FUTURE HYDROCLIMATIC VARIABILITY IN THE VU GIA THU BON RIVER BASIN DERIVED FROM HIGH-RESOLUTION CMIP6-VN PROJECTIONS

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(Received: March 30, 2026; Revised: May 15, 2026; Accepted: June 05, 2026)

DOI: 10.31130/ud-jst.2026.24(7B).584E

Abstract - Heavy rainfall across Central Vietnam in 2025 highlights the increasing intensity of extreme precipitation and the need for reliable regional climate projections. Although CMIP6 global climate models have improved climate simulations, their coarse spatial resolution limits basin-scale applications. This study uses high-resolution (10km) downscaled CMIP6-VN projections from 19 CMIP6 models to assess future rainfall, temperature, and hydrological changes in the Vu Gia Thu Bon River basin during 1985–2099 under four SSP scenarios (SSP1–2.6, SSP2–4.5, SSP3–7.0, and SSP5–8.5). Mean annual precipitation is projected to increase under all scenarios, reaching up to 6.7% above the historical baseline (1985–2014). Although rainfall and flood-season runoff increase, streamflow responses are substantially moderated by reservoir regulation, emphasizing the critical role of reservoir operations in future water management. These findings demonstrate the value of high-resolution climate projections for reducing uncertainty in hydrological impact assessments and supporting climate adaptation and water resources planning in regulated river basin.

Key words - Climate change; CMIP6-VN; Downscale; Vu Gia Thu Bon River basin.

1. Introduction

The Coupled Model Intercomparison Project Phase 6 (CMIP6) general circulation models (GCMs) represent the most advanced climate simulation tools available and play a fundamental role in evaluating future climate scenarios. These models, which have been used extensively in recent IPCC assessments, provide new insights into potential climate futures under various emission scenarios. Future climate impacts across many regions have been extensively studied via CMIP6 [1], in which GCMs are specifically used to examine the effects of increasing greenhouse gas (GHG) emissions on climatic variables and the hydrological cycle [2]. In many applications, including risk assessment, adaptation management, and regional or local decision-making, the resolution of CMIP6 GCMs remains too coarse [3], [4]. Owing to their low spatial resolution (50–100 km), they struggle to accurately reproduce climatic variables for small areas such as basins and subbasins [5], [6]. Beyond their coarse resolution, GCMs also exhibit biases and uncertainties that tend to amplify when scaled from global to regional and local levels, limiting their applicability in regional studies. Consequently, inaccurate assessments resulting from the coarse spatial resolution of GCMs can lead to misinterpretations and incorrect estimations of climate change effects, with serious consequences for long-term planning and extreme event management [7]. Specifically, underestimating regional-scale responses to climate change may result in inadequate preparedness for mitigation and adaptation efforts. However, overestimating these responses can lead to excessive budget and extra effort allocations to address future hydrological extremes.

Investigations into whether finer-scale scenarios significantly alter our perceptions of the impacts of climate change on various resource systems are limited [8]. Additionally, the lack of detailed analysis of how the spatial scale of climate change scenarios affects the resulting impacts stands out as a serious deficiency in research on scenario formation and regional impact assessments [9]. Therefore, downscaling is crucial for refining low-resolution global climate projections to local or regional scales by establishing relationships between observed climate data and GCM simulations [10]. The datasets represent the projected climate conditions, making them more suitable for local-scale and regional assessments.

In this study, we aimed to evaluate the performance of downscaled daily meteorological variables across Vietnam, focusing on the Vu Gia Thu Bon (VGTB) River basin, located in the central part, with the main objectives of evaluating the CMIP6 GCM datasets, downscaled version (10 km for Vietnam). 19 GCMs with spatial resolutions as low as 10 km under the SSP 1–2.6, 2–4.5, 3–7.0, and 5–8.5 scenarios have been employed. Throughout this work, we estimate changes in future precipitation and the basin's hydrological components (peak streamflow) using the hydrological model. Our findings provide important insights that can support evidence-based decision-making by water resource managers, improve flood and drought disaster planning, and inform climate adaptation strategies for the VGTB River basin.

2. Data and Methodology

First, future changes in precipitation will be assessed using nineteen high-resolution (10 km) CMIP6-VN climate models under four Shared Socioeconomic Pathway (SSP) scenarios. Projected changes will be quantified by comparing future periods with the historical baseline, with particular attention to both magnitude and spatial variability.

The basin is significantly regulated by hydraulic infrastructure, including dams and reservoirs, and the hydrological regime has been substantially altered. These structures influence flow discharge patterns and downstream flood dynamics. Therefore, in the Discussion section, we will evaluate the role of reservoirs in changing streamflow by applying the SWAT (Soil & Water Assessment Tool) hydrological model, driven by the same climate forcing datasets used in the precipitation assessment. The model has been calibrated and validated in the previous work of the author [11]. This integrated approach enables us to distinguish between climate-induced changes and reservoir-regulated hydrological responses.

