FLOOD FORECASTING MODEL USING HEC-HMS FOR NAGALAGAM STREET HYDROMETRIC STATION WITH RELATIVE IMPACT OF ANTECEDENT RAINFALL IN KELANI RIVER BASIN

Akila Senadhinatha

(158566 A)

Degree of Master of Science in
Water Resources Engineering and Management

Department of Civil Engineering

University of Moratuwa
Sri Lanka

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Nawarathne Mudiyanselage Akila Senadhinatha

(158566 A)

Supervised By

Dr. R. L. H. L. Rajapakse

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UNESCO Madanjeet Singh Centre for
South Asia Water Management (UMCSAWM)

Department of Civil Engineering

University of Moratuwa
Sri Lanka

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Flood Forecasting Model using HEC-HMS for Nagalagam Street Hydrometric Station with Relative Impact of Antecedent Rainfall in Kelani River Basin

ABSTRACT

The recurrent occurrence of major floods around the world as well as in Sri Lanka has significantly increased in the recent past. Thus, flood forecasting models have been developed to provide reliable and accurate simulation results to mitigate risk and reduce damage. It has been established that antecedent rainfall is an important factor in the determination of runoff magnitude and required to be incorporated in flood forecasting systems, however, lack of quantitative data is a major issue. The Kelani river is 192 km long with a catchment area of 2,292 km^2 and the heavily populated downstream basin is highly flood prone due to its inherent low-lying characteristics. Water levels at downstream Nagalagam Street station with pre-established threshold values are traditionally used to forecast the flood risk to Colombo and suburbs, however with a minimum or no lead time. The present research is focused to better comprehend the adequacy of existing rainfall-runoff models and the effect of antecedent moisture content on flood forecasting models focusing on downstream Kelani Basin as the case study site.

The Nagalagam Street hydrometric station is the selected outlet measuring location which is situated in latitude 60° 57' E, longitude 79° 52' N close to the Kelani River estuary. Since measured flow data are not available at the downstream, the river flow time series was generated by measured stage data at the station with the establishment of a rating curve and verified against discharge values available in the literature. Digital elevation model and GIS applications for generating stream features and a HEC-HMS rainfall-runoff simulation model was formulated based on the delineated basin data and collected meteorological and calculated streamflow data focusing on Nagalagam Street sub-catchment. The model with daily resolution was initially calibrated and validated based on parameter data available in the literature using SCS Curve Number method as the loss method and Unit Hydrograph method as the transform method and fine-tuned until the best fit was obtained by adjusting the parameters following selected objective functions. The calibrated and validated model was then effectively used in the rainfall-runoff simulation of the downstream Kelani basin focusing on multiple scenarios of flood events with different antecedent rainfall conditions to analyze the effect of soil moisture on runoff generation.

The model performance was relatively strong with reported Nash-Sutcliffe Coefficient (NASH) values of 0.80 for calibration stage and 0.89 for validation. Similarly, the coefficient of determination (R^2) indicated 0.83 for calibration and 0.90 for validation. The scenario analysis revealed a significant increment of streamflow while increasing the number of days with antecedent rain and a tendency of increment of runoff was noted even though the total rainfall is decreased. The resultant runoff flow increment was simultaneously accumulated while the antecedent moisture condition of the ground was varied. The study demonstrates that with an increasing number of rainy days from A0 to A10 (in days), 50% to 100% increment in runoff is observed. Further, even when the rainfall is decreased by 85% to 90% for the tenth rainy day (A10) with compared to the first rainy day (A1), the runoff continued to increase.

The results of the study firmly and quantitatively indicate that basin streamflow generation is positively affected by antecedent rainfall. It further emphasizes and concludes the importance of incorporating a factor for antecedent rainfall while estimating catchment runoff. The model was capable of capturing the antecedent moisture condition as a criterion to improve model performance for flood forecasting in downstream Kelani Basin under extreme rainy conditions.

Keywords: Antecedent soil moisture, Flood forecasting, River flow model

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LIST OF ABBREVIATIONS

AMC	- Antecedent Moisture Content
ANN	- Artificial Neural Networks
API	- Antecedent Precipitation Index
AW	- Antecedent Wetness
CN	- Curve Number
DEM	- Digital Elevation Model
DOI	- Department of Irrigation
DS	- Divisional Secretariat
FFC	- Flood Forecasting Centre
GIS	- Geographic Information System
HBV	- HBV model (Swedish Met. and Hydrological Institute)
HEC-HMS	- Hydrologic Engineering Centre - Hydrologic Modelling System
HRS	- Hydrology Report Series
IFM	- Integrated Flood Management
MCM	- Million Cubic Meters
MLR	- Multiple Linear Regression
MW	- Megawatt
NOF	- Normalised Objective Function
NSE	-Nash-Sutcliffe-Efficiency
PRF	- Peak Runoff Factor
R	- Correction Coefficient
RMS	- Root Mean Squire
RMSE	- Root Mean Squire Error
R^2	- Coefficient of Determination
SA	- Sensitivity Analysis
SCS	- Soil Conservation Service
SMA	- Soil Moisture Account
TOPMODEL	- Topmodel Developed by Beven, University of Lancaster
USGS	- United State Geological Survey
Vol	- Volume
WMO	- World Meteorological Organization
$\&_b$	- Percentage Bias

1 INTRODUCTION

1.1 General Aspects

The science concerns with water origin to distribution throughout the earth, both above and below the land surface, and also dealing with their chemical, biological and physical properties, in a cyclic process, is hydrology according to the World Meteorological Organization (WMO-168-Vol-I, 2008). The earth climate is determined by the effects of the radioactive properties of the surface and solar radiation (WMO-No-100, 2011). The phases of the hydrological cycle could be identified as evaporation, precipitation, runoff, and others. The precipitated water becomes overland flow or infiltrates through the soil as subsurface flow and moves toward the streams as surface runoff (Chow, Maidment, & Mays, 1988).

The system concept is a method of understanding complex hydrologic phenomena, however never be completely understood. The set of microflow paths over or through the ground becomes streamflow finally merging into the outlet of the catchment. The laws of conservation of mass and energy are governed by the application of a control volume. The size, shape, texture are the factors of soil particles that vary in time and the place, influencing the wet or dry condition of the soil layer (Chow, Maidment, & Mays, 1988).

Hydrological models have been developed to forecast the hydrologic response of a particular catchment area and to produce hydrological information by using available hydrometeorological data (Duhan & Kumar, 2017). The way of water penetrating from the surface to the underground soil structure is infiltration which is refilling the soil moisture deficiency. The infiltration rate is higher at early stage of precipitation and subject to the temporal variation with the effect of antecedent rainfall. The antecedent rainfall which reflects the wet or dry conditions of the soil could be used in consideration of antecedent soil moisture variations to accurately predict the practical flood circumstances (Sakazume, Masahiro, & Oliver, 2015). While basically meant to improve the initial stage of flood routing, the real-time updating of model state variables is a proven technique in combining field measurements to obtain improved results with a flood forecasting model. Coupled with hydrological and hydrodynamic models, the real-time updating technique has been widely applied to solving problems in single-channel and dendritic channel networks.

1.2 Background

This research is performed to analyze the impact of antecedent moisture content on the river discharge especially during a flood event and based on developing a real-time flood water level forecasting model. The Kelani River, a 192 km long river with 2,292 km^2 extent of the basin, is selected for the research. Kelani River is the fourth-longest river in Sri Lanka which starts from the Adams Peak situated in the central mountainous region, flows through steep slopes, then enters into mild slope mid-range and flat coastal plain, finally flowing towards the Indian ocean. The river drains via six administrative districts, Kegalle, Gampaha, Colombo, Nuwara-Eliya, Kalutara, and Rathnapura and the basin extends over the three provinces, Sabaragamuwa, Western and Central.

Because the river catchment is located in the wet zone, annual average rainfall of 3,450 mm is received with maximum daily rainfall in the south-west monsoon. The catchment is situated in between northern latitude 6° 44' to 7° 13' and eastern longitude 79° 52' to 80° 46'. The basin includes eleven landforms which consist of twenty sub-catchments (Cooray, 1984). Maskeli Oya and Kehelgamu Oya are the two main upland tributaries of the river. The land use of the upper catchment basically consists of vegetation such as tea, rubber, grass, and forest whereas the downstream part of the basin is highly populated (De Silva, Weerakoon, & Shrikantha, 2014). The river basin spreads over seven agro-ecological zones which are WU3, WU2, WU1, WM1, WL1, WL2, and WL3 (Panabokke, 1996).

The coastal plain is very flat with scattered hills rising about 100 m MSL. The Kelani River covers eighty present of water supply to Greater Colombo and the most of the production and services sectors such as fisheries, irrigation, transport, sewage disposal, hydropower production, sand mining are dependent on the river. Losses of lives and properties are significantly increased due to increasing severe flood situations during the past decades (De Silva, Weerakoon, & Shrikantha, 2014).

The severity of floods in the low laying area of the Kelani River has been observed by the gauge post-reading of Nagalagam Street station at Colombo by the Department of Irrigation (DOI). If the river flows at Nagalagam Street could be forecasted accurately, the damages could be effectively minimized in the downstream of Hanwella including in the densely populated City of Colombo.

1.3 Monsoon and Rainfall Characteristics of Kelani River Basin

The island of Sri Lanka is a tropical country with location coordinates 5° 55' to 9° 51' N and from 79° 42' to 81° 53' E in the Indian Ocean. The monsoon system, orography, and cyclonic disturbances are main climatic control factors that affect the spatial and temporal variations of rainfall but the predominant factor is the monsoon system. Climatologists have identified four main climate seasons as southwest monsoon, northeast monsoon, and two inter monsoons within a water year. It could be observed a slight variation of temperature during the year, except in hill country where the variations are prominent (Burt & Weerasinghe, 2014).

The rainfall sequence is influenced by the winds blowing from the Bay of Bengal via the Indian Ocean. Wet zone, intermediate zone, and dry zone are the capital climatic zones in Sri Lanka according to the spatial pattern of rainfall. The average annual rainfall varies from 900 mm to 5000 mm and the mean annual temperature varies around 26.5 °C to 28.5 °C and Nuwara Eliya (1800 MSL) is recorded to have the lowest mean annual temperature of 15.9 °C (Department of Meteorology). The volume of water that is annually received in the island by rainfall is estimated as 188,015 MCM (Wijesekera, 2010a).

The Kalani catchment on average receives about 3,450 mm as annual mean rainfall which generates peak flows in the range of 800-1,500 m^3/s in the downstream and related annual discharge volume is found to be about 7,860 million cubic meters (MCM). The catchment experiences most of the portion of annual rainfall as recorded during the southwest monsoon and second inter monsoon due to topographical location, and hence the lower portion of Kalani catchment is subject to frequent flash floods during the southwest monsoon and second inter monsoon.

1.4 Reservoirs and Hydrometric Stations in Kelani Basin

The Castlereigh reservoir is the main large reservoir of Kehelgamu Oya which is with a 44.8 MCM capacity while the Maussakele reservoir constructed across Maskeli Oya is with a capacity of 123.4 MCM. Water storage of reservoir Castlereigh is used to generate 50 MW hydroelectricity at Wimalasurandra Power Station and similarly flows from Maussakele reservoir is taken along a tunnel to produce 60 MW capacity of hydropower at Canyon Power Station.

Streamflow data are very important to hydrologic studies. The stage is easy to measure and can be reordered continuously. It is the elevation above some arbitrary zero datum to the water surface at a station. It is measured by a staff gauge which is a graduated scale with a portion of that immersed in water. It may be located in any structure side of the stream. The water level of the stage is recorded during the measurement of streamflow and with cross-section measurements, it is possible to graph the stage-discharge relationship for a particular location at the river. It is required to monitor the river stage continuously or at regular intervals in order to obtain instantaneous discharge values based on this relationship. Seven hydrometric stations record hourly water levels operated by the Irrigation Department in the Kelani river basin. The details of hydrometric stations are tabulated in Table 1-1.

Table 1-1: Hydrometric stations, Alert and Major flood levels in Kelani River

Hydrometric Station Name	Coordinate		Alert level (m)	Major flood level (m)	Recorded Highest Water level (m)
	Latitude	Longitude			
Nagalagam Street	6° 57' 35" N	79° 52' 36" E	1.22	2.13	3.85
Hanwella	6° 54' 35" N	80° 04' 54" E	7.00	11.00	11.56
Gleancourse	6° 58' 41" N	80° 12' 11" E	15.50	19.81	22.68
Deraniyagala	6° 55' 28" N	80° 20' 17" E	4.88	6.36	10.67
Kitulgala	6° 59' 21" N	80° 25' 04" E	2.00	5.00	8.29
Norwood	6° 50' 08" N	80° 36' 52" E	1.50	2.15	2.49
Holombuwa	7° 11' 06" N	80° 15' 53" E	3.00	4.87	9.60

Source: Department of Irrigation

1.5 Antecedent Rainfall and Hydrology

Hydrology is an interdisciplinary geoscience built upon the basic science of mathematics, statics, physics, chemistry, and biology. The hydrologic processes encompass a suite of space and time scale. Infiltration is the process of water transportation from the surface into the soil. The volume of water content occupied in voids of soil is called soil moisture. It refills the soil moisture lacuna and the surplus runs to the downward by the gravity force. The infiltration capacity could be defined as the maximum amount of water-absorbed in unit time in any given condition. The infiltration depends on the wetness of the soil or antecedent soil moisture at the starting time of rainfall. The overland flow begins as a thin sheet of water after filling the soil moisture storage.

The infiltration water runs laterally in subsurface pathways that fall into the stream which is termed as interflow and deep percolated water recharges the groundwater table which may establish the steady flow in streams over a much longer duration which is termed as baseflow. The path taken by water flow is determined by many of the catchment characteristics. Overland flow, interflow, and baseflow are ways to contribute to the streamflow. The direct runoffs are the combination of overland flow and interflow which flows much faster than groundwater flow.

The quantity of water in the soil affects the infiltration capacity, overland flow, as well as the interflow at the time of precipitation takes place. It is antecedent catchment wetness arising from past or prevailing rainfall that leads to a variation of available soil moisture with a certain lag time. In estimating streamflow that results from a rainfall event, an account must be taken from the moisture content of the soil which depends on antecedent rainfall and properties of the soil. The meaning of antecedent is preceding conditions. The prevailing relative wetness or dryness of a basin could be explained as antecedent moisture in hydrology. The antecedent rainfall is a major cause affecting the moisture condition of the catchment which changes in real-time, time to time, and resulting in a significant effect on the discharge from the system during the wet season. Apart from that, the antecedent rainfall influences should be identified to forecast catchment rainfall responses.

1.6 Historical Background

It has been reported that 25,032 people are displaced during the recent floods in 2017 according to the news report of Disaster Management Centre (Sunday Observer 10th December 2017). One and a half billion people were affected by floods in the last decade of the twentieth century around the world according to the estimation of WMO (WMO-No-1072, 2011). This fact emphasizes the importance of reliable and real-time flood forecasting systems to minimize flood damage.

Severe flood inundation is experienced downstream of Hanwella including some regions of Colombo, Gampaha, etc., in Kelani basin due to heavy rainfall in the upper basin (De Silva, Weerakoon, Srikantha, Ratnayake, & Mahanama, 2012). The severity of floods in the low laying areas in the Kelani River has been observed by the gauge post-reading of Nagalagam Street in Colombo. According to the record, the most severe flood in terms of water level occurred in August 1947 with a gauge post-recording of 12.85 feet.

Table 1-2: Gauge Post Reading at Nagalagam Street during significant Flood Events

Year	Month	Water Level (feet)	Year	Month	Water Level (feet)
1936	May	9.43	1957	December	6.25
1937	May	10.33	1963	October	6.42
1939	May	9.35	1966	September	8.67
1940	May	11.00	1966	October	9.00
1942	July	8.17	1967	October	9.17
1943	May	6.58	1971	September	7.33
1944	May	6.00	1975	May	6.58
1947	August	12.85	1989	June	9.20
1947	October	6.00	1999	April	6.60
1952	May	8.25	2006	November	5.65
1952	October	6.00	2008	April 29	5.75
1955	October	8.00	2008	May 31	5.90

Source: Department of Irrigation

A flood warning mechanism is a non-structural protective measure to mitigate impacts. The impact of flood damages is severe with comparing other types of natural disasters on a global scale (World Disasters Report, 2003). Soil saturation is a considerable factor in flood generation other than precipitation and evapotranspiration (Sivapalan, Blöschl, Merz, & Gutknecht, 2005).

1.7 Why Real-time Water Level Forecasting is Important

Real-time forecasting is the prediction of immediate future conditions incorporating and analyzing pertinent data by assimilating new information as it appears. There should be available precipitation data in actual or real-time during precipitation takes place to adapt the process. The method has been developed to simulate stream discharge during specified events or continuous precipitation. The model could be able to real-time forecast discharge on the basis of meteorological and other input data continuously updated with most recently assimilated data. Seasonal, medium-term, short-term, and immediate are four types of forecasts depending on the lead time of forecasts according to the definition of WMO. Immediate (near real-time) and short term forecasts mainly attend to the flash discharge or water levels which is a crucial real-time application of extreme hydrological situations.

For flash floods, real-time prediction is capable of minimising potential flood damage to a great extent. The real-time forecasting is helpful to pre-warn flood mitigation authorities and services, people who are living in low land areas, thus enabling them to implement proactive measures to protect property and life. Real-time updating is a technique combining field measurements with a flood forecasting model (Mu & Zhang, 2007). Coupled with hydrological and hydrodynamic models, the real-time updating technique has been widely applied to solving problems in single-channel and dendritic channel networks (Neal, Atkinson, & Hutton, 2007).

1.8 Importance of Antecedent Rainfall in Hydrological Forecasting

The Antecedent moisture condition concept is important in hydrological analysis and studies. The volume of flow, time to peak, and magnitude of the flood could be significantly affected due to the amount of moisture situation at the beginning of the rain period. The rain that has been occurred in the past is identified as antecedent rain. Due to antecedent rain, the surface becomes partially or fully saturated and any additional or subsequent rainfall will lead to the immediate generation of surface run-off since the beginning of this following rain event with an increased flow to the river, while the antecedent soil moisture level simultaneously increases or decrease with the effect of runoff generation and continuation or cessation of rain. The behaviour of antecedent soil moisture is important to implement measures towards flood mitigation as the antecedent soil moisture plays a vital role in runoff generation and flood conditions (Sakazume, Masahiro, & Oliver, 2015).

Soil moisture is considered as a key item in flash floods and its response significantly varies even on an hourly time scale from wilting point to saturation. The infiltration of rainfall is obstructed in saturated soil conditions due to resulting high runoff flow even without considering other environmental facts (Hlavcova, Kohnova, Kubes, Szolgay, & Zvolensky, 2005).

In the hydrological system, the catchment response partially depends on the system itself over a given specified duration. For a hydrological forecast, the following are the principal requirements. A prior calculation of the initial state of the basin including soil moisture and river water level, and flow discharges related to surface storage at the time of forecast made. Accordingly, the antecedent rainfall is much more important to real-time flash flood forecasts.

1.9 Problem Statement

The severity and magnitude of flood damage vary due to the uncertainty of predicting changes in water level both in temporal and spatial scales and damage due to flash floods has increased in the recent past. Introducing of flood prediction and early warning systems play a vital role as an adaptation and mitigation measure to reduce extensive damages. The water level at Nagalagam Street gauging station rising beyond a certain threshold value is traditionally used to predict flood risk to Colombo and suburbs to a considerable extent. For effective mitigation of flood risk and subsequent damage, the flood should be forecasted allowing sufficient lead time to apply mitigation actions. The existing flood forecasting models do not explicitly employ the concept of antecedent rainfall and soil moisture content in updating model estimation procedures thus improving results.

1.10 Main Objective

The main objective of the study is to develop a reasonable accurate river flow model to flood forecast at Nagalagam Street Hydrometric Station by incorporating the impact of antecedent rainfall in the Kelani river basin.

1.11 Specific Objectives

To achieve the main objective, the following specific objectives were identified.

1. Assimilating meteorological data, soil/geological data, and land use data followed by data checking and verification.
2. Develop a HEC-HMS rainfall-runoff simulation model for Nagalagam Street river gauging station in the Kelani River Basin.
3. Calibration and validation of the model with observed water level and discharge data available.
4. Analysis of the impact of antecedent rainfall with the model generated flow.
5. Model application to flood forecasting to mitigate flood damage in flood-prone areas.
6. Discussion and conclusion of the results of the research.

1.12 Scope and Limitation

The scope of the research is to evaluate the impact of antecedent rainfall on the streamflow of the Kelani River and develop a river flow model to predict flood water level at Nagalagam Street gauging station. The following limitations were envisaged and encountered in during research. Some of the required data were missing for over months and the data were corrected according to the guidelines. They are not actual input data to the model and this will lead to flow simulation errors. A software limitation was experienced with HEC-HMS 4.2.1. The various physical processes occurring in the catchment and not represented in the mathematical model will affect the model-predicted results. The uncertainty of measurement, the insufficient correct understanding of processes occurring in catchments, hydrological and meteorological inputs of the systems, inherent errors in the hydrological model are causes of limitation in reliable hydrological forecasts.

2 LITERATURE REVIEW

2.1 General

In the literature review, a comprehensive study was executed hydrological flow simulation model selection and development, data requirement for the model, the impact of antecedent rainfall on streamflow generation, and flood forecasting model in principally. Also, the review was extended to cover reliability of river flow simulation model, Hydrological modeling in Sri Lanka and Kelani River basin, Parameters estimation, Parameter response, and performance criteria for Hydrological model, Linear regressions, Initial conditions, and boundary conditions, Streamflow routing are subjective matters.

2.2 Hydrological Flow Simulation Model Selection and Development

The technique for forecasting hydrological events is called hydrological modeling which can be basically categorized as physical models and abstract models. The physical model is representing catchment in reduced scale abstract models is based on mathematical form (Chow, Maidment, & Mays, 1988). The mathematical models in hydrology can be classified as stochastic models which are considered the concept of probability and deterministic which is a time-independent model (Raghunath, 2006).With the base on spatially, the runoff model classified as a lumped and distributed model and basis of temporally model categories as the continuous model and event model (Gayathri, Ganasri, & Dwarakish, 2015).

The Hydrological flow simulation model consists of variables in functions of space, time, and probability according to the available literature. The result of individual storm is simulating by the use of event-based modeling and continuous simulation models are a collection of event-based models over a catchment. The continuous simulation model is complex because it is model not only precipitation season also soil moisture diminution during dry periods (WMO-No-1072, 2011). Some of the hydrological models are could be either deterministic or stochastic. There were models with difficulty in classification due to nature and complexity.

In literature, no number classification was recognized spatially temporally of the way of estimation (André , Benoît , & Cécile , 2015). The same output has resulted in a deterministic model for a single set of input and stochastic models are able to create different values of output for a given single set of input. The observation oriented data-driven models are categorized as empirical models which are based on a set of mathematical equations without assessing the physical processes of the catchment (Gayathri, Ganasri, & Dwarakish, 2015).

The peak flood flow is highly underestimated in the lumped model compared to the distributed model. The real phenomenon of the catchment is idealized by mathematic inside in a physically-based model. The parameters used in models are functions of both time and space and finite difference equations are calculated water movement of the basin (Getachew, Dong, & Young-Oh, 2017). The black box method is completely empirical techniques that are considered only input and output of the basin. Artificial neural networks provide quick and flexible lead up to hydrological modeling in a variety of circumstances which is a special type of black-box model (WMO-168-Vol-II, 2009). The soil moisture retention concept is an important fact in rainfall-runoff modeling it may be able to divide rainfall volume into two categories as runoff and non-runoff (Raghunath, 2006).

The identification of objective and model framework has to be defined as the initial step of any of the modeling approach. Then model construction, model calibration, and model validation are the general approach of model development (André , Benoît , & Cécile , 2015). The software companies and research institutions have produced a variety of models and some of them have an interface of geographical information systems. Water resources planning, development, and management; for an analysis specific hydrological situation or in activities of hydrological forecasting it has to be a select suitable model to full fill the requirement (WMO-168-Vol-II, 2009).The Multi-model is a combination way of a rainfall-runoff model to avoid the weakness of a single model which is resulting in a combined flow forecast at each time step (WMO-No-1072, 2011). The Characteristics of different categories models are shown in Table 2-1.

Table 2-1: Characteristics of models.

Empirical model	• Data based or metric or black-box model. • Involve mathematical equations; derive value from available time series. • Little consideration of features and processes of the system. • High predictive power, low explanatory depth. • It cannot be generated for other catchments. • ANN, unit hydrograph. • Valid within the boundary of the given domain.
Conceptual model	• Parametric or grey box model. • Based on modeling of reservoirs and • Include semi-empirical equations with a physical basis. • Parameters are derived from field data and calibration. • Simple and can be easily implemented in computer code. • Require large hydrological and meteorological data. • HBV model, TOPMODEL. • Calibration involves curve fitting makes difficult physical interpretation.
Physically-based model	• Mechanistic or white-box model. • Based on spatial distribution, Evaluation of parameters describing physical characteristics. • Require data about the initial state of model and morphology of catchment. • Complex model. Require human expertise and computation capability. • Suffer from scale-related problems. • SHE or MIKE SHE model, SWAT. • Valid for a wide range of situations.

2.3 Data Requirement for Model

Data is the basic requirement for a realistic hydrological model also it is depending on the purpose of the forecast and obligatory of data can be broadly categorized as physiographic, hydrological, hydro-meteorological (WMO-168-Vol-II, 2009). The availability of data is the related location of the world and several types of data is used as inputs of the model but most of them are point data with subject to uncertainties. It is an essential requirement to check the quality and quantity of data before further processing (André , Benoît , & Cécile , 2015).

2.3.1 General data requirement

(A) Watershed characteristics

The elevations, basin area, sub-basin areas, length of the river, length of tributaries, and cross-section profile of river, cross-section profile of canal are useful geomorphic parameters which could be available in the topographic map also digital elevation model (DEM). Categories of soil, the practice of land use, forest, and vegetation, the canopy of the area also the required basic data for the model.

(B) Rainfall characteristics

The one of fundamental data input to rainfall-runoff models is average rain quantity in catchment within the time duration. Several methods were available to estimate mean rainfall in literature. Inverse distance weighting, Thiessen average rainfall, Arithmetic mean and isohyet method is developed methods for estimating mean areal rainfall because some of the sub-basins may not have a rain gauge. Therefore, recoded rainfall data should have to distributed spatially throughout the catchment.

(C) Infiltration and evaporation loss characteristics

The soil infiltration and antecedent soil moisture data are unavailable for the majority of cases due to estimated values are used for analysis by adapting the various types of procedures. Antecedent precipitation index is a method of calculation antecedent soil moisture and evaporation could be estimated as same as rainfall.

(D) Streamflow characteristics

The Water level is measured at the outlet of the basin and most of the situation is available data. Stage level data can be converted to the flow data by using a rating cure method or any other method. The observed flow data is divide into two categories to apply model calibration and model verification.

The record of historical precipitation and climatological data is required to hydrological model calibration real-time observations are used to frequently updating to model and operational purposes (WMO-No-1072, 2011). Comprehensive data should include long term stream flow, measurement rainfall, potential evapotranspiration data collected at one or many locations also with information of the impervious area, land use coverage, and vegetation cover (Vaze, Jorden, Beecham, Forst, & Summerell, 2012).

There is a mechanism to water-level forecasts for downstream in large or slow-rising rivers by input as the upstream stations' water level of the main river or its reaches (WMO-168-Vol-II, 2009). The prediction of the downstream water level is a recently applied data-based mechanistic (DBM) approach which is using upstream water level for river routing (Keith Beven., 2012). Remote sensing is an indirect method of collection characteristics of a catchment and various hydrological information (André , Benoît , & Cécile , 2015).

2.4 Impact of Antecedent Rainfall on Stream Flow Generation

2.4.1 Infiltration and soil moisture

The Porosity of soil, hydraulic conductivity, vegetative cover, and present moisture content of the soil layer are considerable factors of calculating water penetration volume from the surface to underneath (Chow, Maidment, & Mays, 1988). It replenishes the soil moisture deficiency. It depends on the molecular attraction between particles water held in the soil which defined as soil moisture (WMO-168-Vol-I, 2008).

A combination of soil and a land-use is referred to as a soil-cover complex. The runoff curve number (CN) assigned to such a complex serves as a parameter indicative of the runoff potential under given antecedent soil moisture conditions (Krishan P. Singh., 1982).

