig. 3 Landuse/landcover map

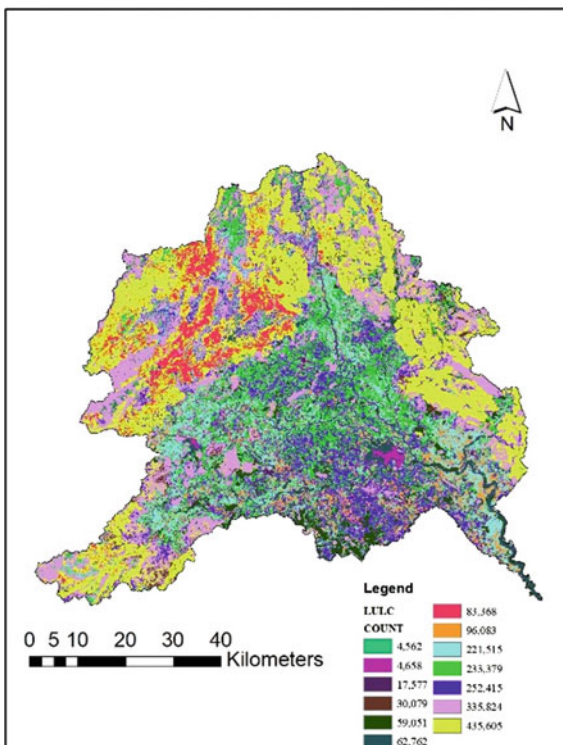
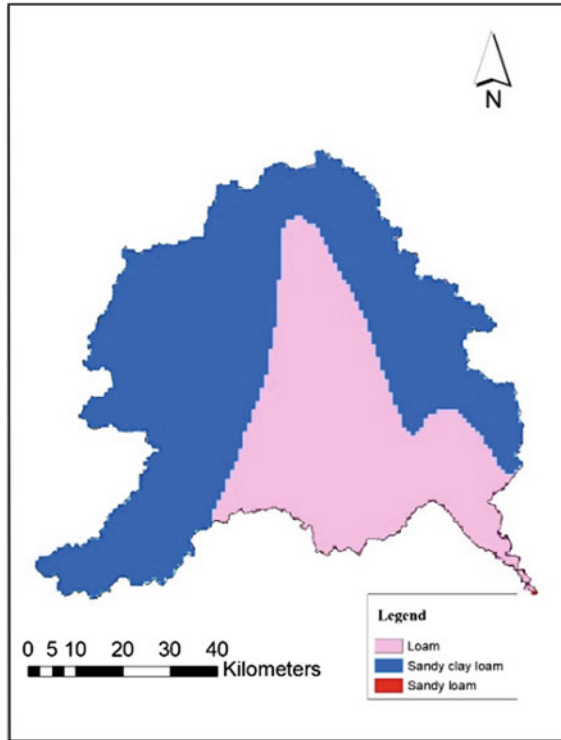


Fig. 4 Soil map



clay loam soil. The stream flow data obtained from the Srikakulam gauge station is essential for the calibration of the SWAT model.

3.2 Methodology

The methodology for the work includes the coupling of climate data with the hydrological model SWAT that is stated in Fig. 5. The study involves analysis of the spatiotemporal trend pattern of precipitation, temperature, and groundwater level. The first step is to analyze the trend of measured and downloaded climatic variables. Then using the geospatial and weather data SWAT model was initially running for the historic period of 1991–2018. In the SWAT model, the basin was subdivided into sub-basins for analysis. The model was calibrated and validated with the observed streamflow data of the Srikakulam gauge station using SWAT CUP. The climate model data from three models namely ACCESS, MPI, CNRM were used for future precipitation and temperature. The data has been downloaded under 2 RCP Scenarios RCP 4.5 and RCP 8.5 and the downloaded model data were bias-corrected using Quantile mapping. The bias-corrected climate variable was given as input for

