

Climate Change Impact on Surface Water Availability in an Ungauged Basin in Northern Sri Lanka

M.Z. Weerabangsa
Dept of Civil Engineering
Faculty of Engineering Technology
The Open University of Sri Lanka
Nugegoda, Sri Lanka
mzwec@ou.ac.lk

A D S Iresh
Irrigation Departemnt, Sri Lanka
Colombo 07
Sri Lanka
shahikaresh@gmail.com

B C L Athapattu
(Dept of Civil Engineering
Faculty of Engineering Technology
The Open University of Sri Lanka
Nugegoda, Sri Lanka
bcli@ou.ac.lk

Abstract— Reliable assessment of water availability in ungauged catchments remains a major challenge in regions where hydrological observations are sparse. This study investigates the challenges associated with modelling the ungauged Kanakarayan Aru basin in northern Sri Lanka and evaluates potential changes in surface-water availability under a future climate. A conceptual rainfall–runoff modelling approach was applied using parameters transferred from the hydrologically comparable Kala Oya basin. Historical meteorological data, including rainfall, temperature, and evaporation, were compiled and quality-controlled where possible. Future climate conditions were represented using PRECIS regional climate-model simulations driven by the HadCM3 global climate model under the A1B emissions scenario for 1960–2099. PRECIS rainfall was adjusted using a change-factor bias-correction procedure before being used as input to the rainfall–runoff model, while potential evaporation was estimated from temperature using the Thornthwaite method. The model estimated mean annual surface-water availability in the Kanakarayan Aru basin at approximately 289 million m³, equivalent to 28% of the estimated mean annual precipitation of 1034 mm. Approximately 77% of the annual water yield occurred between November and January, emphasizing the strong seasonal concentration of runoff. The climate simulations indicated a substantial increase in temperature toward the end of the century, whereas changes in precipitation were comparatively uncertain. Modelled annual water availability decreased from 276 million m³ during 1960–1990 to approximately 149 million m³ during 2070–2099. The reduction occurred despite a small increase in projected annual precipitation and was primarily associated with increasing temperature and consequent increases in evaporative demand. The findings demonstrate both the potential vulnerability of water resources in the basin and the

considerable uncertainty associated with hydrological prediction in ungauged catchments. Improved hydrometeorological monitoring, direct streamflow observations, improved spatial representation of rainfall, and multi-scenario climate modelling are therefore required to support robust long-term water-resources planning.

I. INTRODUCTION

Climate variability and climate change present significant challenges for water-resources management, particularly in regions where river basins are poorly monitored. Sri Lanka exhibits substantial spatial and temporal variability in precipitation associated with the southwest monsoon, northeast monsoon, and two intermonsoon seasons. Surface runoff is an important component of water supply for irrigation and other uses, while several rivers experience very low flows during the dry season [1], [2]. Consequently, changes in rainfall and temperature may have direct implications for reservoir inflows, irrigation reliability, and regional water security.

Previous studies of Sri Lankan climate have identified warming trends and changes in rainfall characteristics, although projections of future precipitation have remained considerably more uncertain than temperature projections [3]–[7]. Regional climate modelling provides an approach for obtaining spatially finer climate information than that available from global circulation models. PRECIS, a regional climate modelling system developed by the UK Met Office, has been applied to generate high-resolution climate projections for South Asian regions [8], [9].

The problem is particularly important in northern Sri Lanka, where water resources are strongly dependent on seasonal rainfall and irrigation infrastructure. The Kanakarayan Aru basin covers approximately 896 km² and supplies the Iranaimadu reservoir, an important source of irrigation water in the region. The basin lacks a sufficiently long and reliable streamflow record for

conventional calibration of a rainfall–runoff model. This creates a fundamental modelling problem: the hydrological response must be estimated without directly observed discharge data.

Prediction in ungauged basins is recognized as a major challenge in hydrology because model parameters cannot be reliably calibrated against observed streamflow at the basin of interest [10]. Approaches based on parameter transfer from hydrologically similar gauged catchments provide one possible solution, although they introduce additional uncertainty [11].