2.1. Study area

The VGTB River basin, one of the nine largest basins in Vietnam (Figure 1), covers an area of approximately 10,350 km² across Da Nang city, and a small part of Kon Tum province in Central Vietnam [12] - [16]. The basin originates in the Ngoc Linh Mountain, and its river system flows eastward through moderately flat coastal plains. The Vu Gia and Thu Bon rivers converge about 36 km upstream of the coast, discharging primarily through the Cua Dai Estuary near Hoi An City, while a network of distributary channels connects their lower reaches to the Han Estuary in Da Nang City. Land use within the basin is dominated by forest cover, followed by cropland and built-up areas [11], [15].

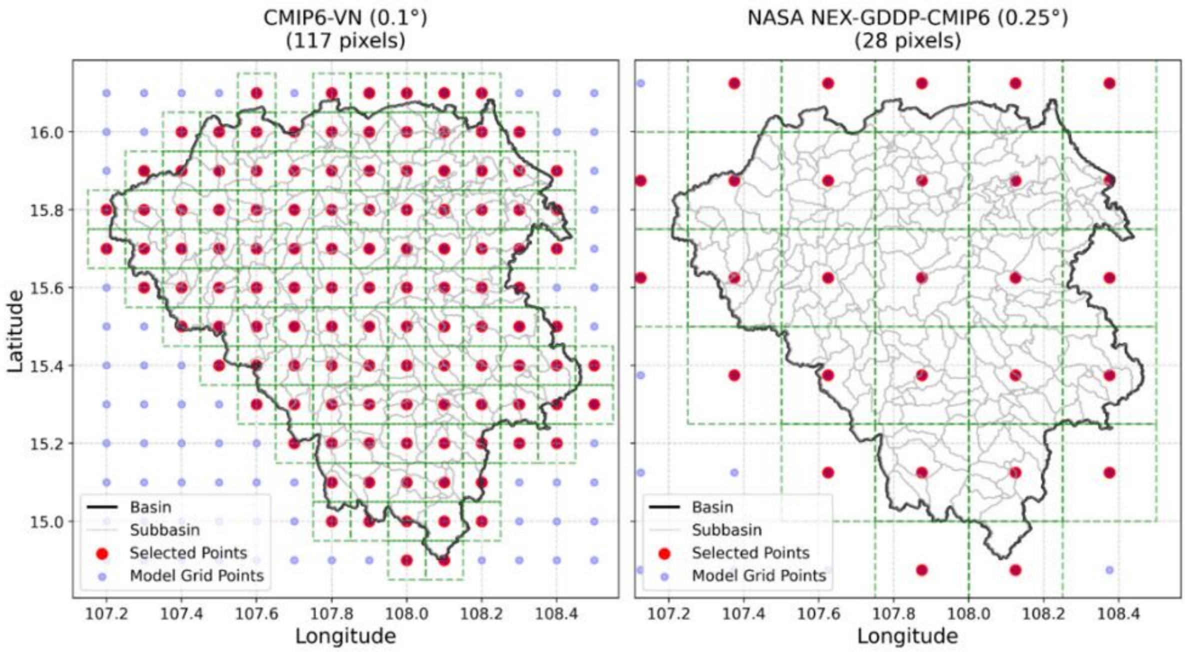

Figure 1. *The VGTB River basin, including the spatial distribution of pixel differences (at resolutions of 10 and 25 km) from the BCC-CSM2-MR model (Beijing Climate Center, China). The VGTB River basin is marked with a blue boundary*

The basin experiences a tropical monsoon climate characterized by distinct wet and dry seasons, which exert a dominant influence on its hydrological regime. Annual precipitation varies geographically, with higher rainfall in the upstream mountainous areas and progressively lower values toward the coastal plains [17]. Surface water availability in the basin is directly linked to seasonal precipitation patterns, reflecting a strong precipitation–runoff relationship. Approximately 70% of the annual discharge is generated during the wet season (September–December), when intense monsoonal rainfall drives high runoff production. In contrast, only about 12% of the annual runoff occurs during the peak dry season (February–March), due to markedly reduced rainfall and diminished baseflow contributions [15], [18].

2.2. Downscale climate projections

An investigation of the potential changes in runoff over the VGTB River basin requires projections of future changes in precipitation and temperature. We used precipitation and temperature from 19 models available through the CMIP6-VN database [10], a dataset providing bias-corrected and statistically downscaled daily temperature and rainfall for GCM outputs available through the CMIP6 (Figure 1, Table 1). We selected GCMs with output data available for both the historical (1980–2014) and future (2015–2099) time periods under four SSPs.

Climate variables were downscaled and bias-corrected using the Bias Correction and Spatial Disaggregation method. Observed station data were first interpolated to a $0.1° \times 0.1°$ gridded dataset using Spheremap and Kriging interpolation techniques. The gridded observations were then used to correct systematic biases in the GCM outputs.

2.3. The extraction process of climate projection and examination using a hydrological model

All daily climate forcings are available at a spatial resolution of 10 km and are listed in Table 1. Future climate forcing from the CMIP6-VN dataset was incorporated into the hydrological SWAT model by spatially linking gridded climate projections to the hydrological model domain. Daily gridded climate forcing inputs for each subbasin were computed using a spatial area-weighted averaging method that explicitly accounts for the fractional area of each grid cell intersecting the subbasin boundary in the SWAT model. The extracted climate series were then assigned uniformly to all hydrological response units (HRUs) within each subbasin.

