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Can Hydrologic Engineering Centre-Hydrologic Modelling System (HEC-HMS) Model Simulate Long Term Flows in Tropical River Basins? A Case Study from the Uruwal Oya River Basin, Sri Lanka

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***Abstract*—**Ensuring the sustainability in water resource management has become a challenge in Sri Lanka, mainly due to the lack of long term river flow data. As a solution, flow prediction models that provide reliable hydrological simulations could be used to generate the long-term flow data. This study attempted to assess the performance of three approaches in the HEC-HMS, for the synthesis of long-term river flow data of the Uruwal Oya tributary. The HEC-HMS (Version 3.5) model was calibrated for the period of 1984–1994 and validated for 1995–2016, based on two loss methods (Deficit and Constant Loss Method [DCLM] and Initial and Constant Loss Method [ICLM]) and Snyder Unit Hydrograph Method (SUHM) as a transformation method, to determine the most suitable flow simulation combination. The Coefficient of Performance (CP_A'), Relative Error (RE), scatter plot method (R^2) and residual method were used in the statistical analysis. The Snyder Unit Hydrograph Method yielded satisfactory results, with a R^2 value of 0.69, CP_A' of 1.65 and a standard error of +0.25. Among the loss methods, the DCLM emerged as the best method, with 63.2%, 93.4%, 0.64, 1.70 and +0.28 values for residual points within mean±1SD, mean±2SD, R^2, CP_A' and RE, respectively. Therefore HEC-HMS model could be recommended as a reliable and effective approach for runoff simulation of similar wet zone river basins in Sri Lanka.

***Keywords*—**HEC-HMS, Hydrological Modelling, River Flow, Uruwal Oya

I. Introduction

Understanding the physical phenomena that take place in river basins has been realized as a crucial requirement in planning and developing eco-conscious regulatory activities such as river basin management etc. in any country, including Sri Lanka (Smakhtin, 2006). Numerous stream flow characteristics, namely seasonal patterning of flow, timing of extreme conditions, frequency, predictability, duration of floods and droughts, seasonal and annual variability, and rates of change are important for the maintenance of riverine ecosystems and biological diversity (Richter *et al*., 1996). Thus, the flow regime of a river is often valued as an overarching master variable of riverine ecosystems (Poff *et al*., 1997; Korsgaard, 2006). Modification of hydrological regimes is considered as a crucial factor that could indirectly alter the composition, structure or functioning of aquatic, riparian and wetland ecosystems through their effects on physical habitat characteristics, including water temperature, oxygen content, water chemistry and substrate particle size (Richter *et al*., 1996).

When the Sri Lankan context is taken into consideration, only 52 river flow gauging stations continue to operate in Sri Lanka at present (Weerakoon and Herath, 2002), regardless of the 142 flow measuring stations that existed in the past (Nakagawa *et al*., 1995). Thus, less or no availability of reliable up-to-date hydrological data has been recognized as a crucial limitation for the in-depth understanding and simulation of hydrological processes such as runoff generation and its transmission to the basin outlet. Among numerous conventional techniques, watershed modelling has gained wide recognition as an effective and reliable tool in describing the hydrological response of river basins due to precipitation (Kalita, 2008; Halwatura and Najim, 2013). Hydrological modelling has advanced rapidly and computerized models have become essential tools for understanding human influences on river flows and designing ecologically sustainable water management approaches (Richter *et al*., 2003).

Similar to most of the tropical developing countries, hydrologic modelling in Sri Lanka is still at its infancy due to the lack of expertise, the complexity of modelling, lack of data availability and technical capabilities etc. (Halwatura and Najim, 2013; Udayanga and Najim, 2016). Hydrological simulation of river basins has been realized to be practically difficult, due to the complexity of hydrological processes (interactions) and increased data requirements associated with the modelling processes (Halwatura and Najim, 2013; Yilma and Moges, 2007). The selection of a better performing and reliable model for the simulation remains difficult, while the application of such models often remains a challenge. The HEC-HMS model, developed by the US Army Corps of Engineers, is a widely accepted hydrological simulation model, which has been successfully used in many countries, under different environmental conditions (Fleming, 2004; Saleh *et al*., 2011; Yilma and Moges, 2007).

