

Multi-Variable Optimization of a Hydrological Model in a Data Scarce Dry River Basin Incorporating Remotely Sensed Data

Hydrological models are mathematical representations that simulate simplified real-world catchment hydrological processes such as rainfall, streamflow, infiltration, etc. Each model has its own set of parameters that control the model simulations (outputs), ensuring a closer match with the real (observed) hydrological variables. This matching process is known as model calibration or optimization, which is conventionally achieved by considering only one hydrological variable (usually streamflow), known as Single Variable Calibration (SVC). The match between the observed and simulated data is quantified by a goodness-of-fit measurement (objective function), which gives a measure of the accuracy and reliability of model outputs.

However, SVC using streamflow may produce unreliable simulations, particularly in data-scarce dry river basins in Sri Lanka, like the Maduru Oya River Basin (Figure 1), as the river flow can drastically fluctuate from a complete absence to floods. In such cases, sole reliance on streamflow data in SVC is insufficient to capture complex watershed hydrological processes over both short and long time-scales.

In response, this study focuses on the Multi-Variable Calibration (MVC) approach, which incorporates two

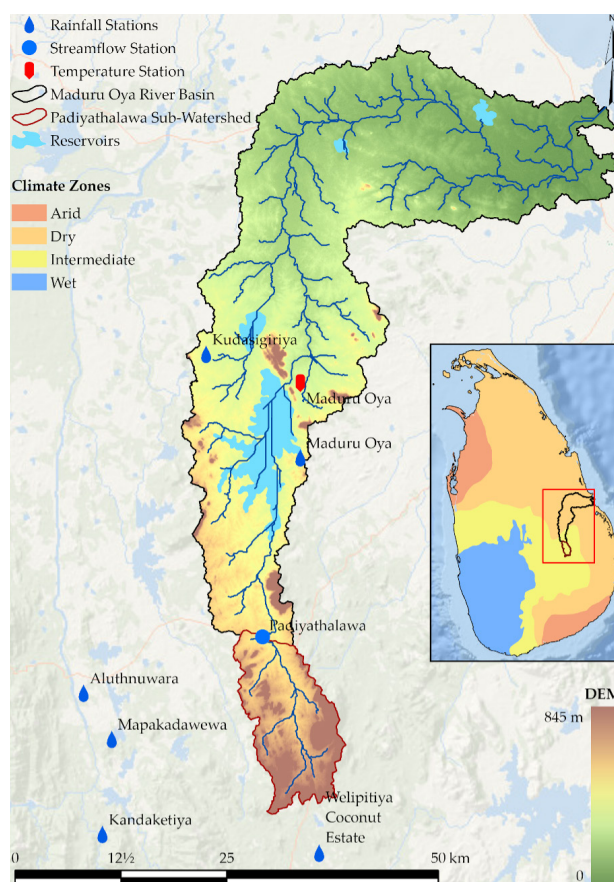


Figure 1: Maduru Oya River Basin [1].

hydrological variables for model optimization. Root Zone Soil Moisture (RZSM) data is selected alongside streamflow as it plays a critical role in distributing rainfall into infiltration and runoff, directly influencing streamflow and groundwater recharge. It is particularly suitable for the selected study area, Padiyathalawa sub-watershed (catchment area: 167 km²) in the upstream of the dry Maduru Oya River Basin (Figure 1).

Further, the limited availability of spatially distributed observed data (rainfall, evaporation, etc.) is one of the major challenges encountered during this study. In response, this study employs a lumped hydrological model, which assumes spatially aggregated hydrological processes. The non-linear, process-oriented Tank Model, developed by the Japanese hydrologist Sugawara is applied, and the model simulates watershed hydrology using a series of interconnected tanks with bottom and side outlets, representing groundwater flows.

Further, to address the lack of in-situ observed RZSM measurements, remotely sensed data from NASA's Soil Moisture Active Passive (SMAP) satellite mission is incorporated. Specifically, this study utilises SMAP Level 4 (L4) Global 3-hourly 9 km EASE-Grid Surface and Root Zone Soil Moisture Geophysical Data (Figure 2), which offer extensive spatial and temporal extent. To accommodate the lumped nature of the Tank Model, remotely sensed RZSM data is aggregated spatially and temporally following a rescaling process to remove systematic biases (Figure 3).

