



## Assessing the impact of climate change on surface water resources (Case study: Babolrood watershed)

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### Abstract

**Background and Objective:** In recent years, climate change and human activities have increasingly intensified the global water scarcity crisis. These changes have disrupted the hydrological cycle, placing surface water resources under serious threat in terms of accessibility, quality, and sustainability.

**Methodology:** To assess the impact of climate change on surface water resources in the Babolrood watershed, meteorological and hydrometric data were initially collected. After addressing statistical deficiencies, removing outliers, and selecting a common temporal baseline, future climate variables (precipitation, minimum temperature, and maximum temperature) were projected for the period 2020–2100 using the CanESM5 climate model under IPCC AR6 scenarios SSP1-2.6, SSP2-4.5, and SSP5-8.5 within the SDSM framework. Streamflow simulation for the future period was conducted using downscaled data processed through an Artificial Neural Network (ANN). Finally, to identify trends in the projected data, non-parametric Mann–Kendall and Sen’s slope estimator tests were applied using the R software environment.

**Results and Findings:** Trend analysis of streamflow using the Mann–Kendall test, Sen’s slope estimator, and the ANN model over the period 2021–2100 revealed a weak and statistically insignificant decreasing trend across all SSP climate scenarios. The most pronounced decline was observed under the SSP5-8.5 scenario. Minimum temperature exhibited a non-significant increasing trend, potentially indicating nighttime or cold-season warming, while precipitation showed no discernible trend. The ANN model results were consistent with the statistical tests, confirming a gradual reduction in streamflow, thereby underscoring the need for sustainable water resource management in the face of climate change. These findings not only confirm the direct impact of climate change on surface water resources but also highlight the importance of employing intelligent models for long-term analysis and sustainable water resource management. Moreover, they underscore the necessity of integrated approaches and region-specific analyses in future studies.

**Keywords:** Artificial Neural Network (ANN), Babolrood watershed, Hydrological modeling, Mann-Kendall test, SSP emission scenarios.

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## **Extended Abstract**

### **Introduction**

Water, as a vital element of life, plays a crucial role in regulating the global climate. Nevertheless, climate change has posed serious threats to surface water resources in terms of availability, quality, and distribution. These threats arise from rising temperatures, altered precipitation patterns, sea-level rise, and extreme weather events, all of which disrupt the hydrological cycle. Climate change refers to significant alterations in temperature and precipitation over extended periods, and the rapid growth of industrial activities along with the increase in greenhouse gas emissions in recent decades has disturbed the Earth's climatic balance. The observed rise in global temperature since the pre-industrial era has intensified fluctuations in the magnitude and distribution of precipitation, and projections suggest that the average global temperature will increase substantially by the end of the century. Such changes exert both quantitative and qualitative impacts on surface water resources, including intensified hydrological and agricultural droughts, reduced river flows, increased flooding, and aggravated water quality issues such as eutrophication, elevated nutrient concentrations, and decreased dissolved oxygen. These consequences have created profound challenges for water resource management and highlighted the necessity of adopting adaptive strategies. To assess climate change, Global Climate Models (GCMs) have been developed, which simulate the interactions among oceans, atmosphere, sea ice, and land surfaces in a hierarchical and integrated system. These models serve as essential tools for reconstructing past climates and projecting future climatic changes.

### **Methodology**

In accordance with the objectives of the study, climatic and hydrological data, including daily precipitation, minimum temperature, maximum temperature, and streamflow, were obtained from meteorological and hydrometric stations within the watershed, provided by the Mazandaran Meteorological Organization and the Regional Water Company. After eliminating outliers, correcting statistical deficiencies, and conducting homogeneity and randomness tests, a common baseline period across the stations (September 23, 1994 to September 21, 2024) was established for model input. Following the initial data analysis and baseline selection, future climatic data were projected. For this purpose, the Sixth Assessment Report of the IPCC (AR6, CMIP6) and the CanESM5 climate model were employed to simulate the period 2020–2100 under scenarios SSP1-2.6, SSP2-4.5, and SSP5-8.5 using the Statistical DownScaling Model (SDSM). To generate stochastic data for future periods, daily records from rain-gauge stations during the baseline period (1994–2014), along with outputs from the general circulation model under the aforementioned scenarios, were utilized. This choice was necessitated by the limitation of CMIP6 historical simulations up to 2014 and the availability of observed measurements within this statistical period. After projecting climatic variables (precipitation, minimum temperature, and maximum temperature) for the future period, streamflow simulation was conducted using the generated data within an Artificial Neural Network (ANN) framework. Finally, to identify trends in the projected series, non-parametric Mann–Kendall tests and Sen's slope estimator were applied in the R software environment.