This study therefore addresses three related questions: 1) whether a rainfall–runoff model calibrated in a neighbouring basin can provide a useful estimate of flow in the ungauged Kanakarayan Aru basin; 2) how projected changes in temperature and precipitation may alter surface-water availability; and 3) what data and methodological limitations constrain the reliability of such estimates.

The objectives were to develop a rainfall–runoff model for the ungauged basin using available meteorological and ancillary information, estimate present-day surface-water availability, assess projected changes in rainfall and temperature, and evaluate the implications of those changes for future water availability

II. STUDY AREA AND DATA

A. Kanakarayan Aru Basin

The Kanakarayan Aru basin is located in northern Sri Lanka and has a catchment area of approximately 896 km². The river extends for approximately 70 km through the Vavuniya, Mullaitivu, and Kilinochchi districts. The basin lies within the dry zone and is characterized by relatively flat terrain and seasonal rainfall. Approximately 80% of annual rainfall in the region occurs during the northeast monsoon period, particularly between October and December.

The Iranaimadu reservoir is a major water-storage facility associated with the basin and supports irrigation in northern Sri Lanka. The regional agricultural economy is strongly dependent on reliable seasonal water availability. The basin therefore represents an important case for evaluating the implications of climate variability and change in an ungauged environment.

B. Hydrometeorological Data

Rainfall observations were available from Iranaimadu and Vavuniya, while temperature data were obtained from Vavuniya and evaporation observations from Mahailupallama. The available

records contained missing observations and incomplete years, particularly for evaporation. Historical rainfall observations at Iranaimadu extended over a long period, although gaps were present. Temperature and evaporation datasets also required filling or adjustment before use.

The study additionally used discharge data from the Rajangana subbasin of Kala Oya to derive rainfall–runoff model parameters for subsequent transfer to the ungauged Kanakarayan Aru basin. The use of a neighbouring gauged basin was necessary because an adequate discharge record was unavailable for Kanakarayan Aru.

C. Climate Data

Future climate information was obtained from PRECIS regional climate simulations driven by the HadCM3 global climate model under the A1B emissions scenario. The simulations covered 1960–2099. Both annual and seasonal precipitation and temperature were examined. The four Sri Lankan rainfall seasons considered were the first intermonsoon (IM1), southwest monsoon (SWM), second intermonsoon (IM2), and northeast monsoon (NEM).

III. METHODOLOGY

A. Rainfall-Runoff Modelling

A conceptual rainfall–runoff modelling framework was adopted to represent precipitation, interception, soil-moisture accounting, effective rainfall, and runoff routing. The approach was selected because conceptual models can represent key hydrological processes while requiring fewer spatially distributed observations than fully physically based models [12].

Because Kanakarayan Aru was ungauged, model parameters were derived from the gauged Kala Oya basin using a constant-parameter transfer approach. The rainfall–runoff modelling tool was calibrated against available discharge observations from Kala Oya, and the resulting parameters were transferred to Kanakarayan Aru.

The optimized parameters included soil-moisture accounting and routing parameters. The manually adjusted values included a root constant of 140 mm, initial deficit of 115 mm, fast-flow residence time of approximately 6 days, slow-flow residence time of approximately 46.1 days, and a fast-flow proportion of 0.008. The selected soil-moisture parameter was consistent with the reported field-capacity range for the dominant Reddish-Brown Earth soils.

B. Representation of Interception

Interception was considered because approximately 40% of the catchment was reported as forested. Since the rainfall–runoff model did not contain a dedicated interception module, a simple conceptual interception

component was proposed. The model assumed a minimum rainfall requirement of 1.5 mm to wet the canopy and a canopy storage capacity of 0.7 mm. The resulting throughfall was subsequently supplied to the soil-moisture accounting component.