This study follows two phases. The first phase is the SVC of the Tank Model using only streamflow, which produces satisfactory objective function results confirming the model's capability for accurate streamflow simulations. The second phase is the MVC with combined streamflow and RZSM data through a weighted objective function. It assesses numerous combinations of contributions from streamflow and RZSM. The results show that the MVC approach improved the accuracy by 2% in streamflow simulations (Figure 4) while showing better RZSM simulations, thereby increasing the reliability of the model performance. However, the relatively short data periods used here may limit the

robustness of the model simulations, thus, incorporating long-term datasets is likely to yield more reliable and generalizable outcomes.

Ultimately, this study has contributed to improved water resource management in dry river basins through accurate and reliable model simulations, where it becomes challenging because water must be allocated for multiple purposes, such as water supply, irrigation, and power generation. Further, this demonstrates the potential of integration of remote sensing data in hydrological modelling, which is beneficial for data-scarce regions.

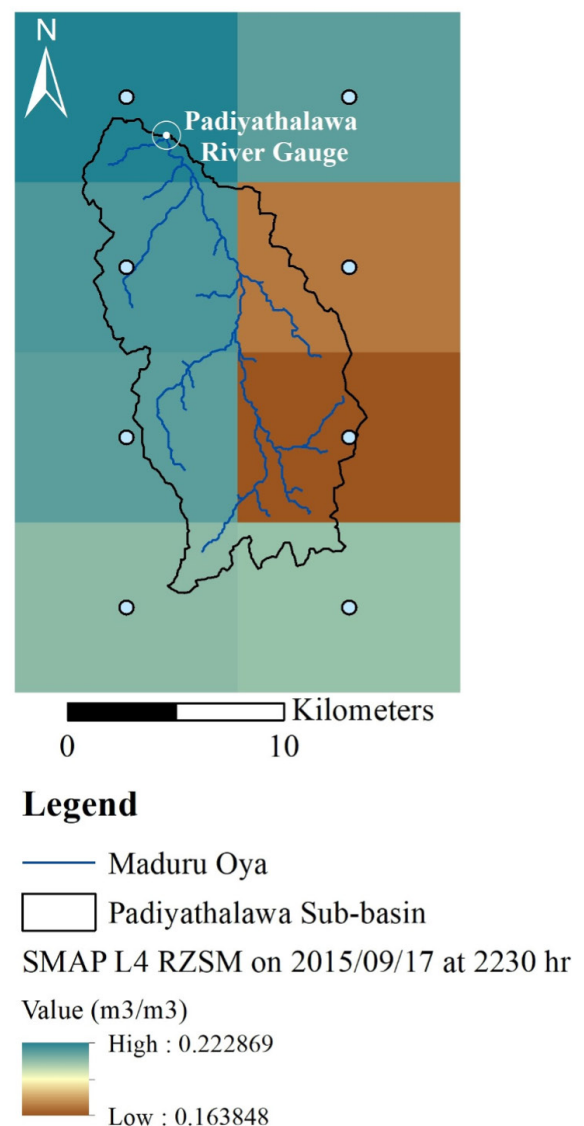


Figure 2: Spatial distribution of remote sensing satellite EASE-Grid arrangement over the Padiyathalawa sub watershed; RZSM data (m³/m³) measured on 17/09/2025 at 2230 hrs.