The Soil Conservation Service (SCS) method is developed to estimate abstractions and depth of excess rainfall from precipitation (Chow, Maidment, & Mays, 1988). Graphical solution of SCS runoff coefficients, classification of antecedent moisture class, and runoff curve numbers are in Appendix 01. The soil moisture content of the catchment, rainfall characteristics, and geography of the basin is directly affected by hydrological losses (Gamagea, Hewaa, & Beechama, 2015). Water holding capacity, soil permeability, percentage of impervious area, initial soil moisture content, topographic slopes, and rainfall intensity are factors affecting flood severity. By the accounting of soil moisture could be determined whether the flash flood or not for a given rainstorm (Hlavcova, Kohnova, Kubes, Szolgay, & Zvolensky, 2005).

2.4.2 Antecedent rainfall and soil moisture account

The method of expression moisture content in the catchment is indicating the antecedent precipitation index which has been derived from studying rainfall and runoff data over a period (WMO-168-Vol-I, 2008). It is defined as;

$$I_t = I_0 k^t + \sum P_i k^{t(i)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where: I_o = initial value of the index; k = recession factor; t = time interval for the computation; P_i = number of daily rainfalls that have occurred during the time interval; t (i) is the number of days since each day with precipitation

The antecedent precipitation index can be estimated by calculating average precipitation over many rainfall stations in the basin which calculation details are in Appendix 01. The antecedent moisture condition is varying from storm to storm due to unable to assessing event-based methods. Antecedent moisture with seasonal average soil moisture is indicating strong correlations according to the research done in southern and eastern Africa (Tramblay, et al., 2012).

In estimating the flood that results from a large rainfall event, the account must be taken into the prevailing catchment wetness. For the same rainfall, a larger flood will result from a saturated catchment than from a dry catchment. Current guidelines for estimating large and extreme floods reflect this limited knowledge, recommending the use of cautiously low values.

The initial losses associated with large rainfall events have not been measured directly, so initial losses are the examination of the rainfall antecedent to such events (HRS-Report-No-06, 1999). The best result was obtained by changing initialization strategies of the soil moisture in a continuous rainfall-runoff model (Berthet, Andréassian, Perrin, & Javelle, 2011).

Antecedent precipitation index, antecedent discharge index, and continuous daily soil moisture accounting model (SMA) are several estimators of wetness conditions based on rainfall and evapotranspiration in the basin. The model SMA successfully estimates the initial conditions of the event-based model (Tramblay, et al., 2012).

The threshold level of soil moisture should have to investigated by the observation and simulation to understand influence for flood situations. The correlation between soil moisture and runoff coefficient was found in the evidence. It was found initial moisture content (θ_{ini}) in relationships to total flow volume (V), Peak Discharge (Q_{peak}), and duration (D). The duration of flood is increased if it is high initial soil saturation and large rainfall volume but relationships between initial soil moisture to flood characteristics were non-significant. Flow volume, peak discharge, and flow duration predictive power increment was 3%, 7%, and 4% respectively (Sakazume, Masahiro, & Oliver, 2015). The knowledge of antecedent soil moisture is crucial in the development of flood forecasting framework (Georgakakos, 2006).

The topography and soil properties are concluded as the most important variables to control soil moisture values and the tendency to maximize runoff with an increased return period (Thea, Korbinian, Janneke, Dinand, & Victor, 2016). Different ways of indicating soil moisture proxies such as antecedent precipitation index (API_k), 5-day antecedent precipitation index, and which are correlated with hydrological losses but the scarcity of data related to soil moisture content has resulted in poor hydrological model development (Mishra, Jain, & Singh, 2004). The correlation between initial loss (IL) and API_k was initially reported in the 1970s (Nandakumar, Mein, & Siriwardena, 1994).

The effect of antecedent soil moisture for flood flow has been analyzed by using a small basin and it is reported contradictory results. Different runoff volumes with the same temporal behavior have been resulted in changing initial soil moisture content. It could not be established relationships between soil moisture and the volume of the flood (Berthet, Andréassian, Perrin, & Javelle, 2011). Some of the expertise is pointed out initial soil moisture condition of the basin is the impact to flow response although some have argued to the opening and they proposed to catchment initial condition is not critically influenced especially major runoff event, the process depends on the dominant mechanisms (Castillo, Gomez-Plaza, & Martınez-Mena, 2003).

The daily soil moisture accounting model (SMA) is reported the best performance for the testing of antecedent wetness conditions of the catchment. The satisfactory result was obtaining about SMA regarding the daily soil moisture dynamics from two satellites of earth observing. It is proving that antecedent soil moisture with the initial condition of the basin is a strong relationship with the event-based model (Tramblay, et al., 2012).

2.5 Real-Time Flow Forecasting Model

The consequentiality of flood forecasting and prediction system is highlighted in the twelfth session of the Commission for Hydrology, held in Geneva in October 2004 (WMO-No-1072, 2011). Real-time rainfall estimation is important to reliable flood forecasts and improvement may be possible to use soil moisture data obtaining from satellite (Owe, De Jeu, & Walker, 2001).

Geomorphological characteristics, Land surface, antecedent soil moisture, and rainfall observation are basic factors influenced for real-time flash flood forecasting systems and the designing of the forecast systems is different from region to region (Jonathan, Gourley, & Robert, 2018). The flood warning system should be in advance which is defend on catchment size and time of concentration.

The flood warning system is required to maintain 12 h duration in advance for the basin size lager than 10 000 km^2, 3 to10 h time portion for the basin size 400–10 000 km^2 and minimum 3 h time range for basin smaller than 400 km^2 (Montesarchio, Lombardo, & Napolitano, 2009).

Rainfall forecasting system, river discharge observation system interconnecting with flood forecasting model software are essential requirements for an effective real-time flood forecasting system (IFM-Tool Series-No.19, 2013). The common features of all flood forecasting system is including data collection from the hydro-meteorological network, updating flood forecasting model, and broadcasting of flood notification. Some of the flood forecasting systems are consisting of simple correlation upstream to downstream forecast location (USGS- TR No. W-10, 2007).

The data assimilation method is the most popular technique in real-time forecasting systems which is ameliorated prediction accuracy and initial conditions of the catchment to be less important while parameters are re-estimated by updating (Aubert, Loumagne, & Oudin, 2003). Incorrect values of model parameters, insufficiency of model structure, data errors, or absence of data, and the incoherent relationship of data are reasons for simulation errors of the rainfall-runoff models. The conceptual models are congruous with updating procedures and more errors are found by the usage of an un-updated model in forecasting (Kachroo & Liang, 1992).

Geostationary and polar-orbiting satellites are providing real-time earth observation data which is available three-hour global precipitation data. Flood Forecasting Centre (FFC) is issued water height of rivers, flood warning notices for vulnerable regions according to the result they achieved by processing the forecasting model during the flood season (WMO-No-1072, 2011).

2.6 Reliability of River Flow Simulation Model

All of the rainfall-runoff forecasting models are associated with lead time and disclose with a number of errors. The accuracy of the forecast will be reduced until the correction of defects of the forecasting model (André , Benoît , & Cécile , 2015).Majority of studies apocalypse the parameter values are arranged to best fit with observed data expert few cases reported in the literature (Parkin, et al., 1996).

The hereditary way is to target single model presumption to be the best method flood forecasting but later development is considered multi-model combination provides much more information and produces a better overall simulation. The forecasting model should be accurate in all circumstances by therefore this concept has been liberally tested (Vel´azquez, Anctil, & Perrin, 2010). The rainfall-runoff model is designed to schematic representations of reality although most sophisticated models would have errors (WMO-No-1072, 2011).

Estimation of the degree of uncertainty should be part of the hydrological model because ambiguity involves input data, model parameters, and structure and finally, the model should be an accurate relabel food forecasting model (Wilby, 2005). The uncertainty factor is neglected in traditional approach model building by prefiguring it as deterministic (Parasuraman & Elshorbagy, 2008).

The outcome of flood modeling may increase or decrease due to uncertainty and it is impossible to accurately input initial and boundary conditions as required. None of the rainfall-runoff models has correctly reflected uncertainty involvement of the model and also observed data for model calibration are not error-free (Keith Beven., 2012). Instead of presenting just one value in time and space with a general uncertainty range the reliability analysis allows us to specify a tolerance range with a given probability, which varies in time and space. Firstly, the reliability analysis comes from the mathematic or statistic field and has to be adapted to an engineering field.

This means to choose a suitable reliability method as well as modifying it to the needs of the morphodynamic numerical models. Secondly, presenting the results becomes not easier if they are distributions instead of single values in time and space (Kopmann & Schmidt, 2010). Model errors, parameter errors boundary condition errors and initial condition errors, observation errors, and forecast errors are different types of errors accretion the degree of uncertainty in the model (WMO-No-1072, 2011).

2.7 Hydrological Modelling in Sri Lanka and Kelani River Basin

The application of different models indicated that a wide variety of models can be successfully applied to Sri Lankan rivers, instead of a particular model. However conceptual models gave superior results especially for rivers subject to prolonged droughts (Dharmasena, 1997).

HEC–HMS rainfall-runoff model was applied for the Deduru Oya river basin with the extent of 1950 km^2 to estimate runoff. Seven stations rainfall data is collected for the period of twenty years and monthly evaporation data is added to the same time duration. The study was carried out by dividing river basins into two sub-basins and the model performance is reported as high accuracy which indicates Nash Sutcliffe efficiencies of 0.80 (Sampath, Weerakoon, & Herath, 2015). The flow duration curve is constructed for the basin Talawakelle, Calidonia, and Huluganga by applying the tank model for the purpose of forecasting daily streamflow. The model was calibrated by using observed stream flows for a period of six years (Hunukumbura, Weerakoon, & Herath, 2004a).

The runoff curve numbers were optimized by applying HEC-HMS model for Torrington and Attidiya catchments which has been executed using fifteen-minute interval rainfall and streamflow data (Wijesekera & Ghanapala, 2003) HEC-HMS, SCS, rational method, and Snyder’s Unit Hydrograph models were used to estimate peak flow for eight small urban watersheds with the extent from 4 ha to 35 ha. The presented peak flow values were significantly different from each other when the watershed area becomes larger (Wijesekera, 2000b).

The research is described information on the flood simulation model which is applied to model the floods in the lower Kelani basin. The model was applied to simulate four flood events that occurred in November 2005, April 2008, May 2008, and May 2010. The observed flood inundation extents shown in flood inundation maps published by the Disaster Management Center were used to compare the simulated inundation extents for the flood events. Simulation results show sound matching with the observed flood maps (De Silva M. , Weerakoon, Srikantha, & Ratnayake, 2012).

The mathematical flood model developed in 1992, is updated to analyze flood level impact and siltation pattern from proposed conservation barrage in Kelani Ganga (Nanseer & Rajkumar, 2006). Fernando (1989) is derived Regional Flood Frequency Curve by studying annual maximum floods in Kelani Ganga. The rainfall data were collected from ten gauging stations for a period of ten years to conduct the research.

Flood simulation model study was conducted to identify vulnerable divisions in the lower Kelani basin due to extreme rainfalls as 50 years and 100 year return period respectively. The inundation extent was spread out to Hanwella, Kaduwela, Kolonnawa, Biyagama, Kelaniya and Colombo DS divisions for 50 years return period and further expands to Kelaniya, Thimbirigasyaya and Sri Jayawardanapura Kotte GN divisions for 100 year return period (De Silva, Weerakoon, Srikantha, Ratnayake, & Mahanama, 2012).

Dharmasena (1992) has presented studying mathematical modeling for flow estimation at Glencourse hydrometric station in the Kelani basin. The analysis has been conducted using five rainfall stations daily data with evaporation values. The executed results were identified as a similar pattern of all six models and low efficiency was reported.

2.8 Parameters Estimation, Parameter Response and Performance Criteria of Hydrological Model

2.8.1 Calibration and validation of the hydrological model

In the calibration process simulation flow results are compared with observed results with remove all possible bias. The simple assumptions are inherent in the model due to the coercion of input data errors and simulation result deviation from observed. The parameter adjustment was required for the achievement of goodness-of-fit statistics. The minimum of two years of data required to model the validation period (WMO-No-1072, 2011). The Hydrological model turning point is the calibration stage which is ensured simulation results the same response overtime against observations (Lijalem, Jackson, & Dilnesaw, 2007).

One of the ways to investigate the suitability of the hydrological model to an application is the process of calibration and validation. Since very rarely guidelines were found in regards to checking the performance of the hydrological model (Daggupati, et al., 2014). The number of parameters is varying with four to several dozen or more and estimation of parameters generally refer to calibration (André , Benoît , & Cécile , 2015).

The process of calibration and forecasting uncertainty is handing together in hydrologic modeling. It is important to building value for uncertainty in a calibrated model to obtain meaning full simulation results (Abbaspour, 2004). The trial and error method and automated method are basic methods of calibration and pre estimation physical features of the basin are essential to the applied any of them (WMO-No-1072, 2011). The decisions should be taken based on scientifically while understanding the influence of model performance in calibration and validating process in model development (Daggupati, et al., 2015). Some of the hydrological models were rejected due to unable to perform validation and additional data should be included in the model for the overcome issue (Keith Beven., 2012).

2.8.2 Objective function and sensitivity analysis

The method of measuring how to fit the computed and observed hydrographs in each other was done by using an objective function which is differed from study to study. In most cases, root mean square error (RMSE) is used as an objective function and some researchers used multiple objective functions to estimate parameters (WMO-No-1072, 2011). The performance of the model is evaluated by using a mathematical equation which is to measure the distance between observed and simulated values of the hydrological model. The form of error vector ($\varepsilon Z(\theta) = Zobs - Zsim(\theta)$) is considered as the objective function (André , Benoît , & Cécile , 2015).

Even though the single objective function was not capable to abstract all important features of the observed data most researchers concern it yet (Vrugt, Gupta, Bouten, & Sorooshian, 2003). The general target of the objective function was to change the variables to achieve goodness-of-fit while minimizing or maximizing an objective function (Vrugt, Gupta, Bouten, & Sorooshian, 2003). The evaluation results showed that multiple objective functions better performance.

Mathematical expressions for a number of recommended objective functions are in Appendix 02. The mathematical techniques of evaluation parameters variation in the calibration process are defined as Sensitivity Analysis (SA) according to the literature. The most important parameters for the simulation results and the number of interdependencies between parameters could be investigated by performing sensitivity analysis. Models parameters were arranged serially according to contribution to overall error (André , Benoît , & Cécile , 2015).

The response surface was more complicated when increasing the number of parameters and difficult to accurately identify global optimum which is having more local optima that indicate similar goodness of fit (Keith Beven., 2012). The mathematicians have been developed in many ways to the optimization of parameter values. The gradient and non-gradient methods are used in hydrology and the solution is depending on the adopted analysis criteria (WMO-168-Vol-II, 2009).

The (SA) Absolute Sensitivity coefficient is defined as;

$$SA = \frac{\partial O}{\partial P} \qquad \text{……………………… (2)}$$

Where; O is the model output and P is a particular input parameter.

The absolute sensitivity cannot be used for the comparison of parametric sensitivities.

The relative sensitivity coefficients are dimensionless and thus can be compared across parameters.

The (SR) Relative Sensitivity is defined as;

$$SA = \frac{\partial O}{\partial P} \cdot \frac{P}{O} \qquad \text{………………… (3)}$$

The (SD) deviation sensitivity is quantified as the changes in the output ΔO which has the same units as the variables O.

$$SA = \Delta O = \frac{\partial O}{\partial P} \cdot \Delta P \qquad \text{………………… (4)}$$

Sensitivity analysis provides a systematic framework for dealing with a system or model involving elements. Sensitivity analysis conventionally investigates the degree to which model responses (or outputs) are affected by the variation in model inputs or parameters (Yeou-Koung & Chi-Leung, 2016).

2.9 Linear Regressions

One of the liberally used mathematical tools is the regression method in prevalent hydrological analyses which is the dissemination of the correlation concept. Linear and nonlinear are two basic categories of regression models that were assistance to find out the power of the relationship among interested variables. Regression equations have many applications in hydrology (WMO-168-Vol-II, 2009).

Regression is the way of building a relationship between two variables, which indicate "x" as the independent variable and "y" as the dependent variable. The connectivity between variables is to participate in the problem. Simple Linear Regression Models is generally being as follows.

$$Y = \alpha + \beta X + \varepsilon \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where: α, β = regression coefficients; ε = residual is observed

The multiple linear regressions (MLR) are the expansion of Simple Linear Regression which is consisting single response variable "y" and multiple independent variables such as x_1, x_2, x_3...x_n (WMO-168-Vol-II, 2009). The general form equation is as follows.

$$Y = \beta_1 X_1 + \beta_2 X_2 + \cdots\cdots + \beta_P X_P \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where: β_1, β_2, β_p = regression coefficients; ε = residual is observed

The technical mechanism inside the Multiple regression equation is initially identified more influenced variable (X1) for the dependent variable and the next second more influenced variable (X2) and method continue to until satisfied (Hay & Clark, 2003). The Multiple regression method in practical hydrological model formulation example is as follows (Asati & Rathore, 2012).

Y= runoff, X_1, X_2, X_3…X_N = rainfall at stations;

Y= runoff at downstream station, X_1, X_2, X_3…X_N = runoff at upstream stations

In multiple linear regression method was used to find missing daily precipitation and evaporation values in stations by using neighboring stations. The confidence level should be exceeding 0.7 for each station to accepted to the MLR method (Caldera, Piyathisse, & Nandalal, 2016). Most of the researches have suggested the MLR method for the estimation of missing data due to advantages and effectiveness. The results for daily precipitation show that in general multiple linear regression methods were better to perform the others, annually and in all seasons (Campozano, Sanchez, Aviles, & Samaniego, 2014).

2.10 Initial Conditions and Boundary Conditions

The initial conditions and boundary conditions should have to inevitably adhere to the hydrological simulation model which is specified according to application. The initial conditions must be determined with careful reasoning. The initial values introduced for variable Y (t) which is executed in the first simulation time step could be recognized as an initial condition (André , Benoît , & Cécile , 2015). The input data for the model parameters and model structure were limited in temporally as well as spatially. The difficulties were raised when the application of initial conditions and boundary conditions in adopting some form of a calibration process (Keith Beven., 2012). The boundary condition errors sometimes refer to time-invariant conditions errors were highly affected when the application of conceptual physical model and errors of initial condition was indicating incorrect results in flood inundation forecasting models.

The initial condition of soil moisture capacity is greatly difficult to infer which was severely effect for event-based simulation than continuous-time models (WMO-No-1072, 2011). The understanding preface of initial conditions and boundary conditions was extremely consequential for the design of a reliable forecasting system and which was required to apply a prosperity set of data to formulate that condition (Matthew & Myles, 2002). The data for boundary conditions should be input to the meteorological model in the HEC-HMS model (William, Scharffenberg, & Matthew, 2009).

2.11 Stream Flow Routing

The scientific mechanism used to investigate features of water profile at any location along the waterway is defined as flood routing. The natural complication flow routing is summarized as both inflows of reaches and the status of the flow path (WMO-168-Vol-I, 2008). The shape of hydrographs and flow volume may be able to calculate with the application of flow routing and when situation changing to flood which is identified as flood routing (Chow, Maidment, & Mays, 1988).

The method of routing is basically categorized as a lumped system method that refers to hydrologic routing and the distributed systems method refers to hydraulic routing. Comparatively lower peak, lengthy-time base, and lag time between two peaks of inflow, outflow hydrograph was configuration at the downstream which it refers to as attenuation (WMO-No-1072, 2011).

2.11.1 Hydrological routing

Reservoir routing and river routing are two types of hydrological routing. The routing model classification is specified as either linear or non-linear and either parametric or non-parametric. The law of continuity and low mass conservation is the theory behind all methods (WMO-No-1072, 2011).

The relationship is building considering the changes in storage at two points to realize solutions while studying wave propagation. The two types of hydrological routing methods are The Muskingum method and specific reach method (WMO-168-Vol-I, 2008). The Muskingum method, which has the following form.

$$S = K[xQ_1 + (1 - x)Q_2] \qquad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where: K and x are constants; S = storage; Q_1, Q_2 = Discharge

Flood routing plays an important role in mitigating floods. Among the available methods of hydrologic flood routing, the Muskingum method of flood routing is widely used especially when limited data is available. A technique resulting in an accurate, simple, and quick estimation of Muskingum model parameters would be helpful in reliable flood routing (Zakwan & Muzzammil, 2016).The method of trial and error was used for estimation basic parameters which were an essential requirement to apply the Muskingum method for flood routing and application also limited to single reach cases (Hossein, Samani, & Shamasipour, 2004).

2.11.2 Hydraulic routing

Flood routing plays a vital role in mitigating floods. The mass conservation and momentum equations are governing the processes of hydrodynamic models. The Saint-Venant equations are described as the behavior of unsteady flow in the catchment (WMO-168-Vol-I, 2008). The equation is as follows.

Continuity: -

$$\frac{\partial Q}{\partial x} + \frac{\partial s_c \quad (A+A_0)}{\partial t} - q = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where: Q = discharge; A=active cross-sectional area; A_0= inactive or dead-storage cross sectional area; S_C = contraction slope.

Momentum: -

$$\frac{\partial(s_m Q)}{\partial t} + \frac{\partial(\beta Q^2/A)}{\partial x} + gA\left(\frac{\partial h}{\partial t} + S_f + S_{ec}\right) - qv_x + W_f B = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

in which: -

$$S_f = \frac{n^e Q}{A^2 R^{4/3}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where: Q = discharge; s_m = depth-weighed sinuosity coefficient; β = momentum coefficient; A = active cross-sectional area; h = water-surface elevation; S_{ec} = expansion-contraction slope; q = discharge at section; v_x = velocity of the x-direction of the river; B=top width of the active cross-sectional area; $W_f B$ = resistance effect of wind on the water surface; n = Manning roughness coefficient; R = hydraulic radius.

A number of studies have been proving that simulated peak discharge of hydrograph is close to the observed peak (Mohsen & Mehdi, 2012). Hydraulic routing calculates the flood amounts accurately but field data scarcity often compels the field engineers to use hydrologic routing procedures (Zakwan & Muzzammil, 2016).

3 METHODS AND MATERIALS

3.1 Methodology

The methodology processed is shown in Figure 3-3. The introduction chapter was carried out to describe the past and present status regarding the research topic. Then the problem is identified and the problem statement was created. The main objective and specific objectives were selected appropriate to the research. The literature review was carried out to search and study in the principally hydrological model and related data, streamflow routing, the impact of antecedent rainfall and flood forecasting to cover the subjective topic.

The meteorological, hydrological, and catchment physical characteristic data collected and data correction process adapt to correct the collected data. Arc GIS 10.3 Computer software is used to delineation to feature of the watershed. The Digital Elevation Model (DEM) was created to obtain elevation data which is required to the river flow model. The HEC-HMS 4.2.1 computer software was selected to develop a river flow simulation model which is an open-source free software based on knowledge gain from literature.

3.1.1 Development of HEC-HMS streamflow simulation model

The model development is achieved with main components of Basin model, Meteorological model, Control specification and Time-Series data. The HEC-HMS model formulation summarisation step is as follows.

(A) Basin Model

The physical catchment is represented in the basin model. Hydrological elements are added and connected to indicate water flow as real-world. Those are source, sub-basin, reach, junction, sink, reservoir and diversion. It was created basin called “Kelani Catchment” by using components in the menu bar and tool Basin Model Manager and then create sub-basins, river tributaries, and junction using related tools. The Screenshot of HEC-HMS developed river model is in Appendix 05.

Different types of mathematical models are available for the determination of losses, excess transformation and adding baseflow for sub-basin element. Also, various river routing methods are available for stream routing in reach element.

It was selected “No Canopy” and “No surface” methods for each sub-basin. For loss method, it was selected SCS Curve Number method and calculated Initial Abstraction, Curve No, and Impervious area percentage in every sub-basin separately. For the transform method, the SCS Unit Hydrograph method was selected with applied graph type Peak factor 100 and the lag time was calculated. Recession method was selected as the baseflow method which is including ratio, recession constant initial discharge parameters. The initial discharge will be the initial condition of the model. All calculation of parameter values is shown in Table 3-1 as well as Appendix 06.

The Saint-Venant equations are expressed as follows.

$$\frac{\partial Q}{\partial x} + \frac{\partial s_c \quad (A + A_0)}{\partial t} - q = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\frac{\partial (s_m Q)}{\partial t} + \frac{\partial (\beta Q^2 / A)}{\partial x} + gA\left(\frac{\partial h}{\partial t} + S_f + S_{ec}\right) - qv_x + W_f B = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The assumption was made in kinematic wave river routing method which is the pressure and inertia terms are negligible compared to the forces of gravity and friction, these last two forces balance and are therefore equal. The friction slope S_f and bed slope S_{ec} being equal, the momentum equation can be approximated by assuming steady flow. Then kinematic wave river routing governing equation as follows.

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} - q = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$\frac{\partial h}{\partial x} + \frac{1}{g} V \frac{\partial V}{\partial x} + \frac{1}{g}\frac{\partial h}{\partial t} - (k-1).\frac{q}{g}.\frac{V}{A} = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where: Q = discharge; s_m = depth-weighed sinuosity coefficient; β = momentum coefficient; A = active cross-sectional area; h = water-surface elevation; S_{ec} = expansion-contraction slope; q = discharge at section; v_x = velocity of the x-direction of the river; B=top width of the active cross-sectional area;

W_fB = resistance effect of wind on the water surface; A_0= inactive or dead-storage cross sectional area; S_f = slope of the energy grade; V= the mean velocity.
The kinematic wave river routing method was selected and calculated values are attached in Appendix 06 and none of the loss or gain method was selected.

(B) Meteorological Model

The meteorological model calculates the precipitation and evapotranspiration input required for sub-basin element. Frequency storm, gage weights, gridded precipitation, Inverse distance, HMR52, SCS Storm, specified hyetograph, and standard project storm are different rainfall input methods. The "Gage weights" method was selected because which is allows for input weighted daily data.

It was created The Meteorological Model called "Gauge" by using components in the menu bar and tool Meteorological Model Manager. Then "Gauge" was highlighted which was appear three number of tabs called "Meteorology model", "Basins", and "Options" in the component editor area. The basins tab was selected and it should be "yes" in front of include sub-basins. Then sub-basins ware appearing under Meteorological Model Manager. It was selected the sub-basin name in "Gauge Weight" tab under Meteorological Model Manager. eg: -Ambalanpiti. Then there were two tab sections and weights in the component editor area. By clicking "yes, no" can add or remove rainfall gauges relevant to each sub-catchment. Then weights tab was selected and "depth weight" and "time weight" were entered according to the calculation which is shown in Appendix 06.

Annual evapotranspiration, monthly average, Penman Monteith, Priestley Taylor, specified evapotranspiration, and gridded options are available evapotranspiration input methods It was selected precipitation type as "Gauge weights" and evapotranspiration as "Specified Evapotranspiration" because daily evaporation data availability.

(C) Control specification and Time-Series data

The control specification is used to manage the simulation run. The time-series data is stored as gage which is shared component data in the project. The simulation requires initial condition and boundary condition.

These components fulfill the required necessity. Start date, time, and end date, time also time interval were specified according to the time duration required for calibration and validation. The time-series data type which was precipitation gages, evapotranspiration gages, and discharge gauge was created by using “Time-Series Data Manager”.

Table 3-1: Values of the parameter for river flow simulation model

Name of the Sub Catchment	CN	Impervious (%)	Initial Abstraction (I_a)	Lag Time (Min)	Initial Discharge (Cumec)	Ratio to Peak
Lower Kelani Ganga	73.04	0.00	18.754	511.762	0.04	0.76
Kehelgamu Ganga	76.66	0.56	15.463	180.215	0.71	0.21
Maskeliya Oya	76.56	2.05	15.555	162.816	0.73	0.22
Magal Ganga	75.51	4.25	16.473	63.172	1.06	0.24
Panapura Oya	78.40	1.27	13.994	50.423	0.51	0.70
Upper Kelani Ganga	77.36	1.18	14.867	228.049	0.36	0.31
Welihel Oya	78.43	2.11	13.974	106.242	0.46	0.29
Ritigaha Oya	78.40	0.81	13.992	111.841	0.53	0.28
Gurugoda Oya	79.52	0.16	13.083	186.227	0.76	0.22
Ambalanpiti Oya	78.26	0.42	14.110	144.579	0.30	0.32
Getahetta Oya	78.64	0.12	13.796	206.137	0.12	0.41
Seethawaka Ganga	78.50	0.14	13.914	311.090	0.27	0.31
Pugoda Oya	80.01	0.36	12.689	218.603	0.14	0.36
Upper Middle Kelani Ganga	78.64	0.27	13.795	588.703	0.25	0.40
Kalatuwawa	76.30	0.00	15.779	168.216	0.31	0.32
Pusweli Oya	78.90	0.00	13.589	304.062	0.19	0.38
Pallewela Oya	79.22	0.00	13.327	251.993	0.15	0.37
Lower Middle Kelani Ganga	76.10	0.00	15.956	694.763	0.13	0.55
Biyagama	79.91	0.00	12.775	207.227	0.18	0.37
Kolonnawa Ela	75.36	2.06	16.606	393.220	0.12	0.42

Start, end time, date, and period of execution were automatically adjusted as include in control specification. It was created Annfield, Colombo, Dunedin, Hanwella Group, Laxapana, Vincit, Weweltalawa as the precipitation gauges and Colombo, Ratnapura, Seetha Eliya as the evapotranspiration gauges. Nagalagam street gauge is a discharge gauge which was to enter the observation flow data. The data source was selected as “Manual Entry” for every gauge and excel data were copy-pasted. The model selected control specification was “calibration, validation” for the purpose of calibration and validation by using tool Control Specifications Manager.