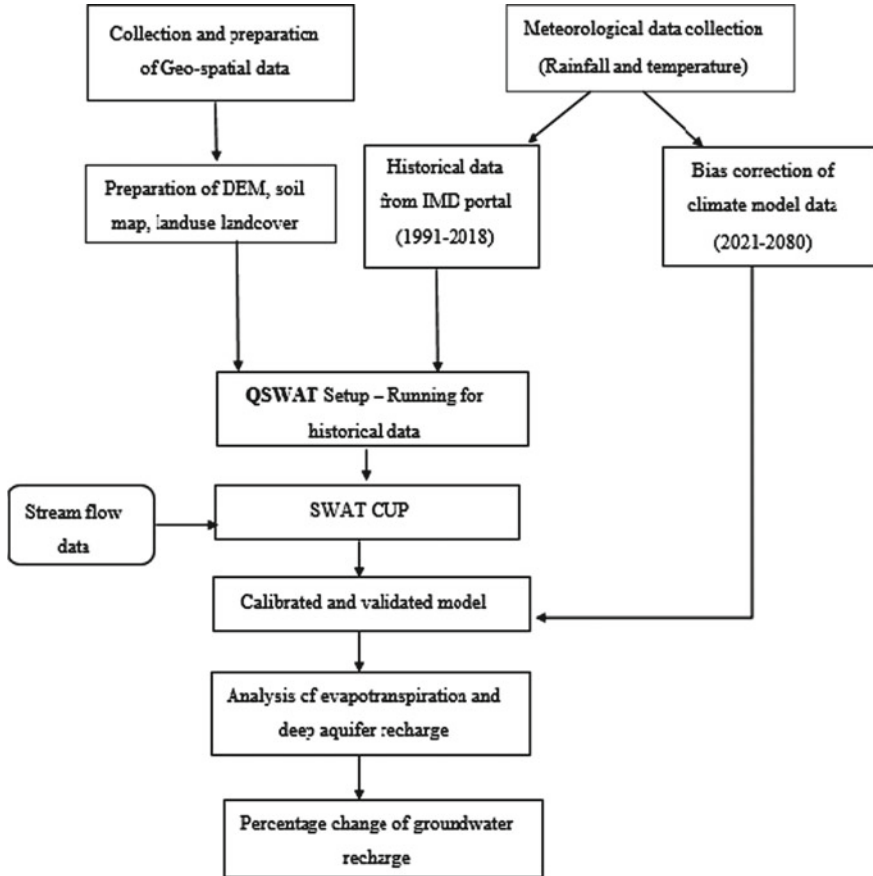


Fig. 5 Conceptual flowchart for assessing the groundwater recharge

calibrated SWAT model. Using the SWAT HRU output file the deep percolation value, evapotranspiration amount for each sub-basin and each land-use type were calculated. Finally, the percentage change in evapotranspiration and groundwater recharge was calculated over 60 years for the prediction of future possibilities of recharge.

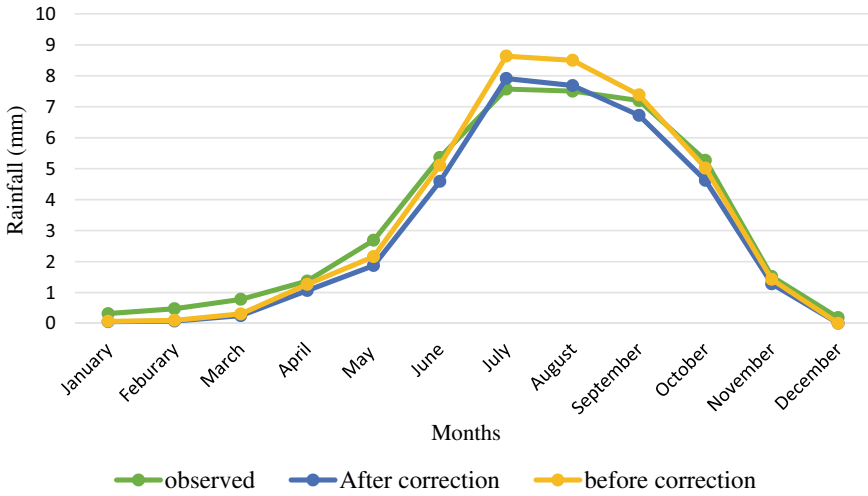


Fig. 6 Correlation between observed and simulated rainfall

4 Result and Discussion

4.1 Bias Correction

The climate data has been corrected for systematic error in the data using Quantile mapping method. The bias corrections of monthly precipitation for the base period of 1950–2005 are presented in Fig. 6. From the figure, corrected precipitation is found to be consistent with observed precipitation. Hence, the corrected data shows close agreement with the observed value in the historic period. So with the best fit transformation function, the future period (2021- 2080) rainfall has been corrected.