The HEC-HMS model includes a variety of internationally accepted loss and transformation methods that could be used in the hydrological simulation of river basins. Therefore, this study aimed to investigate the performance of the HEC-HMS model in hydrological simulation of the Uruwal Oya basin with respect to several loss and transformation methods (namely, Snyder Unit Hydrograph Method [SUHM], Initial and Constant Loss Method [ICLM] and Deficit and Constant Loss Method [DCLM]), in the HEC-HMS model system, so that the applicability and reliability of the model could be investigated, along with the best performing hydrological modelling approaches for the Uruwal Oya basin.

II. METHODOLOGY

A. Study Area

Uruwal Oya River Basin (Figure 1), which is located in-between two major river basins, Kelani River and Maha Oya, was selected as the study basin for the current study. Uruwal Oya, which is located within the Gampaha district, is respected as one of the four major tributaries of the Attanagalu Oya and includes a variety of land uses within its basin. Uruwal Oya is a left bank tributary of Attanagalu Oya, which originates from Radawana at an elevation of around 35 meters above mean sea level and flows into the North-Westerly direction to confluence with Attanagalu Oya, after passing the Gampaha town (Udayanga and Najim, 2015).

B. Data Collection

Daily rainfall data covering the period of January 1984 to March 2016 of Henarathgoda and Horagahalanda rainfall gauging stations scattered within the Uruwal Oya basin were obtained from the Department of Meteorology, Colombo. In addition, monthly evapotranspiration data corresponding to the Henarathgoda agro-meteorological station were also acquired for the same period. Daily river flows of Uruwal Oya, corresponding to the confluence point of Uruwal Oya and Attanagalu Oya, for the last thirty years (1984 – 2016) were acquired from the Department of Irrigation, Colombo, Sri Lanka.

C. Data Map Preparation

The GIS layers such as the entire drainage basin, sub-basins of the entire basin and the land use maps of the Uruwal Oya basin that were required as input data for the HEC-HMS (version 3.5) model were developed by utilizing Arc GIS (version 10.2) software package.

D. Setting up of Model Parameters

Watershed and meteorology information (such as the catchment area, land use patterns of the catchment, daily rainfall data, daily river flow data, monthly evapotranspiration data, base flows, peaking coefficient, imperviousness, standard lag, initial deficit, constant rate, time of concentration and storage coefficient), that were required to simulate the hydrological responses of the Uruwal Oya basin were entered appropriately into the setup of the HEC-HMS model, following the procedure recommended by Halwatura and Najim (2013).

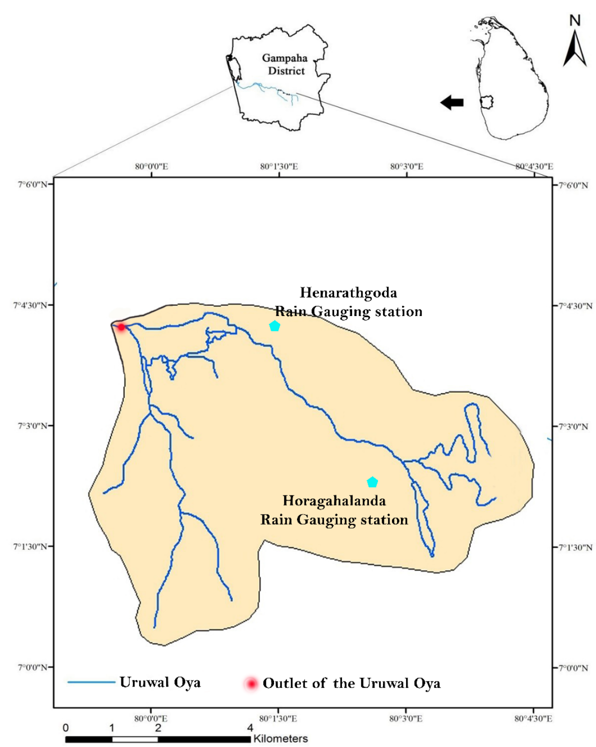

Figure 1: Map of Uruwal Oya basin, Sri Lanka.