C. Climate-Data Adjustment

The raw PRECIS precipitation and temperature outputs were first compared with observations for the historical period. Because discrepancies existed between simulated and observed precipitation, a change-factor approach was used for bias correction. The corrected precipitation was calculated as:

$$X_{\text{corr}} = \mu_{\text{obs}} + \frac{\sigma_{\text{obs}}}{\sigma_{\text{mod}}} (X_{\text{mod}} - \mu_{\text{mod}}) \quad (1)$$

where X_{corr} is the corrected climate-model variable, X_{mod} is the raw model output, and μ and σ denote the mean and standard deviation of the observed and modelled historical datasets.

The corrected PRECIS precipitation and temperature were subsequently used as inputs to the rainfall–runoff model. Potential evaporation was estimated from temperature using the Thornthwaite method.

D. Climate Change Assessment

The 1960–2099 PRECIS simulations were divided into five periods to facilitate comparison:

1. 1960–1990;
2. 1990–2020;
3. 2020–2050;
4. 2050–2070; and
5. 2070–2099.

The analysis examined changes in annual and seasonal precipitation and temperature. The bias-corrected climate series were then propagated through the rainfall–runoff model using the same soil and routing parameters as those transferred from Kala Oya.

IV. RESULTS

A. Rainfall–Runoff Model Performance and Present Water Availability

Temperature exhibited a much stronger and more consistent projected trend than precipitation. The annual mean temperature from the PRECIS simulation increased substantially toward the end of the century. For the 1960–1990 baseline period, the mean temperature was approximately 27.2 °C. By 2070–2099, the projected mean exceeded 30 °C, representing an increase of approximately 3.3 °C. Seasonal analyses also indicated substantial warming, particularly during the NEM and IM2 seasons.

The annual temperature series showed a linear-fit R^2 of approximately 0.83, while seasonal temperature fits also indicated substantial relationships between time and temperature. In contrast, precipitation exhibited very low R^2 values, demonstrating that linear regression provided little explanatory power for its temporal variability.

B. Projected Precipitation

Changes in projected annual precipitation were comparatively small and uncertain. The thesis reported approximately 2.5% higher annual precipitation during 2070–2099 relative to 1960–1990. However, seasonal changes varied considerably, including reductions in SWM and NEM rainfall during some future periods and increases during IM2.

The results therefore did not provide strong evidence for a systematic change in annual precipitation. This contrasts with the much clearer projected warming signal.

C. Projected Surface-Water Availability

The principal climate-impact result was a reduction in modelled surface-water availability despite relatively limited change in annual precipitation. Table I summarizes the modelled results.

The principal climate-impact result was a reduction in modelled surface-water availability despite relatively limited change in annual precipitation. Table I summarizes the modelled results.

TABLE I. PROJECTED CLIMATE AND SURFACE-WATER AVAILABILITY

Period	Annual Rainfall (mm)	Water availability (million m ³)	Runoff ratio (%)	Temp. (°C)
1960–1990	1386	276	22	25.4
1990–2020	1388	253	20	25.9
2020–2050	1361	200	16	27
2050–2070	1510	214	16	27.9
2070–2099	1431	149	12	29.4

The modelled annual water availability declined from 276 million m³ during 1960–1990 to 149 million m³ during 2070–2099. The runoff ratio decreased from 22% to 12%. The thesis attributes this reduction primarily to increasing temperature and associated increases in evaporative demand.

The projected reduction in available water is particularly relevant because the Iranaimadu reservoir was reported to require approximately 148.1 million m³

for irrigation under the development scenario considered by the thesis, while the proposed water-supply project required an additional 9.85 million m³ annually. The thesis also cited an estimated irrigation demand of 181.5 million m³ for the basin.

V. DISCUSSION

A. Implications for an Ungauged Basin

The results demonstrate that a rainfall–runoff model based on parameter transfer can provide a first-order estimate of surface-water availability in an ungauged basin. However, the approach should not be interpreted as equivalent to calibration against observed streamflow within Kanakarayan Aru.

The estimated present-day annual runoff of 289 million m³ was reasonably close to the independent Water Resources Board estimate of 317.5 million m³. When the modelled rainfall was adjusted to the rainfall used by the Water Resources Board estimate, the difference between the two estimates was approximately 14.1%. This provides some external support for the magnitude of the modelled result, but it does not remove the structural and observational uncertainties associated with the model.

