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Application of HEC-HMS Model on Event-Based Simulations in the Seethawaka Ganga River, Sri Lanka

Gamlath Rallage Miyuru Bandara Gunathilake[1*]
Pushpika Panditharathne[1]
Anura Shantha Gunathilake[2]
Narada Dilp Warakagoda[3]

[1]Panditharathne Constructions, Anura Mawatha, Balagolla, Kandy, 20000, Sri Lanka
[2]Central Engineering Consultancy Bureau, Bauddhaloka Mawatha, Colombo, 00700, Sri Lanka
[3]Institute of Technology Systems, Faculty of Mathematics and Natural Sciences, University of Oslo, Gunnar Rander Vei 19, 2007, Kjeller, Norway

Abstract

The upper reaches of the Seethawaka Ganga lie in the highest rainfall receiving regions of the country leaving a strong susceptibility for flood occurrences in the lower parts during erratic rains. In addition, steep topographical characteristics in the Seethawaka Region permit flood waves to propagate faster. Hence, development of a flood simulating application for the Seethawaka Ganga is a timely need. These applications will essentially help in providing early warnings to reduce the vulnerability of catastrophic disasters due to extreme rainfall events. This particular research paper describes a case study of a flood modeling approach for the Seethawaka Ganga in the Kegalle administrative district using a conceptually-based, deterministic and distributed Hydrological Engineering Center's Hydrological Modeling System (HEC-HMS). The aim of this study was to examine the most reliable combination of precipitation loss and base flow methods to simulate floods in the study catchment. In order to find the most effective method, six combinations of direct runoff, precipitation loss methods, base flow methods and routing methods were checked separately. Among the different combinations of precipitation loss and baseflow methods simulated, Soil Conservation Service Curve Number method (SCS_CN) and non-linear Boussinesq method performed fairly well with Clark unit hydrograph, Muskingum and lag methods. The statistical indicators and graphical observations revealed that the developed model through this study can be used to provide reliable flood forecasts (peak discharges and timing of occurrences) under extreme rainfall conditions in future. Therefore, this model will essentially help in providing disaster mitigation and adaptation strategies for the Seethawaka Ganga River.

Keywords: HEC-HMS, Seethawaka Ganga, Event-based, Flood modeling, Calibration, Extreme rainfall.

Abbreviations:

DEM: Digital Elevation Model; HEC-GeoHMS: Hydrological Modeling Center's Geospatial Hydrological Modeling Extension; HEC-HMS: Hydrological Modeling Center's Hydrological Modeling System; HEC-RAS: Hydrological Engineering Center's River Analysis System; NSE: Nash Sutcliffe Efficiency; PEV: Percentage Error in Volume; SCS_CN: Soil Conservational Service Curve Number; SMA: Soil Moisture Accounting; US: United States

Introduction

Physical, mathematical and analog models are the main different forms of modeling approaches. Physical models are reduced dimensions

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***Corresponding author:** Gamlath Rallage Miyuru Bandara Gunathilake, Panditharathne Constructions, Anura Mawatha, Balagolla, Kandy, 20000, Sri Lanka. Tel: +94-71-206-884-3; Email: miyurubandaragunathilake@gmail.com

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of real-world processes. A mathematical model is "an equation or set of equations that represents the response of a hydrological system component change in hydro-meteorological conditions''. An analog method is "the use of another physical system having properties similar to those of the prototype" [1]. Hydrological processes are considered explicitly in distributed modeling whereas in lump-based modeling they are averaged or ignored. In deterministic models "all parameters and processes are free of random variation and known with certainty" [2]. Even though, distributed models require higher amount of data when compared to lump-based models they yield more accurate results. Mathematical models are considered as the most extensively used and universally recognized due to its applications and scientific bases. Due to widespread knowledge in technology, computer modeling is a common approach in hydrological simulation studies today [3].

Due to the increased frequency of extreme rainfall events flood alert applications are of vital importance [4]. Modeling rainfall-runoff processes is an essential component in estimating floods [5]. Understanding catchment's responses due to precipitation events during planning and construction phases is essential when designing hydraulic structures such as spillways, channels etc., [6]. Topographical data, land cover and soil cover, observed hydro-meteorological and soil properties are required in the watershed modeling process [3]. This is especially a critical task which one needs to cope with especially in the Asian context. Recorded hydrological observations in this region is scarce which limits the use of potential users in watershed modeling process.

