CLIMATE CHANGE IMPACT ON OPERATION POLICY AND PERFORMANCE INDICES OF A RESERVOIR USING MACHINE LEARNING TECHNIQUES

By

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CHAPTER V
SUMMARY AND CONCLUSION

The present study entitled "Climate Change Impact on Operation Policy and Performance Indices of a Reservoir using Machine Learning Techniques" was carried out for Malampuzha reservoir in Palakkad district of Kerala. Fifteen AOGCM model (ACCESS-CM2, ACCESS-ESM1-5, CMCC-ESM2, CNRM-CM6-1, EC-Earth3, E3-SM-2-0, GFDL-ESM4, IITM-ESM, MIROC6, MPI-ESM1-2HAM, MPI-ESM1-2-HR, MPI-ESM1-2-LR, MRI-ESM-2-0, NESM3, TaiESM1) predictions of precipitation, maximum and minimum temperatures were compared with the observed data to select a suitable model for the study area for the period 1990-2014. Most of the GCMs under predicted the precipitation particularly in monsoon months, under predicted the maximum temperature and over predicted the minimum temperature. Compromise programming (CP) was applied to determine the ranking of CMIP6 GCMs based on four statistical performance metrics such as NRMSE, PBIAS, R^2 and KGE. CNRM-CN6-1 model for precipitation and MRI-ESM2-0 model for maximum and minimum temperature were selected based on their performance in prediction of climate variables. Different bias correction techniques (Linear scaling, Distribution mapping, Power transformation and Local intensity scaling for precipitation; Linear scaling, variance scaling and distribution mapping for maximum and minimum temperature) were applied to improve the raw predictions of GCMs and found power transformation for precipitation and variance scaling technique for temperatures have shown superiority over other techniques.

Three future scenarios were considered in this study from CMIP6 Shared Socioeconomic Pathways (SSP126, SSP245 and SSP585). Selected bias correction techniques were applied to the future period to get bias corrected future climate variables. Future period was divided into three periods namely, near future (2025-49), mid future (2050-74) and far future (2075-99). Selected GCM models predicted an increase in average annual maximum temp (from 0.23°C in near future to 3.26°C in far future), an increase in average annual minimum temp (from 0.62°C in near future to 3.12°C in far future) and a decrease in average annual precipitation (from 2.73% in near future to 10.89% in far future) compared with the base period.

To estimate the inflow of Malampuzha reservoir for future period, it was decided to develop a rainfall-runoff model in base period using hydrological and machine learning approaches. Wavelet coupling was applied to the developed machine learning techniques to increase the prediction accuracy. Comparison of hydrological models such as IHACRES, SWAT, and HEC-HMS against machine learning models such as ANN, SVM, RF, WANN, WSVM, WRF and MLR was done to find suitable method for reservoir inflow estimation with greater accuracy. All developed models were compared quantitatively using RMSE, PBIAS, NSE, PCC, WI, LMI and qualitatively using line plot, scatter plot, Taylor diagram, violin plot and flow duration curve. Both SWAT and IHACRES models exhibited best performance among hydrological models and WRF model showed superiority among ML models. WRF model was used for future reservoir inflow estimation for different SSP scenarios.

The decline in inflow was observed across all SSPs, with more severe reductions occurring in higher-emission scenarios and in far future periods (from 3.4% in near future to 27.3% in far future). The combined effect of decreasing precipitation, rising temperatures and increasing variability in seasonal patterns resulted in a pronounced decline in reservoir inflow over time.

CROPWAT model was used to estimate the irrigation water requirement of paddy in the command area for baseline and future periods. Land use change analysis was carried out using MOLUSCE plug-in of QGIS to understand the changes in crop land area. The LULC changes indicate a shift towards urbanization and plantation expansion, with a concurrent decline in agricultural lands (2425 ha (14%) reduction by the end of the century) and water bodies. A decrease in average annual reservoir inflow (from 3.4% to 27.3%) and increase in average annual crop water demand (2.9% to 11.7%) was predicted by different SSPs for Malampuzha reservoir. Due to this increase in crop water demand and decrease in reservoir inflow, the amount of water allocation under optimal reservoir management conditions was less than the demand.

Optimization program was developed by considering all the necessary constraints with the objective of minimizing squared relative deficiency in water allocation. Optimal water allocation for Malampuzha reservoir was derived from the developed optimization technique using genetic algorithm for baseline and future periods. The command area water demand will not be met by the reservoir for far futures of SSP245 and SSP585 scenarios because of increase in temperature (3.26°C) and erratic behavior of precipitation which indicates the adverse effects of climate change.

Reservoir performance indices such as Reliability, Vulnerability, resiliency and sustainability were calculated and compared for both timelines. Climate change impact on reservoir performance was evaluated. The decline in reliability and resiliency, coupled with increased vulnerability (0.028% to 9.47%) highlights the significant challenges climate change poses to reservoir operation, underscoring the need for adaptive management strategies to ensure sustainable water resource management in far future.

Suggestions for Future Research

1. Although this study primarily used GCM data due to its wide availability and standardization under CMIP6, it is recognized that Kerala's small spatial extent and complex terrain necessitate the use of high-resolution RCMs for future work to enhance the accuracy of regional climate projections by better capturing local-scale variability especially for rainfall dependent phenomenon like reservoir management.
2. To estimate the inflow into the reservoir, coupling of hydrological models with ML techniques can be suggested to improve the accuracy of prediction and reduce the uncertainty.
3. An interactive Decision Support System (DSS) can be developed to help water managers, irrigation department and policy makers in making informed and real time decisions on reservoir operation, water allocation and water demand management under both current and future climate scenarios.