INCORPORATING RAINFALL PROJECTIONS INTO HYDROLOGICAL MODELING FOR ENHANCED DESIGN HYDROGRAPH ESTIMATION

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In the context of changing climate conditions, the design of hydrographs faces increasing uncertainties due to shifts in precipitation patterns, hydrological regimes, and a rise in extreme weather events. This study assesses potential uncertainties in design hydrographs linked to future climate change in the Kalu River Basin, Sri Lanka, focusing on the Ellagawa sub-basin. The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) was selected based on a comprehensive literature review to account for anticipated changes in rainfall patterns and their impact on streamflow. Seven precipitation gauging stations (Alupolla, Balangoda, Galatura, Halwathura, Pussella, Ratnapura, and Wellandura) were chosen following World Meteorological Organization (WMO) guidelines, based on data availability and percentages of missing data. Streamflow data for Ellagawa and Ratnapura stations were obtained from the Sri Lankan Irrigation Department, with daily precipitation and streamflow data from 1980 to 2017 used for analysis. The model was calibrated and validated using data from four extreme events identified through frequency analysis, each associated with daily precipitation levels corresponding to a 100-year return period. Future changes in precipitation extremes were evaluated using outputs from three General Circulation Models (GCMs): CNRM-CM6-1, HadGEM3-GC31-LL, and MRI-ESM2-0, under two Shared Socioeconomic Pathways (SSP2 and SSP5) from the Coupled Model Intercomparison Project Phase 6 (CMIP6), downscaled to local scale, focusing on the period from 2081-2100. The annual maximum daily precipitation for both observed and projected scenarios was analyzed using Generalized Extreme Value (GEV), Weibull, and Gamma distribution functions. The Nash-Sutcliffe efficiency (NSE) coefficients, ranging from 0.79 to 0.85 during calibration and validation, indicated a close match between simulated and observed river flows. Different GCMs and SSPs predicted varying changes in rainfall regimes and design hydrographs. Specifically, factors such as the frequency and intensity of extreme precipitation events, changes in the seasonal distribution of rainfall, and prolonged dry spells were identified as critical drivers affecting peak flow in the future. Compared to the baseline period (1980-2017), annual total rainfall is projected to increase by -8% to 40% under SSP2-4.5 and -10% to 36% under SSP5-8.5. The maximum daily precipitation is expected to rise from 79 mm to 139 mm under SSP2-4.5 and from 82 mm to 138 mm under SSP5-8.5. Consequently, the peak flow of the design hydrograph may increase by 3% to 106%. These findings underscore the importance of considering climate change uncertainties in hydrological and hydraulic design. By integrating future climate projections into design processes, engineers and policymakers can better adapt infrastructure and planning to evolve conditions, enhancing resilience and sustainability in water management systems.

Keywords: CMIP6, GCMs, HEC-HMS, LARS-WG, SSPs

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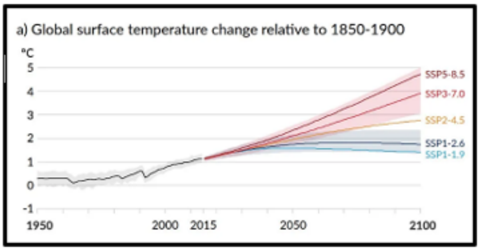
Incorporating Rainfall Projections into Hydrological Modelling for Enhanced Design Hydrograph Estimation

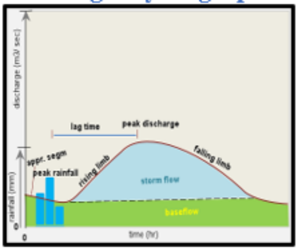
Background

Climate Change Effects



Introduces Uncertainties on Design Hydrographs

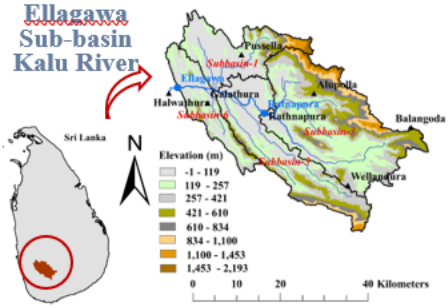
Design Hydrograph

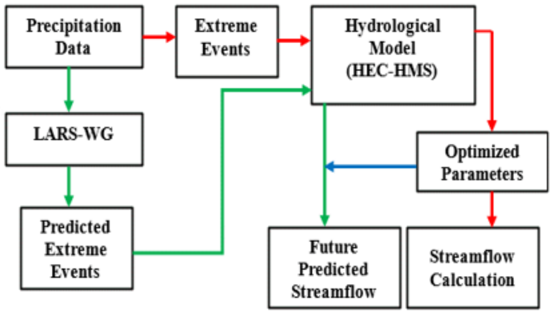


Source: Climate Change Widespread, Rapid, and Intensifying – IPCC — IPCC, 2021. https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/

Research Methodology

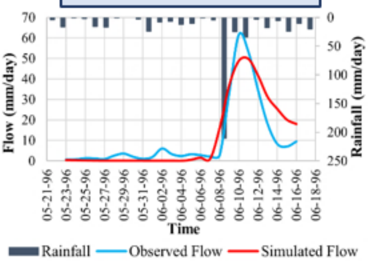
Ellagawa Sub-basin Kalu River



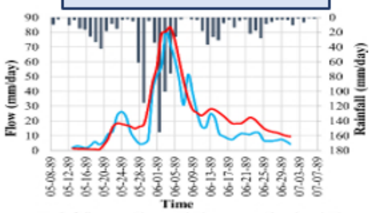


Results

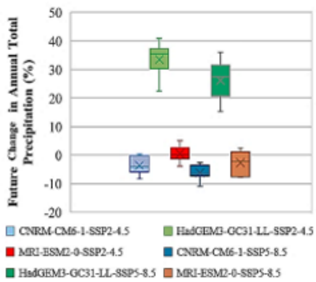
Model Calibration



Model Validation

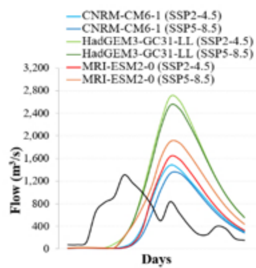


Future Rainfall Variation (In seven Gauging Stations)



Model	Scenario	Maximum
CNRM-CM6-1	SSP2-4.5	169 - 281
	SSP5-8.5	186 - 355
HadGEM3-GC31-LL	SSP2-4.5	244 - 607
	SSP5-8.5	263 - 602
MRI-ESM2-0	SSP2-4.5	201 - 362
	SSP5-8.5	201 - 393

Future Streamflow Variation



Observed Peak Flow	1,308 m^3/s	
Model	Percentage Increase in Projected Peak Flow	
	SSP2-4.5	SSP5-8.5
CNRM-CM-6	13%	3%
HadGEM3-GC31-LL	106%	94%
MRI-ESM2-0	25%	45%