The main factors which the modeler needs to consider when selecting a hydrological model are the objectives of the research and the availability of data in the selected study area. [3] stated the importance of analyzing the study watershed and obtaining a sound knowledge of the particular study area. Prior to developing a hydrological model, data should be analyzed firsthand. In the past rational methods, empirical methods and unit hydrograph were commonly used to estimate design floods [3,7]. With the increased attention in rainfall-runoff processes and flood forecasting, numerous tools and computer software have evolved extensively. A conceptually based, distributed hydrological model, Hydrological Engineering Center's Hydrological Modeling System (HEC-HMS) was used in this study. The HEC-HMS model has proved to be a valuable hydrological modeling tool which has extensive use in many parts of the world in different climatic and topographical conditions [8-14].

The HEC-HMS model has been applied in major river basins of Sri-Lanka to simulate streamflow and floods under future climatic conditions. [5] reported that the HEC-HMS was capable of both event and continuous simulations in the Kelani River Basin, Sri-Lanka (Drainage area: 2300 km^2). [15] attempted to calibrate HEC-HMS for continuous simulations of the Attanagalu River Basin in the Western Province, Sri Lanka (Drainage area: 337 km^2). [3] calibrated the HEC-HMS model on event scale for the Kaluganga River Basin, Sri Lanka (Drainage area: 2658 km^2). [16] modeled the Deduru-Oya River Basin for continuous simulations with intrabasin diversions using the HEC-HMS model (Drainage area: 2620 km^2). [17] used the HEC-HMS model for event-based modeling studies in the Nilwala River Basin (Drainage area: 1073 km^2). Hence, considering the suitability of this model in simulating watershed processes in the tropical climatic conditions it was selected to model rainfall-runoff processes in the Seethawaka Ganga Watershed for this study. The aim of this study is to determine the most suitable combination of loss and base flow methods in the HEC-HMS to simulate floods in the Seethawaka Ganga. Hence, the reliability of six different combinations of loss and base flow were checked individually.

This paper is organized as follows. The introduction provides a brief background of different modeling techniques, the modeling approach used in this study, the importance of flood modeling and previous attempts of HEC-HMS in the tropical region. Section 2 describes the study area characteristics and the climate setting in the Seethawaka Region. This chapter also describes different methods and combinations adopted in the HEC-HMS model to represent rainfall-runoff processes in the Seethawaka Ganga. The calibration and validation results are described in section 3. This section provides a detailed description of parameters used and their values assigned in the developed HEC-HMS model. Finally, the conclusions and recommendations based on this study are presented in section 4. The methodology adopted in this study can be implemented in other watersheds which have similar topographic and climatic conditions.

Materials and Methods

Study area

The Seethawaka Ganga is a subbasin of the Kelani River Basin. The study catchment drains an area of 223 km^2. Figure 1 schematically represents the Seethawaka Ganga in the Kegalle administrative district of Sabaragamuwa Province. The main tributaries of the Seethawaka Ganga are Magal Ganga River and Panapura Oya Stream. The Seethawaka Ganga lies between latitudes of 6° 50' and 7° 00' N and longitudes of 80° 17' and 80° 30' E. The upstream of the study area receives an average annual rainfall of 4500 mm while the downstream area receives an average annual rainfall of 3825 mm. The length of the Seethawaka Ganga main river is approximately 57 km. The mean temperature is around 27 °C throughout the year in the studied area. The day time relative humidity varies between 60-75% in the Seethawaka Region [18]. The two dominant land use types are forests and rubber plantations in the study area (Figure 2b). The remaining land use mainly comprises homestead gardens, tea and paddy cultivations. The soil types in the area is clay loam characterized by inherit moderate infiltration rates [19]. The altitude of the Seethawaka Ganga River Basin ranges between 50 to 1831 m above mean sea level (Figure 2a). The steep slopes of the Seethawaka River ranges between 20-25%. These steep areas are highly prone to soil erosion and land degradation. The impacts and associated risks would be severe if proper soil and water conservation practices are not adopted. The rich bio-diversity has provided an added value

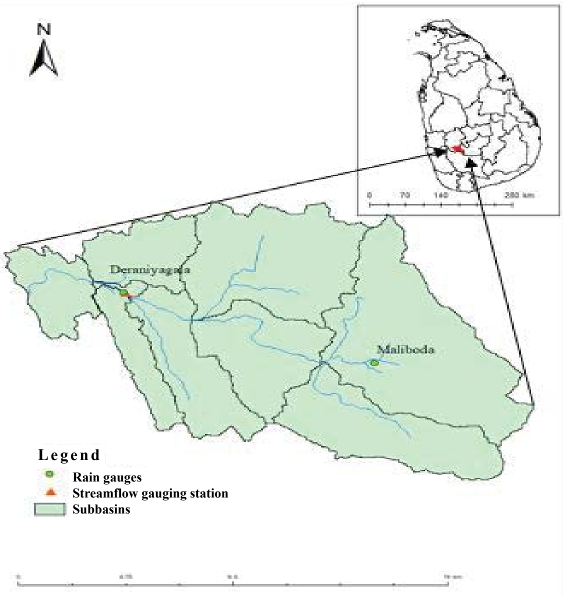

Figure 1: Location of rainfall stations and streamflow gauging station in the Seethawaka Ganga, Kegalle District, Sri Lanka.