4.2 Trend Analysis

4.2.1 Precipitation

MK test statistic (S) indicates a significant increasing trend in future precipitation. Rainfall is predicted to increase gradually in both the scenarios. From Fig. 7 the rainfall variation compared to base period shows that there is 6% increase in RCP 4.5 scenario and 85% increase in RCP 8.5 scenario. The average annual precipitation was 2192.93 and 1186.54 mm. There is a decrease in precipitation for the years 2024, 2025, and 2026 compared to the present average precipitation. Hence, in the future, these years may receive less rainfall.

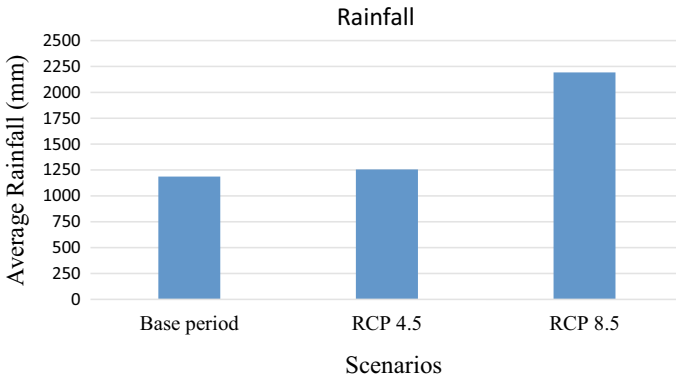


Fig. 7 Rainfall variation

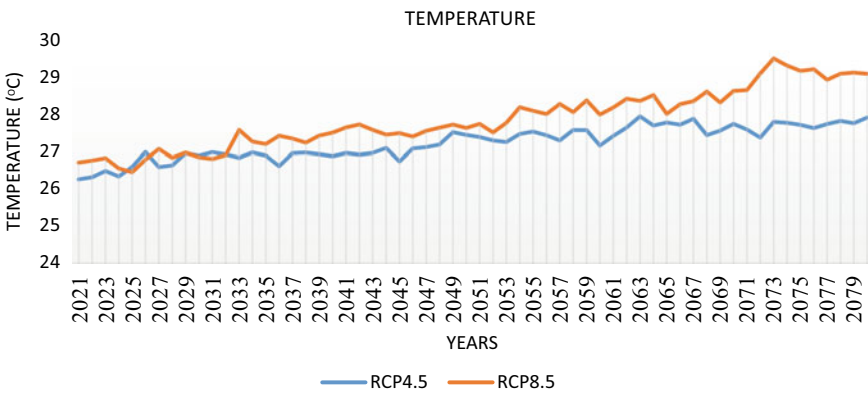


Fig. 8 Trend plot of future temperature

4.2.2 Temperature

For the base period, the maximum average temperature was 32.26 °C and the minimum average temperature was 20.92 °C. The average temperature increases by 2% and 4% under RCP 4.5 and RCP 8.5 scenarios. The temperature plot shown in Fig. 8 depicts that the temperature is more under RCP 8.5 scenario.

4.2.3 Evapotranspiration

The average evapotranspiration is 119.39 and 126.91 mm under RCP 4.5 and RCP 8.5 scenarios, respectively. The increase in temperature by 4% under RCP 8.5 is causing more evapotranspiration compared to RCP 4.5 scenario (Fig. 9).