E. Calibration, Validation and Statistical Analysis

The created model was initially calibrated for the period of 1984 – 1994, employing two loss methods, Deficit and Constant Loss Method (DCLM) and Initial and Constant Loss Method (ICLM) and Snyder Unit Hydrograph Method (SUHM) as the transformation method.

1) Deficit and Constant Loss Method (DCLM): The Deficit Constant Loss Method (DCLM), considers a single soil layer to account for continuous changes in moisture content. The potential evapotranspiration is also taken into consideration to account for the dryness of soil in between precipitation events. This method assumes that runoff only occurs, when the soil layer is saturated, while an initial deficit is lost from the precipitation, for the saturation of soil. When the DCLM is used as the loss method, the initial deficit, maximum storage constant rate and the imperviousness of the basin have to be calibrated based on the watershed characteristics.

2) Initial and Constant Loss Method (ICLM): The Initial and Constant Loss Method (ICLM) is a simple, but widely utilized method, which requires a limited knowledge on soil information. The ILM assumes that an amount of incoming precipitation will be infiltrated or stored in soil, prior to the generation of surface runoff and the maximum potential rate of precipitation loss after saturation remains constant throughout the entire precipitation event. Therefore, under the ICLM, the initial loss and constant rate of precipitation loss have to be calibrated, based on the physical properties of the watershed such as soil type, landuse and the antecedent condition.

3) Snyder Unit Hydrograph Method (SUHM): The Snyder Unit Hydrograph Method is a synthetic unit hydrograph method, which eliminates the necessity of developing a unit hydrograph based on past observed hydrographs. Instead, a time versus area curve built into the model could be utilized to develop the translation hydrograph resulting from a precipitation event, which is then routed through a linear reservoir to account for the storage attenuation across the basin. Under this method, the standard lag and peaking coefficients have to be optimized during calibration.

During calibration, the loss methods were calibrated initially, maintaining the SUHM as the transformation method, with the standard lag and peaking coefficients recommended by Halwatura and Najim (2013) for Attanagalu Oya catchment. After identifying and calibrating the best performing loss method, the SUHM method was optimized to yield the best simulation. The performance of the HEC-HMS model in runoff simulation of Uruwal Oya basin was evaluated at each phase, by subjecting the synthesized daily river flows of Uruwal Oya into a variety of statistical tests.

Initially, the scatter plot technique (R^2) was used as a primary assessment technique. Then, the "Coefficient of Performance for the error series A (CP_A)" was calculated using Equation 1 and the "Coefficient of Performance (CP_A')" was calculated subsequently, using the Equation 2, as recommended by Bennett *et al*. (2013). Finally, the Percentage Relative Error (RE %) was calculated by using the Equation 3.

$$CP_{\mathrm{A}} = \sum_{i=1}^{N} [S(i) - O(i)]^2 \tag{1}$$

$$CP_{\mathrm{A}}{}^{'} = \frac{CP_{\mathrm{A}}}{\sum_{i=1}^{N} [S(i) - O(i)]^2} \tag{2}$$

Where,
S(i) = i^{th} simulated parameter; O(i) = i^{th} observed parameter; O_{avg}= mean of the observed parameter; and N = total number of events.

$$RE\% = \frac{Simulated - Observed}{Observed} \times 100 \tag{3}$$

The inclusion of 68.2% of residual points within mean ± 1 Standard Deviation (SD), and 95.4% of residual points within mean ± 2 SD, an R^2 value closer to 1, lower RE % and a CP_A' value closer to 0, denotes a higher goodness of fit between the simulated and actual flows. The calibrated models were validated for the period of 1995 – 2016, while maintaining the best performing model parameters unchanged.

III. Results and Discussion

The summarized results of the statistical analysis on the performance of different modelling approaches are shown in Table 1. During the calibration period, the SUHM resulted 64.8% and 93.1% residual points within mean ± 1SD, mean ± 2 SD, respectively. Further, the R^2 (0.69), CP_A' (1.65) and RE (+0.25) values were also satisfactory, denoting it's potential in generating reliable and accurate flow simulations. Meanwhile, the DCLM, emerged as the most appropriate loss method in hydrological simulation of Uruwal Oya basin, yielding 63.2% and 93.4%, for residual points within mean ± 1SD, mean ± 2 SD, along with 0.64, 1.70 and +0.28 values, for R^2, CP_A' and RE, respectively (Table 1).