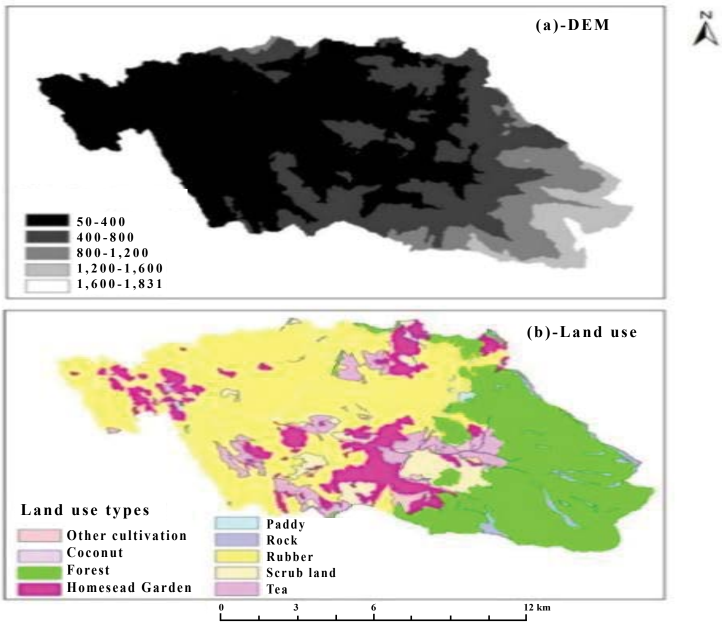

Figure 2: (a) DEM and (b) land use in the Seethawaka Ganga.

to the Seethawaka Region. The upper part is characterized by tropical wet evergreen forests characterized by dense canopies. Several endangered species are also found in the study area [18].

HEC-HMS model description

The Hydrological Engineering Center's Hydrological Modeling System (HEC-HMS) was developed by the United States (US) Army Corps. The current HEC-HMS model is a successful outcome of continuous efforts by many scientists and researchers since its first version, HEC-1 developed by Leo R. Beard released in 1967. The HEC-1 was developed to simulate floods in complex river basins [6]. This particular study utilizes the HEC-HMS version 4.3 to simulate rainfall-runoff processes on event-based scale in the Seethawaka Ganga. The HEC-HMS model is capable of performing flood frequency studies, reservoir spillway capacity studies, urban flooding etc., [20]. This model comprises mainly of four components; basin model, meteorological model, specification control manager and time series data manager. The availability of the software in the public domain has turned out be a major advantage for potential users worldwide. An extensive amount of studies has reported successful applications of HEC-HMS on event and continuous-based simulations in many parts of the world [14]. The software poses an added advantage for the potential user by offering a multitude of choices for selecting different methods to simulate different parts of the hydrological cycle depending on the availability of data, topographic and climate settings [21].

Table 1: Description of obtained temporal and spatial data.

Data type	Stations	Resolution	Source
Rainfall	Deraniyagala Maliboda	Hourly Daily	Department of Meteorology, Sri-Lanka
Streamflow	Deraniyagala	Hourly	Department of Irrigation, Sri-Lanka
Topography	-	10 m × 10 m	Global Mapper Website

Data

Hourly rainfall data at the Deraniyagala rain gauging station and daily rainfall data at the Maliboda rain gauging station were obtained from the Department of Meteorology, Sri Lanka. Hourly streamflow data at the Deraniyagala streamflow gauging station were obtained from the Department of Irrigation, Sri Lanka. The Digital Elevation Model (DEM) of 10 m × 10 m resolution was downloaded from the Global Mapper website through https://www.bluemarblegeo.com/products/global-mapper.php site accessed on 7th February 2019. A detailed description of obtained data types, station descriptions, resolution and the sources obtained are provided in Table 1.