3.1.2 Selection of objective function and parameter estimation

Before the parameter estimation of hydrological model, one or more performance criteria should be specified. The mathematical function is used to evaluation of model performance quantitatively. It is generally measures the gap between the observed and simulated values of the considered hydrological variable. This function is referred to as the objective function. The most widely used objective functions are presented in Appendix 02.

The selected objective function is the Nash-Sutcliffe Coefficient (NASH). It expresses the relative difference between the error of the hydrological model and the error of the observation with respect to the mean of the discharges. The value closer to 1, the observation and simulation coincide with each other. In general, model simulation can be judged as “satisfactory” if NASH greater than 0.50. If the NASH is greater than 0.66 in calibration and NASH is greater than 0.69 in validation, the hydrologic model is acceptable refers to as a “good” model for flood modelling (Moriasi, et al., 2007). The great advantage of the Nash Sutcliffe Coefficient is used to compare the performance of a model in different simulation contexts. The Nash Sutcliffe Coefficient equation is as follows.

$$NASH = \frac{\sum_{i=1}^{n}(\hat{Q}_i - Q_i)^2}{\sum_{i=1}^{n}(Q_i - \bar{Q})^2} \qquad \text{.....................} (5)$$

Where: i = time step; n = total number of step considered; $\hat{Q}_i$= simulated discharge at i-th time step; Q_i= observed discharge at i-th time step; $\bar{Q}$ = mean observed discharge

Parameter estimation implies making selections concerning a calibration strategy. The most widely used method is aimed at identifying the optimal set of parameters while considering minimize the simulation error. The model was calibrated manually as initial stage by iteratively adjusting parameter values so that simulated results match the observed streamflow as closely as possible while full fill the requirement of the objective function. The Model performance was evaluated after each adjustment. The method was continued until the performance reached is considered to be reasonable. The judgment is based on the combination of numerical value of objective function and graphical performance of flow hydrograph and flow duration curve. Finally, the “Univariate Gradient” method was selected for automatic calibration.

The verification is the process of evaluating model weather it complies with observation results. Thus, model should be tested weather simulation results are closer to the real observations before further usage. That means model should pass the verification step to flood forecasting in a particular basin. The validation is a process to check whether the model assurance to reproduce the basin response for a given set of observations. Bias correction measures the tendency of a model to underestimate or overestimate the observed discharges.

This criterion is used to validate model parameters that condition the simulated hydrological balance in such a way that the balance is close to the zero estimated based on observations. The model was validated with the selection of optimised parameters by using the method of “Univariate Gradient”. The period of the year 2008 to 2012 was used for model calibration purposes and the model validation period considered as the year 2013 to 2017. Then the validated river flow model was used for scenario analysis for a Kelani river basin.

3.1.3 Stage–Flow relationship

The water discharge is required to calibrate the model at the outlet of Nagalagam street but only available data is water level. Mixed semidiurnal tidal wave pattern was investing around Sri Lanka and the outlet location is influenced. The hydraulic relation in-between stage and discharge may be defined according to the nature of the water flow cross-section. The rating curve general representation as follows.

$$Q = a(H - H_0)^b \qquad \text{………………… (6)}$$

Where: a and b are constants; H, H_0 = Hydraulic head; Q, = Discharge

Similarly, the rating curve was developed to calculate the observed discharge. The location cross-section is used to construct the rating curve which in appendix 07. The rating curve formula is as follows.

$$Rating\ Curve\ Formula$$

$$= 3.75\left(\frac{105.535h^{\frac{5}{3}}}{(105.535 + 2h)^{\frac{3}{2}}} - 4\right) + 1000h - 204h^{2.65} - 40$$

$$Rating\ Curve\ Formula = 21.08\left(\frac{105.535h^{\frac{5}{3}}}{(105.535+2h)^{\frac{3}{2}}} - 4\right) + 10 \quad ;\text{ If h}<= 0.4 \qquad \text{…...... (7)}$$

Where: h = Observed water level.

The graph of the rating curve is shown in Figure 3-1 and the rating curve was verified by using observed peak discharge from 2010,2016 and 2017. The different publication values are contradictory. The water level exceeding 1.2 m the flood circumstances is experienced. Frequency analysis was exercised by plotting the log curve. The log curve of variation of peak discharge with the probability is shown in Figure 3-2. Then return period values were checked with flow characteristics values published by Lanka Hydraulic Institute.

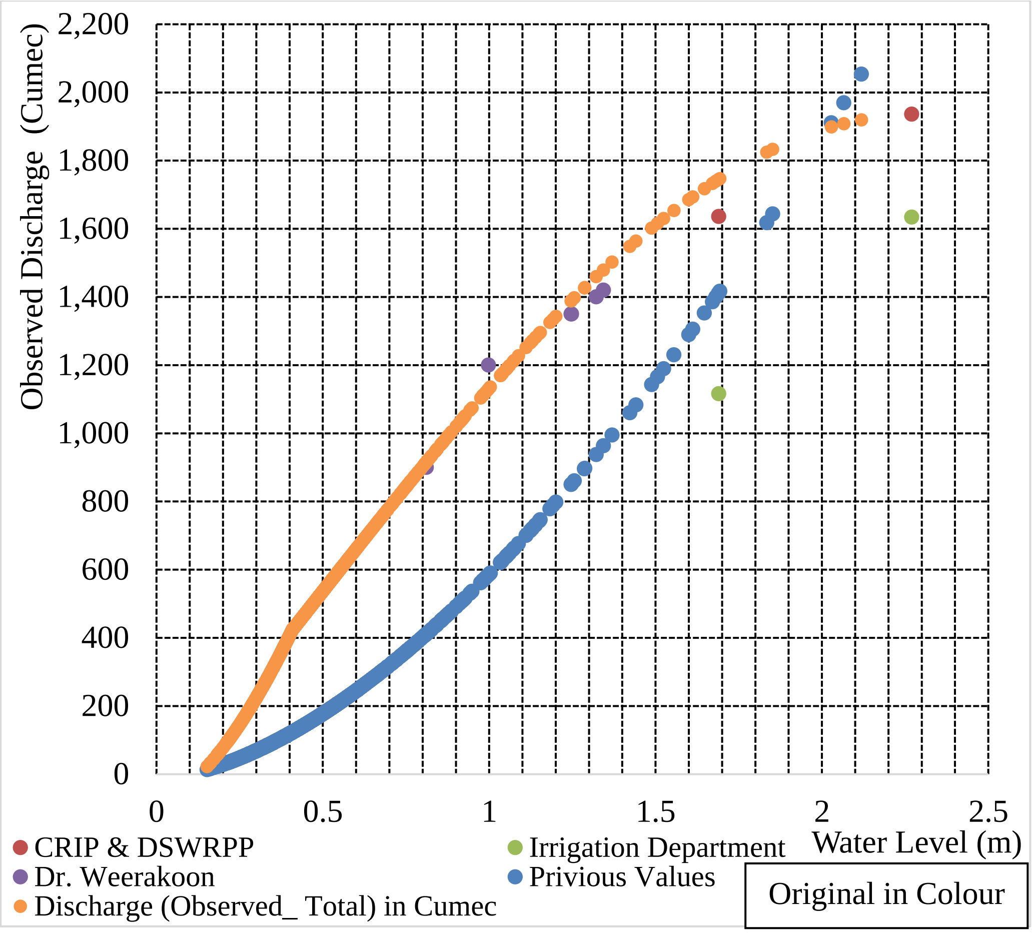


Figure 3-1: Rating curve for Nagalagam Hydrometric Station

The rating curve was adjusted until the low flow and high flow event frequency within the acceptable limit with considering observed discharge in 2010,2016 and 2017. Table 3-2 is shown event frequency values and finally, the rating curve was fixed. The daily average discharge flow was calculated by using the above formula for Nagalagam Street. The calculated observed discharge and frequency graph for the period of 2008 January to 2017 December is shown in Appendix 07.

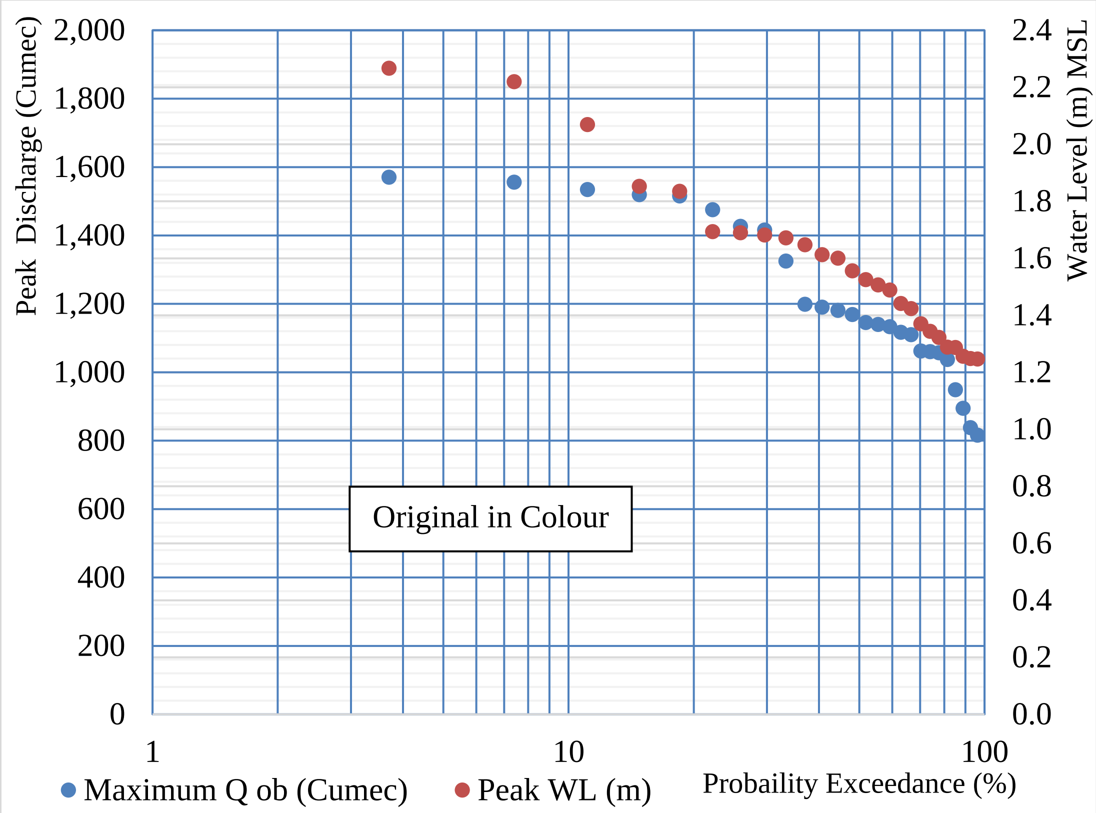


Figure 3-2: Log curve of variation of peak discharge with the probability exceedance

Table 3-2: Values of high and low flow event frequency

Frequency	1 in 2 years (T2)	1 in 5 years (T5)	1 in 10 years (T10)
Event Exceedance in flood	6	3	2
Limitation According to LHI	5	2	1
Low flow values According to LHI (Cumec)	19.75	14.08	11.26
Low flow values Event	0	0	0

3.1.4 Methodology flow chart

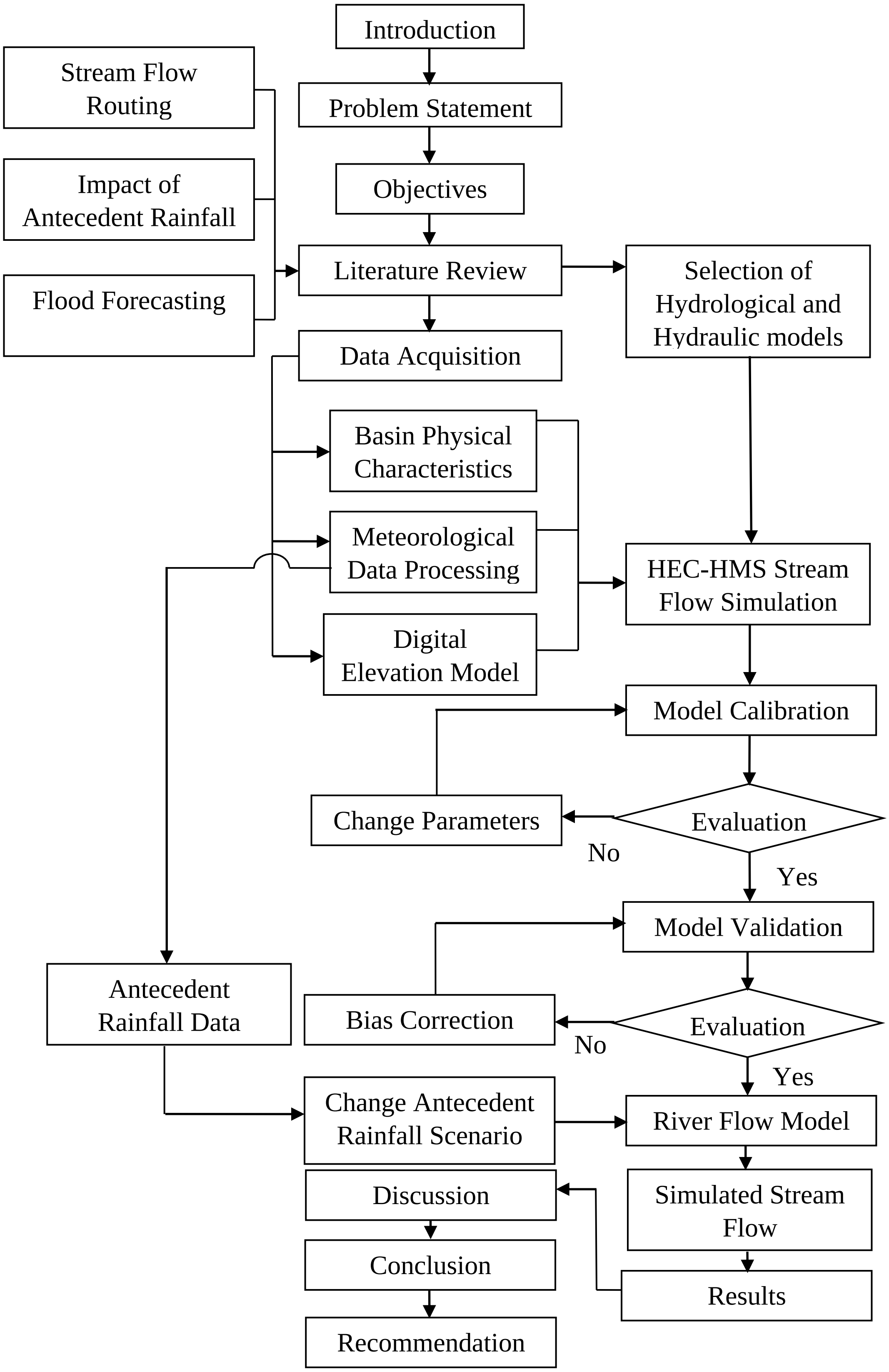


Figure 3-3: Methodology flow chart

3.2 Study Area

The Kelani river basin has been selected as a study area which is the fourth-longest river in Sri Lanka. Lower peneplain, middle peneplain, and upper peneplain are three regions of the Kelani river basin based on significant topographical variations along the longitudinal section of the river. The study area is bound by northern Maha Oya and Attanagall Oya catchments, southern Bolgoda Lake, Kalu Ganga, and Walawe Ganga Catchments and eastern Mahaweli river basin. Kelani River is located in the wet zone of the country. The hydrology of this river basin depends on the moisture volume bring from the monsoon systems.

The selected water level staff gauge station for research is Nagalagam street hydrometric station. The water level of staff gauge is recorded during the measurement of streamflow. The Nagalagam street hydrometric station is located latitude 6° 57' N, longitude 79° 52' E close to the estuary. The river originated from Adam’s peak and the extent of the study area is approximately 2,240 km^2 that lies upstream of the Nagalagam street river gauging station. The set of rainfall, evaporation, and streamflow water level is used for the research from 2008 to 2017. The rainfall stations and evaporation stations which are selected for the model as follows.

Table 3-3: Coordinate of the river gauging station

River Gauging Station	Coordinate	
	Latitude	Longitude
Nagalagam Street	6° 57' 35" N	79° 52' 36" E

The selection of seven rainfall gauging stations was spread as cover to the maximum extent of the Kelani River basin up to the stream gauging station. It was considered with the guideline of the World Meteorological Organization (WMO) was complying with an acceptable range.

Table 3-4: Distribution of gauging station in Kelani River Catchment

Catchment	Type of Gauging Station	Number of Gauging Station	Density of Gauging Station (km^2 /Station)	
			Research	WMO Guideline
Kelani River	Rainfall	7	318.57	575
	Evaporation	3	743.33	50000

Source: WMO-No.168 Volume I –Table 1.2.6

Table 3-5: Coordinate of the rain gauging station

Rainfall Gauging Station	Coordinate	
	Latitude	Longitude
Colombo	6° 54' 00" N	79° 51' 36" E
Annfield (CEB)	6° 52' 12" N	80° 37' 48" E
Dunedin	7° 01' 48" N	80° 16' 48" E
Hanwella Group	6° 52' 48" N	80° 07' 12" E
Laxapana	6° 54' 10" N	80° 30' 36" E
Vincit	7° 04' 48" N	80° 13' 12" E
Weweltalawa	7° 03' 00" N	80° 22' 48" E

Table 3-6: Coordinate of Evaporation station

Evaporation Station	Coordinate	
	Latitude	Longitude
Colombo	6° 54' 00" N	79° 51' 36" E
Seetha Eliya	6° 55' 48" N	80° 48' 00" E
Ratnapura	6° 40' 48" N	80° 24' 00" E

The study area map is shown in Figure 3-4 and which is indicate Nagalagam Street river gauging station, the network of the rain gauge, and the evaporation station in the Kelani River basin which is related to research.

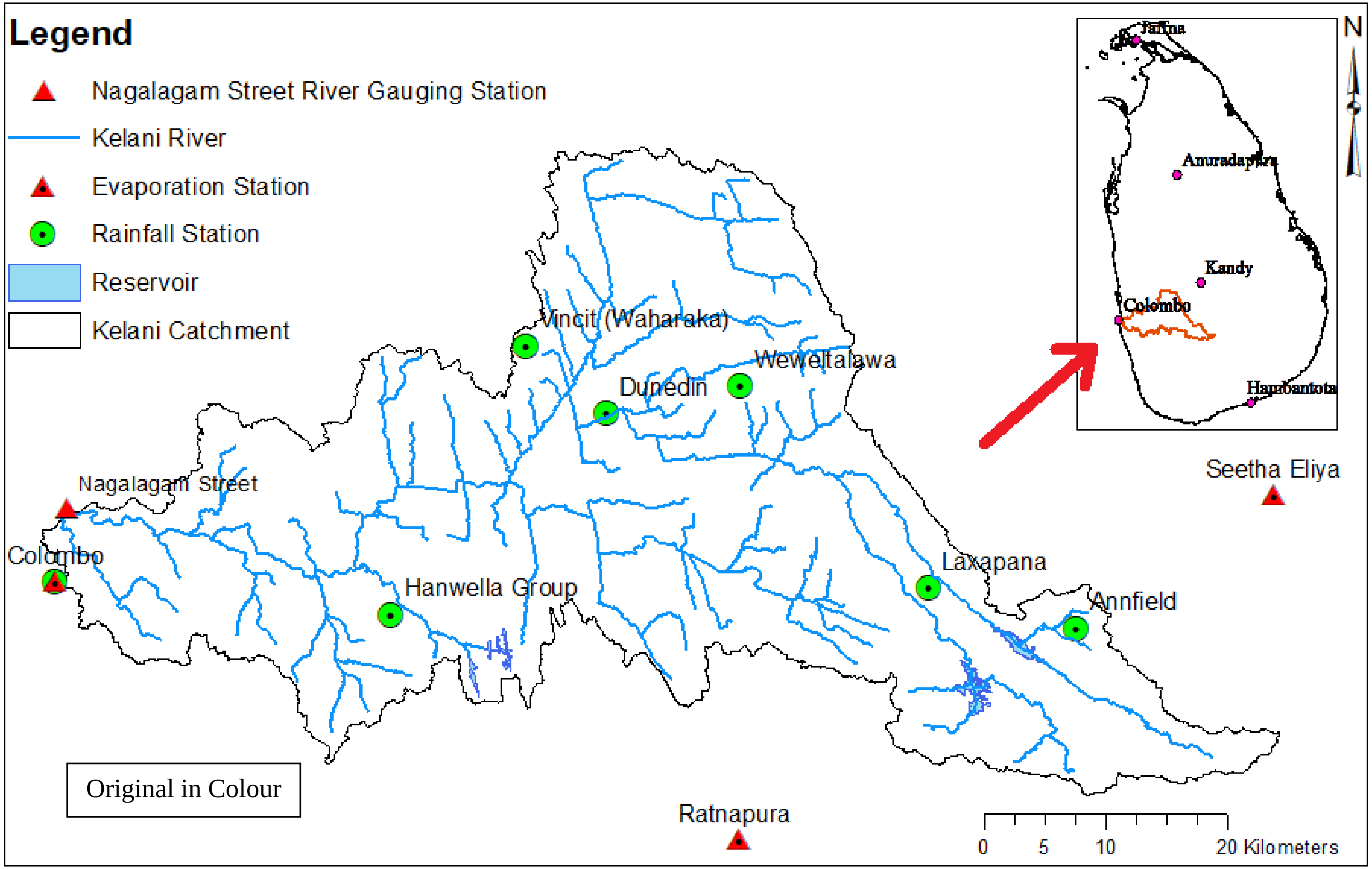


Figure 3-4: Map of the Study Are

3.3 Data

3.3.1 Data collection

As principally hydrological, meteorological and topographical data were used for this study. The detail of data sources and resolution are tabulated in Table 3-7. The selected data period is from 2008 to 2017.

Table 3-7: Data Sources and Resolution

Type of Data	Resolution	Source	Period/Year
Evaporation	Daily	Department of Meteorology	2008 to 2017
Rainfall	Daily	Department of Meteorology	2008 to 2017
Streamflow	Daily	Department of Irrigation	2008 to 2017
Contour	1:10,000	Department of Survey	2011
Land use	1:50,000	Department of Survey	2011
Soil Type	1:50,000	Department of Survey	2011

3.3.2 Catchment characteristics

The Kelani River is extending over three provinces, namely, Western, Sabaragamuwa, and Central which covers administrative districts of Nuwara-Eliya, Kegalle, Rathnapura, Gampaha, Kalutara, and Colombo. Survey Department has divided the basin into twenty sub-basins (Mallawatantri, Rodrigo, & De Silva, 2016). The name of sub-catchment and related river details are tabulated in Table 3-8 which is shown in Figure 3-5.

The runoff coefficient is depending on the storm, soil type, and land use conditions. The consideration of the land use or land cover and type of soil are essential requirements when the application of the hydrological simulation model. As we develop the land, construction of structures onto the surface, such as roads, buildings, and parking lots is increased the impervious surfaces area and the amount of water infiltration is reduced and it is forced to either evaporate or runoff. The rate of increasing soil moisture was not much as previous ground cover.

Abstractions include interception of precipitation on vegetation above the ground surface as water accumulates in hollows over the surface and infiltration water into the soil (Chow, Maidment, & Mays, 1988).

Table 3-8: Name of Sub catchment and River

Name of Sub catchment	Area (km^2)	Name of River	Length (km)
Lower Middle Kelani	151.986	Lower Middle Kelani Ganga	27893.40
Kehelgamu	212.186	Kehelgamu Ganga	47971.63
Maskeliya	199.409	Maskeliya Oya	43471.49
Seethawaka	140.603	Seethawaka Ganga	27551.24
Magal	111.357	Magal Ganga	17669.56
Panapura	42.821	Panapura Oya	8034.62
Getahetta	41.432	Getahetta Oya	13049.17
Ambalanpiti	71.840	Ambalanpiti Oya	15282.88
Upper Kelani	136.049	Upper Kelani Ganga	23081.00
Upper Middle Kelani	244.113	Upper Middle Kelani Ganga	27536.75
Gurugoda	235.760	Gurugoda Oya	41047.33
Ritigaha	98.200	Ritigaha Oya	24073.51
Welihel	82.140	Welihel Oya	24537.68
Pusweli	94.207	Pusweli Oya	17995.17
Pallewela	62.133	Pallewela Oya	14252.02
Kalatuwawa	88.243	Wak Oya	17427.67
Pugoda	51.062	Pugoda Oya	14505.82
Kolonnawa	81.856	Kolonnawa Ela	18556.83
Biyagama	60.828	Biyagama	11111.59
Lower Kelani	38.010	Lower Kelani Ganga	13657.78

Land use classification Nagalagam Street basin is developed by the 1:50,000 digitized topographical maps collected from the Department of Survey of Sri Lanka. The largest land use categories are Rubber which is cover 35% and, Home Gardens, Tea, and Forest are holding second and third places with respectively. The percentage and extent area of land use shown in Table 3-9 and Figure 3-8 represent land use maps of the study area.

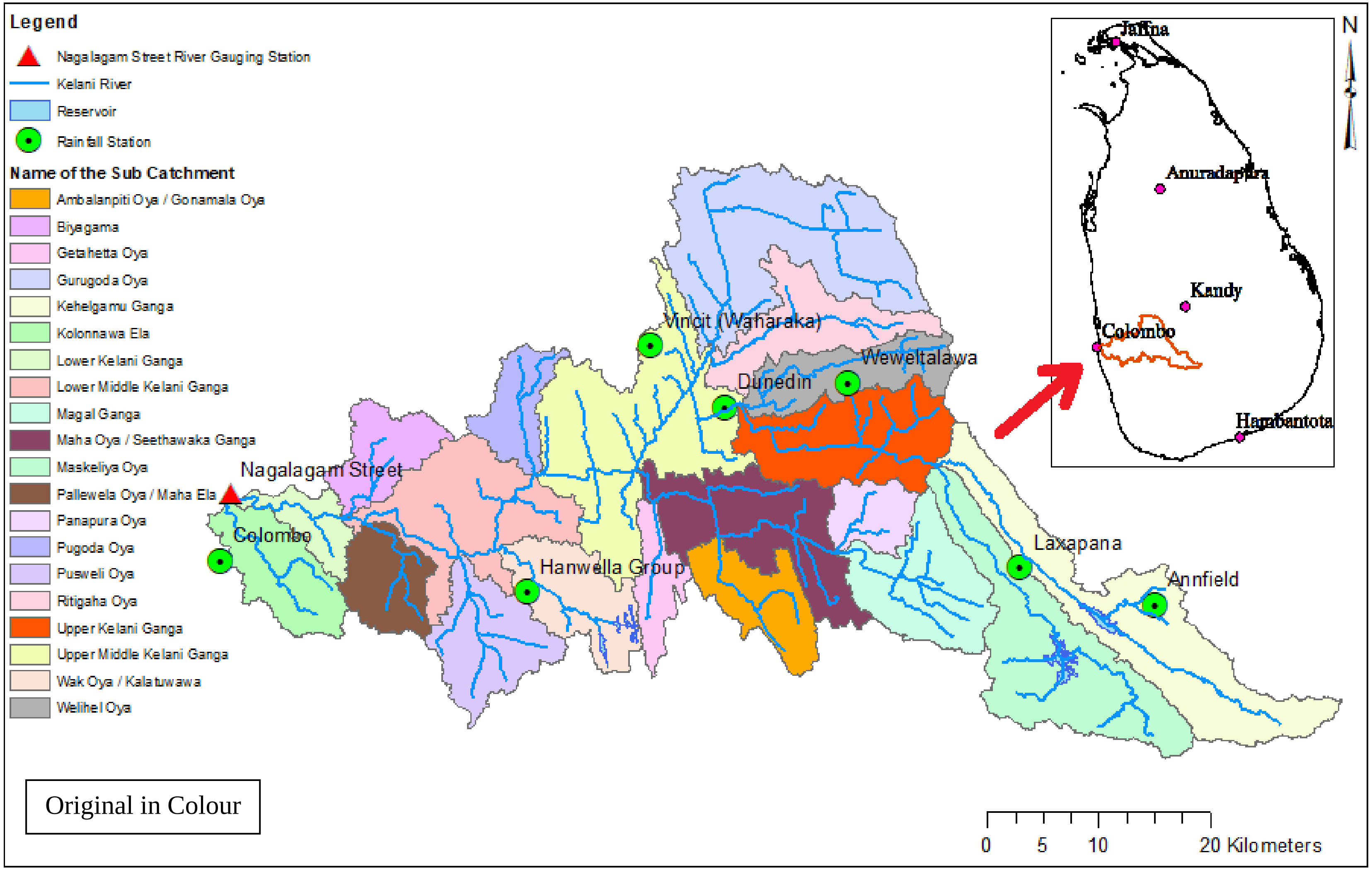


Figure 3-5: Map of the Sub Catchment and River

Table 3-9: Type of Land use and coverage Area

Land use Categories	Area (km^2)	Percentage (%)
Built-up Area	2.599	0.12
Chena	2.005	0.09
Coconut	102.968	4.59
Forest	238.240	10.62
Grass Land	9.727	0.43
Home garden	530.311	23.63
Marsh	14.941	0.67
Other Cultivation	25.407	1.13
Paddy	163.800	7.30
Rock	16.452	0.73
Rubber	780.326	34.77
Sand	0.360	0.02
Scrub Land	53.086	2.37
Streams	27.174	1.21
Tea	275.576	12.28
Unclassified	0.007	0.00
Water Bodies	1.257	0.06

Soil type classification Nagalagam Street basin is developed by the 1:50,000 digitized soil maps collected from the Department of Survey of Sri Lanka. The largest soil type category is Red-Yellow podzolic soil which is covers 89%. The type of soil classification is tabulation shown in Table 3-10 and map shown in Figure 3-9.