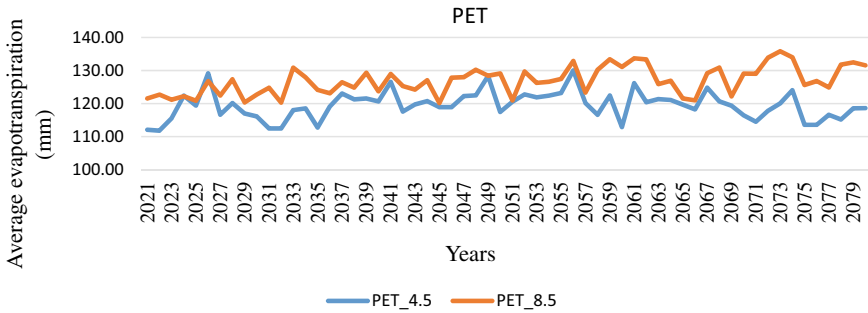


Fig. 9 Potential evapotranspiration

4.3 Estimation of Groundwater Recharge

4.3.1 Calibration and Validation of Model

The SWAT model was calibrated with the observed monthly streamflow data with the simulated streamflow data using SWAT CUP. The model was calibrated for the period of 1991–2005 and validated for the period for 2006–2014. The statistical model performance indicators R^2 and NSE for the period of the calibration were 0.85 and 0.80, respectively and for the period of validation was 0.73 and 0.70, respectively.

4.3.2 Water Balance Component and Groundwater Recharge

After running the calibrated SWAT model, the water balance components and groundwater recharge have been simulated for the future period of 2021–2080. The rainfall, evapotranspiration, and recharge variation have been presented in the table show that there is an increase in future precipitation with the increase of temperature by 0.46 and 1.08 °C under climate change scenarios (RCP 4.5 and RCP 8.5). However, there is a possibility of decrease in the rate of evaporation due to an increase in rainfall amount (Table 1).

Therefore, the decrease in PET by 16% to 11% under RCP 4.5 and RCP 8.5 leads to an increase of recharge rate by 57–90%. The average groundwater recharge (Amount of water entering the deep aquifer) is 9.62 m of water and 11.64 m of water under scenarios 4.5 and 8.5. The reason for the increase in recharge is due to the

Table 1 Percentage change of water balance components

	Rainfall (mm)	% change	AET (mm)	% change	Recharge (m)	% change
Base period	1187.4		142.04		6.13	
RCP4.5	1255.84	6	119.45	−16	9.62	57
RCP8.5	2192.93	85	126.91	−11	11.64	90

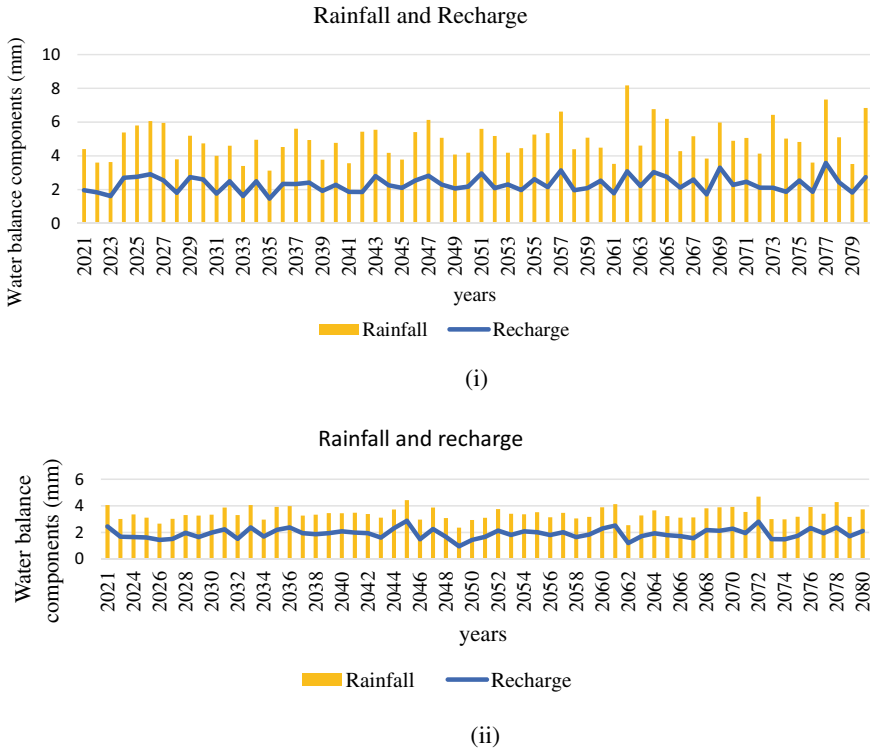


Fig. 10 Trend plot of recharge and rainfall under **a** RCP 4.5, **b** RCP 8.5

permeability of the soil and the increase in precipitation rate. The combination plot of rainfall and recharge is shown in Fig. 10a, b indicates that the rainfall has direct influence on the recharge. Therefore, the year with higher rainfall has higher recharge capacity.