HEC-HMS model development

The user can either develop the basin model in HEC-HMS itself or else by feeding the DEM into HEC- Geospatial Hydrological Modeling Extension (HEC-GeoHMS) which is an extension tool of ArcGIS. In this particular study the basin model was developed by HEC-GeoHMS tool. The Seethawaka Ganga River Basin was delineated into ten sub-basins in this study. Subbasin properties including flow length, centroid locations and average slopes were calculated in ArcGIS. Since hourly rainfall data was not available at the Maliboda rain gauging station, the same temporal distribution of rainfall throughout the day at the Deraniyagala rain gauging station was used to derive hourly rainfall at Maliboda rain gauging station. In this study the precipitation was defined by the specified hyetograph method. This was done by taking the proximity of the rain gauge to the subbasin into account. The developed model was simulated in hourly time steps. The delineated subbasins of Seethawaka Ganga are schematically represented in Figure 3.

Modeling channel routing: Routing is used to model channel flow from upper catchment to basin outlet. A total of eight routing methods are available in the HEC-HMS to model channel flow. Muskingum, Muskingum Cunge, lag method, kinematic wave, Straddler Stagger, lag, lag and k and normal depth methods are available in this software package to route the flow in main streams and tributaries of a watershed [2]. [3] reported that the lag method is suitable for routing channel flow in steep reaches. The lag method was utilized to route streamflow in the steeper reaches of the upstream and the Muskingum method to route flow in the mild slopes of lower reaches in the Seethawaka Ganga. The lag time is the only required input for this method [2]. Since there is no attenuation, the shape of the ordinates does not change in the lag method [3]. [3] described the applicability of lag method to route channel flow in the Kalu Ganga River Basin, Sri-Lanka. The Muskingum method requires parameters “k” and “x”. The parameter “k” is measured in hours and “x” has no units. The parameter k could be varied between 0.1 to 150 hours and x between 0.1 and 0.5 [2]. The Muskingum method has been used extensively to route channel flow in the tropical region [16].

Modeling direct runoff: The direct runoff is the process of transforming excess precipitation to point runoff. The HEC-HMS model offers a total of nine methods to calculate direct runoff. They are Clark unit hydrograph, Synder’s unit hydrograph, SCS_CN unit hydrograph, S curve, user specified unit hydrograph, Modclark and kinematic wave [2]. The Clark unit hydrograph was used in this study since it requires less parameters when compared to other direct runoff methods [23]. The input parameters required for the Clark unit hydrograph method are time of concentration and storage coefficient. The time of concentration is defined as the time taken for a water particle to travel from the most hydraulically remote point to the catchment outlet. The storage coefficient (R) can be calculated by the flow at the inflection point on the falling limb of the hydrograph divided by the time derivative of the flow. The units of R are hours

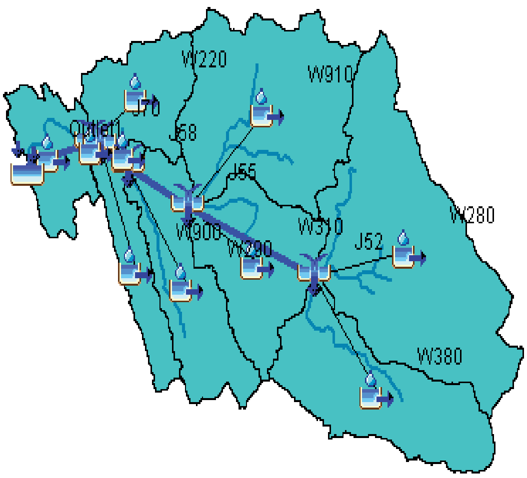

Figure 3: Delineated subbasins in Seethawaka Ganga for this study.

and storage effects are reflected by the value of R [5]. The Clark unit hydrograph overland flow translation is based on synthetic time-area histogram and time of concentration [3,15]. [22] used Clark unit hydrograph to model all sub catchments of Rio Rancho Watershed in the United States (US). [17] used Clark unit hydrograph to transform excess precipitation to catchment outlet in the Nilwala River Basin, located in the wet zone of Sri-Lanka. [16] used the Clark unit hydrograph for transformation of excess rainfall to point runoff in the Deduru-Oya River Basin, Sri-Lanka.

The time of concentration calculated by Kirpich formula is given by Equation 1 [24]

$$T_c = \frac{0.0179 \times L^{0.77}}{S^{0.385}} \tag{1}$$

where Tc (Time of Concentration in minutes), L (waterway length in meters), S (Slope (m/m))

Modeling baseflow: The baseflow is defined as the dry weather flow sustained during dry periods in a river or stream. The baseflow comprises groundwater flow, saturated overland flow and interflow. Several methods including recession method, bounded recession method, non-linear Boussinesq, linear reservoir method and constant monthly flow are used to calculate baseflow in the HEC-HMS model [2]. In this study baseflow recession method and non-linear Boussinesq methods were used to model baseflow.

