

QUANTIFYING RESERVOIR CAPACITY ENHANCEMENT AND SPILLWAY DESIGN UNDER FUTURE CLIMATE SCENARIOS IN THE KATTIYAWA WEWA, KNUCKLES BASIN, SRI LANKA

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Abstract

This study assessed future climate impacts on Sri Lanka's Kattiyawa Wewa Reservoir, located downstream of the Knuckles Basin. It quantified the reservoir capacity augmentation and spillway design upgrades required under those scenarios. Future daily precipitation projections from three Coupled Model Intercomparison Project Phase 6 (CMIP6) global climate models (GCMs) (CNRM-CM6-1, HadGEM-GC31-LL, and MRI-ESM2-0) under SSP2-4.5 and SSP5-8.5 scenarios were statistically downscaled to the watershed level for the 2041–2060 and 2081–2100 periods using LARS-WG software. The downscaled daily data were disaggregated to sub-daily durations using to develop Intensity-Duration-Frequency curves. These rainfall inputs were incorporated into the HEC-HMS hydrological model, configured with SCS Curve Number loss method and unit hydrograph transforms, to simulate design flood hydrographs and estimate critical peak discharges for various return periods. Results show peak discharges rising drastically, up to 1,378 m³/s under the HadGEM-GC31-LL SSP5-8.5 scenario by 2081–2100, representing a 215% increase from baseline conditions. Using area–capacity curves derived from the non-dimensional relationship developed for small tanks in Sri Lanka, required storage enhancement ranges from 55% to over 200%, depending on the climatic scenario. Spillway capacity must be upgraded to 1,100–1,200 m³/s with concurrent storage expansion, or up to 1,380 m³/s without it. Existing infrastructure is shown to be inadequate under most scenarios. Adaptive strategies include reservoir capacity enhancement, combined with operational flexibility to manage variable inflows, preventing overtopping, reducing downstream flooding, and ensuring long-term dam safety.

Keywords: Climate change, Downscaling, HEC-HMS, SSP scenarios

1. Introduction

Climate change introduces substantial uncertainty into hydrological design by altering extreme precipitation and streamflow patterns [1]. Global warming has intensified the hydrological cycle and increased the occurrence of extreme flood events, challenging the stationarity assumption underlying conventional reservoir design based on historical records [1,2]. The Knuckles Basin is a crucial watershed in central Sri Lanka, supporting over 1.3 million people through agriculture, hydropower, and water supply. Although it harbours rich biodiversity, it is highly vulnerable to climate-induced hydrological extremes. Particularly, intensification of extreme events challenges the stationarity assumption in conventional reservoir design, leaving much existing infrastructure vulnerable to future conditions. Recent literature highlights increasing hydrological variability and growing flood risks under global warming [1], while regional studies emphasise Sri Lanka's susceptibility to changing inflows and the need for adaptive infrastructure [3]. However, quantitative Coupled Model Intercomparison Project Phase 6 (CMIP6)-based vulnerability assessments remain scarce for the Knuckles Basin. Therefore, this study aims to assess the adequacy of the existing Kattiyawa Wewa Reservoir

and identify the required modifications to its storage capacity and spillway system under future climate conditions.

2. Methodology

This study focuses on the Kattiyawa Wewa Reservoir within Sri Lanka's Knuckles Basin, covering an area of 114.57 km². Historical observed rainfall data were collected from local meteorological authorities, while future climate projections were downscaled from three CMIP6 GCMs (CNRM-CM6-1, HadGEM-GC31-LL, and MRI-ESM2-0) under SSP2-4.5 and SSP5-8.5 scenarios for the 2041–2060 and 2081–2100 periods using the LARS-WG statistical downscaling tool [4]. The resulting daily rainfall series were then used to develop future Intensity-Duration-Frequency (IDF) curves, with daily rainfall values disaggregated using regionally developed by Engr. Ponrajah. The projected rainfall scenarios were then incorporated into the HEC-HMS hydrological model to simulate design flood hydrographs and estimate critical peak discharges. However, during data analysis the model was not calibrated. Concurrently, DEM data were used to develop the reservoir area–capacity curve based on the non-dimensional relationship developed for small village tanks in Sri Lanka [4]. This approach requires only a limited number of key measurements, enabling rapid estimation of reservoir storage characteristics without the need for extensive field surveys. The estimated peak discharges and required storage augmentation were then integrated to guide spillway design, ensuring the reservoir can safely accommodate future flood conditions. Finally, all findings were synthesised to formulate recommendations for climate-resilient reservoir management and necessary infrastructure upgrades.

3. Results and Discussion

Figure 1 shows the systematic analysis of future flood dynamics through an integrated hydrological and reservoir modelling framework. The design hydrograph illustrates projected discharge variations over time. The peak discharge indicates that the HadGEM-GC31-LL model projects the most extreme values, reaching 1378.1 m³/s under both SSP2-4.5 and SSP5-8.5 scenarios for the 2081–2100 period, more than three times the baseline peak discharge of 437.2 m³/s for 1994–2024. In contrast, the CNRM-CM6 model yields moderate projections (679.8–751.2 m³/s). The CNRM-CM6 and the MRI-ESM2-0 under SSP5-8.5, 2081–2100 had identical peak discharge. This inter-model variability emphasises the inherent uncertainty in climate projections and highlights the critical role of GCM selection in flood risk assessment.

