Evaluating Climate-Driven Water Quality Risks in an Urbanized River Basin Through Coupled Hydrological and Water Quality Modeling

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Introduction

River water quality in highly urbanized basins is increasingly vulnerable to climate change and intensifying human activities, posing growing challenges for disaster prevention and adaptive water environment management [1;2]. Integrated modeling frameworks that couple watershed hydrology with in-stream water quality processes are therefore essential for simulating current conditions and predicting future risks under changing climate scenarios. This study develops a coupled SWAT–WASP modeling framework to simulate river water quality and conduct scenario-based predictions in the Yamato River Basin, Japan.

Study Basin

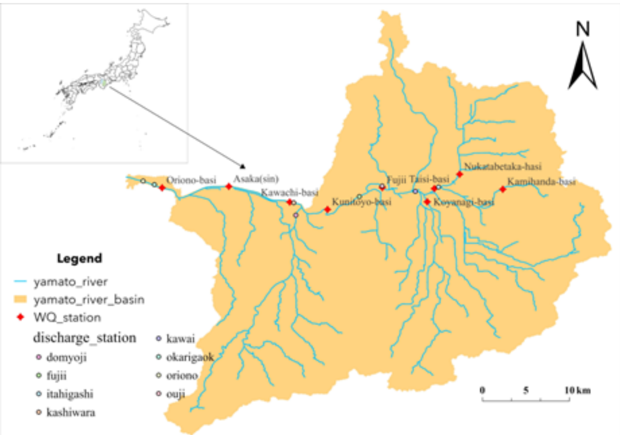

Figure 1. Infographic of the Yamato River basin, water quality, and meteorological monitoring station location.

The Yamato River Basin (~1,070 km²), situated in the Kansai region, is one of the most urbanized river basins in Japan, exhibiting pronounced spatial heterogeneity in land use, population density, and hydrological regimes, as shown in Figure 1. The Soil and Water Assessment Tool (SWAT) was employed at a daily time scale to simulate watershed-scale hydrological processes and non-point source pollutant loads, including runoff, sediment, and nutrient fluxes [3]. These daily outputs were subsequently transferred to the Water Quality Analysis Simulation Program (WASP) [4], which represents continuous in-stream physical, chemical, and biochemical processes along the river network. This daily-to-continuous coupling enables a consistent representation of land–river interactions and water quality dynamics.

Material and method

The coupled SWAT–WASP model was calibrated and validated using long-term monitoring data from multiple stations along the Yamato River for the period 2005–2024, covering both upstream and downstream reaches. Key water quality indicators, including dissolved oxygen (DO), carbonaceous biochemical oxygen demand (CBOD), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), and suspended solids (SS), were selected to characterize organic pollution, nutrient enrichment, and sediment transport. Observed discharge and water quality variables were used to evaluate the model's ability to reproduce hydrological variability and in-stream water quality dynamics under different flow regimes [5].

Future climate forcing was derived from the d4PDF (Database for Policy Decision Making for Future Climate Change) dataset [6], a large-ensemble high-resolution climate projection dataset developed in Japan. The d4PDF provides physically consistent climate simulations for both historical and future conditions and is specifically designed for impact assessment and disaster risk analysis. Meteorological variables extracted for this study include precipitation, daily maximum and minimum air temperature (T_{max} and T_{min}), solar radiation, relative humidity, and wind speed. These variables were used to construct future climate scenarios that drive the SWAT model, enabling scenario-based predictions of river water quality responses under projected climate change conditions.

Results

The coupled SWAT–WASP model demonstrates a satisfactory ability to reproduce observed hydrological variability and in-stream water quality dynamics during the historical period, providing a reliable basis for scenario-based analysis. The calibrated model captures key seasonal patterns of discharge (Figure 2), organic pollution, and nutrient concentrations across upstream and downstream reaches of the Yamato River Basin.

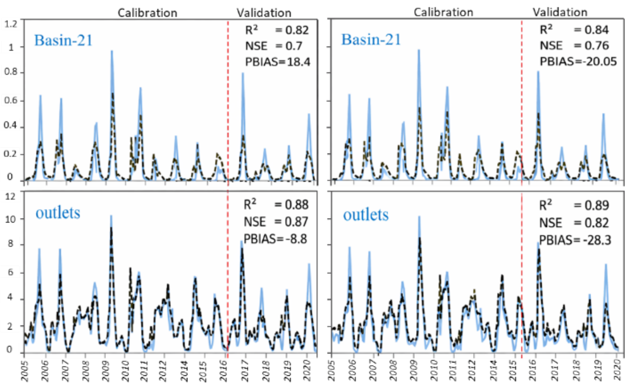

Figure 2. SWAT calibration and validation results for river discharge (Q) in the Yamato River Basin.

Preliminary scenario simulations suggest that river water quality responses are sensitive to changes in both temperature (T) and precipitation (P). Increased air temperature is expected to enhance in-stream biochemical reaction rates, potentially leading to greater oxygen consumption and elevated organic pollution levels during low-flow conditions. Variations in precipitation are likely to influence non-point source nutrient and sediment transport by modifying runoff generation processes, with downstream urban reaches showing higher sensitivity to hydrological changes. These initial findings highlight the potential for nonlinear interactions between climate forcing, watershed processes, and in-stream water quality responses.

Comprehensive quantification of future water quality changes under multiple climate scenarios is currently ongoing. The final results will provide a more detailed assessment of the magnitude and uncertainty of climate-induced water quality impacts in the Yamato River Basin.

Limitations

Currently, bias correction has not been applied to the meteorological data within the D4PDF dataset; this limitation will be addressed in subsequent research efforts.

References

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