The CMIP6 climate models offer a new and improved representation of processes and a higher spatial resolution relative to the previous generation (CMIP5). However, a subset of models shows a climate sensitivity above the "likely" or even the "very likely" range assessed in IPCC AR6 based on multiple lines of evidence. Hence, using the ensemble mean of CMIP6 models for regional climate impact assessments may lead to an overestimation of the magnitude of change. To overcome this issue, in this study, we follow the Chen et al. [3] using the ensemble model, resulting from the nineteen CMIP6-VN models, to assess future climate variation.

Table 1. *List of 19 downscaled CMIP6 GCMs*

No.	Name model	Resolution (lon. × lat.)	Resolution downscaled (lon. × lat.)	Institution
1	ACCESS-ESM1-5	1.88° × 1.25°	0.1° × 0.1°	Commonwealth Scientific and Industrial Research Organization and Bureau of Meteorology, Australia
2	AWI-CM-1-1-MR	0.93° × 0.94°	0.1° × 0.1°	Centre National de Recherches Meteorologiques, France
3	BCC-CSM2-MR	1.13° × 1.13°	0.1° × 0.1°	
4	CanESM5	1.41° × 1.39°	0.1° × 0.1°	Canadian Centre for Climate Modelling and Analysis, Canada
5	CMCC-ESM2	1.25° × 1.25°	0.1° × 0.1°	Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici, Italy
6	CNRM-CM6-1-HR	0.5 × 0.5	0.1° × 0.1°	National Center for Meteorological Research, France and CNRS laboratory
7	CNRM-ESM2-1	0.5° × 0.5°	0.1° × 0.1°	National Center for Meteorological Research, France and CNRS laboratory
8	EC-Earth3	0.7° × 0.7°	0.1° × 0.1°	EC-Earth-Consortium, European Union
9	EC-Earth3-Veg	0.7° × 0.7°	0.1° × 0.1°	EC-Earth-Consortium, European Union
10	FGOALS-g3	2° × 2.03°	0.1° × 0.1°	LASG, Institute of Atmospheric Physics, China
11	GFDL-ESM4	1° × 1°	0.1° × 0.1°	NOAA Geophysical Fluid Dynamics Laboratory, America
12	GISS-E2-1-G	2.5° × 2.5°	0.1° × 0.1°	Goddard Institute for Space Studies, NASA
13	INM-CM5-0	2° × 1.5°	0.1° × 0.1°	Russian Academy of Science, Russia
14	IPSL-CM6A-LR	2.5° × 1.27°	0.1° × 0.1°	Institute Pierre Simon Laplace, France
15	MIROC6	2.81° × 2.77°	0.1° × 0.1°	Atmosphere and Ocean Research Institute, Japan
16	MIROC-ES2L	1.41° × 1.41°	0.1° × 0.1°	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute, The University of Tokyo, National Institute for Environmental Studies, and RIKEN Center for Computational Science, Japan
17	MPI-ESM1-2-HR	0.94° × 0.94°	0.1° × 0.1°	Max Planck Institute for Meteorology, Germany
18	MRI-ESM2-0	1.13° × 1.13°	0.1° × 0.1°	Meteorological Research Institute, Japan
19	UKESM1-0-LL	1.88° × 1.25°	0.1° × 0.1°	Met Office Hadley Centre, UK

3. Results

3.1. The precipitation changes across Vietnam

The spatial distribution of future precipitation across Vietnam for the period 2015–2099 was derived from the ensemble mean of 19 CMIP6-VN models. The analysis focuses on the four-peak rainy-season months (September–December) to assess projected changes in monthly and seasonal rainfall patterns, as well as spatial variability.

The projections indicate a pronounced intensification of rainfall during October and November, consistent with the peak activity of the Northeast monsoon and enhanced tropical disturbance frequency. The central region of Vietnam exhibits the strongest precipitation response, with monthly totals potentially reaching approximately 1,200 mm. This amplification is likely influenced by the combined effects of monsoonal circulation strengthening and increased atmospheric moisture availability under warming conditions. In contrast, other regions show comparatively moderate increases, highlighting substantial spatial heterogeneity in climate change responses.

At the annual scale, precipitation remains strongly concentrated in the central region (Figure 2), while northern and southern areas exhibit lower annual accumulations. Future annual precipitation in the central region may approach 4,000 mm, suggesting a potential intensification of the regional hydrological cycle. Such increases could exacerbate flood risk, particularly when combined with short-duration extreme rainfall events and existing river basin regulation. These findings underscore the importance of integrating climate projections with hydrological and reservoir operation analyses to comprehensively assess future flood hazards.