The study therefore illustrates an important trade-off in ungauged-basin modelling. Parameter transfer enables hydrological estimation where direct calibration is impossible, but the transferred parameters implicitly assume sufficient hydrological similarity between the donor and target basins.

B. Climate-Change Signal

The dominant projected climate signal in the study is warming rather than a robust change in annual precipitation. This finding is consistent with the broader literature reviewed in the thesis, which generally indicated greater confidence in projected temperature increases than in precipitation changes over Sri Lanka [3]–[9].

The projected reduction in runoff despite relatively modest changes in precipitation demonstrates the importance of considering temperature-driven evaporative demand in water-resource assessments. Under the model assumptions, increasing temperature reduced the proportion of precipitation converted into runoff.

The results also highlight the importance of seasonality. Approximately 77% of annual water yield occurred between November and January under the historical assessment. Consequently, changes affecting these months could have disproportionate implications for annual reservoir inflow and water availability.

C. Water-Resources Implications

The projected reduction in water availability is particularly relevant to an agricultural region dependent on seasonal storage. The modelled availability of 149 million m³ during 2070–2099 is approximately 46% lower than the 276 million m³

estimated for 1960–1990. This magnitude of reduction would have important implications for irrigation reliability if the modelled scenario were realized.

The comparison with reported irrigation and proposed domestic water requirements indicates that future water demand and supply should be evaluated jointly. The thesis therefore emphasizes the need for improved water-resources information and investigation of alternative management options rather than relying solely on historical hydrological conditions.

D. Uncertainty and Limitations

Several limitations constrain interpretation of the results.

First, the Kanakarayan Aru basin lacked an adequate streamflow record for direct calibration and validation. Model parameters were transferred from Kala Oya, meaning that uncertainty associated with the donor basin is propagated into the target-basin estimates.

Second, the calibration and validation periods available for the donor catchment were relatively short and did not adequately represent all seasons. The thesis specifically identifies this as an important limitation.

Third, the hydrological model assumed catchment homogeneity despite spatial variability in soil, vegetation, rainfall, infiltration, and evaporation. The dominant Reddish-Brown Earth soil was used as a representative soil condition.

Fourth, the observed meteorological datasets contained missing values and required modification. Consequently, uncertainty in the observed data may have been transferred into the bias-corrected PRECIS series.

Fifth, the PRECIS output exhibited problems in seasonal representation. The thesis also reported that bias correction and randomization could produce unrealistic extreme daily rainfall values, including simulated values exceeding 900 mm d⁻¹, while the historical maximum was below 400 mm d⁻¹. This illustrates the potential for statistical adjustment procedures to introduce unrealistic extremes.

Finally, the future simulations assumed that land use, soil conditions, and irrigation practices remain unchanged. Such assumptions are unlikely to represent all future socioeconomic and land-management changes and therefore add structural uncertainty to the projections.

These limitations mean that the projected values should be interpreted as scenario-based model estimates rather than deterministic forecasts.

E. Research and Monitoring Priorities

The study identifies several measures that would substantially improve future assessments. These include transforming point rainfall measurements into spatially representative areal rainfall, incorporating

interception explicitly into the rainfall–runoff model, obtaining Iranaimadu reservoir spill data, and installing streamflow gauges in the Kanakarayan Aru channel. The thesis further recommends evaluating multiple climate scenarios rather than relying on a single A1B projection. Such an approach would provide a broader representation of climate uncertainty and allow the sensitivity of water availability to different emissions pathways to be examined.

VI. CONCLUSION

This study investigated the feasibility of estimating surface-water availability and climate-change impacts in the ungauged Kanakarayan Aru basin in northern Sri Lanka. A conceptual rainfall–runoff model using parameters transferred from the gauged Kala Oya basin provided an estimated mean annual surface-water availability of approximately 289 million m³, corresponding to 28% of the estimated mean annual precipitation.

The analysis demonstrated a pronounced seasonal concentration of runoff, with approximately 77% of annual water yield occurring between November and January. This seasonal dependence is important for reservoir operation and irrigation planning.