The spatial distribution map of recharge and evapotranspiration for both the scenarios was prepared in GIS environment under both the scenarios. The recharge map is shown in Fig. 11. It is seen that the future period (2021–2080) has possibility of higher recharge capacity over the basin under both scenarios. The evapotranspiration plot is shown in Fig. 12.

4.3.3 Temporal Analysis of Water Balance

The temporal analysis refers to the seasonal analysis of weather and water balance components. For seasonal analysis, the entire year was divided into three seasons which is presented in Table 2. Season I refers to the monsoon season (June to September), Season II refers to the winter season (October to January), and Season III is termed as the summer season (February to May).

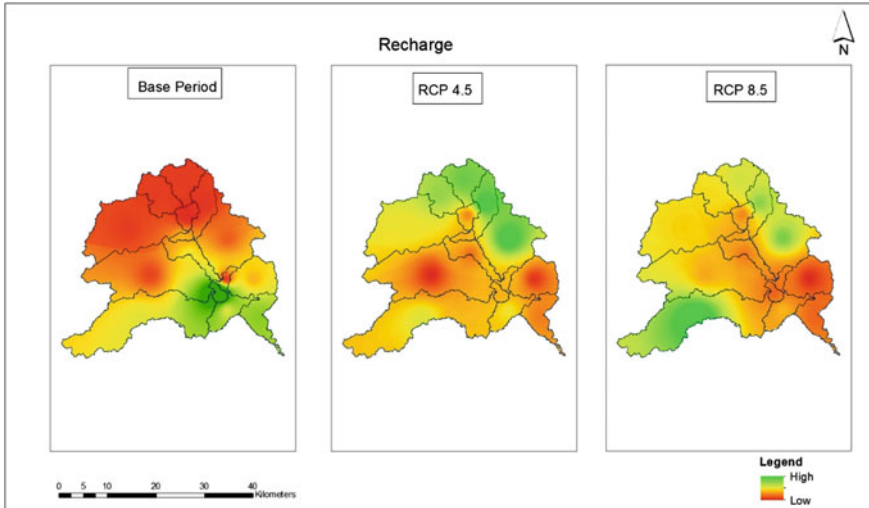


Fig. 11 Spatial distribution of recharge in the basin

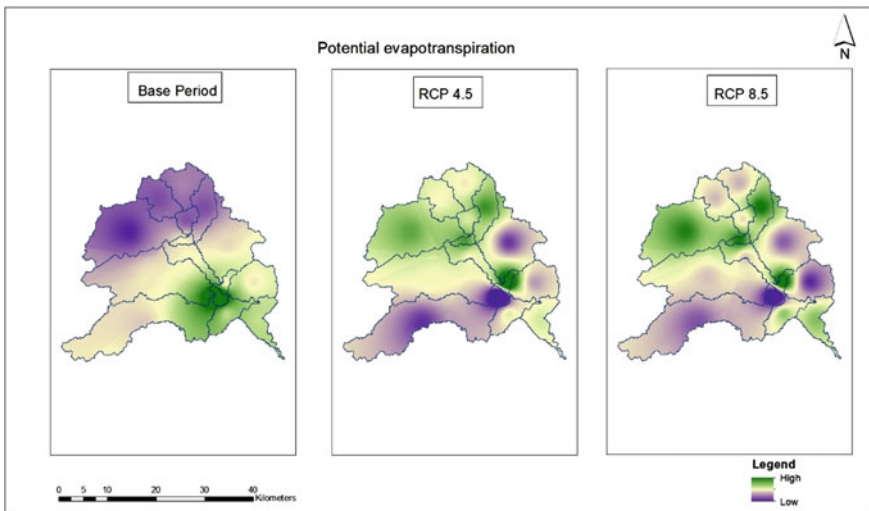


Fig. 12 Spatial distribution of evapotranspiration in the basin

The season-wise analysis of the water balance is presented in Table 2. Under RCP 4.5 scenario, the monsoon season receives 76% of total rainfall, contributes 56% of total recharge, and 25% of evapotranspiration. However, in the summer season, the increase of temperature contributes to 40% of total evapotranspiration, 1% of total recharge. Hence, in the summer season, the recharge rate is limited with increased evapotranspiration with increased temperature.