Table 3-10: Soil Type of Study Area

Type of Soil	Area (km^2)	Percentage (%)
Reddish-brown lateritic soils	51.784	2.31
Red-Yellow podzolic soils	1996.256	88.95
Rock Land	85.973	3.83
Alluvial Soils	71.797	3.20
Bog and Half-Bog Soils	38.425	1.71

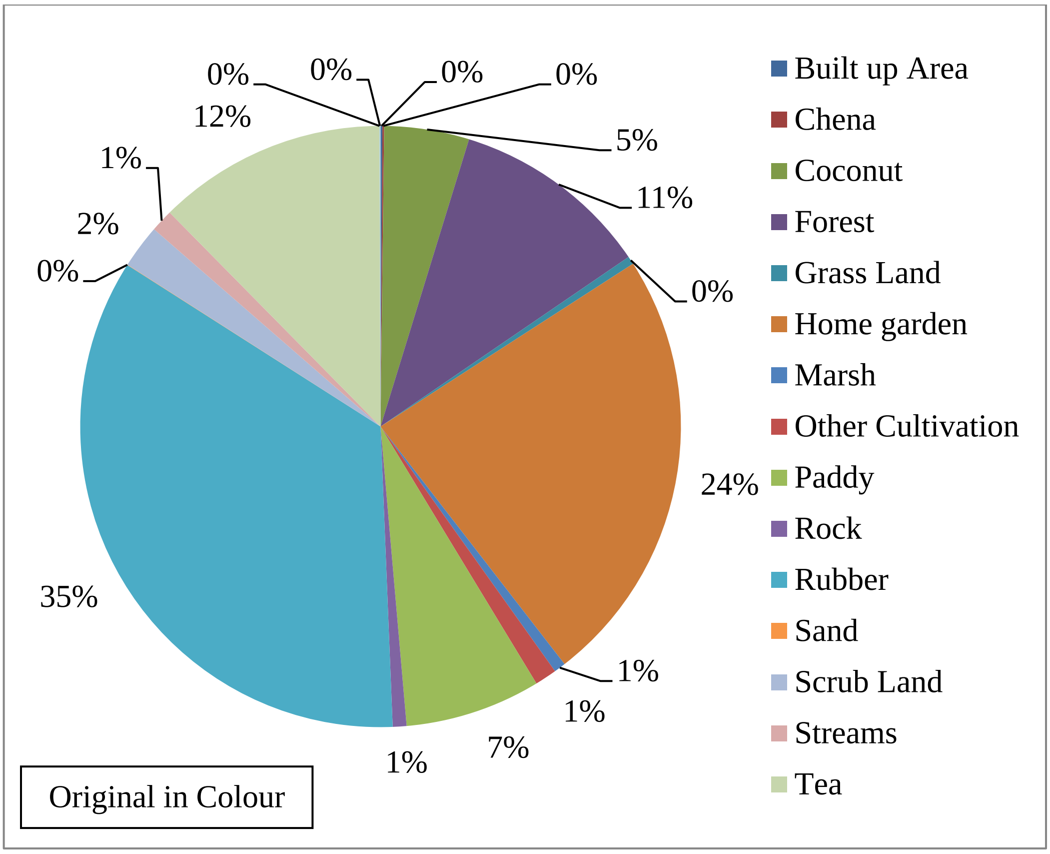


Figure 3-6: Percentages of Land Use Categories

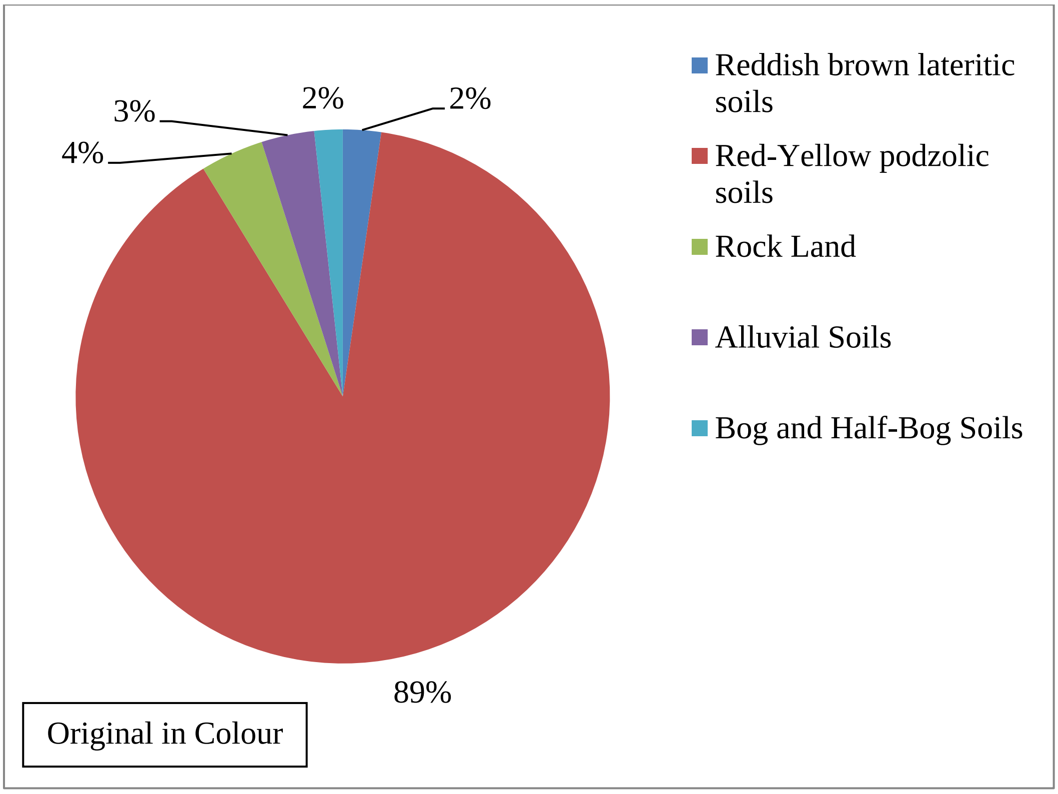


Figure 3-7: Percentages of Soil Categories

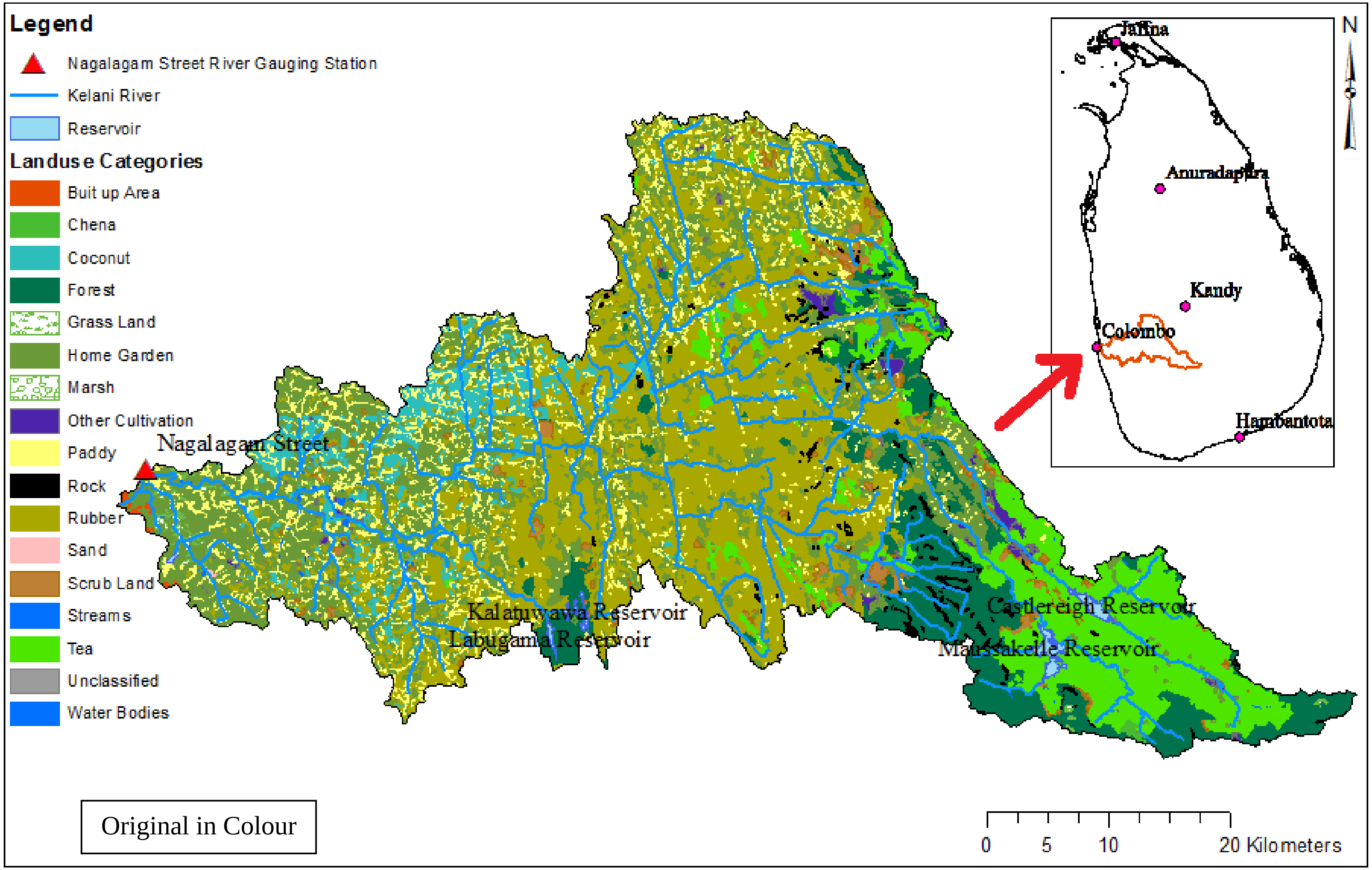


Figure 3-8: Land use Map of the Study Area

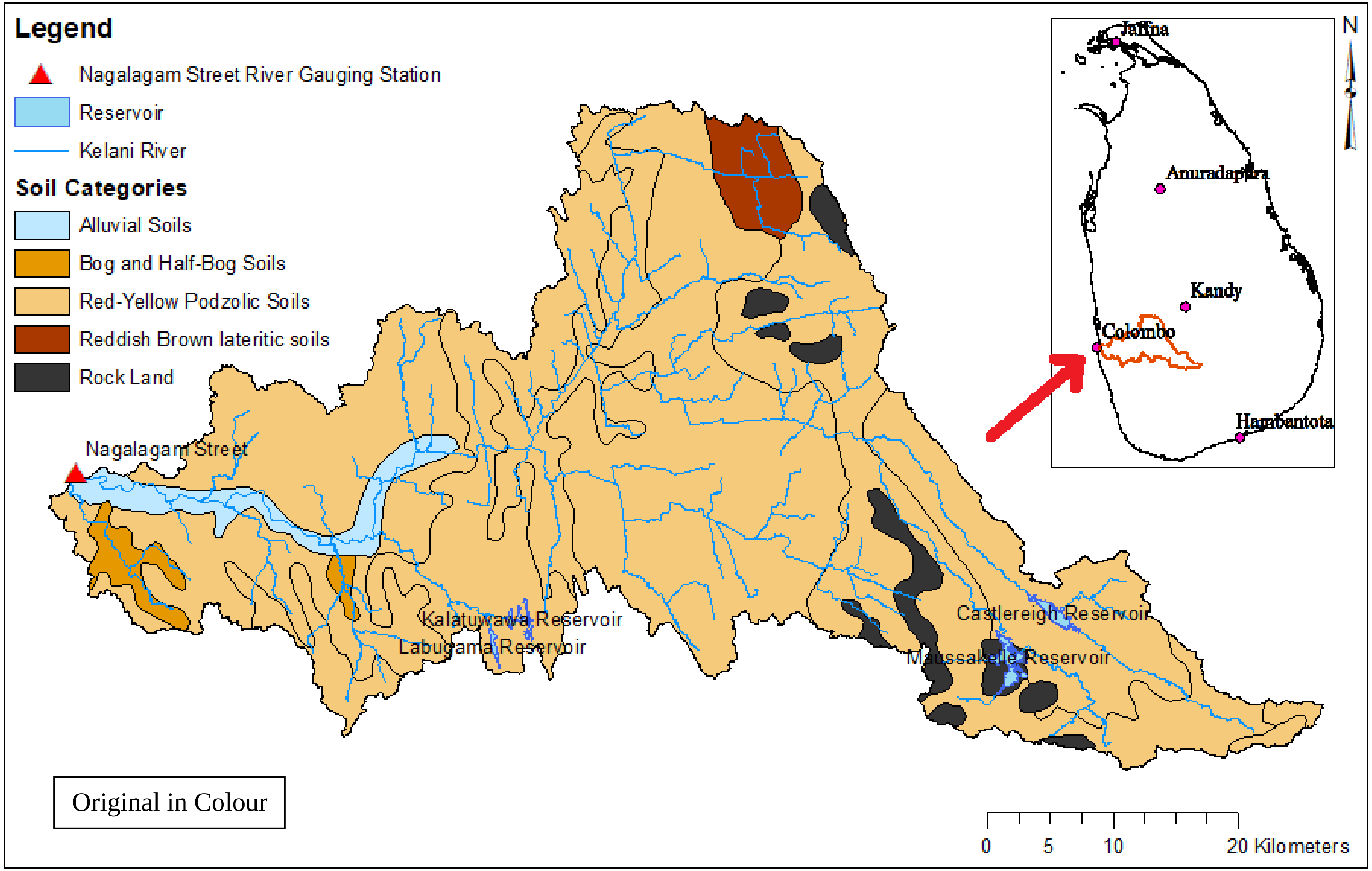


Figure 3-9: Soil Classification Map of the Study Area

3.3.2.1 Sub catchment characteristics

The land-use categories in sub-catchment are in Appendix 04 and the hydrological soil group of sub-catchment is shown in Table 3-11 which are classified according to the guideline of hydrological practices of the World Meteoroidal Organization (WMO). The elevation variation along the catchment is shown in Figure 3-10.

Table 3-11: Hydrological Soil group of Sub catchment

Name of the Sub Catchment	Hydrological Soil Group	Area (km^2)
Lower Kelani Ganga	C	21.061
	A	16.948
Kehelgamu Ganga	C	212.186
Maskeliya Oya	C	155.344
	D	44.065
Magal Ganga	C	93.883
	D	17.474
Panapura Oya	C	42.821
Upper Kelani Ganga	C	133.565
	D	2.484
Welihel Oya	C	74.401
	D	7.739
Ritigaha Oya	C	93.337
	D	4.863
Gurugoda Oya	C	174.628
	D	61.132
Ambalanpiti Oya	C	71.840
Getahetta Oya	C	41.432
Seethawaka Ganga	C	140.603
Pugoda Oya	C	49.531
	A	1.531
Upper Middle Kelani Ganga	A	4.947
	C	239.166
Kalatuwawa	A	0.257
	C	87.986
Pusweli Oya	A	1.503
	B	7.343
	C	85.361
Pallewela Oya	A	3.565
	C	58.568
Lower Middle Kelani Ganga	A	35.288
	B	0.413
	C	116.285
Biyagama	A	0.893
	C	59.934
Kolonnawa Ela	A	6.865
	B	30.669
	C	44.323

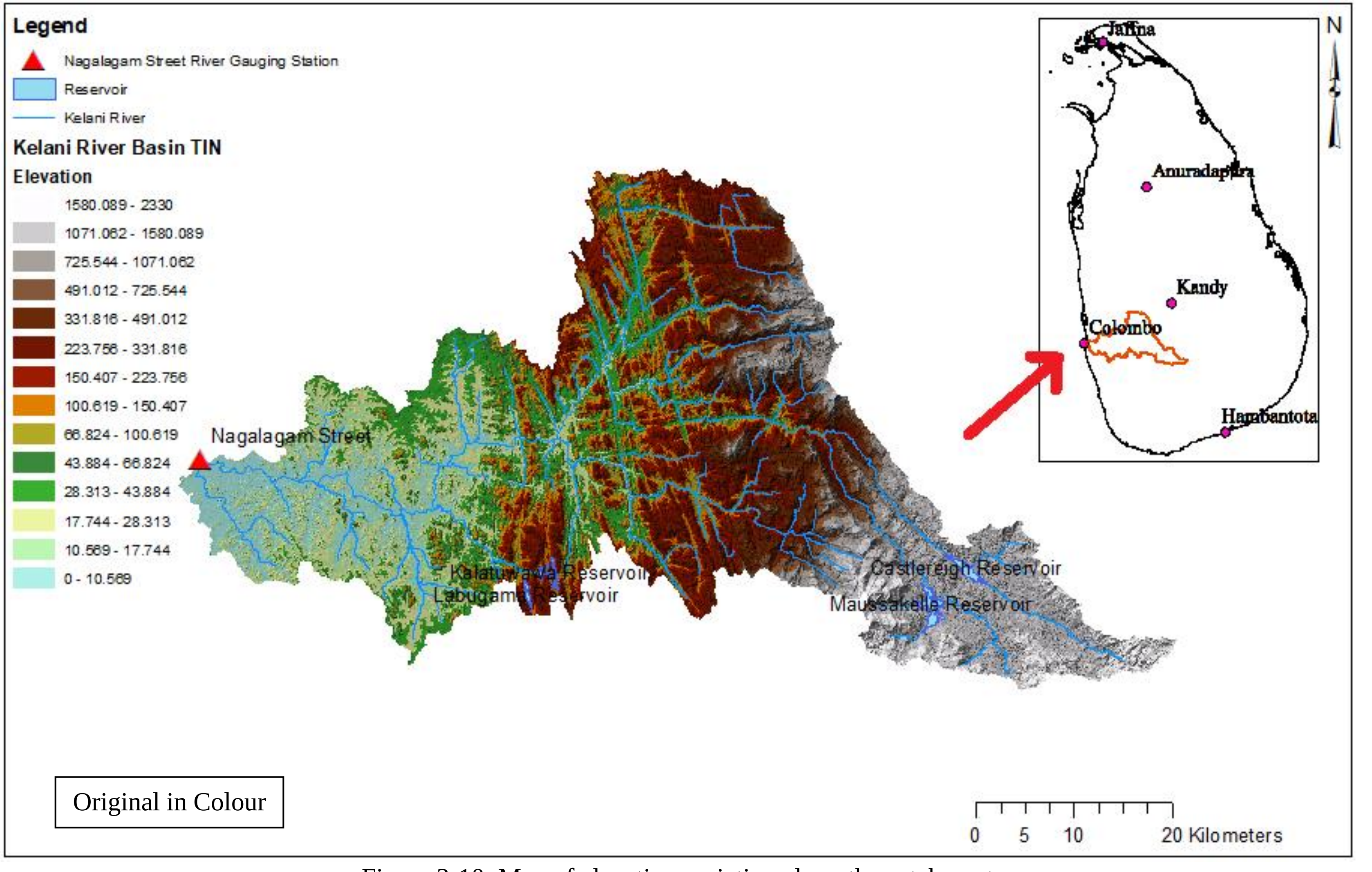


Figure 3-10: Map of elevation variation along the catchment

3.3.3 Meteorological and hydrological data processing

The objective of data processing is to verify whether a reported data value is representative of what was intended to be measured. Data should be satisfactory for model application after they have been subjected to adequate processing. The recorded values reliably reflect current conditions, and that there is consistency among the observed elements. Checks should be made to assess the validity, continuity, or homogeneity of the data record.

3.3.3.1 Estimation of missing data

Precipitation events were measured by rain gauges at specific locations as well as pan evaporation method was used to estimate evapotranspiration and streamflow was calculated from water level indication in river gauge. The availability of a complete data record is very important in the development of a reliable hydrological model. Even though we expect continuity of selected data range it may not so particularly as an example the rain gauge is not an operative part of the month which is called missing data. That is the absence of observation or recording. Details of missing data with regards to rainfall, evaporation, and streamflow are tabulated in Table 3-12.

Table 3-12: Details of Missing Data in each Gauging Station

Type of Data	Station Name	Number of Missing Month	Percentage (%)
Rainfall	Vincit (Waharaka)	14	0.12
	Weweltalawa	5	0.04
	Colombo	0	0.00
	Annfield	6	0.05
	Dunedin	21	0.18
	Hanwella Group	1	0.01
	Laxapana	2	0.02
Evaporation	Colombo	4	0.03
	Ratnapura	11	0.09
	Seetha Eliya	20	0.17
Water Level	Nagalagam street	0	0.00

3.3.3.2 Inserting of missing data and adjustment of records

All measurements are samples of elements that vary in spatially as well as temporally. The measurements and records are useful in practical hydrology. It is a necessary requirement to make changes to maintain the homogeneity of records while keeping integrity (WMO-No-100, 2011). The records may impact to reliability of the model and correctness of a study. The linear regression method is useful for filling the missing values of rainfall data (Caldera, Piyathisse, & Nandalal, 2016).

The multiple linear regression method was used for the evaluation of rainfall and evaporation missing data. Also, a linear interpolation method was performed to estimate missing values of evaporation such as by computing the average of the values observed in both sides of the gaps in some cases. In the present study, the Multiple Linear Regression technique was employed using MS Excel. The analysis of variance was done and coefficient of determination (R^2), roots mean squared errors (RMSE) were computed. The Microsoft Excel software was used to obtain a correlation of the station and equation of the regression line. The confidence level of 95% is used to obtain the correlation coefficient. The single mass curve was plotted after replacing missing values according to the slope of each station which is shown in Figure 3-11 for daily rainfall data and Figure 3-13 for daily evaporation data.

Water level data related to Nagalagam street station was collected from the irrigation department in hourly temporal resolution and calculated daily mean water levels. The missing values were not identified in the period of 2008 to 2017. The single mass curve for daily water level data is plotted which is shown in Figure 3-12.