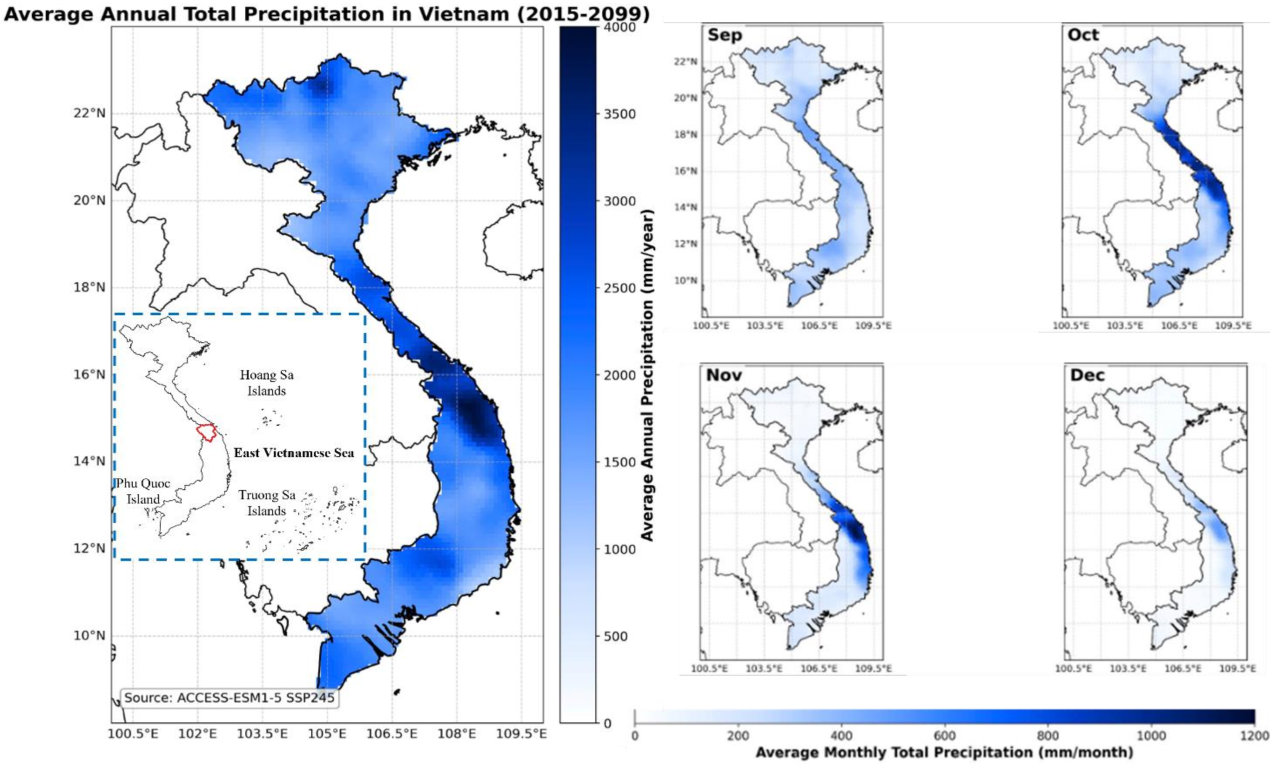

Figure 2. *The spatial distribution of future precipitation across Vietnam during the period 2015–2099 is derived from the ensemble of 19 CMIP6-VN models, and is detailed in 4 months of the rainy season (September, October, November, and December)*

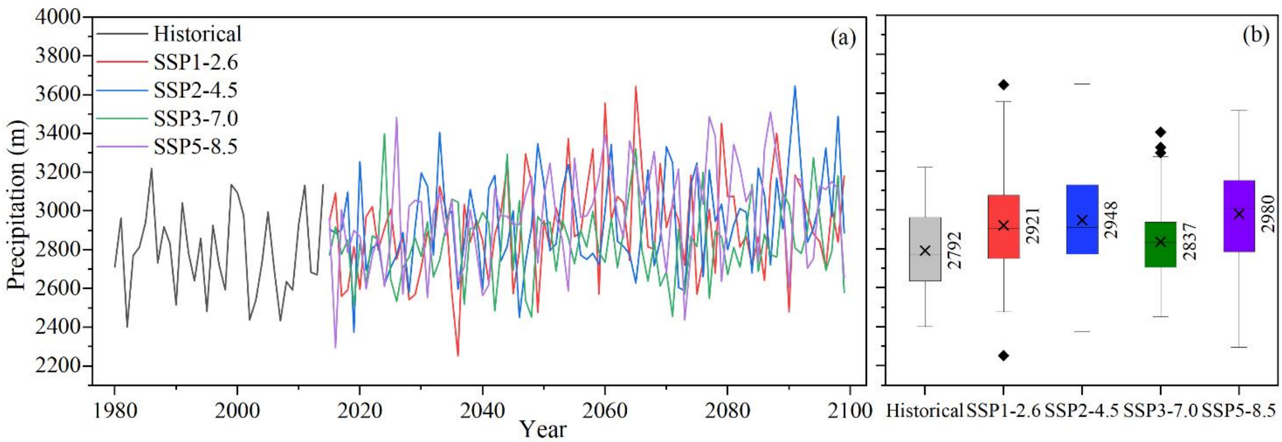

Figure 3. *Annual precipitation over the VGTB River basin during the historical period (1980–2014) and the future period (2015–2099) was derived from the ensemble of 19 CMIP6-VN models. A boxplot was employed to illustrate the distribution of annual precipitation, including the ensemble mean, interquartile range, and variability across models*