### **Results and Findings**

The results of the Mann–Kendall test and Sen's slope estimator revealed that maximum temperature shows an increasing trend across all scenarios, with Z values ranging from 1.478 to 1.926. This indicates a gradual upward tendency in maximum temperature. The p-value in scenario SSP5-8.5 was 0.054, which is close to the statistical significance threshold of 0.05, while in the other two scenarios it was slightly higher. Kendall's  $\tau$  was positive but very small

in all scenarios, confirming the presence of a very weak increasing trend. Sen's slope was also positive in each case, reflecting a slow but steady rise in temperature over time. Thus, although the increasing trend in maximum temperature was observed in all scenarios, only SSP5-8.5 approached statistical significance. Despite the weak intensity, the large dataset suggests that this trend may be climatically meaningful. Analysis of precipitation data showed no significant trends. In SSP1-2.6,  $Z$  was negative (-0.519), indicating a weak decreasing tendency, but the p-value of 0.603 was far from significance. In the other two scenarios,  $Z$  was positive but less than 1.2, with p-values above 0.25. Kendall's  $\tau$  was extremely small (less than 0.005) and Sen's slope equaled zero in all scenarios, confirming the absence of meaningful changes in precipitation during the study period. Future streamflow projections using the ANN model indicated decreasing trends in all scenarios, with negative  $Z$  values. However, none of the p-values reached the 0.05 significance level. In SSP5-8.5, the p-value was 0.138, closer to significance compared to the other scenarios. Kendall's  $\tau$  was negative and very small (less than 0.006) in all cases, showing a very weak decreasing trend. Sen's slope was more negative in SSP2-4.5 and SSP5-8.5 than in SSP1-2.6, suggesting that stronger climate change and global warming are associated with greater reductions in streamflow. This decline may be attributed to rising temperatures, increased evapotranspiration, altered precipitation patterns, and more frequent droughts, all recognized consequences of climate change. Overall, the findings highlight a gradual rise in maximum temperature, no significant changes in precipitation, and weak but concerning reductions in streamflow under high-emission scenarios. Although most trends are statistically weak, their direction—particularly under SSP5-8.5—carries important climatic and management implications.

## **Conclusion**

These findings confirm the direct influence of climate change on surface water resources, revealing rising maximum temperatures, stable precipitation, and weak but concerning declines in streamflow under high-emission scenarios. They emphasize the importance of intelligent modeling approaches, such as SDSM and ANN, for long-term projections and sustainable water management. Moreover, the results highlight the need for integrated strategies and region-specific analyses to address future climatic challenges. Although most detected trends are weak statistically, their direction—particularly under SSP5-8.5—underscores significant implications for adaptation, resilience, and effective resource planning in the face of global warming.

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### **Authors' Contribution**

Authors contributed equally to the conceptualization and writing of the article. All of the authors approved the content of the manuscript and agreed on all aspects of the work declaration of competing interest none.

### **Conflict of Interest**

The authors declare no conflict of interest.