The required parameters to model baseflow in this model are initial discharge, recession constant and ratio to peak [5]. They were adjusted after several calibration steps in order to obtain a best fit between observed and simulated values. The initial conditions can be defined as initial discharge $\left(\frac{m_3}{s}\right)$ or initial discharge per area $\left(\frac{m_3}{s}/m^2\right)$. The initial discharge method was selected for this study. The recession base flow method is designed to approximate the typical behavior observed in watersheds when the channel flow recedes exponentially after an event. The parameter recession constant describes the rate at which baseflow recedes between storm events [3,15,17].

The non-linear Boussinesq method requires initial discharge, ratio to peak, flow length, hydraulic conductivity and porosity of soils. The values for hydraulic conductivity and porosity of soils were fixed based on the soil in the study area. The initial discharge and the ratio to peak were adjusted after conducting several trials to obtain the best fit between observed and simulated values [2].

Modeling precipitation losses: Canopy interception, retention and detention storages account for precipitation losses in a watershed. The precipitation loss rates depend on canopy cover and rainfall characteristics [21]. Seven methods are available in HEC-HMS to define precipitation losses. They are SCS_CN method, Green and Ampt infiltration model, initial and constant loss method, exponential loss, initial and deficit method, soil moisture accounting model (SMA), gridded SMA, gridded Green and Ampt, gridded SCS_CN methods. Among these different loss models soil moisture accounting method and initial and deficit methods are recommended for continuous simulations [2]. In this study the reliability of initial and constant loss method, Green and Ampt infiltration method and SCS_CN methods were examined.

The initial and constant loss method requires initial and constant losses and percent imperviousness. The values fixed for this study for initial losses, constant losses and percent imperviousness were 1.5 (mm), 0.5 mm/hour and 65%.

The Green and Ampt infiltration model requires initial loss, moisture deficit, suction head, hydraulic conductivity and percent imperviousness. [17] used Green and Ampt infiltration model to account for precipitation losses in the Nilwala River Basin of Sri Lanka on event-based scale. [5] attempted to model precipitation losses by the Green and Ampt infiltration model in the Kelani River Basin, Sri-Lanka. The values assigned for Green and Ampt infiltration model for this study are listed in Table 2. The values for suction head, saturated content and hydraulic conductivity were obtained from [5]. Initial moisture content and percent imperviousness were adjusted after conducting several trials to obtain a best fit between observed and simulated streamflow values.

The Green and Ampt infiltration method which described the infiltration rate for a particular soil is given by Equation 2 [5].

$$f(t) = K\left[1 + \frac{\varphi \Delta\theta}{f(t)}\right] \tag{2}$$

f(t), F(t), K, φ and Δθ are infiltration rate (mm/h), cumulative infiltration (mm), saturated hydraulic conductivity (mm/h), wetting front soil suction head (mm) and moisture content deficit respectively.

The SCS_CN is a function of land use type, soil type and antecedent moisture conditions. The values of Curve Number (CN) ranges between 35-98. A CN value of 98 attributes to water bodies whereas a value 35 indicates land under good hydrologic conditions. This method requires values of SCS_CN, initial abstraction and percent imperviousness of the study watershed. The SCS_CN were adjusted within the ranges suggested by [25]. In this study the values fixed for SCS_CN, Initial abstraction and percent imperviousness were 60, 5 mm and 60%. The accumulated precipitation excess is given by Equation 3 [25].

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \tag{3}$$

Table 2: Green and Ampt model parameters used in this study [7].

Parameter	Value
Initial moisture content (ratio)	0.10
Saturated content (ratio)	0.40
Suction head	208.8 mm
Conductivity	2 mm/hr
Percent Imperviousness	65%

Table 3: Different combinations adopted to simulate floods in the study.

Combination	Direct runoff method	Loss method	Baseflow method	Routing method
C1	Clark UH	Green and Ampt	non-linear Boussinesq	lag and Muskingum
C2	Clark UH	SCS_CN	non-linear Boussinesq	lag and Muskingum
C3	Clark UH	initial and constant	non-linear Boussinesq	lag and Muskingum
C4	Clark UH	Green and Ampt	baseflow recession	lag and Muskingum
C5	Clark UH	initial and constant	baseflow recession	lag and Muskingum
C6	Clark UH	SCS_CN	baseflow recession	lag and Muskingum

where Pe=accumulated precipitation excess at time t; P=accumulated rainfall depth at time t; Ia=Initial abstraction and S=potential maximum retention.