The climate-change assessment indicated a substantially stronger and more consistent warming signal than precipitation signal. Although projected annual precipitation showed only modest changes, the increase in temperature resulted in declining modelled runoff and surface-water availability. Under the A1B/PRECIS scenario, estimated annual availability decreased from 276 million m³ during 1960–1990 to 149 million m³ during 2070–2099, while the runoff ratio declined from 22% to 12%.

The study consequently demonstrates that assessments of future water resources in northern Sri Lanka cannot rely solely on projected precipitation. Temperature-driven changes in evaporative demand can substantially alter runoff even where annual precipitation remains relatively stable. Nevertheless, the magnitude of the projected reduction is subject to considerable uncertainty because of the absence of direct streamflow observations, transfer of parameters from another catchment, incomplete meteorological data, simplified representation of catchment processes, uncertainty in climate-model precipitation, and assumptions concerning future land use and water management.

Future research should therefore prioritize long-term streamflow monitoring in Kanakarayan Aru, improved spatial rainfall measurement, incorporation of reservoir operation and spill observations, explicit representation of interception and other hydrological processes, and ensemble climate modelling using multiple climate scenarios. These improvements would provide a stronger basis for assessing the resilience of northern

Sri Lanka's water resources under future climate condition.

REFERENCES

- [1] U. A. Amarasinghe, L. Mutuwatta, and R. Sakthivadivel, *Water Scarcity Variations within a Country: A Case Study of Sri Lanka*, IWMI Research Report No. 32, International Water Management Institute, 1999.
- [2] C. S. Weeraratna and P. A. Weerasinghe, "Importance of rainwater harvesting in Sri Lankan agriculture," 2006.
- [3] T. K. Fernando, "Recent variations of rainfall and air temperature in Sri Lanka," in *Proc. 53rd Annual Session of the Sri Lanka Association for the Advancement of Science*, Section E1, 1997, p. 318.
- [4] B. R. S. B. Basnayake, T. K. Fernando, and J. C. Vithanage, "Variation of air temperature and rainfall during Yala and Maha agricultural seasons," in *Proc. 58th Annual Session of the Sri Lanka Association for the Advancement of Science*, Section E1, 2002, p. 212.
- [5] B. R. S. B. Basnayake, J. Rathnasiri, and J. C. Vithanage, "Rainfall and temperature scenarios for Sri Lanka under the anticipated climate change," presented at the 2nd AIACC Regional Workshop for Asia and the Pacific, Manila, Philippines, Nov. 2004.
- [6] L. Chandrapala, "Calculation of areal precipitation of Sri Lanka on district basis using Voronoi tessellation method," presented at the National Symposium on Climate Change, Colombo, Sri Lanka, 1996.
- [7] M. Domroes and D. Schaefer, "Trends of recent temperature and rainfall changes in Sri Lanka," in *Proc. International Conference on Climate Change and Variability*, Japan, Sept. 2000, pp. 197–202.
- [8] R. G. Jones, M. Noguer, D. C. Hassell, D. Hudson, S. Wilson, G. J. Jenkins, and J. F. B. Mitchell, *Generating High Resolution Climate Change Scenarios Using PRECIS*, UK Met Office, 2004.
- [9] R. V. Cruz *et al.*, "Asia," in *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M. L. Parry *et al.*, Eds. Cambridge, U.K.: Cambridge Univ. Press, 2007, pp. 469–506.
- [10] M. Sivapalan, "Prediction in ungauged basins: A grand challenge for theoretical hydrology," *Hydrological Processes*, vol. 17, pp. 3163–3170, 2003, doi: 10.1002/hyp.5158.
- [11] N. McIntyre, H. Lee, H. Wheeler, A. Young, and T. Wagener, "Ensemble predictions of runoff in ungauged catchments," *Water Resources Research*, 2005.
- [12] G. H. Leavesley, "Modeling the effects of climate change on water resources—A review," *Climate Change*, vol. 28, pp. 159–177, 1994.
- [13] M. B. Beck, "Forecasting environmental change," *Journal of Forecasting*, vol. 10, nos. 1–2, pp. 3–19, 1991.
- [14] A. Becker and R. Serban, *Hydrological Models for Water-Resources System Design and Operation*, Operational Hydrology Report No. 34, WMO No. 740, World Meteorological Organization, 1990.
- [15] D. G. Tarboton, *Rainfall–Runoff Processes: A Workbook to Accompany the Rainfall–Runoff Processes Web Module*, Utah State University, 2003.
- [16] D. Alwis, "Development of a management model for a river basin dominated by irrigated agriculture," in *Proc. 2nd ICID Asian Regional Conference on Irrigation and Drainage*, Moama, NSW, Australia, Mar. 2004, pp. 9–20.
- [17] C. S. De Silva, E. K. Weatherhead, J. W. Knox, and J. A. Rodriguez-Diaz, "Predicting the impacts of climate change—A case study of paddy irrigation water requirements in Sri Lanka," *Agricultural Water Management*, vol. 93, nos. 1–2, pp. 19–29, 2007.