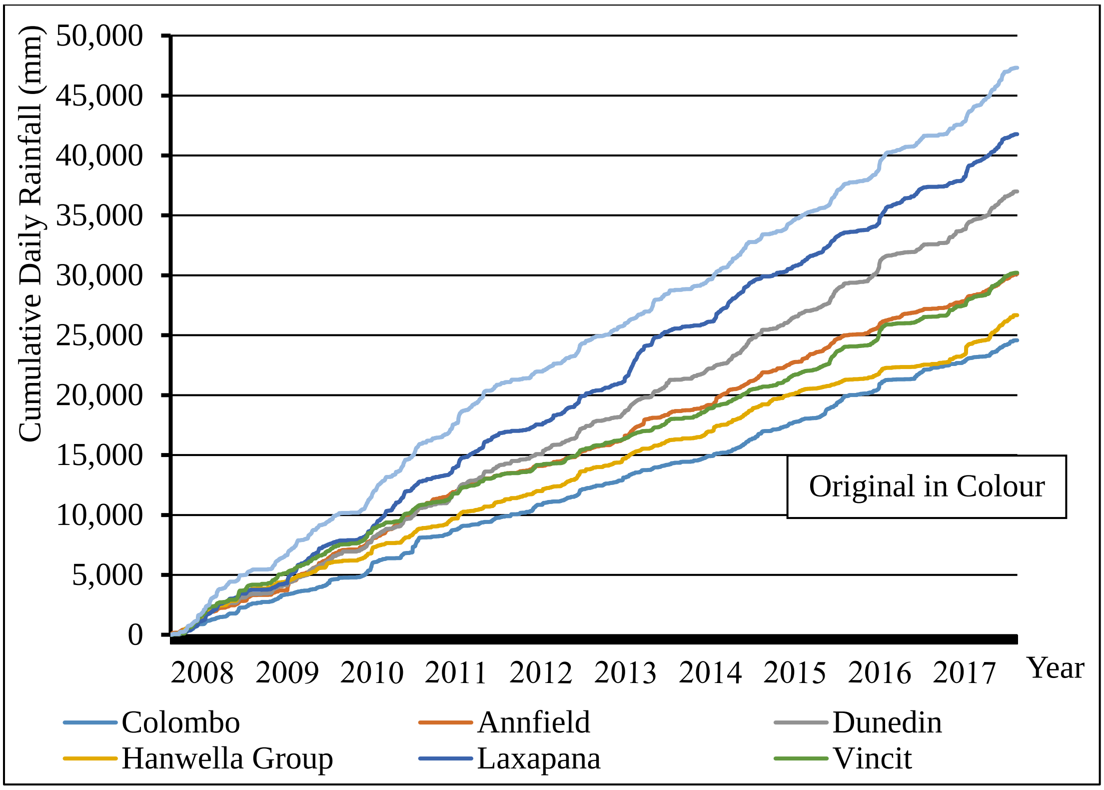


Figure 3-11: Single Mass Curve for Rainfall Data

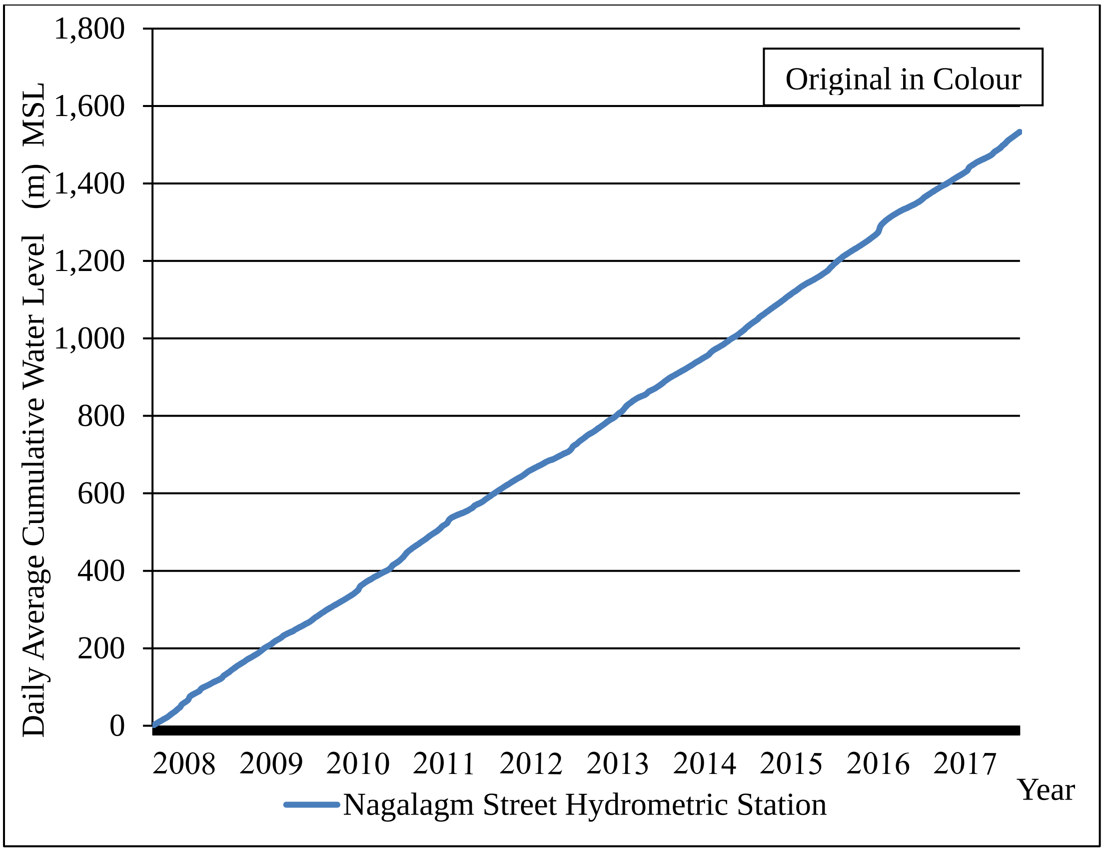


Figure 3-12: Single Mass Curve for Water Level Data

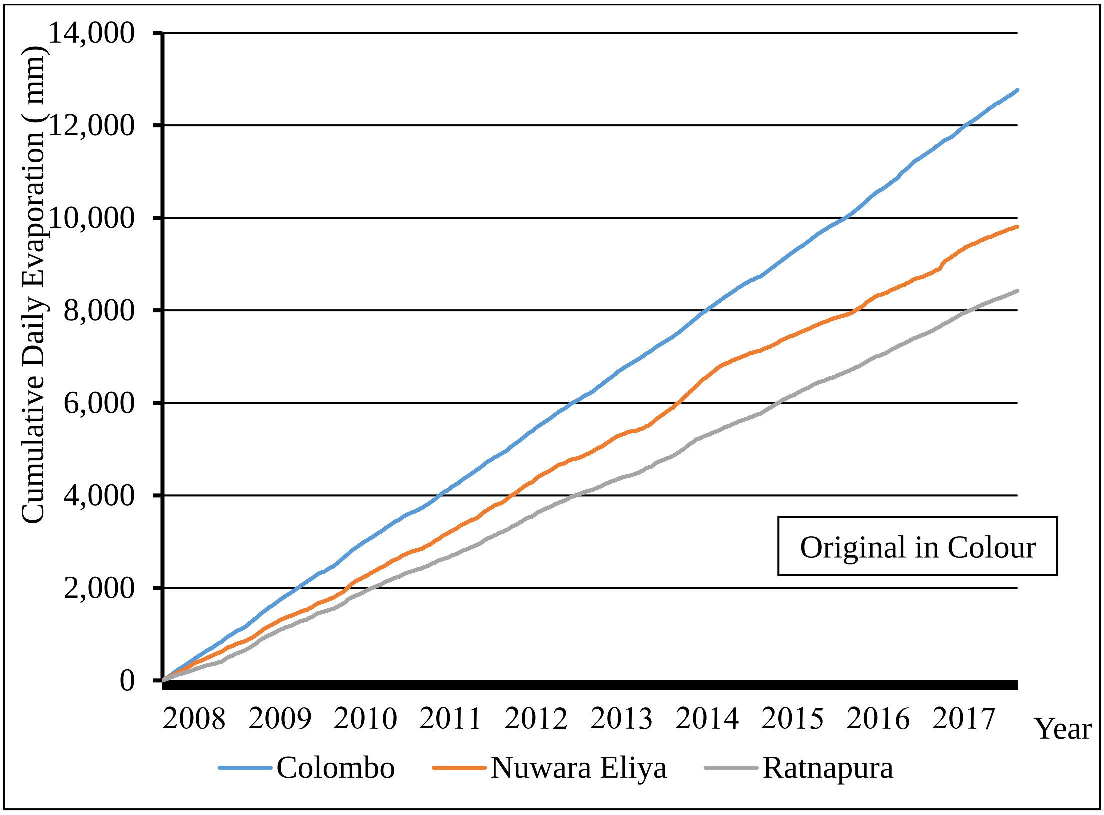


Figure 3-13: Single Mass Curve for Evaporation Data

The technique of a double mass curve is to check the consistency of data of a specific gauge with a number of surrounding gauges which indicates past variations and trends of a particular gauge. The data records of the station may slightly change with time due to changes in the environment of the station. By plotting accumulated annual data at a station against the concurrent mean of cumulative annual values of selected stations which is given the double mass curve of a specific station. The records of the station were adjusted according to the ratio of the slope of the straight line.

The slope of the double mass curve means that a change in the constant of proportionality between the two variables. The break in the slope indicates that the time at which a different phenomenon occurs in the relation between the two quantities. The difference in the slope of the lines on either side of the break in the slope indicates the degree of changes. All seven rainfall gauge stations were used in the test of the double mass curve in this study and each and every record was tested for consistency by plotting it against the mean of cumulative annual of related stations if there is an inconsistency that should be eliminated from the pattern. The same procedure was applied to check daily evaporation data also. If so the data indicate inconsistency of series it should be adjusted according to without process to further analysis.

The double mass curve for rainfall each and every station was plotted to identify the consistency of selected data series which is shown in Figure 3-14. Hanwella group rain gauging station has identified as a slight variation of data series with respect to other gauging stations in which the R^2 value is 0.9971. There could not be analyzed significant inconsistency of data series of rainfall gauging stations in the test of a double mass curve. It was unable to found a break of the slope of the double mass curve of evaporation data shown in Figure 3-15. Therefore, considering all facts regarding double mass curve analysis it was not required to adjust the rainfall data or evaporation data in the present study. Root mean squire (RMS) values of the double mass curve in each rain gauging station are tabulated in Table 3-13.

Table 3-13: RMS values of DMC in each Rain Gauging Station

Specified Gauging Station	R^2 Value of Trend line
Colombo	0.9981
Annfield (CEB)	0.9983
Dunedin	0.9988
Hanwella Group	0.9971
Laxapana	0.9987
Vincit	0.9980
Weweltalawa	0.9988

The tolerance tests set upper or lower limits on the possible values of a data series. It is also important to identify the most appropriate data series and justification is required to the rationale for determining these limits. In the application of tolerance tests, it was able to identified outliers or extremes. An outlier is an observation that deviates significantly from the bulk of the data, which may be due to errors in data collection, or recording, or due to natural causes. In analyzing of present data set of the research it was identified following months reported minimum extremes of rainfall and evaporation data which is tabulated in Table 3-14.

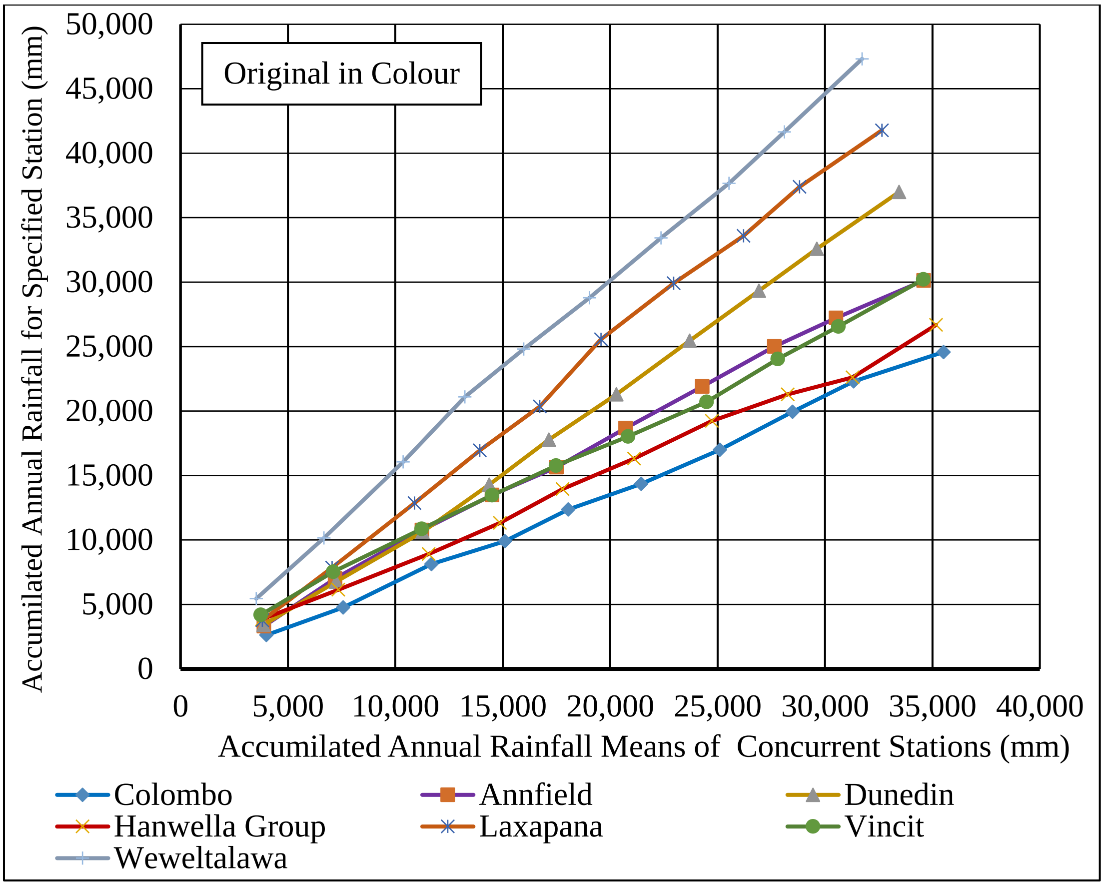


Figure 3-14: Double Mass Curve for Rainfall Data

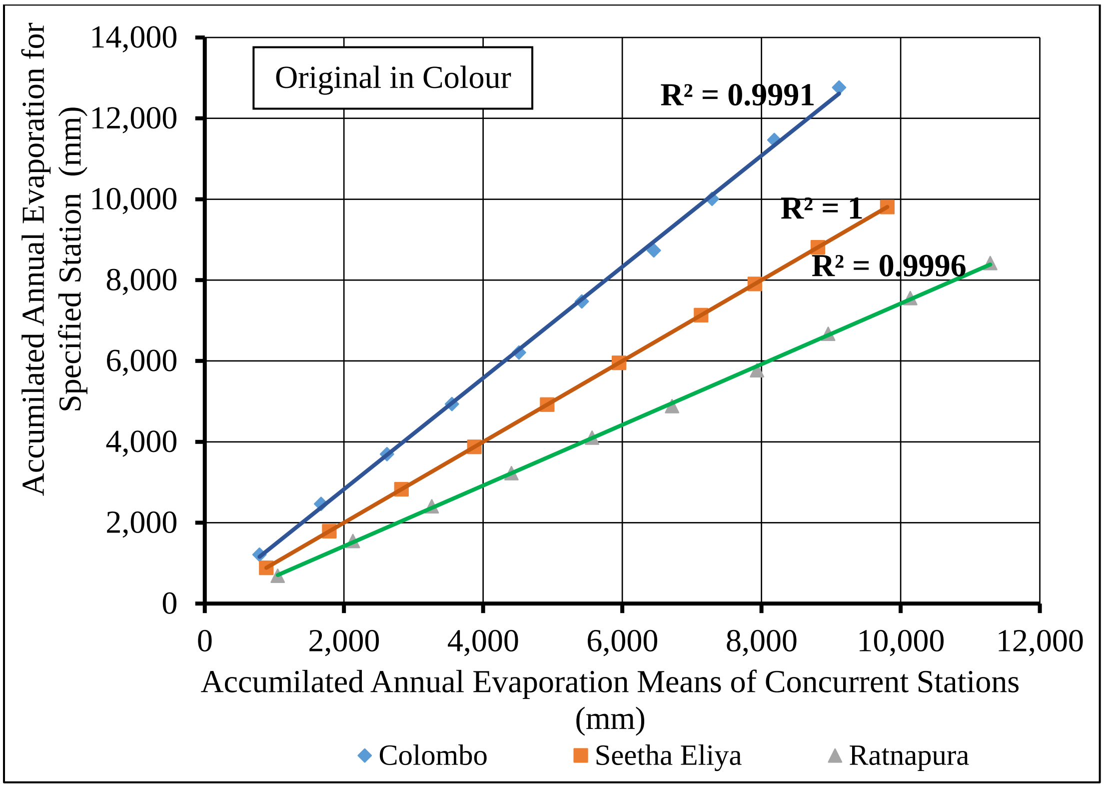


Figure 3-15: Double Mass Curve for Evaporation Data

Table 3-14: Values of Extreme Minimum

Type of Data	Gauging Station	Month	Value / (mm)
Rainfall	Colombo	2009 February	4.9
		2010 February	4.5
		2016 August	1.1
	Annfield (CEB)	2009 February	4.3
	Dunedin	2010 February	8.0
		2013 December	8.2
	Hanwella Group	2014 February	3.2
		2016 August	6.5
	Laxapana	2009 January	5.9
		2010 February	5.0
		2015 January	6.1
	Vincit	2013 December	7.6
Evaporation	Colombo	2009 November	62.2

3.3.4 Visual display assessment of data

The series of data should have to pass accuracy and validity checking before any of the hydrological applications. The accuracy is an indication of the correctness of data degree of applicability is related to the validity of data range. There should be well defined stepwise all acceptable methodology have required to recognizing similar features and the otherwise large number of data unable to process easily. The method of visual inspection is providing precious solutions for the above question. The data series could be arranging to tabulate foam or graphically to the identification of some characteristics (WMO-No-100, 2011). Visual checks were also carried out to find whether there are inconsistencies in data. The response of water level to Thiessen weighted average rainfall was plotted for each year for Nagalagam Street Catchment in Kelani River in Appendix 03.

3.3.5 Thiessen weighted rainfall and evaporation

The distribution of rainfall is not similar throughout the basin which is spatially varying. Even though, the fair method is required to calculate rainfall data with considering spatial distribution which may be average value calculation. The Thiessen rainfall method is an acceptable method for mean depth calculation for rainfall data which is postulated that any point in the basin declares the nearest gauge depth in any bearing (Chow, Maidment, & Mays, 1988). The polygon area under each rain gauge station should be divide by the total area to calculate the weighting factor related to each station. The subscription value of recorded precipitation is obtaining by multiplying of weighting factor with rainfall data (WMO-No.1095, 2012). The rainfall Thiessen polygon plotted map for Nagalagam street catchment in Kelani River is shown in Figure 3-16 and the weighting factor for each gauge is in Table 3-15.

Table 3-15: Rainfall Thiessen Polygon area and Weighting Factor for Nagalagam Street Catchment

Station Name	Thiessen Area (km^2)	Thiessen Weighting Factor
Vincit (Waharaka)	244.251	0.109
Weweltalawa	427.518	0.190
Colombo	182.619	0.081
Annfield (CEB)	223.933	0.100
Dunedin	323.299	0.144
Hanwella Group	508.953	0.227
Laxapana	333.661	0.149

As the same method was applied to produce a map of evaporation Thiessen polygon shown in Figure 3-17 related weighting factor is in Table 3-16. The integration weights are proportional to the areas of each vicinity.

Table 3-16: Evaporation Thiessen Polygon area and Weighting Factor for Nagalagam Street Catchment

Station Name	Thiessen Area (km^2)	Thiessen Weighting Factor
Ratnapura	1235.947	0.551
Seetha Eliya	302.015	0.134
Colombo	706.273	0.315

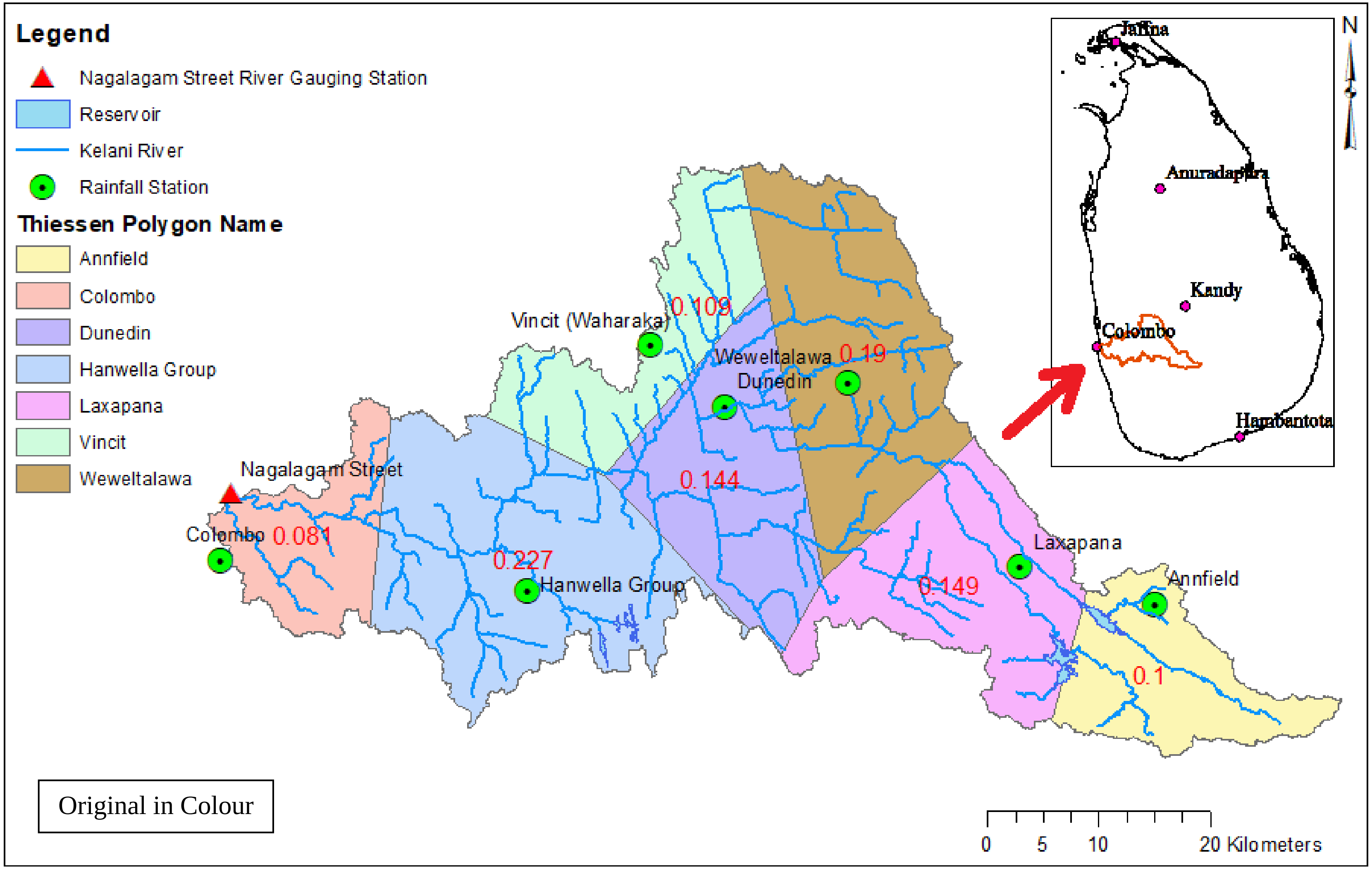


Figure 3-16: Rainfall Thiessen Polygon Map of Nagalagam Street Catchment

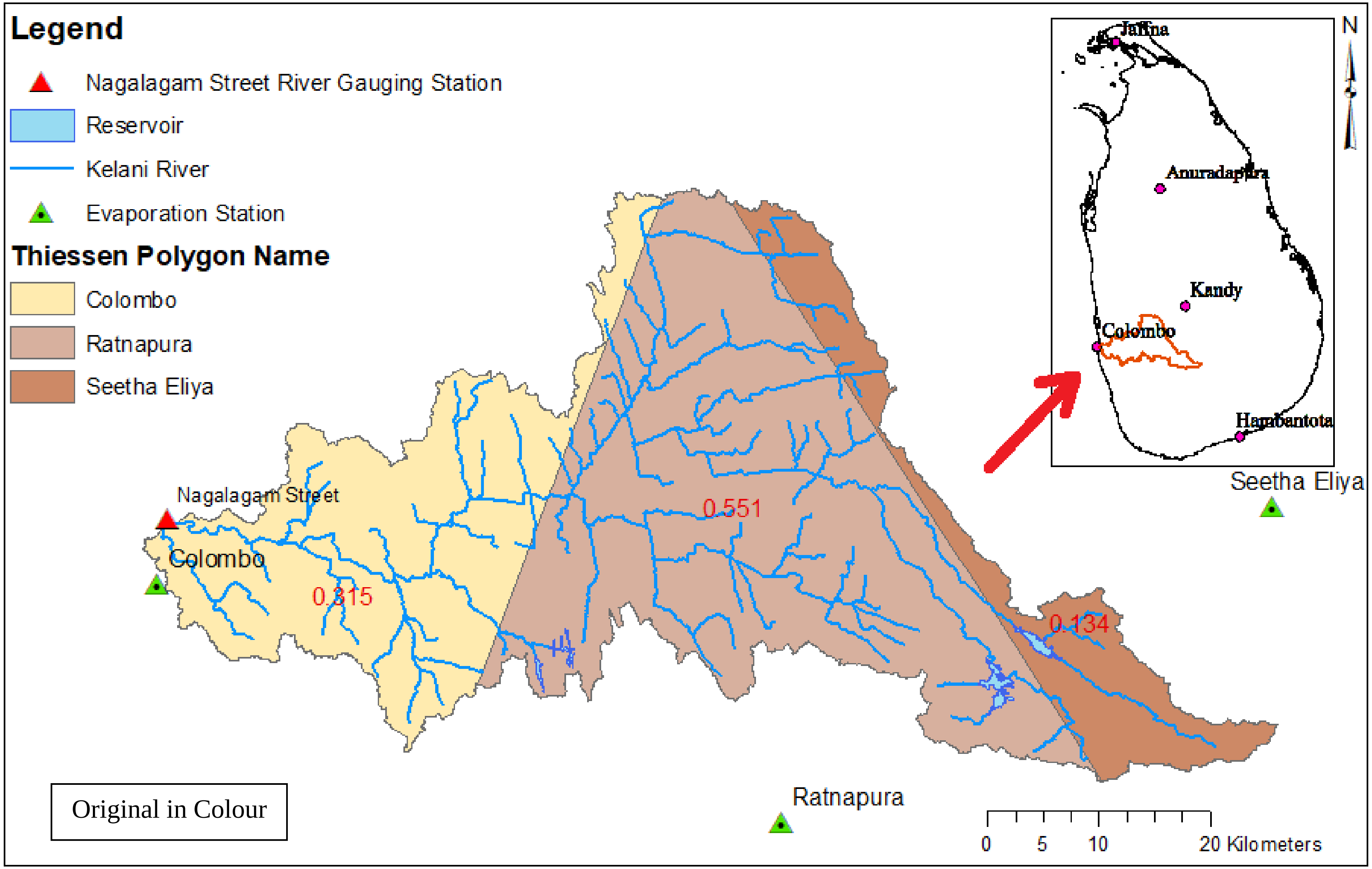


Figure 3-17: Evaporation Thiessen Polygon Map of Nagalagam Street Catchment

4 ANALYSIS AND RESULTS

4.1 Analysis Results of Model Calibration and Validation

The Nagalagam street hydrometric station is a selected location for collecting flow data which is observed data. The model also generated flow data for the same location but the values are not matched with observation data. The calibration process was adopted with Nash-Sutcliffe Coefficient (NASH) as an objective function.

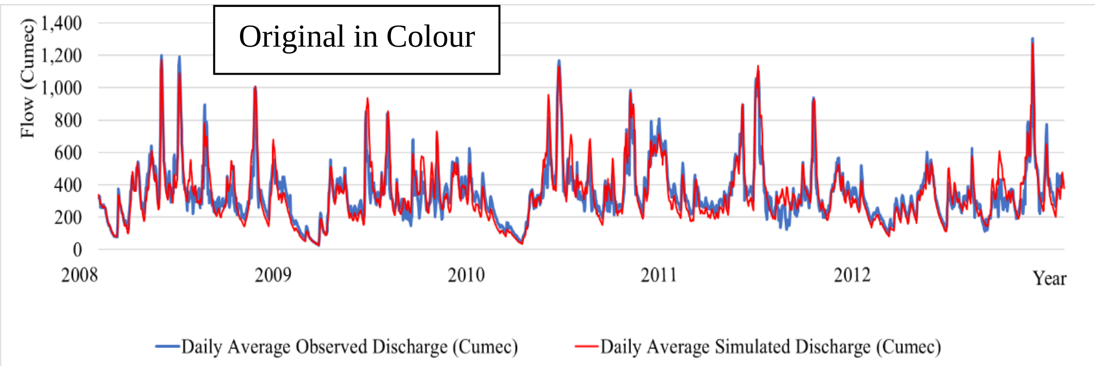


Figure 4-1: Flow hydrograph for observed flow and simulated flow in the calibration stage.

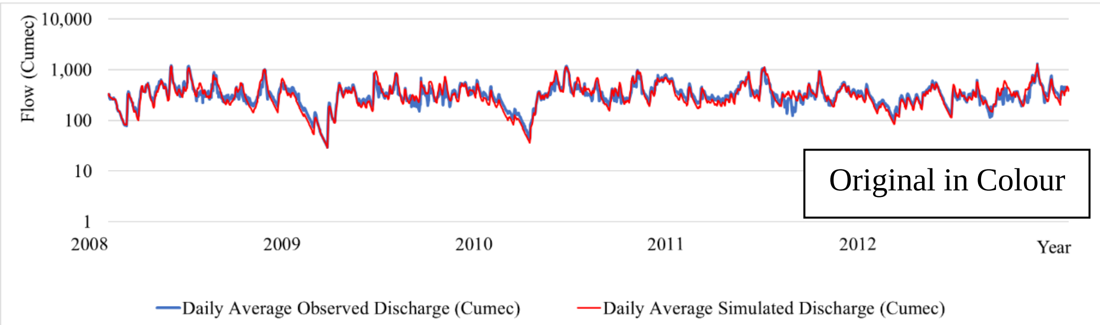


Figure 4-2: Flow hydrograph for observed flow and simulated flow in the calibration stage (Log scale).

The result of NASH equation was calculated as 0.80 in the calibration stage. The flow hydrograph of the calibration stage is shown in Figure 4-1, Figure 4-2 which indicates graphically how much best fit simulated flow with the observed flow with regard to the selected time range. The calibrated discharge variation with Thiessen rainfall is shown in Figure 4-3.

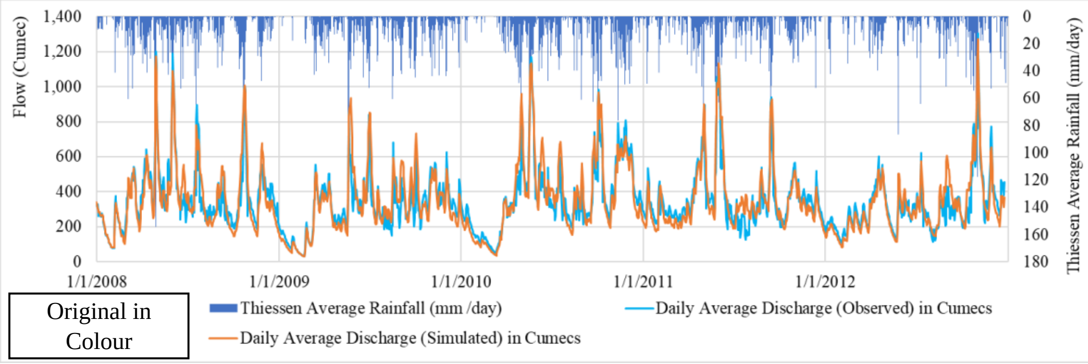


Figure 4-3: The daily average discharge observed and simulated with Thiessen rainfall in the calibration stage.

Bias criterion measures the tendency of a model to underestimate or overestimate the observed discharges which give the relative error for the simulated and observed flow volumes at the basin outlet over the simulation period. The equation is as follows.

$$F = \frac{1}{n}\sum_{i=1}^{n}\left(Q_i - \hat{Q}_i\right) \qquad \text{.....................} (1)$$

Where: i = time step; n = total number of step considered; $\hat{Q}_i$= simulated discharge at i-th time step; Q_i= observed discharge at i-th time step.