When both the DCLM and SUHM were used together as the loss and transformation methods, respectively, the simulated flows yielded 65.3%, 94.2%, 0.84, 1.60 and +0.24 values for residual points within mean ±1 SD, mean ±2 SD, R^2, CP_A' and RE, respectively during the validation period (Figure 2). A previous study carried out by Halwatura and Najim (2013) in the Attanagalu Oya catchment, has evaluated the performance of the HEC-HMS model in hydrological simulation, by utilizing the DCLM, along with Clark Unit Hydrograph and SUHM, whereby the SUHM and DCLM have been recommended as the most reliable transformation and loss methods, respectively for the synthesis of river flow in Attanagalu Oya. On the contrary, a previous study conducted by Saleh *et al*. (2011), in Kan Watershed, Iran, has shown that approximately 70% of simulations reported a low degree of deviations, when ICLM is utilized. In another study, the use of initial and constant loss method for excess runoff volume determination along with the SUHM has been reported as the best model combination for short and long-term flood forecasting in the Ethiopian Nile river basin (Yilma and Moges, 2007).

Figure 3, illustrates the goodness of fit of actual and simulated flows of the actual and simulated monthly flows of Uruwal Oya for the period of 1984 – 2016. A reasonable fit between the simulated flows derived by the model and observations (in terms of hydrograph shape and timing of peaks) could be identified, which has also been reported to exist by Halwatura and Najim (2013). It was evident that

Table I: Summarized results of statistical assessments of each studied modelling approach of HEC-HMS during calibration (1984 – 1994)

Modelling approach		Residual plot technique (Percentage of residuals)		R2	CPA'	RE %
		±1 SD range	±2 SD range			
Loss Method	Deficit Constant Loss Method	63.2	93.4	0.64	1.70	+0.28
	Initial and Constant Loss Method	61.5	90.7	0.60	1.95	+0.39
Transformation Method	Snyder Unit Hydrograph Method	64.8	93.1	0.69	1.65	+0.25

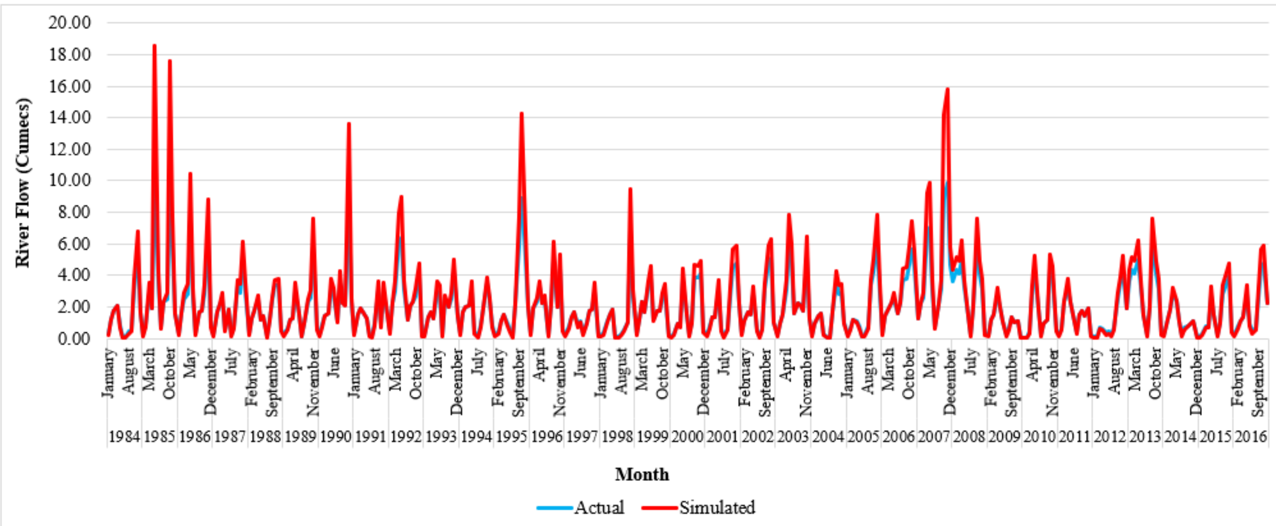

Figure 2: Goodness of fit of actual and simulated monthly flows of Uruwal Oya (1984 – 1994))