The initial abstraction is approximated by Equation 4 [25]

$$I_a=0.2S \tag{4}$$

S is approximated by Equation 5 [25]

$$S=\frac{25400-254CN}{CN} \tag{5}$$

The six different configurations of precipitation loss and baseflow methods are listed in Table 3. Clark UH, Green and Ampt infiltration model, non-linear Boussinesq, lag and Muskingum methods were used in combination C1. The SCS_CN method and initial and constant methods are used respectively for modeling precipitation losses in combinations C2 and C3 while direct runoff, baseflow and routing techniques are similar to configuration C2. In combinations C4, C5 and C6 baseflow recession methods were used to simulate baseflow whilst Green and Ampt infiltration model, initial and constant method, and SCS_CN methods were used to model precipitation losses respectively.

Model evaluation criteria: The Nash-Sutcliffe efficiency **(N.S.E)**, percentage bias (δ_b), percentage error in volume (P.E.V), ratio of root mean square to standard deviation (RSR) are recommended statics to evaluate hydrological performance [4,6,11,14,26].

The Nash-Sutcliffe Efficiency (N.S.E.) is given by the Equation 6

$$N.S.E=1-\frac{\sum_{i=1}^{n}(S_i-O_i)^2}{\sum_{i=1}^{n}(O_i-O_{mean})^2} \tag{6}$$

The percentage bias (δ_b) is given by the Equation 7

$$\delta_b=\left|\frac{\sum_{i=1}^{n}(S_i-O_i)}{\sum_{i=1}^{n}O_i}\right|\times 100\% \tag{7}$$

The percentage error in volume (P.E.V) is given by the Equation 8

$$PEV=\left(\frac{vol_0-vol_s}{vol_0}\right)\times 100\% \tag{8}$$

The ratio of root mean square error to standard deviation (RSR) is given by Equation 9

$$\text{RSR}=\frac{\sqrt{\sum_{i=1}^{n}(S_i-O_i)^2}}{\sqrt{\sum_{i=1}^{n}(O_i-O_{mean})^2}} \tag{9}$$

Where O_i, S_i, n, O_{mean} are observed discharge, simulated discharge, number of observational values mean of observed values. vol_s and vol_0 are total streamflow volume in simulated model and total streamflow volume in observed case. The ranges of values used for the performance evaluation criteria are tabulated in Table 4.

Results and Discussion

The rainfall events for calibration and validation were selected based on the availability of streamflow and rainfall data records for the most extreme events which happened in the recent past. Therefore, the model was calibrated at the Deraniyagala streamflow gauging for a 5-days extreme rainfall event between 14th May 2016 to 18th May 2016. An extreme rainfall event of 3-days duration between 25th May to 28th May 2017 was selected for model validation. The sensitivity analysis showed that the most sensitive parameters for streamflow were imperviousness, infiltration parameters and SCS_CN. During the calibration process, parameters were adjusted within the acceptable ranges following the guidelines of [2]. It was ensured that physically meaningful set of parameter values were used in the developed model. The observed and simulated hydrographs at the Deraniyagala streamflow gauging station were compared based on several statistical indicators including flood volume, flood peaks, time to peak which were the important performance indicators in event-based modeling [5]. Figures 4 and 5 graphically represent the observed and simulated hydrographs at the Deraniyagala streamflow gauging station during calibration and validation time periods for the combination C2. The goodness of fit was evaluated using hydrograph visualization and computed statistics values. From visual observations it is evident that peak discharges match fairly accurate with observed values even though with slight under predictions during calibration time period. The time to peak also agrees with all simulated cases during calibration and validation.

The statistical values computed for N.S.E., P.E.V, R.S.R. and δ_b for the six different combinations of precipitation loss and baseflow methods are presented in Table 5.

Table 4: Performance evaluation criteria [20,3].

Performance rating	N.S.E.	P.E.V(%)	RSR	δ_b(%)
Very good	0.75 to 1	$< \pm 10$	0 to 0.5	$\leq \pm 10$
Good	0.65 to 0.75	± 10 to ± 15	0.5 to 0.6	± 10 to ± 15
Satisfactory	0.50 to 0.65	± 15 to ± 25	0.6 to 0.7	± 15 to ± 25
Unsatisfactory	< 0.50	$\succ \pm 25$	≥ 0.7	$\succ \pm 25$