The flow duration curve (log) was plotted to identified variation clearly among the simulated flow and observed flow in the range of high, middle, and low discharge. The values of parameters were adjusted until the best fit for both flows. The flow duration curve for the calibration stage is shown in Figure 4-4 and the flow duration curve (log scale) for the calibration stage is shown in Figure 4-5.

The validation stage was executed by using adjusted parameters. The result of NASH (R_{NS}^2) the equation was calculated as 0.89 for the validation stage. As an alternative to numerical verification criteria, graphical verification criteria have been adapted to the identification of quality of fit which is shown in Figure 4-6, Figure 4-7, and Figure 4-8 for validation. The daily average discharge observed and simulated hydrograph with Thiessen rainfall for year 2008 to 2017 annually is shown in Appendix 09.

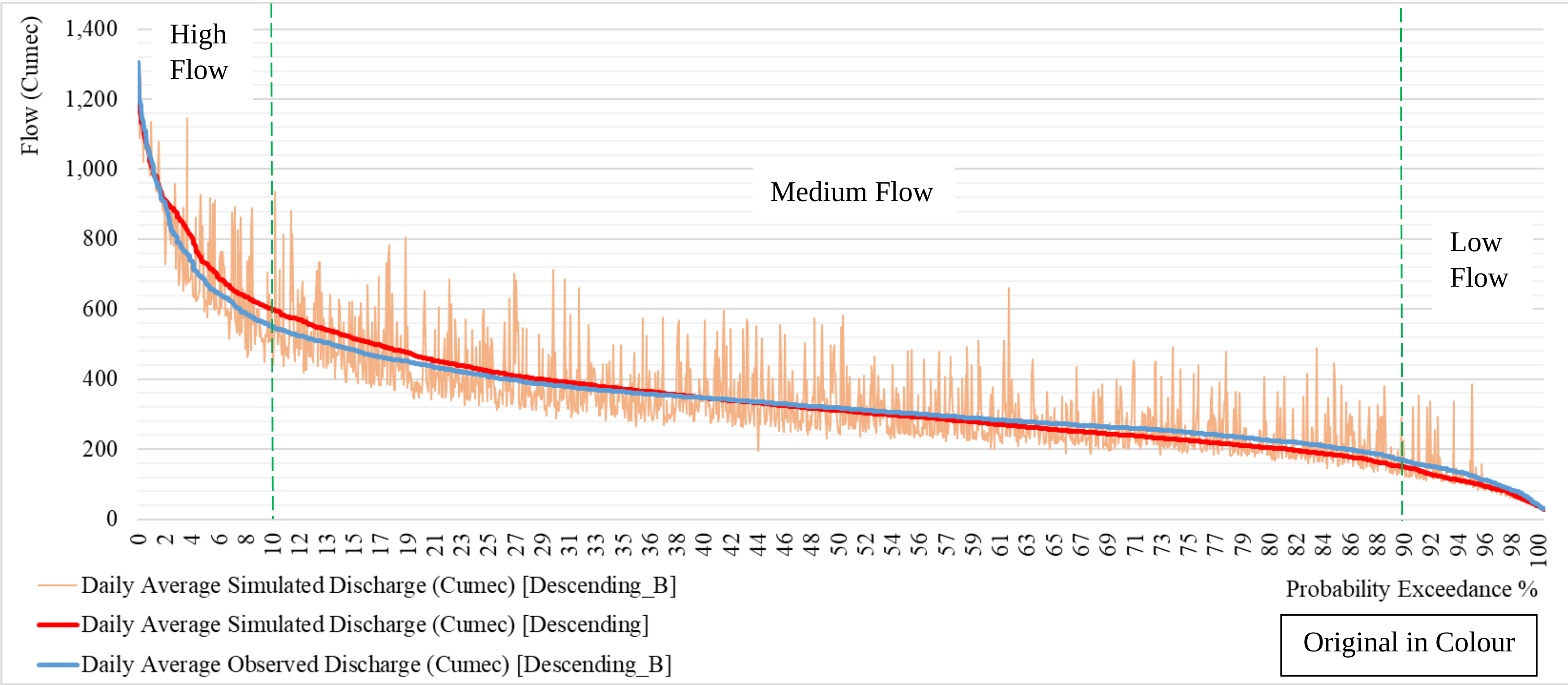


Figure 4-4: The flow duration curves for observed and simulated flows in the calibration stage.

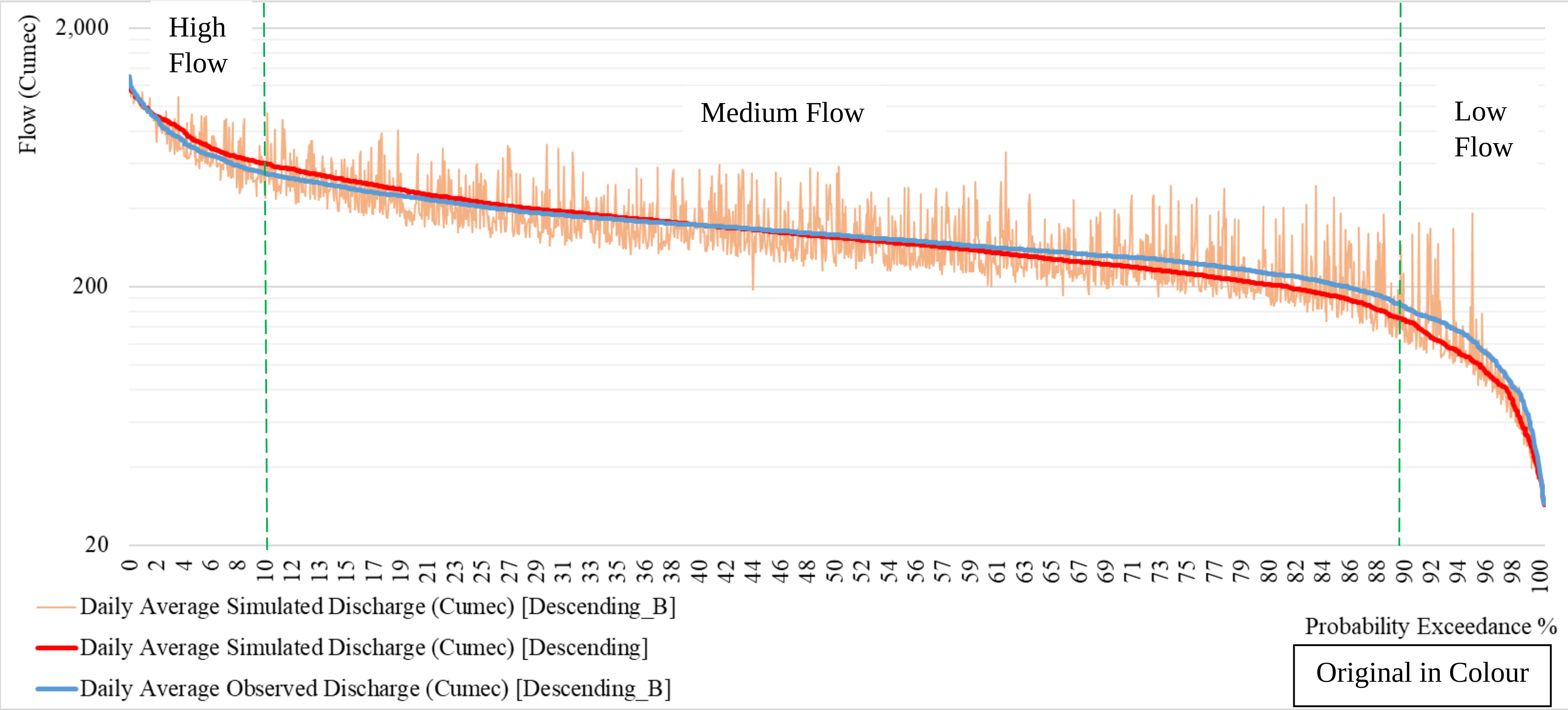


Figure 4-5: The flow duration curves (log scale) for observed and simulated flows in the calibration stage.

Table 4-1: HEC-HMS Model Performance of Streamflow Modelling at different Flow condition for the Calibration stage

Flow condition	Objective Function		
	Nash-Sutcliffe Coefficient (R_{NS}^2)	Percentage Bias (δ_b)	Coefficient of Determination (R^2)
Overall Flow	0.80	0.31	0.83
High Flow	0.93	5.67	0.98
Medium Flow	0.93	0.64	0.99
Low Flow	0.91	14.83	0.99

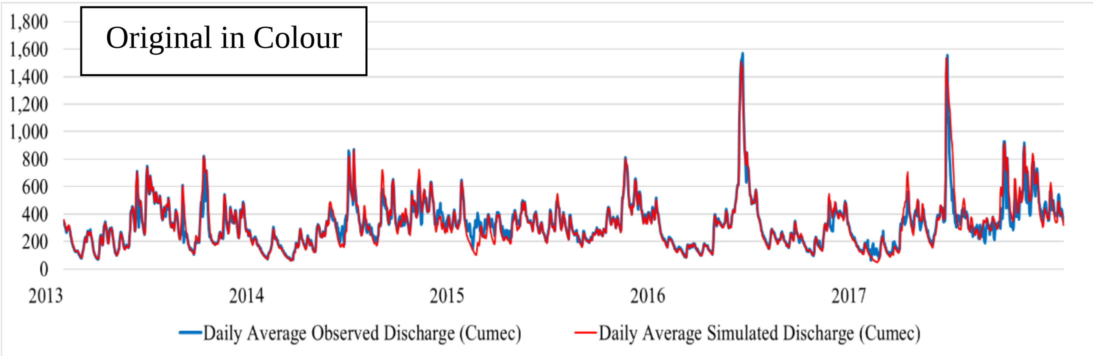


Figure 4-6: Flow hydrograph for observed flow and simulated flow in the validation stage.

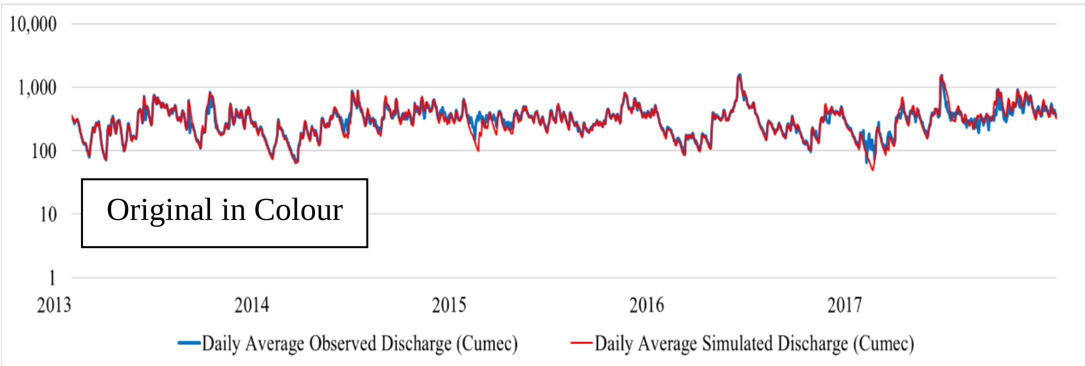


Figure 4-7: Flow hydrograph for observed flow and simulated flow in the validation stage (Log scale).

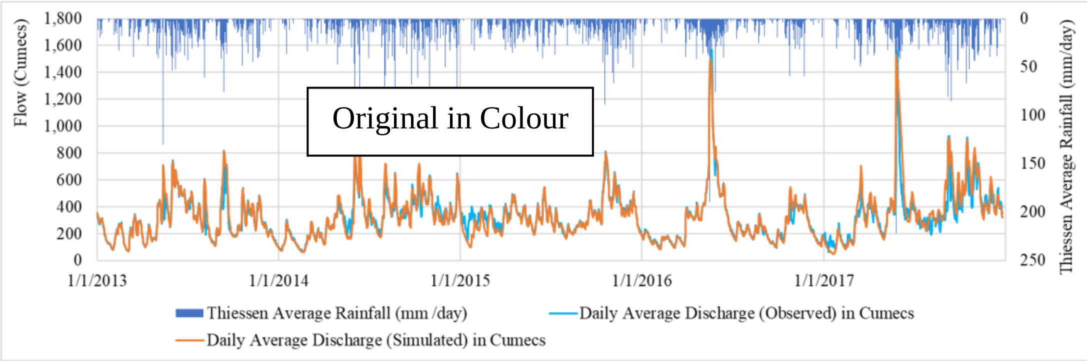


Figure 4-8: The daily average discharge observed and simulated with Thiessen rainfall in the validation stage.

Similarly, the flow duration curve was plotted to identified variation clearly among the simulated flow and observed flow in the range of high, middle, and low discharge for the validation stage also. The resulted from both curves were best fit to each other which are shown in Figure 4-9 and Figure 4-10.

The model flows slightly underestimated of low flows and slightly overestimated middle flow according to the Figures 4-9. There would be a significant change for the simulated streamflow model with respect to the observed flow at validation. The normalized objective function (NOF) and Percentage bias (δ_b) were calculated which is in Table 4.3. The equation as follows.

$$NOF = \frac{1}{\bar{Q}}\sqrt{\frac{1}{n}\sum_{i=1}^{n}(Q_i - \hat{Q}_i)^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\delta_b = \left|\frac{\sum_{i=1}^{n}(\hat{Q}_i - Q_i)}{\sum_{i=1}^{n} Q_i}\right| * 100\% \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where: i = time step; n = total number of step considered; $\hat{Q}_i$= simulated discharge at i-th time step; Q_i= observed discharge at i-th time step; $\bar{Q}$ = mean observed discharge.

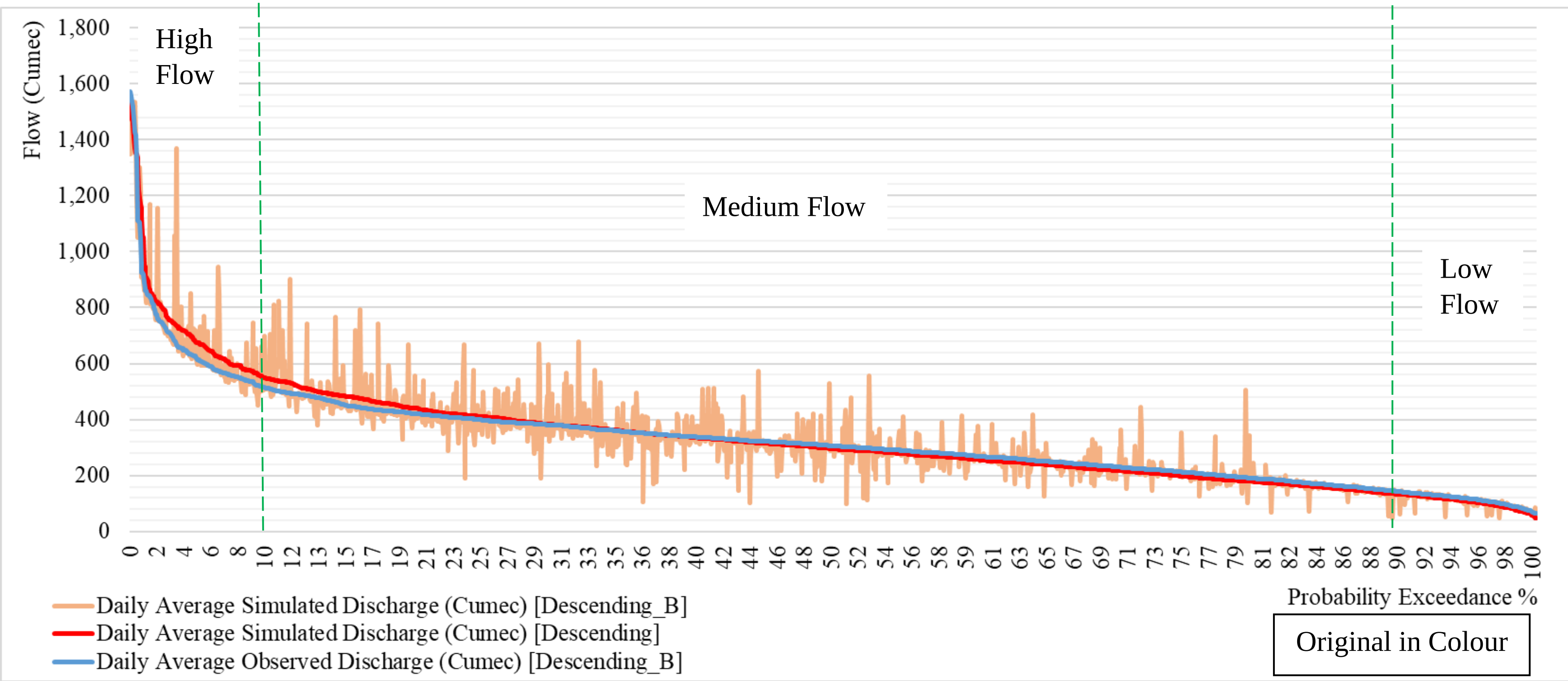


Figure 4-9: The flow duration curves for observed and simulated flows in the validation stage.

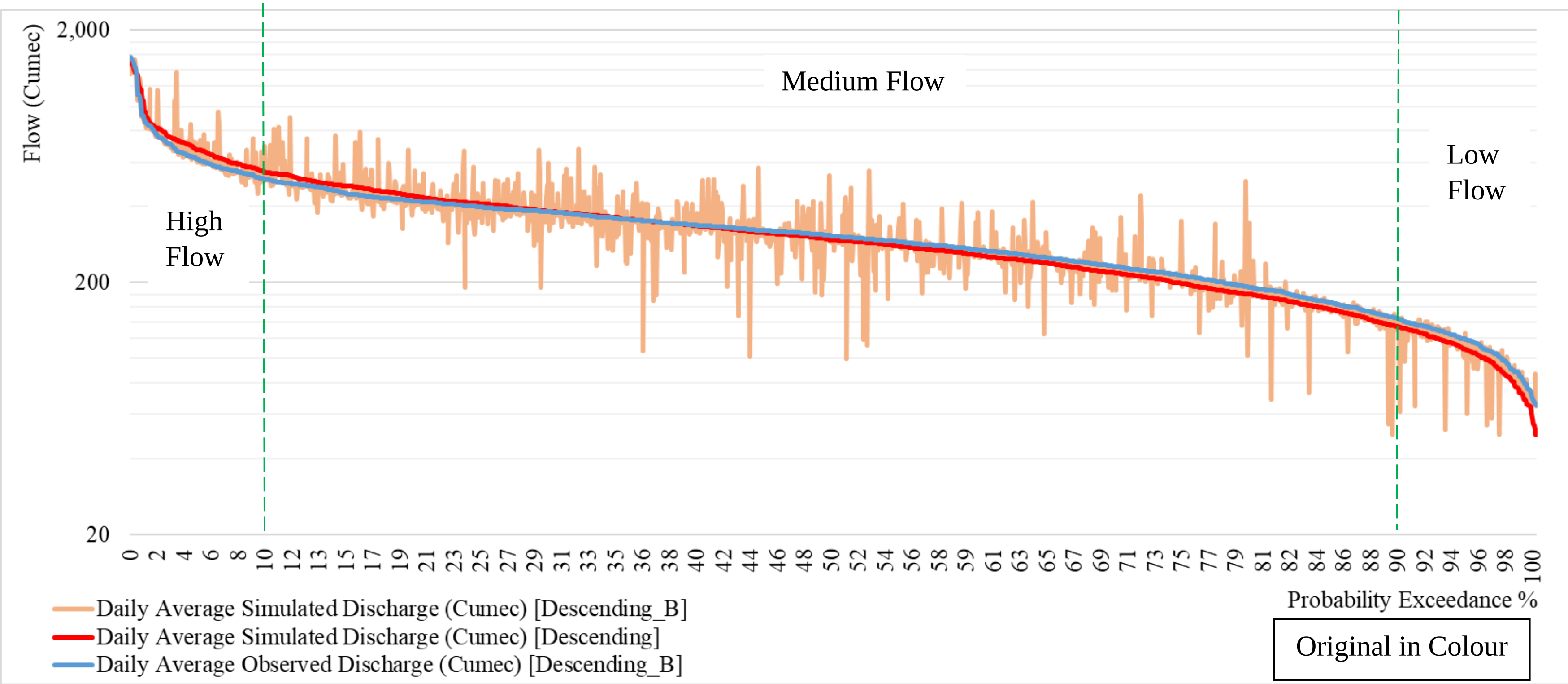


Figure 4-10: The flow duration curves (log scale) for observed and simulated flows in the validation stage.

Table 4-2: HEC-HMS Model Performance of Streamflow Modelling at different Flow condition for the Validation stage

Flow condition	Objective Function		
	Nash-Sutcliffe Coefficient (R^2_{NS})	Percentage Bias (δ_b)	Coefficient of Determination (R^2)
Overall Flow	0.89	0.75	0.90
High Flow	0.98	7.24	0.98
Medium Flow	0.98	0.71	0.99
Low Flow	0.99	8.87	0.99

Figure 4-11,4-12 square plot is indicating model performance with respect to the goodness of fit value (R^2) which is representing the 83.45% for calibration and 90.7% for validation. The Screenshot of HEC-HMS hydrograph comparison related calibrated and validated river model is in Appendix 05.

Table 4-3: HEC-HMS Model Performance of Streamflow Modelling for the Calibration stage and Validation stage

Nagalagam Street Catchment	Nash-Sutcliffe Coefficient (R^2_{NS})	Percentage Bias (δ_b)	NOF
From January 2008 to December 2012	0.80	0.31	0.22
From January 2013 to December 2017	0.89	0.75	0.18

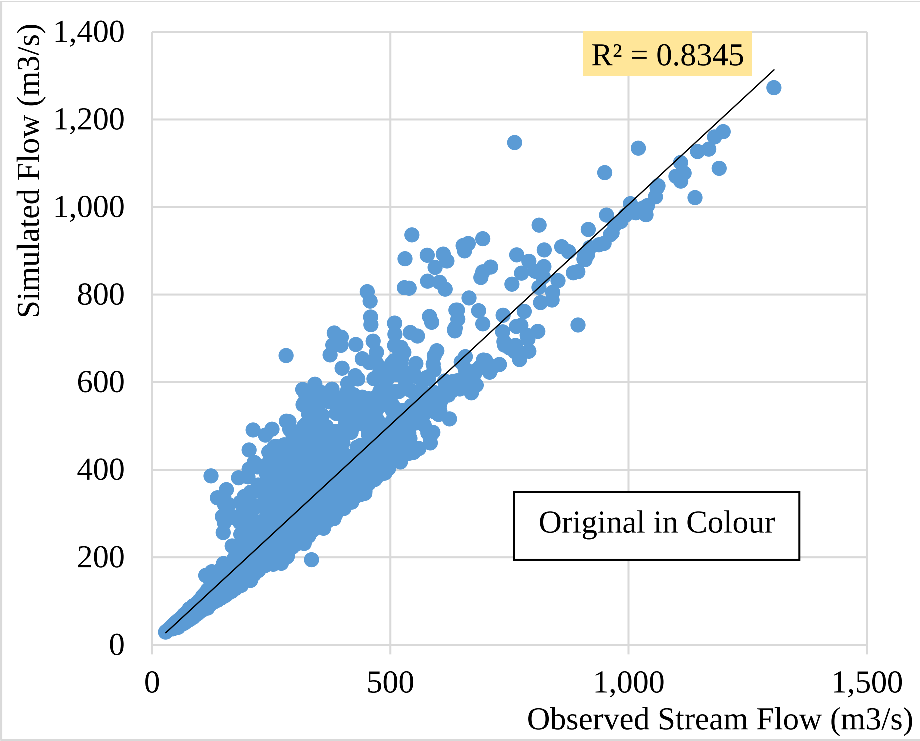


Figure 4-11: Simulated streamflow model performance with respect to the observed streamflow for the calibration stage

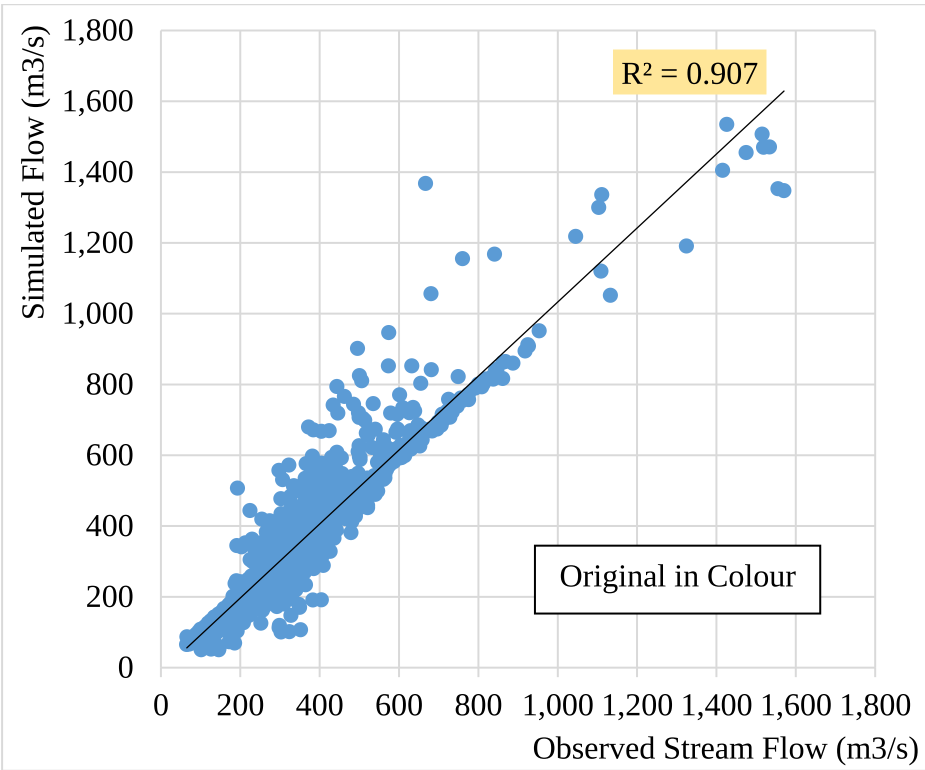


Figure 4-12: Simulated streamflow model performance with respect to the observed streamflow for the validation stage

4.2 Sensitivity Analysis of Calibrated Catchment Model

The sensitivity analysis is used to check to the degree of influence by each and every parameter to the model simulated flow in regarding objective function. The baseflow parameters of initial discharge and initial abstraction were identified as sensitive parameters. The details of modified parameters are in tabulated Table 4-4.

Table 4-4: Result of Sensitivity Analysis

Nagalagam street Catchment	Initial Discharge			Initial Abstraction		
Name of Sub Catchment	Existing Value	New Value	(%) Change	Existing Value	New Value	(%) Change
Kehelgamu	2.23	3.34	50	15.46	10.31	33
Maskeliya	35.32	31.79	10	15.56	23.33	50
Upper Kelani	36.74	36.74	0	14.87	22.30	50
Welihel	23.20	23.20	0	13.97	13.70	2
Gurugoda	38.00	43.70	15	13.08	12.94	1
Ritigaha	26.35	17.57	33	13.99	16.09	15
Magal	52.90	53.11	0	16.47	16.47	0
Panapura	25.50	25.61	0	13.99	11.41	18
Ambalanpiti	14.91	22.36	50	14.11	13.83	2
Getahetta	6.03	6.03	0	13.80	13.52	2
Seethawaka	13.56	13.68	1	13.91	20.87	50
Upper Middle Kelani	12.45	12.45	0	13.80	13.66	1
Pugoda	7.01	7.01	0	12.69	12.69	0
Kalatuwawa	15.75	15.75	0	15.78	15.78	0
Pusweli	9.29	9.11	2	13.59	13.45	1
Pallewela	7.40	7.25	2	13.33	19.99	50
Lower Middle Kelani	6.56	6.62	1	15.96	15.51	3
Biyagama	8.81	8.70	1	12.78	12.52	2
Lower Kelani	2.25	3.38	50	18.75	19.66	5
Kolonnawa	6.25	6.27	0	16.61	11.07	33

According to Table 4-4, the initial discharge was increased by 50%, initial abstraction increased by 50% most of the sub-catchment, and some sub-catchment increment was reported as 1%, 2% with respect to the existing baseflow and loss parameters. The calibrated HEC-HMS model was used to evaluate the antecedent rainfall scenario for streamflow generation in Nagalagam street catchment.

4.3 Scenario Identification Basis

The antecedent precipitation is precipitation which occurs before the specified rainy date. The basis of definition and notations has been developed as follows which is in Table 4-5.