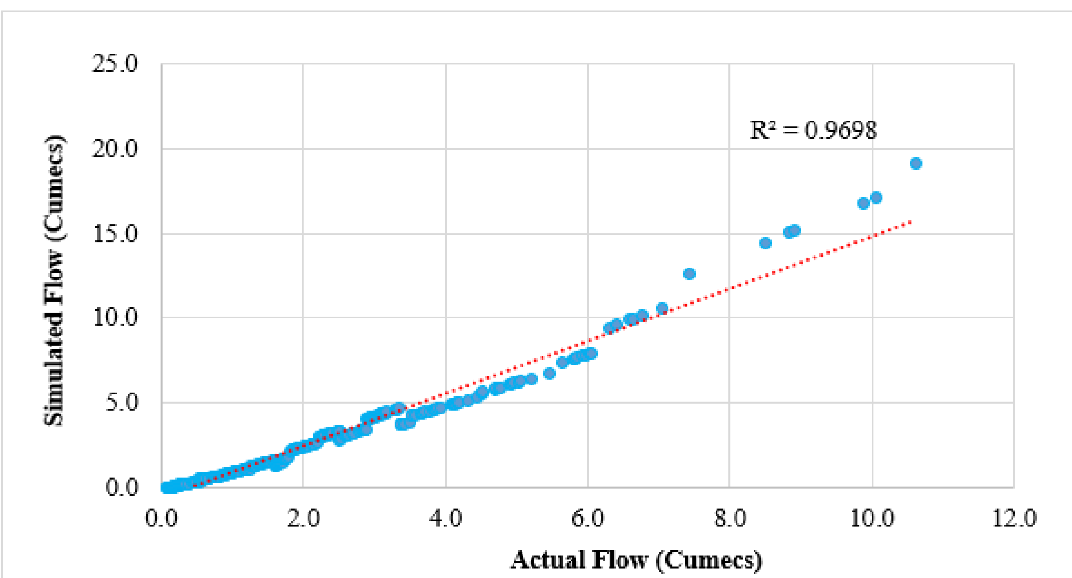

Figure 3: Goodness of fit of simulated and actual monthly flow data during the validation period (1995 – 2016)

even the best performing modelling setup of the HEC-HMS model tend to over predict the peaks during the hydrological simulation of Uruwal Oya, which has also been noted in several other studies (Halwatura and Najim, 2013; Udayanga, 2015). On the other hand, it was evident that the lowest monthly flows were slightly under predicted by the model. The reason for this over prediction of extreme peaks and under prediction of lower peaks by the HEC-HMS model, could be due to assumptions such as rainfall is uniform throughout a defined region of the sub-catchments and basin always responds at the same degree given a unit of rainfall excess (Halwatura and Najim, 2013). Regardless of the slight over and under predictive nature of extreme flows, the HEC-HMS model proved its capability in runoff simulation of the Uruwal Oya at an acceptable degree of reliability and accuracy (Table 1, Figure 2).

Meanwhile, a study carried out in Tungabhadra catchment in India indicates that certain advanced hydrological simulation models such as Soil and Water Assessment Tool (SWAT) that account respects numerous basin parameters are capable of yielding more reliable simulations even during peak flows (Singh *et al*., 2015). Yet, the limitations in long-term availability of required data restrict the application of such complex and advanced models to cater to flow simulation requirements.

IV. Conclusion

HEC-HMS is capable of yielding reliable simulations of daily flows for Uruwal Oya. The Deficit Constant Loss Method and the Snyder Unit Hydrograph Method could be recommended as the best loss and transformation methods for the simulation of long-term river flow in the Uruwal Oya basin. Combined application of the DCLM and SUHM as the loss and transformation methods, yielded 65.3%, 94.2%, 0.84, 1.60 and +0.24 values for residual points within mean ±1 SD, mean ±2 SD, R^2, CP_A' and RE, respectively. Since most of the Sri Lankan rivers are characterized by non-availability of long term daily flow data, the HEC-HMS model could be reliably applied for the synthesis of daily river flows of the Sri Lankan rivers.

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