3.2. The precipitation changes across the VGTB River basin

Compared with the historical baseline, mean annual precipitation across the VGTB River basin is projected to increase under all SSP scenarios (Figure 3), although the magnitude of change differs among pathways. The largest increase is projected under SSP5-8.5 (6.7%), followed by SSP2-4.0 (5.6%) and SSP1-2.6 (4.6%), while the smallest increase occurs under SSP3-7.0 (1.6%). In absolute terms, future mean annual precipitation is projected to reach 2,921 mm (SSP1-2.6), 2,948 mm (SSP2-4.0), 2,837 mm (SSP3-7.0), and 2,980 mm (SSP5-8.5) (Figure 3b).

SSP1-2.6 generally projects higher extreme rainfall intensity during the mid-century period (2050–2070). In contrast, SSP5-8.5 produces the highest extreme rainfall intensities during the late-century period (2070–2090), while SSP2-4.5 exhibits comparatively higher extreme rainfall intensity toward the end of the century (Figure 3a).

The comparatively lower increase under SSP3-7.0 may reflect differences in regional circulation responses and moisture transport patterns simulated under this scenario, despite its relatively high radiative forcing. This highlights that precipitation responses are not solely determined by emission intensity but are also influenced by complex interactions among large-scale atmospheric dynamics, monsoonal variability, and regional topographic effects. The more pronounced increases under SSP5-8.5 suggest a stronger intensification of the hydrological cycle under higher warming levels, which may amplify flood risk and hydrological extremes in the basin.

To examine spatial variability in precipitation, monthly precipitation time series were extracted at the centroid of each sub-basin within the VGTB River basin. These time series were compared to assess differences in precipitation patterns and their temporal evolution among sub-basins. As shown in Figure 4, projected rainfall under all SSP scenarios increases relative to the historical period across all sub-basins. Furthermore, precipitation in the upstream areas is consistently higher than in the downstream and coastal regions. This spatial gradient likely reflects regional controls on rainfall distribution, including topographic effects, geographic location, etc. The projected spatial pattern is consistent with previous analyses based on observed rainfall records from rain gauge stations, thereby supporting the reliability of the model projections.