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## References

- Abbaszadeh, M., Bazrafshan, O., Katipoğlu, O. M., & Jamshid, S. (2025). Harnessing artificial intelligence for streamflow predictions under climate change scenarios in arid region. *Theoretical and Applied Climatology*, 156(4), 1-13. <https://doi.org/10.1007/s00704-025-05451-w>
- Ali, M. A., & Kamraju, M. (2023). Climate Change and Natural Resources. In *Natural Resources and Society: Understanding the Complex Relationship Between Humans and the Environment* (pp. 143-158). Cham: Springer Nature Switzerland.
- ASCE Task Committee on Application of Artificial Neural Networks in Hydrology. (2000). Artificial neural networks in hydrology. II: Hydrologic applications. *Journal of Hydrologic Engineering*, 5(2), 124-137.
- Benti, K. K., Dinka, M. O., Rwanga, S. S., & Aredo, M. R. (2025). Assessing Streamflow Response to Climate Change Under Shared Socioeconomic Pathways (SSPs) in the Olifants River Basin, South Africa. *Hydrology*, 12(9), 244. <https://doi.org/10.3390/hydrology12090244>
- Bi, W., Weng, B., Yuan, Z., Ye, M., Zhang, C., Zhao, Y., ... & Xu, T. (2018). Evolution characteristics of surface water quality due to climate change and LUCC under scenario simulations: a case study in the Luanhe River Basin. *International journal of environmental research and public health*, 15(8), 1724. <https://doi.org/10.3390/ijerph15081724>
- Caretta, M. A., et al. (2022). Water. In *Climate change 2022: Impacts, adaptation and vulnerability* (pp. 551–712). Cambridge University Press. <https://doi.org/10.1017/9781009325844.006>
- Dawson, C. W., & Wilby, R. L. (2001). Hydrological modelling using artificial neural networks. *Progress in physical Geography*, 25(1), 80-108. <https://doi.org/10.1177/030913330102500104>
- Fahimirad, Z., Rajaei, T., & Shahkarami, N. (2022). The effect of climate change on climatic variables and runoff in the Kamal Saleh Dam watershed, Markazi Province. *Irrigation and Water Engineering*, 12(47), 261–282. <https://doi.org/10.22125/iwe.2022.146407> **[In Persian]**.
- Gacu, J. G., Monjardin, C. E. F., Mangulabnan, R. G. T., & Mendez, J. C. F. (2025). Application of artificial intelligence in hydrological modeling for streamflow prediction in ungauged watersheds: A review. *Water*, 17(18), 2722. <https://doi.org/10.3390/w17182722>
- Goswami, G., Prasad, R. K., & Mandal, S. (2025). Streamflow variability under SSP2-4.5 and SSP5-8.5 climate scenarios using QSWAT plus for Subansiri River Basin in Arunachal Pradesh, India. *Theoretical and Applied Climatology*, 156(5), 1-23. <https://doi.org/10.1007/s00704-025-05496-x>
- Hamidianpour, M., Fallah Qalehri, G., & Alimoradi, M. R. (2021). Evaluation of the efficiency of the SDSM model in assessing climate change impacts for different climatic zones of Iran. *Climate Change Research*, 2(5), 1–14. <https://doi.org/10.30488/ccr.2020.248188.1023> **[In Persian]**.
- Heshamati, S., Nazari, B., & Nikoo, M. R. (2025). Enhancing accuracy in streamflow prediction under climate change scenarios based on an integrated machine learning–metaheuristic optimization approach. *Journal of Water and Climate Change*, 16(2), 456-473. <https://doi.org/10.2166/wcc.2025.499>
- IPCC, 2001. Climate change 2001: IPCC Special Report Emissions Scenarios. A Special