- [18] C. S. De Silva, "Impacts of climate change on water resources in Sri Lanka," presented at the 32nd WEDC International Conference, Colombo, Sri Lanka, 2006.
- [19] K. R. Kumar *et al.*, "High-resolution climate change scenarios for India for the 21st century," *Current Science*, vol. 90, no. 3, pp. 334–345, 2006.
- [20] S. U. Islam and N. Rehman, "Assessment of future change in temperature and precipitation over Pakistan simulated by PRECIS RCM for A2 scenario," 2004.
- [21] U. Ratnayake and G. Herath, "Changes in water cycle: Effect on natural disasters and ecosystems," in *Workshop on Sri Lanka National Water Development Report*, World Water Assessment Programme, 2005.
- [22] K. H. M. S. Premalal, "Weather and climate trends, climate controls and risks in Sri Lanka," presented at the Sri Lanka Monsoon Forum, Apr. 2009.
- [23] Northern Provincial Council, Sri Lanka, *Statistical Information 2010*, Trincomalee, Sri Lanka, 2010.
- [24] Department of Agriculture, Sri Lanka, *Crop Recommendations: Climate of Rice Growing Regions in Sri Lanka*, 2006.
- [25] Department of Meteorology, Sri Lanka, "Climate in Sri Lanka," 2012.
- [26] The International Fund for Agricultural Development, *Iranaimadu Project: Design Report*, 2011.
- [27] Water Resources Board, Sri Lanka, *Water Resources in Northern Province*, Colombo, Sri Lanka, n.d.
- [28] H. Horiuchi *et al.*, "Estimation of canopy water storage capacity from sap flow measurements in a Bornean tropical rainforest," *Journal of Hydrology*, vol. 252, pp. 288–295, 2008.
- [29] D. A. Woolhiser and D. L. Brakensiek, "Hydrologic system synthesis," in *Hydrologic Modeling of Small Watersheds*, C. T. Haan, H. P. Johnson, and D. L. Brakensiek, Eds., ASAE Monograph No. 5. St. Joseph, MI, USA: American Society of Agricultural Engineers, 1982.
- [30] J. C. I. Dooge, "Hydrologic models and climate change," *Journal of Geophysical Research*, vol. 97, no. D3, 1992.
- [31] C. S. Basnayake, L. Chandrapala, G. H. P. Dharmaratne, and H. M. Jayatilake, "Water resources and climate change," in *Workshop on Sri Lanka National Water Development Report*, World Water Assessment Programme, 2005.
- [32] K. Shanmugarajah, *Water Resources Development: Jaffna Peninsula*. Australia: Fast Book, 1993.
- [33] Ministry of Economic Development, Sri Lanka, *Food Security in Northern, Eastern, North Central Provinces: A Food Security Assessment*, 2011.
- [34] Ministry of Irrigation and Water Management, Sri Lanka, *Water Resources in Northern Province*, Water Resources Board, Colombo, Sri Lanka,

Community Engagement, Mass Communication, and Educational Initiatives for Social Wellbeing and a Plastic-Free Society