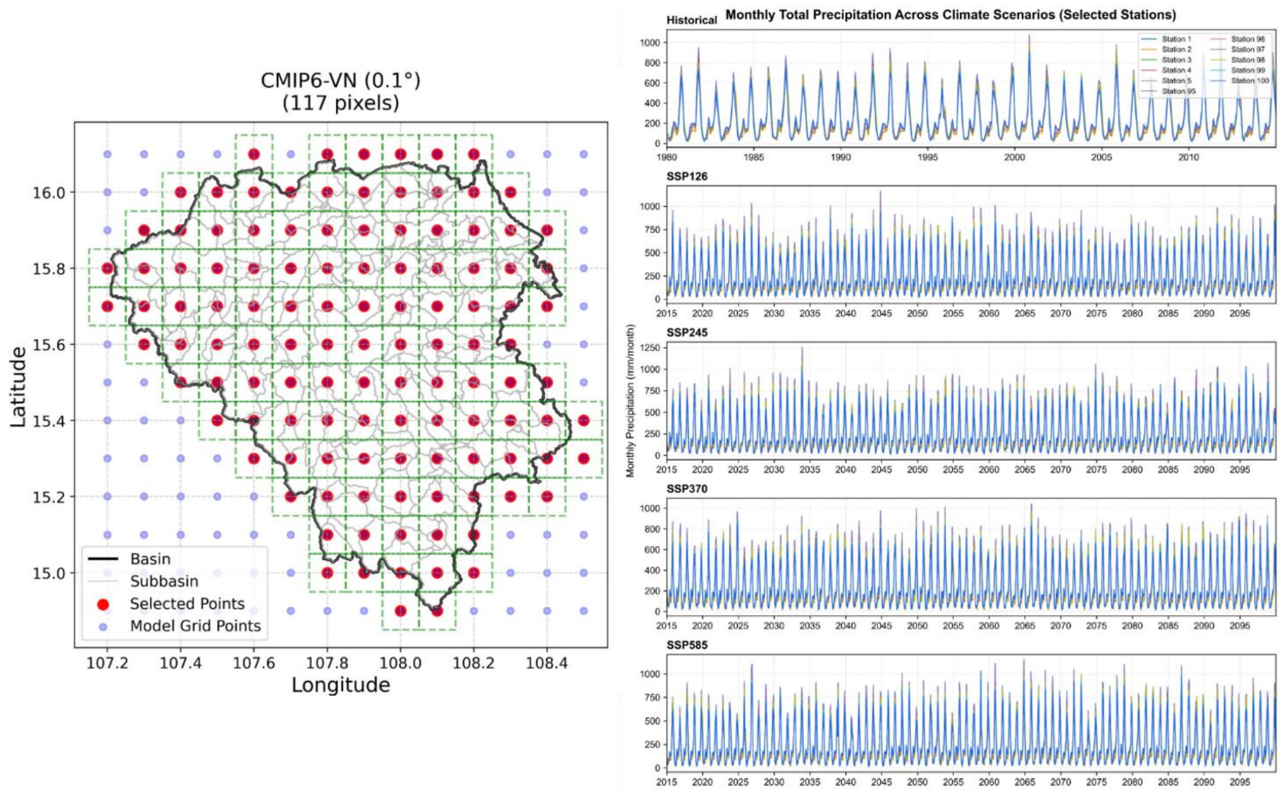

Figure 4. *The time series shows the spatial difference in precipitation by comparing the monthly precipitation value at the centroid of each subbasin across the VGTB River basin. The number of basins increases sequentially from the outlet to the upstream region*

4. Discussion

The analysis indicates that projected rainfall increases under all future scenarios (Figure 2 – Figure 4). However, this precipitation signal is not fully consistent with the observed changes in river streamflow indices at the hydrological stations. The discrepancy is particularly evident at the Thanh My and Nong Son stations, representing streamflow in the Vu Gia and Thu Bon rivers, respectively. This contrasting behavior highlights the combined influence of climate variability and the cascade of reservoirs constructed along the mainstem, which have substantially altered the natural flow regime. The role of reservoir regulation is examined in greater detail in the following sections.

Overall, the projected range of future streamflow is generally larger than that of the historical period across all scenarios, regardless of assumptions concerning human intervention. The increase is especially pronounced for extreme events, with the largest magnitudes simulated under SSP5-8.5. The projections suggest a higher likelihood of extreme flood events in the basin, comparable to the historic flood of 2025, during which water levels at downstream stations such as Giao Thuy exceeded historical records.

As illustrated in Figure 5, reservoir regulation leads to a marked shift in streamflow regimes at Thanh My station. During the historical simulation, the daily maximum discharge reached approximately 4,540 m^3/s, with considerable interannual variability. In contrast, future projections (2026–2099) under the four SSP scenarios indicate substantially higher extreme discharges, exceeding 8,265 m^3/s (an increase of approximately 90%) under the BCC-CSM2-MR model developed by the Beijing Climate Center.

A similar pattern is observed at Nong Son station on the Thu Bon River. During the historical period, the simulated daily maximum discharge reached approximately 8,920 m^3/s, whereas future projections indicate peaks of up to 16,850 m^3/s, corresponding to an increase of about 88.9%.

Although projections suggest an overall intensification of flood-season streamflow, the simulated increases in both the Vu Gia River (Thanh My station) and the Thu Bon River (Nong Son station) remain strongly modulated by reservoir operations. In particular, the magnitude of average flood-season discharge is considerably attenuated relative to the potential climate-driven increase. Reservoir regulation typically reduces peak flows during the flood season to enhance water storage for dry-season hydropower production, thereby dampening flood-season discharge and partially offsetting the effects of intensified precipitation.

The present study primarily focuses on assessing overall future hydroclimatic tendencies in the VGTB River basin using the CMIP6-VN climate projection dataset, especially the 4 months of flood season (September – October). However, given the substantial variability among climate models and emission scenarios, further investigation is required to better understand the seasonal and extreme characteristics of future climate change in Central Vietnam. In particular, future studies should examine projected changes in air temperature, seasonal rainfall distribution, extreme precipitation intensity, and flood-season runoff, as these variables directly influence hydrological hazards and water resource security in the basin.

A key source of uncertainty arises from the differences among the 19 selected models in simulating regional monsoon dynamics, aerosol forcing, and atmosphere–topography interactions. These differences can produce considerable variation in projected rainfall magnitude, seasonal timing, and hydrological responses. Such uncertainty is especially important in the VGTB basin, where runoff generation is highly sensitive to the complex terrain and to variations in monsoon circulation patterns. Consequently, relying solely on ensemble mean projections may obscure the range of possible future hydroclimatic conditions.

Future work should therefore incorporate comprehensive uncertainty analysis using ensemble statistics such as projection range, standard deviation, confidence intervals, and percentile bands (e.g., 10th–90th or 25th–75th percentiles). These approaches would allow a more robust evaluation of the spread and reliability of future climate projections and help identify high-risk scenarios associated with extreme hydrological conditions. In addition, separating wet-season and dry-season responses would improve understanding of future flood and drought dynamics under different SSP scenarios.