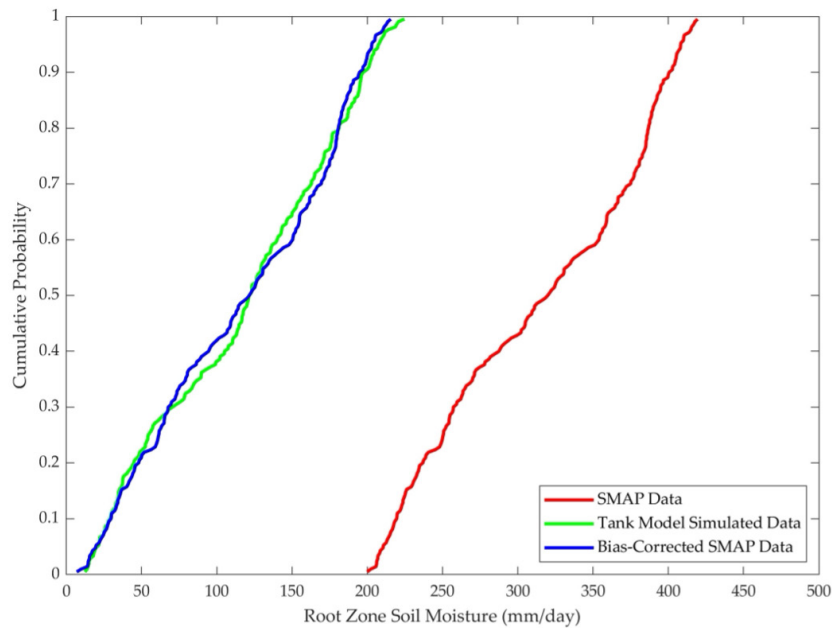


Figure 3: Rescaling of SMAP L4 RZSM data by the Cumulative Distribution Function (CDF) Matching method [1].

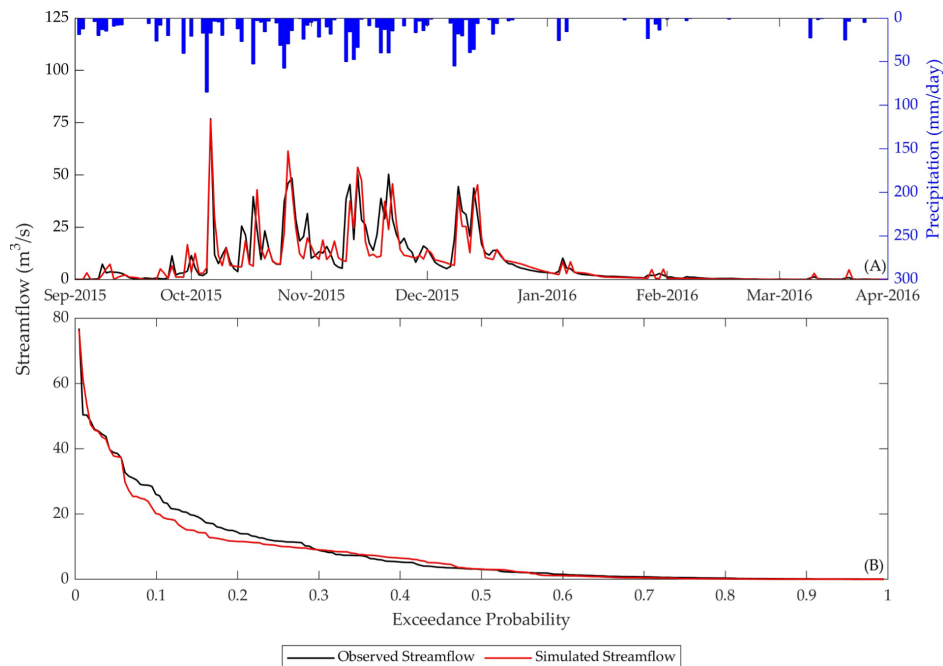


Figure 4: Observed and simulated flow hydrographs (A) and flow-duration curves (B) at the Padiyathalawa outlet for the validation period [1].

References:

[1] K. Pabasara, L. Gunawardhana, J. Bamunawala, J. Sirisena, and L. Rajapakse, "Significance of Multi-Variable Model Calibration in Hydrological Simulations within Data-Scarce River Basins: A Case Study in the Dry-Zone of Sri Lanka," *Hydrology*, vol. 11, no. 8, Aug. 2024, doi: 10.3390/hydrology11080116.

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