Table 4-5: Notation of Antecedent rainfall

Description	Notation	Measure Name
0 Day Antecedent Rainfall	A0	Dry
1 Day Antecedent Rainfall	A1	Dry
2 Day Antecedent Rainfall	A2	Dry
3 Day Antecedent Rainfall	A3	Intermediate Wet
4 Day Antecedent Rainfall	A4	Intermediate Wet
5 Day Antecedent Rainfall	A5	Intermediate Wet
6 Day Antecedent Rainfall	A6	Wet
7 Day Antecedent Rainfall	A7	Wet
8 Day Antecedent Rainfall	A8	Wet
9 Day Antecedent Rainfall	A9	Highly Wet
10 Day Antecedent Rainfall	A10	Highly Wet

The rainfall scenario identified as an event of particular year which is noted "Enumber-Year". Eg:-E1-2008. The rainfall of that scenario is noted as "Rf-Enumber-Year" and the cumulative flow of Nagalagam street is noted as "Flow-Enumber-Year". Eg:-Rf-E1-2008, Flow-E1-2008. The increment of precipitation with respect to the first day of the scenario selected is noted as "Rf-In-Enumber-Year" and flow increment "Flow-In- Enumber-Year".

4.4 Scenario Analysis and Results

Quantity of Thiessen rainfall and related flow is tabulated for arbitrary selected ten days according to the model simulated results. The graph of the event no E1-2008 is shown in Figure 4-13.

Table 4-6: Thiessen rainfall and simulated flow for event E1-2008

Date	Notation	Thiessen rainfall (mm)	Simulated Flow (Cumec)
2/5/2008	A0	0.00	81.6
2/6/2008	A1	41.00	144.6
2/7/2008	A2	36.23	276.5
2/8/2008	A3	10.84	335.1
2/9/2008	A4	8.26	333.9
2/10/2008	A5	3.40	312.2
2/11/2008	A6	3.84	286.6
2/12/2008	A7	15.87	278.5
2/13/2008	A8	5.27	266.0
2/14/2008	A9	2.81	242.6
2/15/2008	A10	6.84	229.2

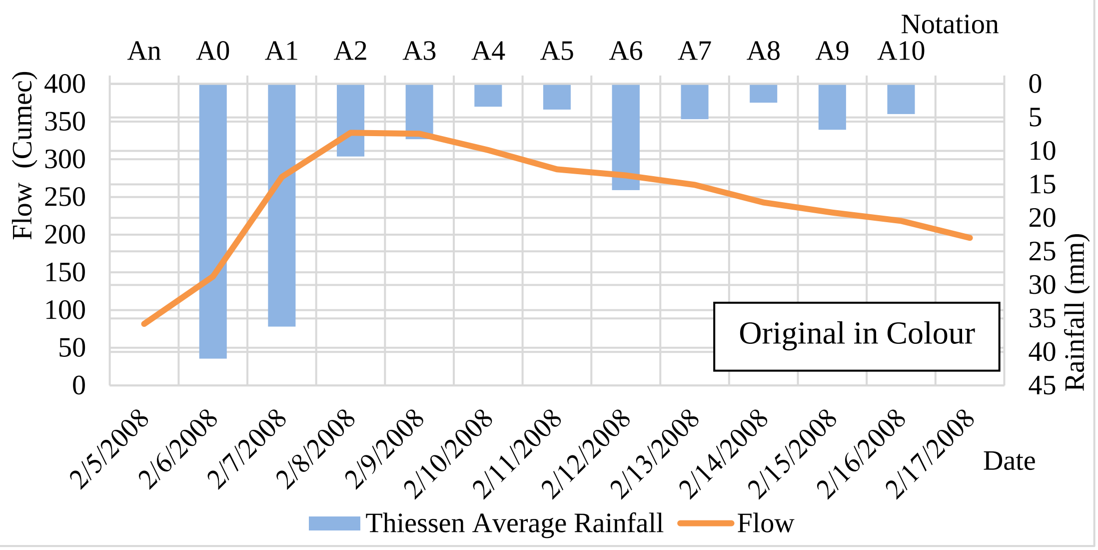


Figure 4-13: The event No E1-2008

According to the graph, five days after the rainfall (A5) is recoded below 4mm and flow is recoded above 310 m^3/s. The second-day rainfall is 41mm and flow 145 m3/s. After five days of rainfall started which is noted as A5 even though rainfall is lesser value flow is higher value with respect to the second day.

Simulated flow concerning Thiessen rainfall and increment of rainfall, flow with respect to the first day of rainfall (A0) is graphed for each and every scenario form year 2008 to 2017 which are shown in Figure 4-14 to 4-34 and Appendix 08.

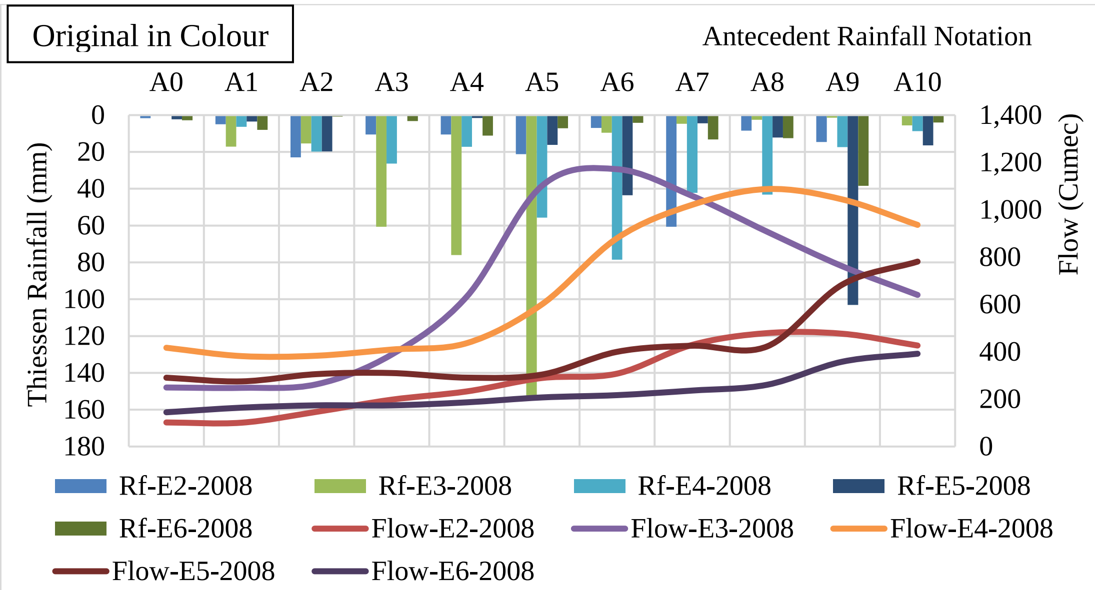


Figure 4-14: Simulated flow and Thiessen rainfall for the year 2008

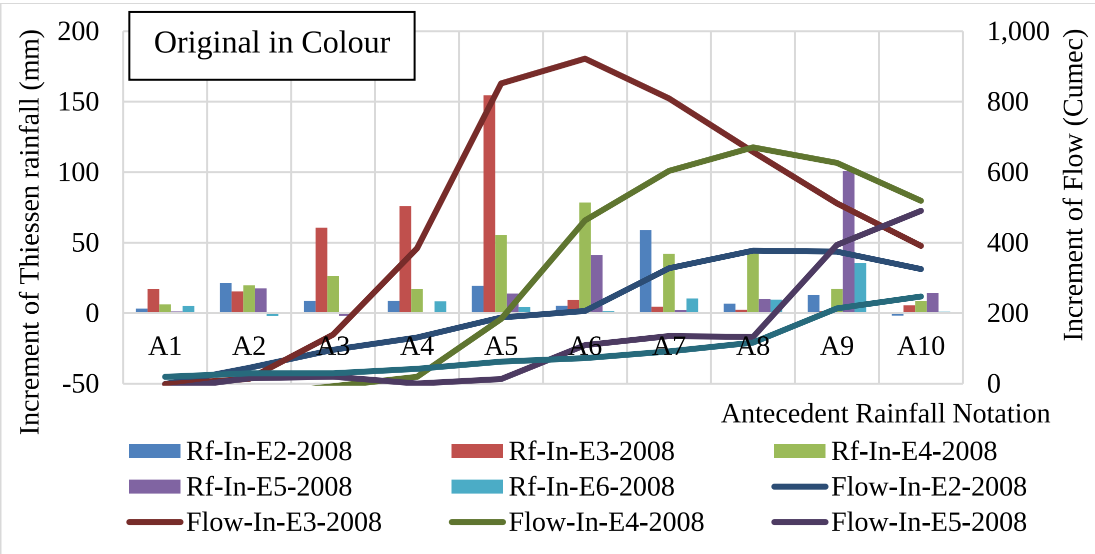


Figure 4-15: Increment of Simulated flow and Thiessen rainfall for the year 2008

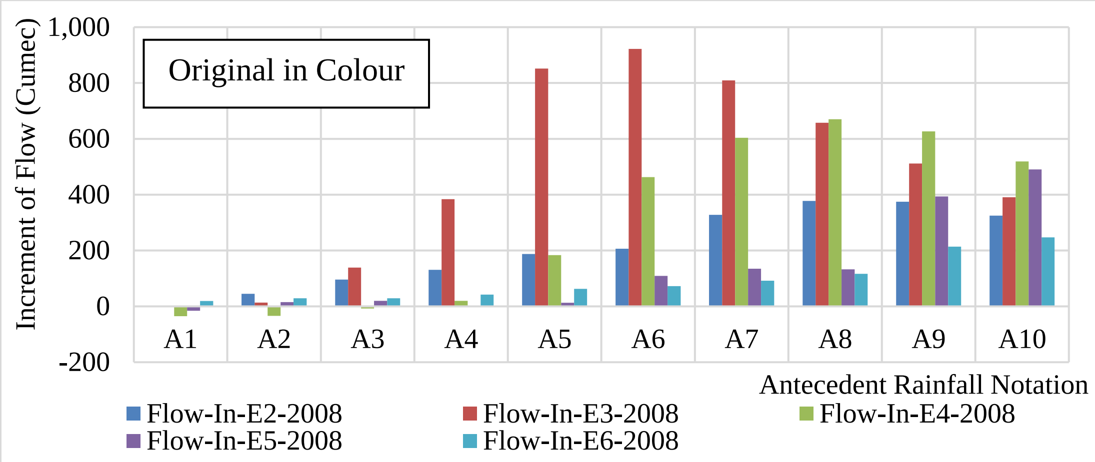


Figure 4-16: Increment of simulated flow for the year 2008

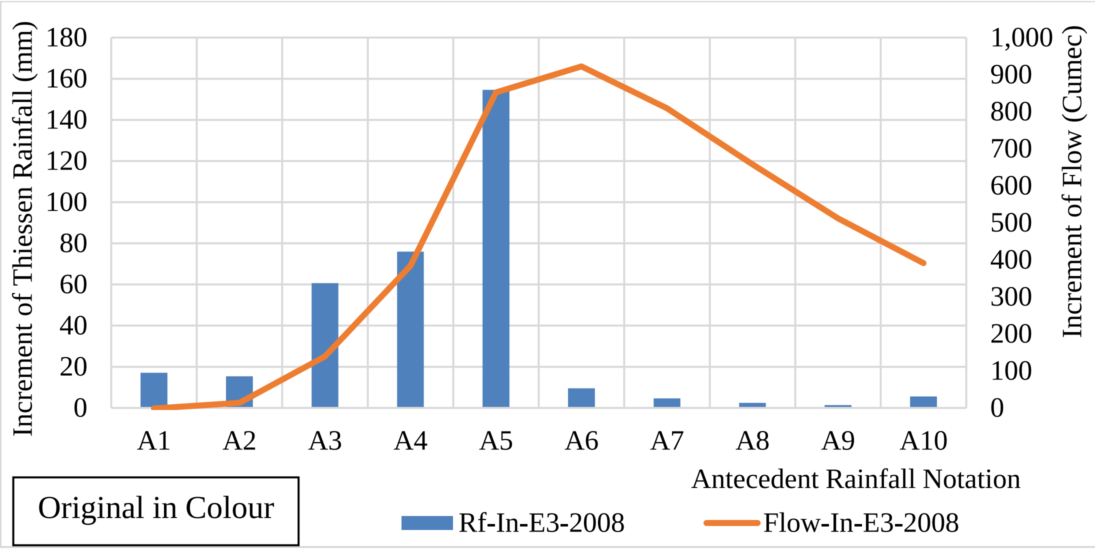


Figure 4-17: Increment of simulated flow and Thiessen rainfall for scenario E3-2008

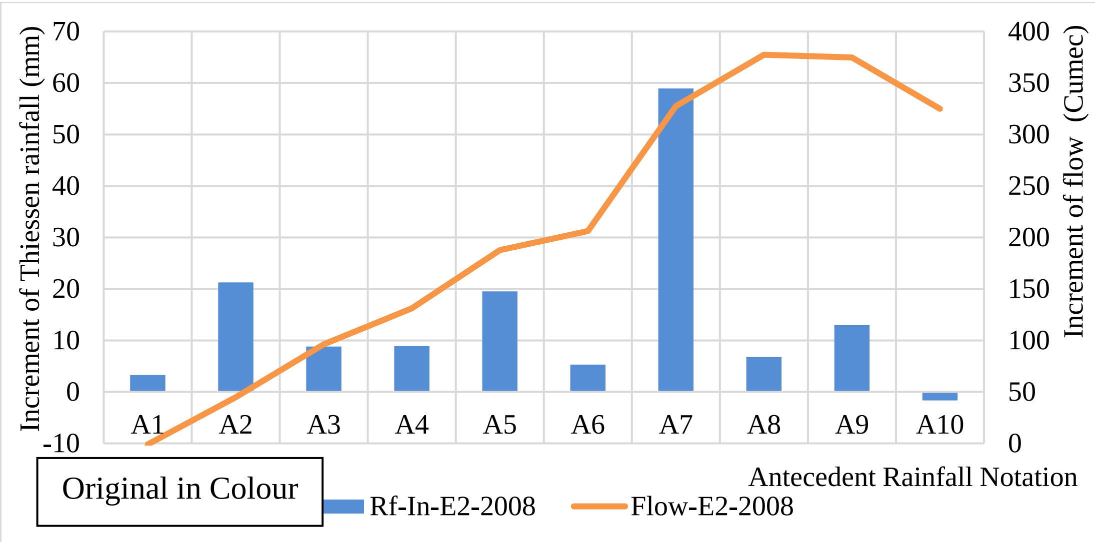


Figure 4-18: Increment of simulated flow and Thiessen rainfall for scenario E2-2008

It was noticed rainfall continuously increased until the seventh day from start date and decreased as same as flow increased and decreased. The highest valve of rainfall was reported at A8 and the negative increment value was reported at tenth-day. But the recoded flow increment value was higher than A1 according to scenario E2-2008 in Figure 4-16,4-18. The recorded rainfall increment was more than 150 mm at the date A5 and flow increment was also higher with comparing initial dates according to the scenario E3-2008 which is shown in Figure 4-16,4-17. Figure 4-16 is representing all scenarios of flow increment for the year 2008 which is outwardly observed flow increment is positive all for the scenario and percentage increment of flow 50% to 350% with respect to 5-day antecedent rainfall.

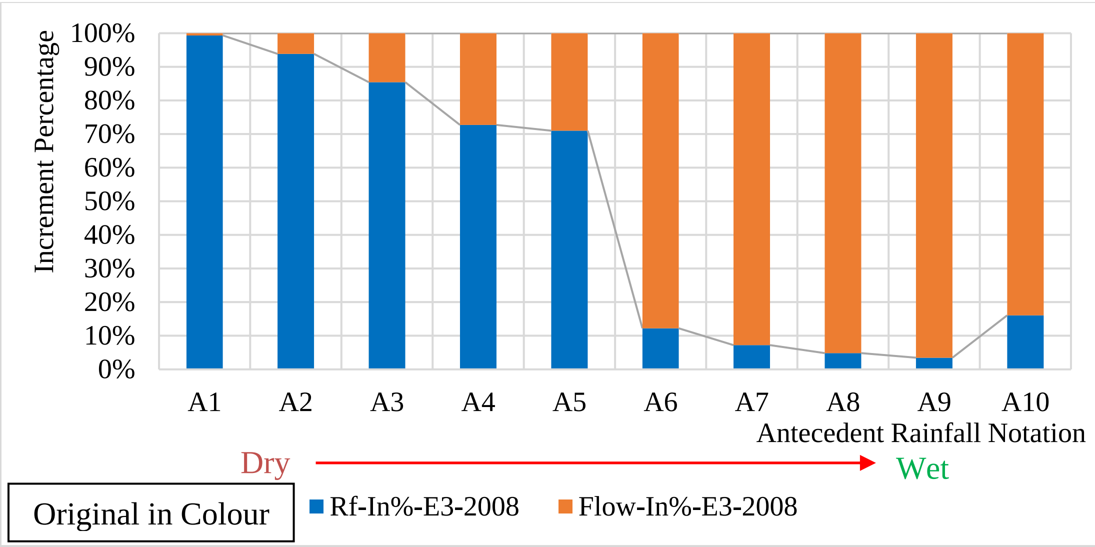


Figure 4-19: Percentage increment of simulated flow and Thiessen rainfall for scenario E3-2008

The percentage of increment rainfall and flow with respect to the A0 is shown in Figure 4-19 for scenario E3-2008. It is conspicuously observed percentage of rainfall has been decreased and simultaneously, the flow has been increased when the ground wetness was changing from dry to wet.

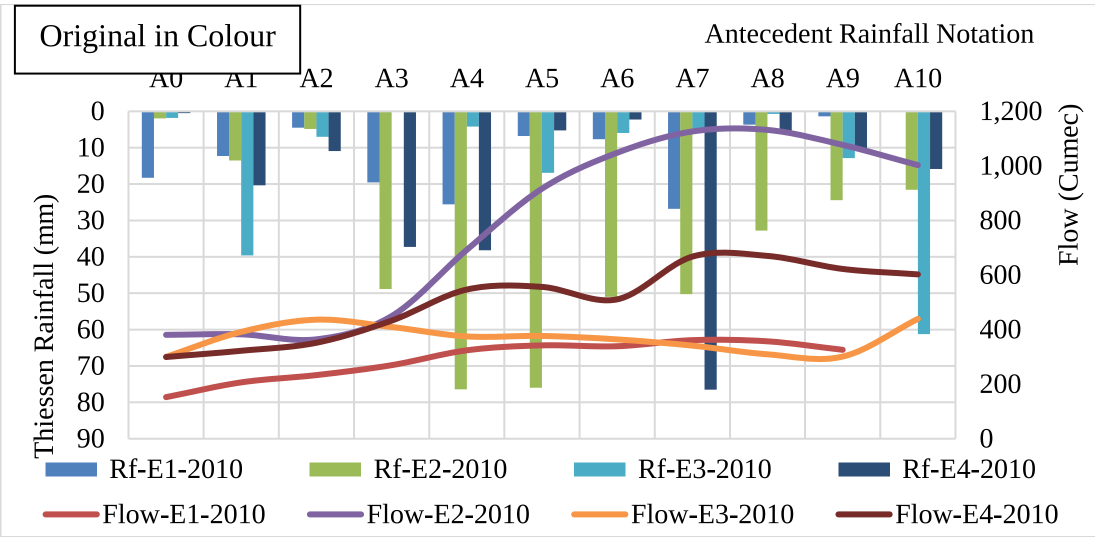


Figure 4-20: Simulated flow and Thiessen rainfall for the year 2010

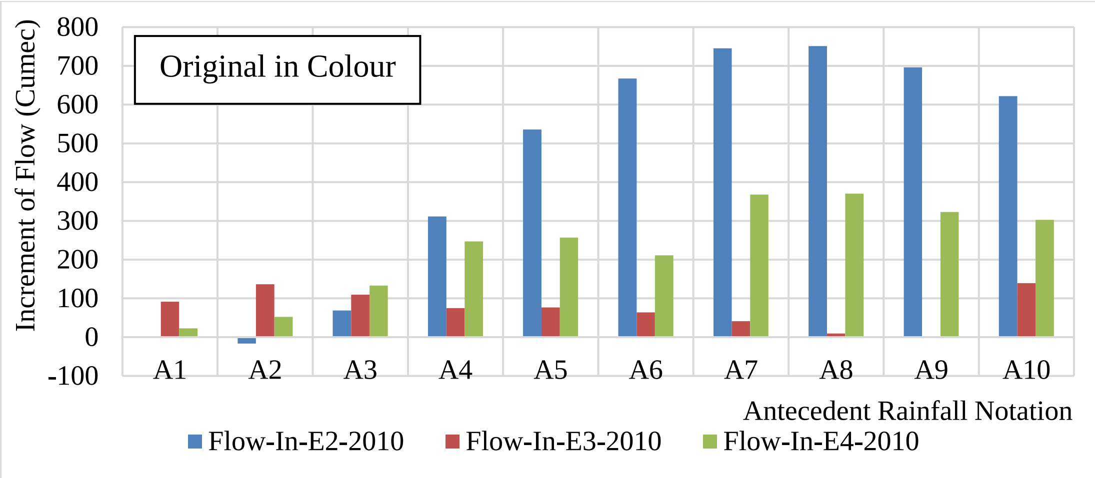


Figure 4-21: Increment of simulated flow for the year 2010

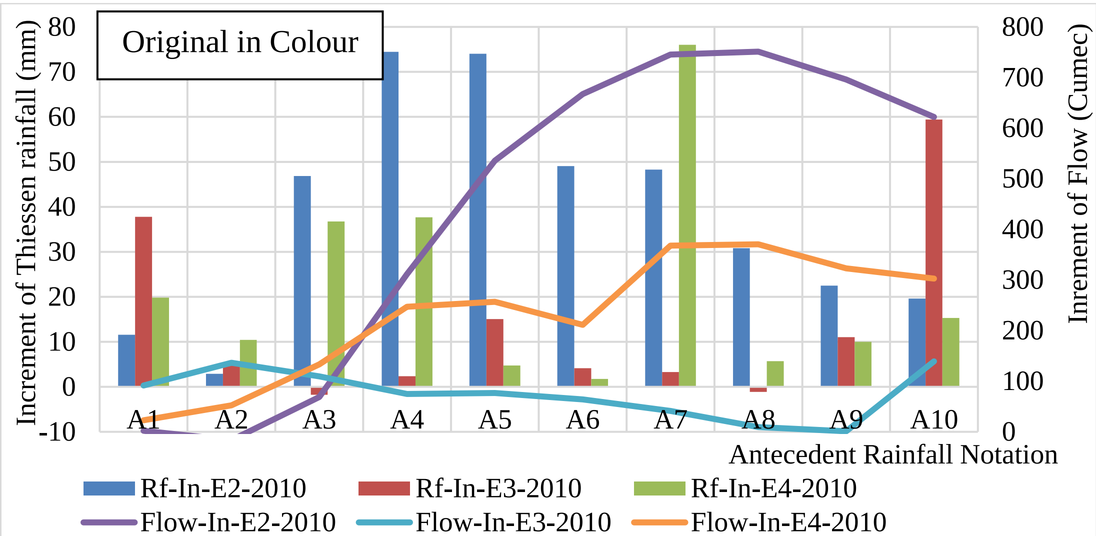


Figure 4-22: Increment of simulated flow and Thiessen rainfall for the year 2010

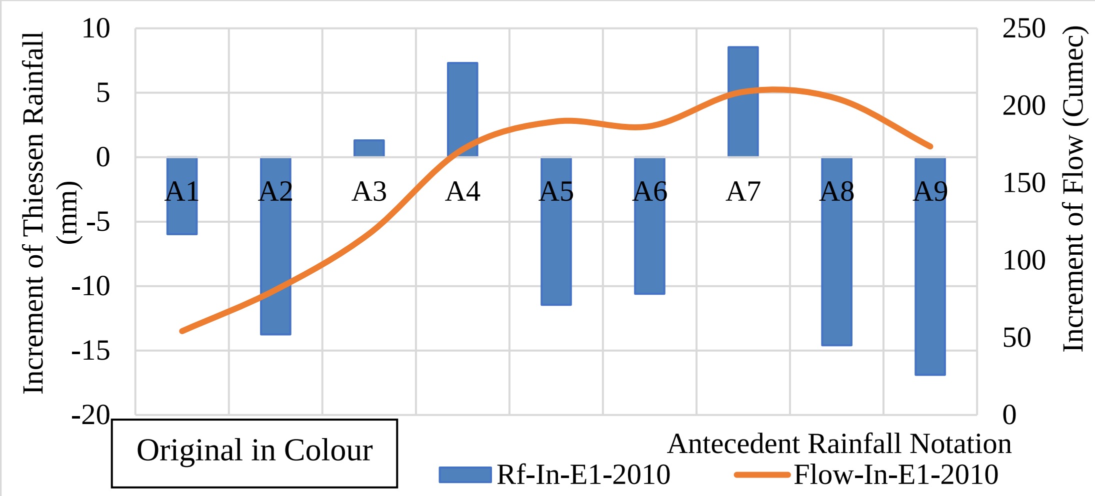


Figure 4-23: Increment of simulated flow and Thiessen rainfall for scenario E1-2010

Even though calculated rainfall increment was negative up to A7 and the flow increment was increased according to the scenario E1-2010 which is shown in Figure 4-23. Figure 4-21 is representing all flow scenarios for the year 2010. The flow increment was increased with the number of rainy days for all scenarios.

The percentage of increment rainfall and flow with respect to the A0 is shown in Figure 4-24 for scenario E4-2010. It was the patently observed percentage of rainfall increment that has been decreased and flow increment has been increased until date A6. The increment percentage of rainfall was increased gradually by 30% and similarly, the flow increment percentage was decreased.

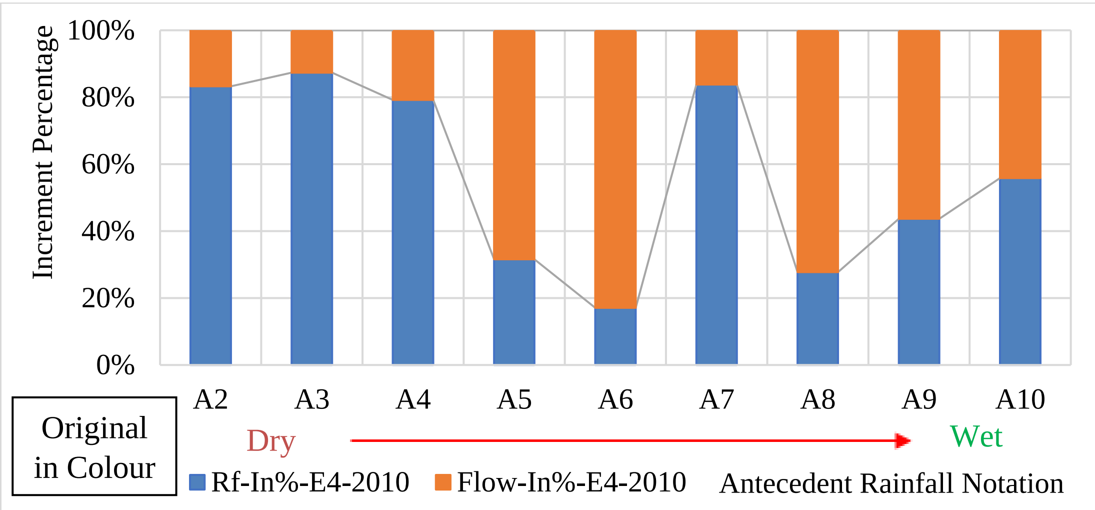


Figure 4-24: Percentage increment of simulated flow and Thiessen rainfall for scenario E4-2010

In the selected areas, where streams do not often go to dry, base flow in the form of groundwater discharge, at the beginning of a storm it is small flow and it is continuously increased if the storm is increased flow is further increased with help of prevailing catchment moisture. The antecedent rainfall scenario for the year 2013 is shown in Figure 4-25,4-26.