Table 2 Season-wise water balance

Scenario and period	Season	Precipitation		Evapotranspiration		Recharge	
		<i>P</i> (mm)	%	ET (mm)	%	R (mm)	%
RCP 4.5 (2021–2080)	Monsoon	952.55	76	365.48	25	5389.17	56
	Post monsoon	193.86	15	432.00	30	4126.71	43
	Pre-monsoon	109.43	9	635.87	44	101.09	1
	Total	1255.84		1433.35		9616.97	
RCP 8.5 (2021–2080)	Monsoon	1527.19	70	386.56	25	6918.46	59%
	Post monsoon	584.82	27	448.93	29	4620.68	40%
	Pre-monsoon	80.92	4	687.5	45	103.82	1%
	Total	2192.93		1522.99		11,643	

Under RCP 8.5 Scenario, the monsoon season receives 70% of total rainfall, contributes 59% of total recharge with 25% of evapotranspiration. The rate of recharge is less and potential evapotranspiration is more during the summer season. Hence the increase in temperature is affecting the recharge condition. In the RCP 8.5 scenario, the percentage of winter rainfall is 27% that is more than RCP 4.5 winter rainfall and it indicates that there is, possibility of a shift in the rainfall if the likely emission scenario of the atmosphere is 8.5.

5 Conclusions

The study involves the change in recharge with the influence of climatic conditions. This study analyses the spatiotemporal patterns of weather, groundwater recharge, and evapotranspiration during the period of 2021–2080 under RCP scenarios of 4.5 and 8.5. Trend pattern of rainfall and temperature shows that it increases gradually in the upcoming years. There is a decrease in the future evapotranspiration by 16 and 11% under RCP 4.5 and 8.5 scenarios compared to the present status. From the simulation output, it is seen that the groundwater recharge is increasing in the future period. The average groundwater recharge for the study area in the base period was 6.13 m. In the future period, the average recharge over the basin was 9.62 and 11.64 m under RCP 4.5 and RCP 8.5, respectively and average evapotranspiration was 119.45 mm and 126.91 m. There is decrease in recharge during summer season with the increase of evapotranspiration rate. The increase in precipitation by 6–85% is causing the recharge to increase by 57–90% in the future period. Overall, in the Nagavali basin, there is increase in groundwater recharge in the upcoming years. The reason for the increase of recharge is increase in rainfall rate and soil with higher permeability.