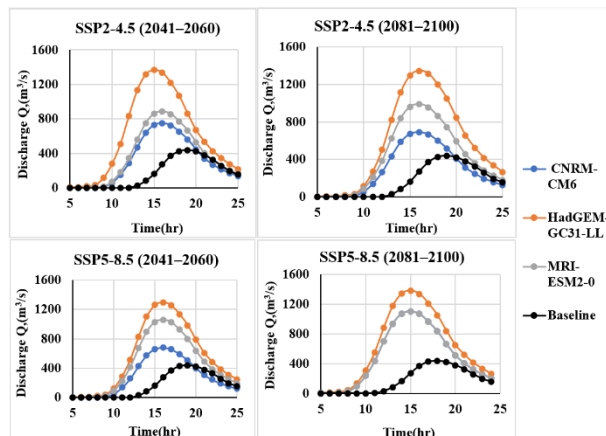


Figure 1: Design hydrograph.

Table 1 presents the projected peak discharge values (in m³/s) for the Kattiyawa Wewa reservoir under three different GCMs and two emission scenarios and future time periods.

Table 1: Peak discharge projections under future climate scenarios.

Peak Discharge (m ³ /s)					
CNRM-CM6, SSP2-4.5	2041–2060	751.2	HadGEM- GC31-LL, SSP5-8.5	2041–2060	1297.6
	2081–2100	691.8		2081–2100	1378.1
CNRM-CM6, SSP5-8.5	2041–2060	679.8	MRI-ESM2-0, SSP2-4.5	2041–2060	887.3
	2081–2100	1102.4		2081–2100	988.9
HadGEM- GC31-LL, SSP2-4.5	2041–2060	1370.5	MRI-ESM2-0, SSP5-8.5	2041–2060	1059.9
	2081–2100	1346.2		2081–2100	1102.1

Sometimes, under different climate scenarios and parameters, the peak discharge can be similar. The HadGEM-GC31-LL model consistently produces the most extreme flows, exceeding baseline levels (437.2 m³/s) by over 215%, underscoring the urgency for reservoir capacity and spillway upgrades.

These findings reveal extreme flood vulnerability in the coming decades, with impacts strongly dependent on GCM and emissions trajectory. The integrated design hydrograph and reservoir routing framework underscores the critical need to augment the reservoir capacity and increase spillway length to tackle future extreme climatic events.

References

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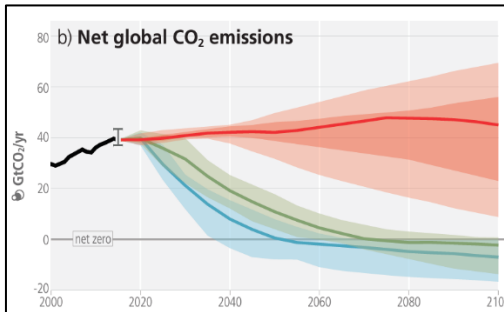
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Background

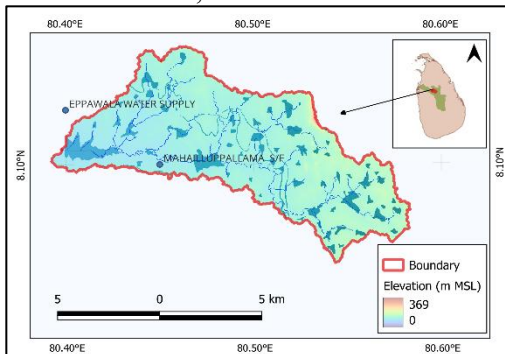


- The frequency and intensity of heavy precipitation events have increased since the 1950s.
- Annual wettest-day precipitation is projected to increase in almost all continental regions, even in areas where mean soil moisture is projected to decline.

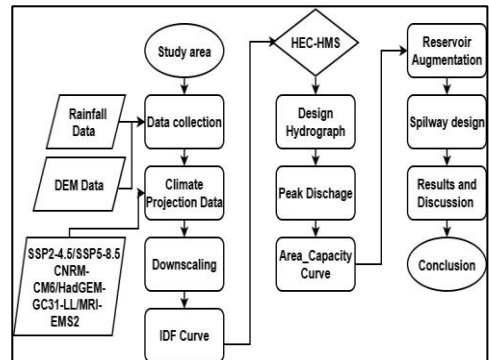
Source: IPCC AR6 Figure SPM.5: Global emissions pathways

Research Methodology

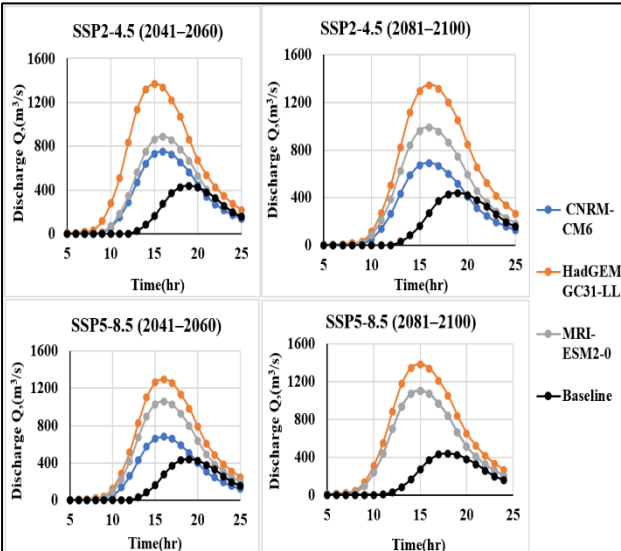
Study area: The Kattiyawa Wewa, Knuckles Basin, Sri Lanka



Research Methodological Flowchart



Results and Conclusion



- Peak discharges are projected to rise by up to 215% above the baseline.
- Reservoir storage capacity must be increased by 55% to over 200%
- Spillway discharge capacity must be upgraded to at least 1,100–1,200 m³/s.