- Report of IPCC Working Group III, Intergovernmental Panel on Climate Change, ISBN: 92-9169, 113-115.
- IPCC, 2007. The scientific Basis. Contribution of working group I to the third assessment report of the intergovernmental panel on climate change, Cambridge University Press. New York, USA.
- Javadizadeh, F., Kardavani, P., Alijani, B., & Asadian, F. (2019). Efficiency of statistical downscaling model (SDSM) patterns in predicting temperature parameters in the Minab watershed. *Physical Geography*, 11(42), 47–66. <https://dorl.net/dor/20.1001.1.20085656.1397.11.42.4.2> [In Persian].
- Kendall, M.G. (1975) Rank Correlation Methods. 4th Edition, Charles Griffin, London.
- Lettenmaier, D.P., Wood, E.R. & Wallis, J.R. (1994). Hydro-Climatological Trends in the Continental United States, 1948-88. *Journal of Climate*, 7(4), 586-607.
- Mann, H.B. (1945). Non-parametric tests against trend, *Econometrica* 13:163-171. <https://doi.org/10.2307/1907187>
- Mimeau, L., Künne, A., Devers, A., Branger, F., Kralisch, S., Lauvernet, C., ... & Detry, T. (2025). Projections of streamflow intermittence under climate change in European drying river networks. *Hydrology and Earth System Sciences*, 29(6), 1615-1636. <https://doi.org/10.5194/hess-29-1615-2025>
- Oyebode, O., & Stretch, D. (2019). Neural network modeling of hydrological systems: A review of implementation techniques. *Natural Resource Modeling*, 32(1), e12189.
- Ray, R. L., & Tikuye, B. G. (2025). Impact of Climate Change on Surface Water Resources. <https://doi.org/10.5772/intechopen.1011407>
- Rezaei, M., Nahtani, M., Abkar, A., Rezaei, M., & Mirkazahi Rigi, M. (2014). Evaluation of the efficiency of the statistical downscaling model (SDSM) in predicting temperature parameters in two arid and hyper-arid climates (Case study: Kerman and Bam). *Watershed Management Research Journal*, 5(10), 117–131. <http://jwmr.sanru.ac.ir/article-1-417-fa.html> [In Persian].
- Rummukainen, M. (2012). Changes in climate and weather extremes in the 21st century. *Wiley Interdisciplinary Reviews: Climate Change*, 3(2), 115-129.
- Samadi Neqab, S., Habibi Nokhandan, M., & Zabol Abbasi, F. (2011). Application of the SDSM model for downscaling GCM precipitation and temperature data: A case study of station-based climate projections in Iran. *Climatology Research*, 2(5–6), 57–68.
- Sheikha-BagemGhaleh, S., Babazadeh, H., Rezaie, H., & Sarai-Tabrizi, M. (2023). The effect of climate change on surface and groundwater resources using WEAP-MODFLOW models. *Applied Water Science*, 13(6), 121. <https://doi.org/10.1007/s13201-023-01923-4>
- Sigmond, M., Anstey, J., Arora, V., Digby, R., Gillett, N., Kharin, V., Yang, D., (2023). Improvements in the Canadian Earth system model (CanESM) through systematic model analysis: CanESM5. 0 and CanESM5. 1. *Geoscientific Model Development*, 16(22): 6553-6591. <https://doi.org/10.5194/gmd-16-6553-2023>
- Singh, D., Vardhan, M., Sahu, R., Chatterjee, D., Chauhan, P., & Liu, S. (2023). Machine-learning-and deep-learning-based streamflow prediction in a hilly catchment for future scenarios using CMIP6 GCM data. *Hydrology and Earth System Sciences*, 27(5), 1047-1075. <https://doi.org/10.5194/hess-27-1047-2023>
- Sobkowiak, L., & Wrzesiński, D. (2024). Impacts of Climate Change on Water Resources: Assessment and Modeling-First Edition. *Water*, 16(24), 3578. <https://doi.org/10.3390/w16243578>
- Sudarsan, G., & Lasitha, A. (2023). Rainfall Trend analysis using Mann-Kendall and Sen's slope test estimation-A case study. In *E3S Web of Conferences* (Vol. 405, p. 04013). EDP Sciences. <https://doi.org/10.1051/e3sconf/202340504013>

- Swart, N. C., Cole, J. N., Kharin, V. V., Lazare, M., Scinocca, J. F., Gillett, N. P., ... & Winter, B. (2019). The Canadian earth system model version 5 (CanESM5. 0.3). *Geoscientific Model Development*, 12(11), 4823-4873. <https://doi.org/10.5194/gmd-12-4823-2019>
- Whitehead, P. G., Wilby, R. L., Battarbee, R. W., Kernan, M., & Wade, A. J. (2009). A review of the potential impacts of climate change on surface water quality. *Hydrological sciences journal*, 54(1), 101-123. <https://doi.org/10.1623/hysj.54.1.101>
- Yousefi, H., Amini, L., Ghasemi, L., & Emraei, N. (2018). Evaluation of the efficiency of the statistical downscaling model (SDSM) in simulating and predicting climatic parameters (Case study: Karaj synoptic station). *Ecohydrology Journal*, 5(3), 957–968. <https://doi.org/10.22059/ije.2018.254290.847> [In Persian].
- Zhang, C., Xiao, X., Wang, X., Yi, S., Meng, C., Qin, Y., ... & Dong, J. (2025). Climate-induced losses of surface water and total water storage in Northeast Asia. *Communications Earth & Environment*, 6(1), 479. <https://doi.org/10.1038/s43247-025-02449-0>