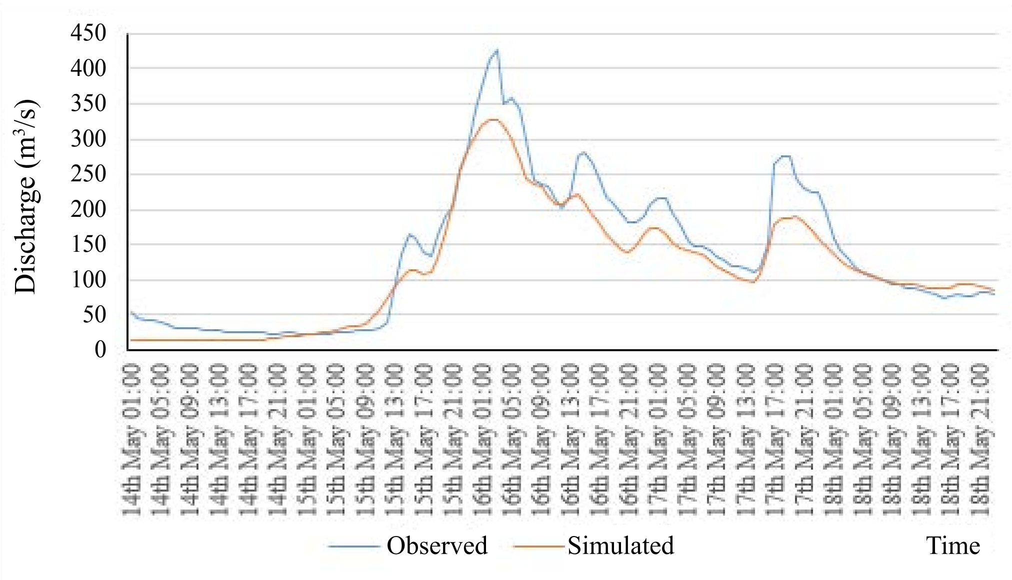

Figure 4: Hydrograph for C2 during calibration (14th May-18th May 2016) at the Deraniyagala streamflow gauging station.

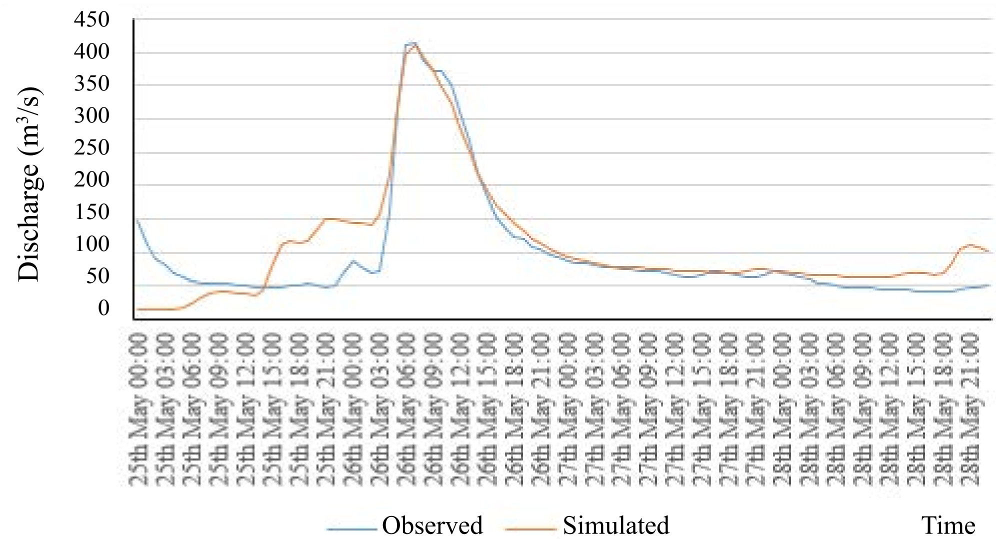

Figure 5: Hydrograph for C2 during validation (25th-28th May 2017) at the Deraniyagala streamflow gauging station.

During calibration time period of combination C1, N.S.E., P.E.V, RSR and δ_b were reported to be 0.87, -16, 0.40 and -16.1. For the same case during validation time period these values yielded to be 0.77, 18, 0.50 and 17.8 respectively. Green-Ampt and linear Boussinesq methods were used with Clark unit hydrograph, Muskingum and lag methods to simulate hydrological processes in this combination. Combination C2 which used linear Boussinesq and SCS_CN methods showed the highest efficiency among all cases examined. The statistical descriptors evaluated: N.S.E., P.E.V., RSR and δ_b yielded values 0.89, 14, 0.30 and -15 during calibration and 0.81, 12, 0.40 and 12 during validation respectively. In calibration time period of combination C3 which used Clark unit hydrograph, non-linear Boussinesq, initial and constant method, Muskingum and lag methods showed N.S.E, P.V.E., RSR and δ_b values of 0.88, 14, 0.30 and -14 respectively. During validation time period for combination C3 these values yielded to be 0.74, 22, 0.50 and 21 respectively. For C4 and C5 combinations at the Deraniyagala streamflow gauging station the values of statistical descriptions were not satisfactory according to model performance evaluation criteria. The results of statistical descriptors for combination C6 during calibration and validation time periods were acceptable. This might be because precipitation losses were simulated by SCS_CN method in this configuration. Analyzing the results, it was understood that the combination of SCS_CN and non-linear Boussinesq with direct runoff and routing methods provided more reliable estimates in flood forecasting in the study area.