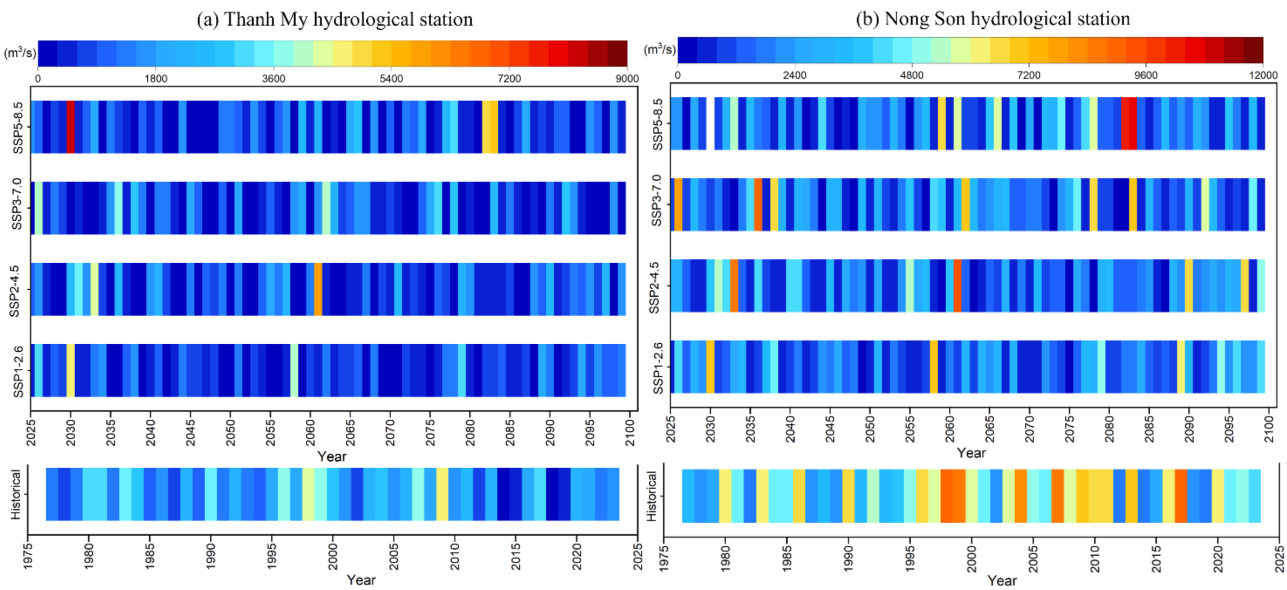

Figure 5. *The flow discharge at two main hydrological stations, Thanh My in the Vu Gia River and Nong Son in the Thu Bon River, during the historical period (1980–2023), using observed data, and future prediction using the BCC-CSM2-MR model of Beijing Climate Center, China*

5. Conclusion

This study evaluated outputs from 19 CMIP6 Global Climate Models dynamically downscaled to a spatial resolution of 10 km to assess future rainfall and temperature variability across Vietnam, and focused on the VGTB River basin located in the central region. The results indicate a general intensification of the regional hydrological cycle, with projected annual precipitation in the central region approaching 4,000 mm under future climate conditions.

For the VGTB River basin, mean annual precipitation is projected to increase under all considered SSPs scenarios relative to the historical baseline, although the magnitude of change varies among pathways. The largest increase is projected under SSP5-8.5 (6.7%), followed by SSP2-4.0 (5.6%) and SSP1-2.6 (4.6%), whereas SSP3-7.0 shows the smallest increase (1.6%). In absolute terms, projected mean annual precipitation ranges from approximately 2,837 mm to 2,980 mm depending on the scenario.

Despite the projected intensification of rainfall and flood-season runoff, simulated streamflow increases remain strongly moderated by reservoir regulation. The magnitude of average flood-season discharge in the Vu Gia and Thu Bon Rivers is substantially attenuated relative to the potential climate-driven increase. These findings highlight the critical role of reservoir operations in shaping basin-scale hydrological responses and underscore the need for adaptive management strategies to address increasing rainfall variability and future flood risk for Danang city.

Acknowledgments: This study is supported by the JSPS KAKENHI Grant Number JP25H00757, led by Prof. Sameh Kantoush for the 3S project; the Japan Science and Technology Agency (JST) under the NEXUS Program, Grant Number JPMJNX24A2.

REFERENCES

[1] B. Bhatta, S. Shrestha, P. K. Shrestha, and R. Talchabhadel, "Evaluation and application of a SWAT model to assess the climate change impact on the hydrology of the Himalayan River Basin", *Catena*, vol. 181, no. 104082, pp. 1–13, 2019. https://doi.org/10.1016/j.catena.2019.104082

[2] K. Ostad-Ali-Askari, H. G. Kharazi, M. Shayannejad, and M. J. Zareian, "Effect of climate change on precipitation patterns in an arid region using GCM models: case study of Isfahan-Borkhar Plain", *Natural Hazards Review*, vol. 21, no. 2, pp. 1–16, 2020. https://doi.org/10.1061/(ASCE)NH.1527-6996.000036

[3] C. Chen, R. Gan, D. Feng, F. Yang, and Q. Zuo, "Quantifying the contribution of SWAT modeling and CMIP6 inputting to streamflow prediction uncertainty under climate change", *Journal of Cleaner Production*, vol. 364, no. 132675, pp. 1–12, 2022. https://doi.org/10.1016/j.jclepro.2022.132675