References

1. Alam, S., Gebremichael, M., Dozier, J., & Lettenmaier, D. P. (2019). Climate change impacts on groundwater storage in the Central Valley, California. *Climatic Change*, 157(3–4), 387–406. <https://doi.org/10.1007/s10584-019-02585-5g>
2. Batelaan, O., & De Smedt, F. (2007). GIS-based recharge estimation by coupling surface—subsurface water balances. *Journal of Hydrology*, 337(3–4), 337–355. <https://doi.org/10.1016/j.jhydrol.2007.02.001>
3. Chung, I. M., Kim, N. W., Lee, J., & Sophocleous, M. (2010). Assessing distributed groundwater recharge rate using integrated surface water-groundwater modelling: Application to Mihocheon watershed, South Korea. *Hydrogeology Journal*, 18(5), 1253–1264. <https://doi.org/10.1007/s10040-010-0593>
4. Chunn, D., Faramarzi, M., Smerdon, B., & Alessi, D. S. (2019). Application of an integrated SWAT-MODFLOW model to evaluate potential impacts of climate change and water withdrawals on groundwater-surface water interactions in west-central Alberta. *Water (Switzerland)*, 11(1). <https://doi.org/10.3390/w11010110>
5. Feng, W., Shum, C. K., Zhong, M., & Pan, Y. (2018). Groundwater storage changes in China from satellite gravity: An overview. *Remote Sensing*, 10(5), 1–25. <https://doi.org/10.3390/rs10050674>
6. Gajbhiye, S., Meshram, C., Mirabbasi, R., & Sharma, S. K. (2016). Trend analysis of rainfall time series for Sindh river basin in India. *Theoretical and Applied Climatology*, 125(3–4), 593–608. <https://doi.org/10.1007/s00704-015-1529-4>
7. Ghazavi, R., & Ebrahimi, H. (2019). Predicting the impacts of climate change on groundwater recharge in an arid environment using modeling approach. *International Journal of Climate Change Strategies and Management*, 11(1), 88–99. <https://doi.org/10.1108/IJCCSM-04-2017-0085>
8. Goderniaux, P., Brouyère, S., Blenkinsop, S., Burton, A., Fowler, H. J., Orban, P., & Dassargues, A. (2011). Modeling climate change impacts on groundwater resources using transient stochastic climatic scenarios. *Water Resources Research*, 47(12). <https://doi.org/10.1029/2010WR010082>
9. Gosain, A. K., Rao, S., & Basuray, D. (2006). Climate change impact assessment on hydrology of Indian river basins. *Current Science*, 90(3), 346–353.
10. Jalota, S. K., Vashisht, B. B., Sharma, S., & Kaur, S. (2018). Climate change projections. *Understanding Climate Change Impacts on Crop Productivity and Water Balance*. <https://doi.org/10.1016/b978-0-12-809520-1.00002>
11. Jana, S., Das, M., Roy, D., Das, S., & Mazumdar, A. (2015). Simulation of climate change impact in a river basin in Eastern India. *International Journal of Hydrology Science and Technology*, 5(4), 314–332. <https://doi.org/10.1504/IJHST.2015.072631>
12. Kahsay, K. D., Pingale, S. M., Hatiye, S. D. (2018). Impact of climate change on groundwater recharge and base flow in the sub-catchment of Tekeze basin, Ethiopia. *Groundwater for Sustainable Development*, 6, 121–133. <https://doi.org/10.1016/j.gsd.2017.12.002>
13. Kambale, J. B., Singh, D. K., & Sarangi, A. (2017). Impact of climate change on groundwater recharge in a semi-arid region of northern India. *Applied Ecology and Environmental Research*, 15(1), 335–362. https://doi.org/10.15666/aeer/1501_335362
14. Kumar, C. P. (2016). Impact of climate change on groundwater resources. *Natural Resources Management: Concepts, Methodologies, Tools, and Applications*, 3–2 (January 2010), 1094–1120. <https://doi.org/10.4018/978-1-5225-0803-8.ch052>
15. Loukika, K. N., Reddy, K. V., Rao, K. H., & Singh, A. (2020). Estimation of Groundwater recharge rate using SWAT MODFLOW model. *Springer Singapore*. <https://doi.org/10.1007/978-981-13-7067-0>
16. Marhaento, H., Booij, M. J., & Hoekstra, A. Y. (2018). Hydrological response to future land-use change and climate change in a tropical catchment. *Hydrological Sciences Journal*, 63(9), 1368–1385. <https://doi.org/10.1080/02626667.2018.1511054>