[17] obtained N.S.E. values between 0.83 and 0.91 for calibration and validation for an event-based study using HEC-HMS in the Nilawala River Basin, Sri Lanka. [5] reported that for event-based simulations the N.S.E. ranged between 0.80 and 0.90 in the Kelani River, Sri Lanka. The percentage bias varied between 9-17% during calibration and validation in the same study. In an event-based study

Table 5: Statistical descriptors for event-based simulation by using different combinations of baseflow and loss in the Seethawaka Ganga.

Combination	N.S.E.	P.E.V.	RSR	δ_b
C1				
Calibration (14th-18th May 2016)	0.87	16	0.40	-16
Validation (25th-28th May 2017)	0.77	18	0.50	18
C2				
Calibration (14th-18th May 2016)	0.89	14	0.30	-15
Validation (25th-28th May 2017)	0.81	12	0.40	12
C3				
Calibration (14th-18th May 2016)	0.88	14	0.30	-14
Validation (25th-28th May 2017)	0.74	22	0.50	21
C4				
Calibration (14th-18th May 2016)	0.86	8	0.40	-9
Validation (25th-28th May 2017)	0.69	-31	0.60	30
C5				
Calibration (14th-18th May 2016)	0.90	-1	0.30	1
Validation (25th-28th May 2017)	0.58	-40	0.60	39
C6				
Calibration (14th-18th May 2016)	0.88	7	0.30	-7
Validation (25th-28th May 2017)	0.76	20	0.50	25

conducted in the Jhelum River Basin, Pakistan the N.S.E. and percentage bias varied between 0.86-0.92 and 12-17% respectively [27]. Hence model performance ranges obtained through this study are proved be reasonable when comparing with previous attempts of HEC-HMS model in event-based modeling applications.

From graphical observations it is evident that simulated values follow the same trend of the observed values. Since the Curve Number (CN) method was developed for temperate climatic conditions in United States (US) there remains an uncertainty when applying it to tropical watersheds. One study reported that decreasing CN values resulted in increase of groundwater recharge rates of St. Antonia River Basin of America [8]. The land use of the Seethawaka Ganga Watershed is dominated by forests in the upper part and rubber plantations in the downstream which result in greater amount of interception storage. This might be true for Seethawaka Ganga because the upper part of the studied watershed is dominated by evergreen forests which occupies dense canopy cover [18]. A similar result was reported in another forest dominated watershed conducted by [15] in the Attanagalu River Basin in the Western Province, Sri Lanka. The same study reported that SCS_CN method perform well in agricultural watersheds when compared to forested watersheds. Even though the SCS_CN loss method performs well compared to other loss methods aforementioned reasons might be attributed to the under prediction of runoff during calibration time period in this study [28].

The initial loss parameter defines the basin initial condition. Under basin saturated conditions initial loss will reach zero. Therefore, it is evident that antecedent moisture conditions will significantly affect the values of initial loss. The constant rate in this method is defined as the ultimate infiltration capacity of soils [15]. The results could have been improved when simulating losses by this method if field measured values for ultimate infiltration rates were available. The values used in this study were obtained from literature and other secondary data sources.

The mismatches in flood peaks during calibration might be attributed to localized storm events. The results of calibration and validation could have been improved if a dense network of rain gauges were available in the Seethawaka catchment [29].

Conclusion

The HEC-HMS model was calibrated and validated for the Seethawaka Ganga on event-based scale for historical extreme rainfall events occurred in May 2016 and May 2017 years respectively. Different combinations of precipitation losses and base flow methods were checked with routing and direct runoff methods. From the results obtained, SCS_CN method and non-linear Boussinesq methods can be recommended for simulating precipitation losses and base flow in the Seethawaka Ganga. The graphical observations and statistical indicators reveal that the developed model can simulate floods in the catchment fairly well. The model's ability to predict flood peaks and timing of peak is an essential eligibility in applications of early warning systems and as a flood prediction tool. Hence, possible adaptation measures can be taken beforehand to reduce the damages caused. The authors recommend the use of HEC-HMS model in various other catchments in the wet zone of Sri-Lanka to simulate rainfall-runoff processes. The output hydrographs of HEC-HMS of this study can be used in HEC-RAS to determine the areas under inundation. This will be useful in planning of reservoirs and other hydraulic structures in Seethawaka Ganga. The results of this can be served as input for flood risk assessment studies.

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