[4] N. Q. Binh, D. V. Binh, T. T. N. Duc, S. Kantoush, and T. Sumi, "Response of streamflow and sediment variability to cascade dam development and climate change in the Sai Gon Dong Nai River basin", *Climate Dynamics,* vol. 62, no. 8, pp. 7997–8017, 2024. https://doi.org/10.1007/s00382-024-07319-7

[5] M. Ozbuldu and A. Irvem, "Projecting and Downscaling Future Temperature and Precipitation Based on CMIP6 Models Using Machine Learning in Hatay Province, Türkiye", *Pure and Applied Geophysics*, vol. 182, no. 4, pp. 1825–1842, 2025. https://doi.org/10.1007/s00024-024-03656-0

[6] M. Ozbuldu and A. Irvem, "Evaluating the effect of the statistical downscaling method on monthly precipitation estimates of global climate models", *Global NEST Journal*, vol. 23, no. 2, pp. 232–240, 2021. http://doi.org/10.30955/gnj.003458

[7] D. Rastogi, S. Kao, and M. Ashfaq, "How may the choice of downscaling techniques and meteorological reference observations affect future hydroclimate projections?", *Earth's Future*, vol. 10, no. 8, pp. 1–15, 2022. https://doi.org/10.1029/2022EF002734

[8] L. O. Mearns, W. Easterling, C. Hays, and D. Marx, "Comparison of agricultural impacts of climate change calculated from high and low resolution climate change scenarios: Part I. The uncertainty due to spatial scale", *Climatic Change*, vol. 51, pp. 131–172, 2001. https://doi.org/10.1023/A:1012297314857

[9] P. Willems and M. Vrac, "Statistical precipitation downscaling for small-scale hydrological impact investigations of climate change", *Journal of Hydrology*, vol. 402, no. 3–4, pp. 193–205, 2011. https://doi.org/10.1016/j.jhydrol.2011.02.030

[10] T. A. Quan, N. D. Thanh, E. Espagne, and T. T. Long, "A 10-km CMIP6 downscaled dataset of temperature and precipitation for historical and future Vietnam climate", *Scientific Data*, vol. 10, no. 257, pp. 1–12, 2023. https://doi.org/10.1038/s41597-023-02159-2

[11] N. Q. Binh, S. Kantoush, D. V. Binh, M. Saber, V. N. Duong, and T. Sumi, "Quantifying the impacts of hydraulic infrastructure on tropical streamflows", *Hydrological Processes*, vol. 37, no. 3, pp. 1–19, 2023. https://doi.org/https://doi.org/10.1002/hyp.14834

[12] V. N. Duong, N. Q. Binh, and N. T. T. Van, "Using the FFC-WRED tool to evaluate the impact of rain gauging station density on flood flow in Danang city's reservoirs", *The University of Danang - Journal of Science and Technology*, vol. 9, no. 130, pp. 17–20, 2018.

[13] N. Q. Binh, S. Kantoush, N. H. Thinh, B. T. P. Thao, N. P. Sinh, D. T. N. Canh, and V. N. Duong, "Cumulative impacts of interbasin water transfer and salinity intrusion on water security in central Vietnam", *Science of The Total Environment*, vol. 998, no. 180250, pp. 1–15, 2025. https://doi.org/10.1016/j.scitotenv.2025.180250

[14] N. Q. Binh, S. Kantoush, N. H. Thinh, T. Sumi, and S. Kobayashi, "Long-term assessment of hydropeaking and cumulative impacts on sediment transport, grain size dynamics, channel stability and water resource management", *Journal of Environmental Management*, vol. 380, no. 124983, pp. 1–13, 2025. https://doi.org/10.1016/j.jenvman.2025.124983

[15] N. Q. Binh, S. Kantoush, and T. Sumi, "Quantifying the consequences of unsustainable sand mining and cascade dams on aspects in a tropical river basin", *Scientific Reports*, vol. 14, no. 1, pp. 1–16, 2024. https://doi.org/10.1038/s41598-024-51405-z

[16] N. Q. Binh, S. Kantoush, and T. Sumi, "Assessing the multidimensional impacts of riverbed sand mining on geomorphological change and water transfer rate: A comprehensive investigation of Central Vietnam's Vu Gia Thu Bon River system", *Journal of Hydrology*, vol. 654, no. 132853, pp. 1–19, 2025. https://doi.org/10.1016/j.jhydrol.2025.132853

[17] D. N. D. Phuong, V. N. Q. Tram, T. T. Nhat, T. D. Ly, and N. K. Loi, "Hydro-meteorological trend analysis using the Mann-Kendall and innovative-Şen methodologies: a case study", *International Journal of Global Warming*, vol. 20, no. 2, pp. 145–164, 2020. https://doi.org/10.1504/IJGW.2020.105385

[18] N. Q. Binh, S. Kantoush, D. V. Binh, M. Saber, V. N. Duong, and T. Sumi, "Understanding the anthropogenic development impacts on long-term flow regimes in a tropical river basin, Central Vietnam", *Hydrological Sciences Journal*, vol. 68, no. 2, pp. 341–354, 2023. https://doi.org/10.1080/02626667.2022.2153298