17. Meresa, E., & Taye, G. (2019). Estimation of groundwater recharge using GIS-based WetSpss model for Birki watershed, the eastern zone of Tigray, Northern Ethiopia. *Sustainable Water Resources Management*, 5(4), 1555–1566. <https://doi.org/10.1007/s40899-018-0282-0>
18. Mogaji, K. A., Lim, H. S., & Abdullah, K. (2013). Regional modelling of climate change impacts on groundwater resources sustainability in peninsular Malaysia. *Modern Applied Science*, 7(5), 72–97. <https://doi.org/10.5539/mas.v7n5p72>
19. Ng, G. H. C., McLaughlin, D., Entekhabi, D., & Scanlon, B. R. (2010). Probabilistic analysis of the effects of climate change on groundwater recharge. *Water Resources Research*, 46(7), 1–18. <https://doi.org/10.1029/2009wr007904>
20. Niraula, R., Meixner, T., Dominguez, F., Bhattarai, N., Rodell, M., Ajami, H., Gochis, D., & Castro, C. (2017). How might recharge change under projected climate change in the Western U.S.? *Geophysical Research Letters*, 44(20), 10407–10418. <https://doi.org/10.1002/2017GL07542>
21. Nistor, M. M., Dezsi, Ş., Cheval, S., & Baciu, M. (2016). Climate change effects on groundwater resources: A new assessment method through climate indices and effective precipitation in Beliş district, Western Carpathians. *Meteorological Applications*, 23(3), 554–561. <https://doi.org/10.1002/met.1578>
22. Nkwasa, A., Chawanda, C. J., Msigwa, A., Komakech, H. C., Verbeiren, B., & van Griensven, A. (2020). How can we represent seasonal land use dynamics in SWAT and SWAT+ models for African cultivated catchments. *Water (Switzerland)*, 12(6). <https://doi.org/10.3390/W12061541>
23. Nyenje, P. M., & Batelaan, O. (2009). Estimating the effects of climate change on groundwater recharge and baseflow in the upper Ssezibwa catchment, Uganda. *Hydrological Sciences Journal*, 54(4), 713–726. <https://doi.org/10.1623/hysj.54.4.713>
24. Pisani, B., Samper, J., & Marques, J. E. (2019). Climate change impact on groundwater resources of a hard rock mountain region (Serra da Estrela, Central Portugal). *Sustainable Water Resources Management*, 5(1), 289–304. <https://doi.org/10.1007/s40899-017-0129-0>
25. Reszler, C., Harum, T., Poltnig, W., Saccon, P., Reichl, P., Ruch, C., Kopeinig, C., & Freundl, G. (2012). Impact of climate change on groundwater resources in Southern Austria. 14(October), 7871. <https://doi.org/10.13140/RG.2.2.25462.45125>
26. Sahoo, S., Dhar A., Debsarkar A., Pradhan B., & Alamri AM (2020) Future Water Use Planning by Water Evaluation and Planning System Model. *Water Resources Management*, 34(15), 4649–4664. <https://doi.org/10.1007/s11269-020-02680-8>
27. Setti, S. (2018). Nagavali paper assessment of water balance for a forest dominated coastal river basin in India using a semi distributed hydrological model. *Modeling Earth Systems and Environment*. <https://doi.org/10.1007/s40808-017-0402-0>
28. Setti, S., Maheswaran, R., Radha, D., Sridhar, V., Barik, K. K., & Narasimham, M. L. (2020). Attribution of hydrologic changes in a tropical river basin to rainfall variability and land-use change: Case study from India. *Journal of Hydrologic Engineering*, 25(8), 05020015. [https://doi.org/10.1061/\(asce\)he.1943-5584.0001937](https://doi.org/10.1061/(asce)he.1943-5584.0001937)
29. Setti, S., Rathinasamy, M., & Chandramouli, S. (2018). Assessment of water balance for a forest dominated coastal river basin in India using a semi distributed hydrological model. *Modeling Earth Systems and Environment*, 4(1), 127–140. <https://doi.org/10.1007/s40808-017-0402-0>
30. Shrestha, S., Bach, T. V., & Pandey, V. P. (2016). Climate change impacts on groundwater resources in Mekong Delta under representative concentration pathways (RCPs) scenarios. *Environmental Science and Policy*, 61, 1–13. <https://doi.org/10.1016/j.envsci.2016.03.010>
31. Singh, A. K., Tripathi, J. N., Kotlia, B. S., Singh, K. K., & Kumar, A. (2019). Monitoring groundwater fluctuations over India during Indian Summer Monsoon (ISM) and Northeast monsoon using GRACE satellite: Impact on agriculture. *Quaternary International*, 507(October), 342–351. <https://doi.org/10.1016/j.quaint.2018.10.036>
32. Trzaska, S., & Schnarr, E. (2014). A review of downscaling methods for climate change projections. United States Agency for International Development by Tetra Tech ARD, September (pp. 1–42).