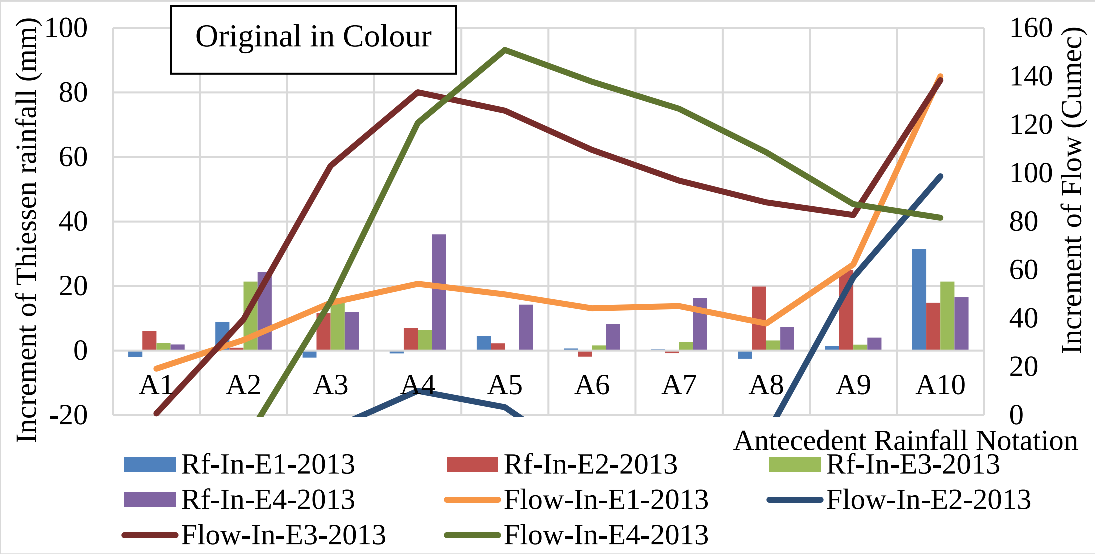


Figure 4-25: Increment of simulated flow and Thiessen rainfall for the year 2013

The rainfall increment was not much observed in A5, A6 stages and also flow increment was reduced but the amount of decrease is lesser then the rainfall because of rainfall influence of previous days.

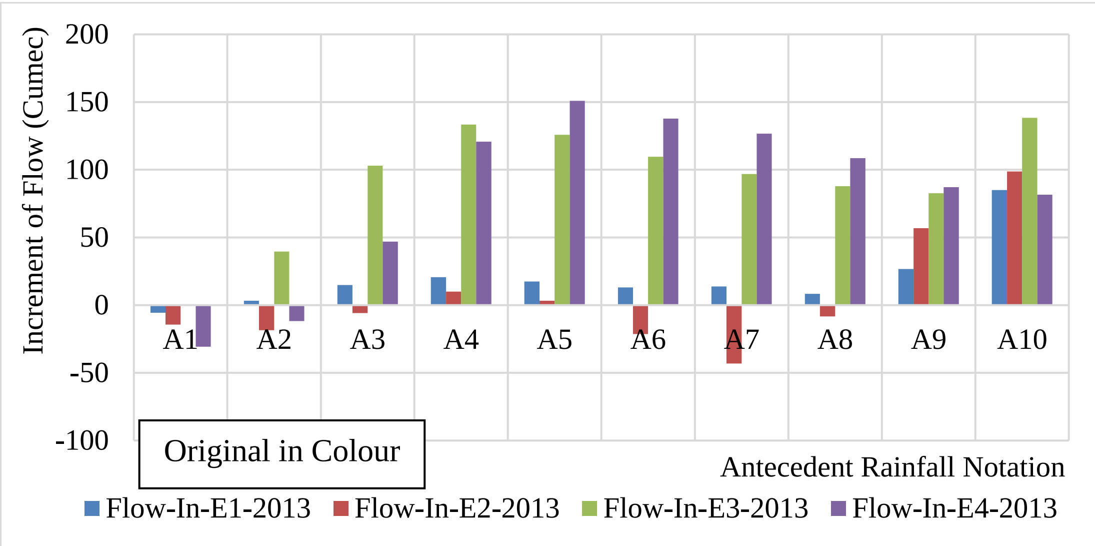


Figure 4-26: Increment of simulated flow for the year 2013

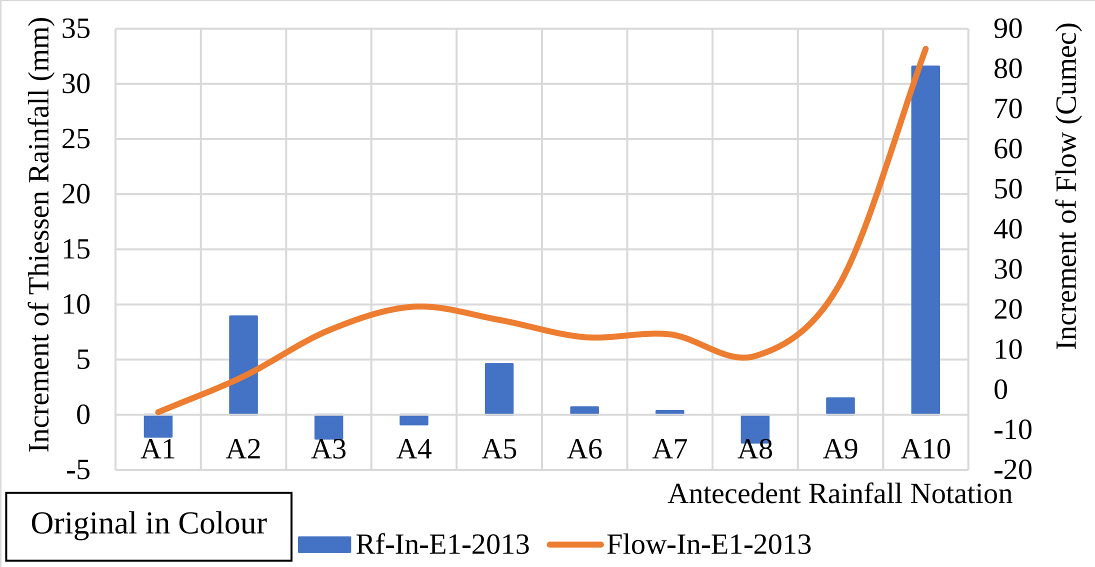


Figure 4-27: Increment of simulated flow and Thiessen rainfall for scenario E1-2013

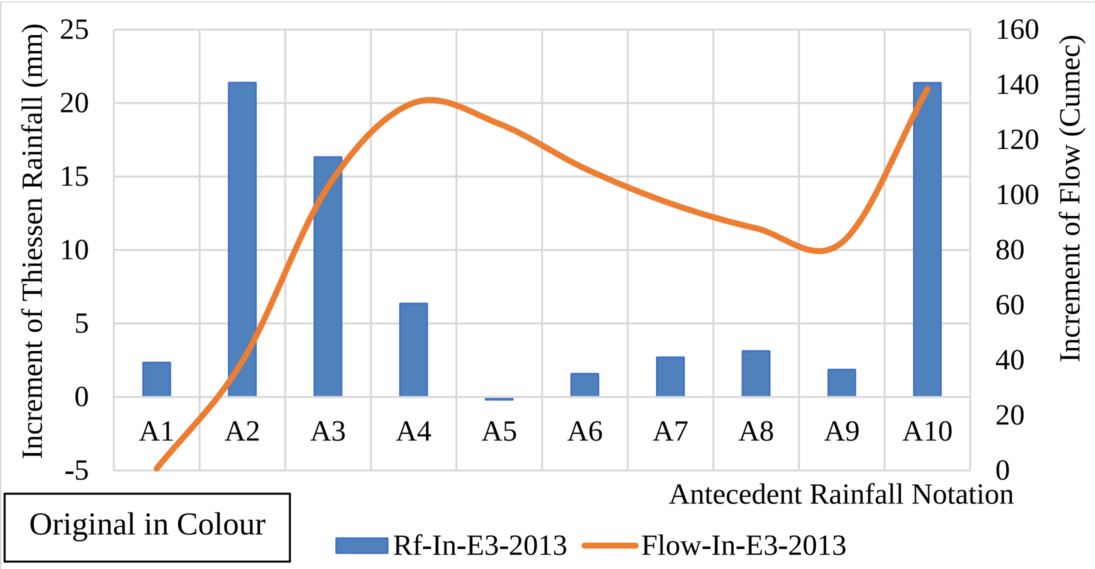


Figure 4-28: Increment of simulated flow and Thiessen rainfall for scenario E3-2013

The minus rainfall increment was observed at stages A1, A3, and A4 also small increment at A6 and A7 according to scenario E1-2013 shown in Figure 4-27. Due to the antecedent condition of catchment flow volume is raised. Figure 4-28 is shown scenario E3-2013 which is indicating the second highest flow at stage A4, but rainfall increment is lesser than A2. The flow variation is happening due to the effect of daily rainfall and prevailing flow. At A10 stage rainfall was highest recorded as same as the flow was highest due to prevailing catchment condition and rainfall increment.

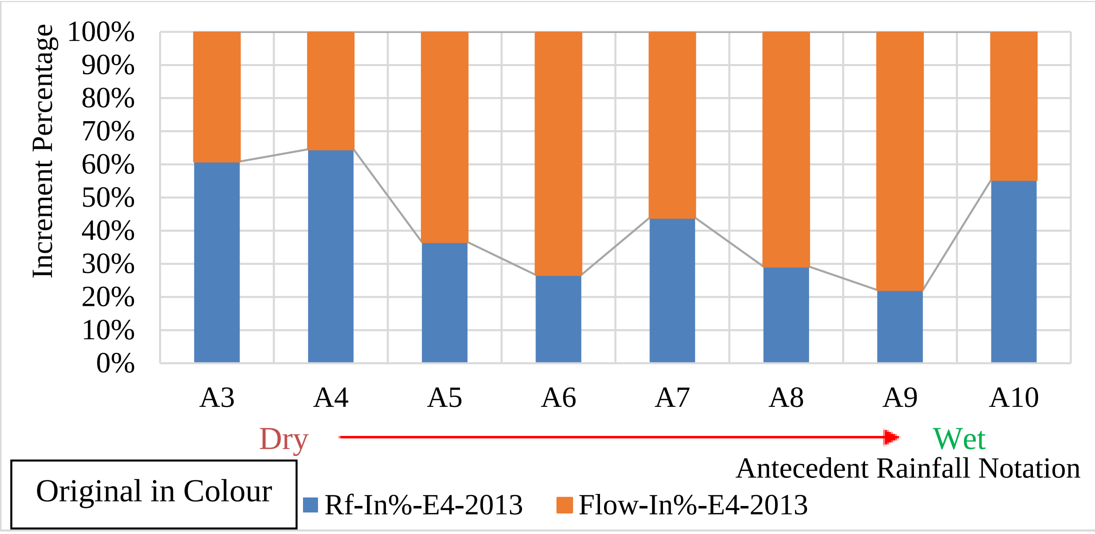


Figure 4-29: Percentage increment of simulated flow and Thiessen rainfall for scenario E4-2013

The increment percentage of rainfall was decreased by 40 % from A3 to A9 and flow increment was increased as same. From A6 to A7 the percentage of rainfall increment slightly increased and then decreased. The flow increment percentage behaviour is observed inverse of rainfall increment percentage. The related detail graph is shown in Figure 4-29 for scenario E4-2013.

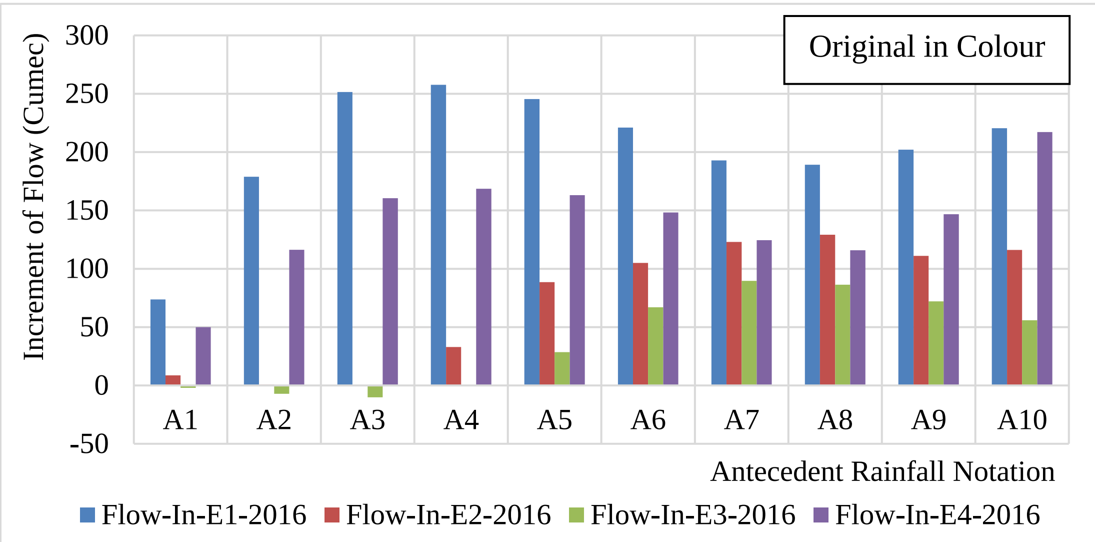


Figure 4-30: Increment of simulated flow for the year 2016

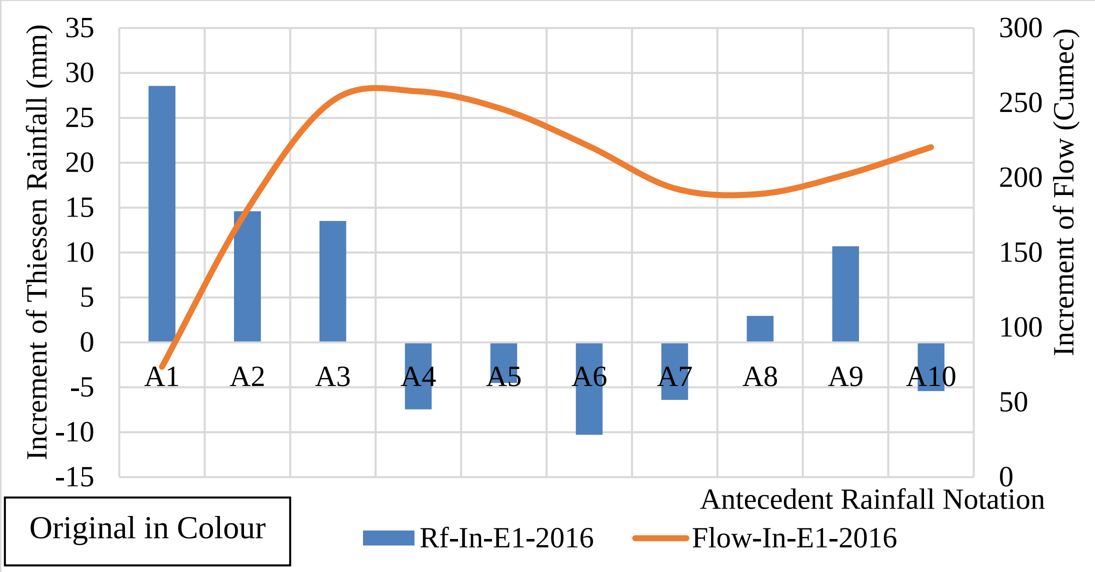


Figure 4-31: Increment of simulated flow and Thiessen rainfall for scenario E1-2016

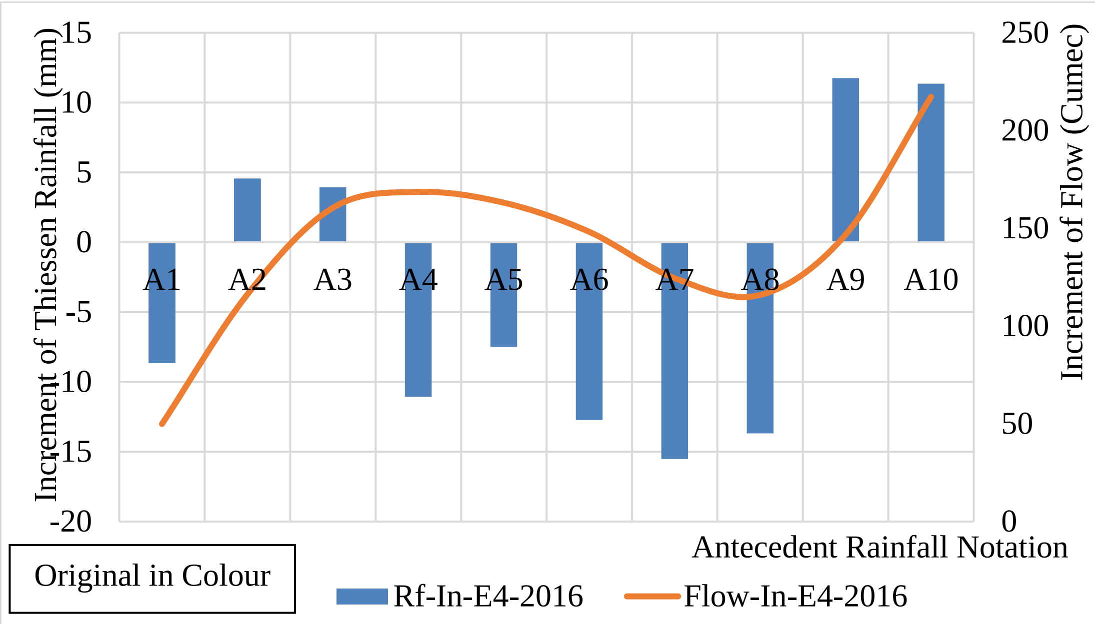


Figure 4-32: Increment of simulated flow and Thiessen rainfall for scenario E4-2016

There are two independent scenarios E1-2016 and E4-2016 were shown in Figure 4-31,4-32. The rainfall increment was negative from stage A4 to A7 and flow increment was decreased regularly as well as instantaneously raised when rainfall increment was positive. When it is estimating for correlation between storm rainfall to resultant runoff it beholds percentage increment of rainfall was decreased 50% while flow increment was increased 70% from A2 to A6 in scenario E2-2017 which is shown in Figure 4-34.

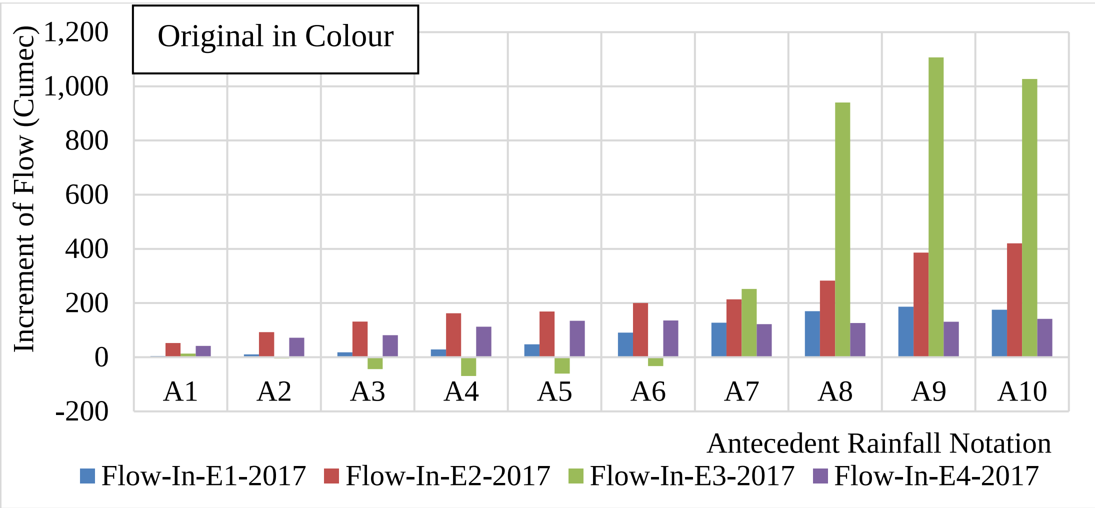


Figure 4-33: Increment of simulated flow for the year 2017

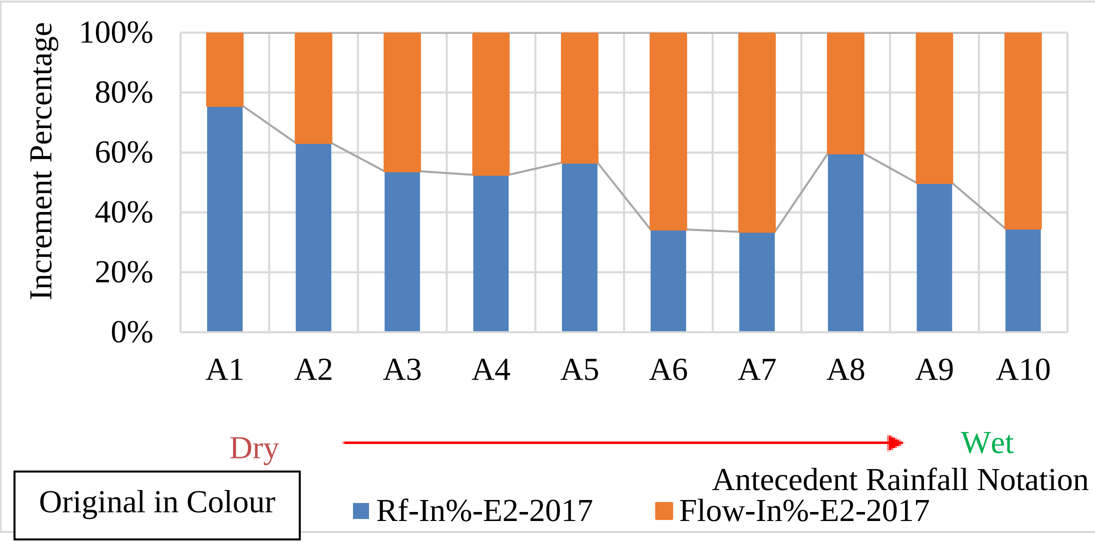


Figure 4-34: Percentage increment of simulated flow and Thiessen rainfall for scenario E2-2017

The initial stage of rainfall (A1) runoff is lesser value and gradually increased with respect to the rainfall it is correlated with catchment wetness according to the above scenario analysis. The season of AMC and group of AMC for all scenarios is shown in Appendix 08 with details of 5-Day,10-Day increment of rainfall and discharge with respect to the A0.

5 DISCUSSION

5.1 Data and Data Period

The availability of good quality sufficient data corroborates aspects of research. The data used for this hydrological model, as discussed in the previous chapters, can be widely categorized as Physiographic; Hydrological; Hydrometeorological. The minimum sufficient length of data period should be two years to calibrate the model parameters, and for validation also the same required according to the WMO recommendation. For Kelani river basin up to Nagalagam gauging station selected seven number of rainfall stations and three evaporation stations which have the ten years data record from 2008 to 2017 with correction of missing data according to the guideline of WMO.

5.2 Usage of GIS and HEC-HMS Software to Construct the Model

It is essentially required a strong information system to collect and manage spatial and physical basic information such as the nature of the river system, vegetation cover, land-use, soil classification, and geology. GIS layers are a convenient way of holding such data and the creation of area distribution maps, Thiessen rainfall maps. Elevation, sub-catchment area, length of river reach data is feed from GIS to HEC-HMS. Arc GIS 10.3 version is used for mange all features.

The selected model is a deterministic conceptual semi-distributed model among various types of predictive models that are inapplicable for flood forecasting. The model resolution depends on the spatially as well as temporally. The frequency of input data is a daily basis within the limit of temporal resolution and the spatial characteristics of the area also not exceed the model spatial resolution. Kelani catchment river network is a dendritic type network. The HEC-HMS 4.2.1 software is cover the above aspect. HEC-HMS software is freelance software for hydrological modeling. Constructed catchment model by separating the boundaries around the sub-catchment is used to simulate the runoff at a point of the outlet.

5.3 Sensitivity and Uncertainty Involved in Calibration and Validation Process

The result of models is only approximate solutions to reality. It was unable to represent natural systems precisely. Through the calibration and validation process model results are compared with observed data and check weather model performs adequately for a given purpose. The rainfall, evaporation data is modeled from 2008 to 2012 years as calibration and from the 2013 to 2017 period for validation. The sensitivity analysis study is performed to identify the most sensitive parameters of the model.

Even though much of the attempt is constructed to build a reliable river flow model, which could not present accurate solutions because of model forecasts are inevitably affected by different sources of uncertainty. The input of the model is daily rainfall and evapotranspiration data may cause errors of observation and recording which can be effectively incorporated into the deviation simulated result. As same as observed water level or flow discharge could not be correct.

The simulated flow is slightly underestimated than observed flow in extreme rainfall events in this research result. But simulated flow exactly matches with low flow event. The justification matters could be expressed as data errors or following general facts of the rainfall-runoff model. The model structure represents a simplification of the actual hydrological processes in the catchment by solving the mathematical equation. This implies a non-linear phenomenon in real situation linearly model with approximation referred to as the model error.

There are major reservoirs in the Kelani river basin which are used to hydropower generation and also small reservoirs. The inflow, outflow, or spill releases is not accounted for the project which causes to variation of observed flow values. These types of uncertainty issues are effect for deviation to simulated flow and observed flow. Despite its effect of uncertainty, the model is used as a flood forecast model by applying the calibration and validation process with an adequate level of accuracy and precision.

5.4 Identified Features of Antecedent Rainfall Scenarios

The construction of the rainfall sequences(scenario) began with the choose an arbitrary ten days’ rainfall season throughout the years from 2008 to 2017. The identification included daily-read seven number of rain gauges which are cover the Kelani catchment and which had provided useful rainfall data to the research project. The Thiessen rainfall method is used to calculate to total rainfall associate from each station. The flow generation is done by calibrated HEC-HMS model related to the rainfall event.

In the hydrological process, antecedent rainfall relates to surface runoff and baseflow. As the above analysis rainfall scenario which is indicted outflow is increased with the increment of catchment wetness. The wet ground surface has less capacity to store rainwater. The only possible way to water goes through as surface runoff because of evapotranspiration is not much. Therefore, surface runoff flowing to a river is generated promptly.

In calculating the flow that results from a rainfall event, the considerable factor must take note of the prevailing rainfall event due to antecedent catchment wetness. For the same rainfall, a larger flow will result in the flood situation from a saturated catchment than from a dry catchment.

There is always used accepted method when in the calculation of initial abstraction for the catchment but it does not change with the catchment wetness related antecedent rainfall. By therefore initial loss is the same for every rainfall event. Initial loss is very according to the prevailing rainfall condition. The ground is saturated due to antecedent rainfall further rain will occur much more flow than expected which is the same as the results of the scenario.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. The river flow time series up to Nagalagam Street station was generated by measured stage data at the station with the establishment of a rating curve. The model performance was relatively stronger with reported Nash-Sutcliffe Coefficient (NASH) values of 0.80 for the calibration stage and 0.89 for validation. Similarly, the coefficient of determination (R^2) indicated 0.83 for calibration and 0.90 for validation.

2. In this study, a selected set of scenarios were considered to study the effect of antecedent rain using calibrated and validated HEC-HMS model and it was identified that increment of stream runoff flow in the range of 350 to 850 m^3/s or by 200% to 300% when the antecedent rainy days increased from six to eight from the initial or inception date of rain.

3. According to the antecedent rainfall scenario analysis, it is noted a tendency of increment of stream runoff in the range 50 to 300 m^3/s or by 50% to 160% even though total rainfall decreased from the starting date or inception date of rain by 85% to 65%.

4. The study demonstrates that with an increasing number of rainy days from A0 to A10 (in days), a 50% to 100% increment of runoff is observed even when the rainfall is decreased 85% to 90% for the tenth rainy day (A10) with compared to the first rainy day (A1).

5. The study demonstrates that with an increasing number of rainy days from A0 to A5 (in days), a 50% to 300% increment of runoff is observed in the case of AMC III class scenario and a 5% to 140% increment of runoff is observed in the case of AMC II class scenario, irrespective of the season with compared to the first rainy day (A1).

6. The study demonstrates that with an increasing number of rainy days from A0 to A10 (in days), a 30% to 400% increment of runoff is observed in the case of AMC III class scenario and a 30% to 300% increment of runoff is observed in the case of AMC II class scenario, irrespective of the season with compared to the first rainy day (A1).

7. These results clearly indicate the importance of incorporating a factor for antecedent rainfall while estimating of catchment runoff flow to improve model performance for flood forecasting in downstream Kelani Basin under extreme rainy conditions.

6.2 Recommendations

1. It is recommended to consider further investigations to check the reliability of the output results for application to flood forecasting and update the model as appropriate.
2. It is useful to conduct further research to evaluate the relative influence of antecedent rainfall on flood magnitude with including reservoir storage and spill release function.
3. It is recommended to analyze flow variation with the effect of antecedent rainfall by using another rainfall-runoff model and comparison of results.
4. It is important to come up with a sophisticated framework for studying such models to understand the impact of antecedent rainfall on the catchment scale. This framework should be improved to mitigate flood risk.

REFERENCES

Abbaspour, K. (2004). Calibration of Hydrologic Models: When is a Model Calibrated?

André , M., Benoît , H., & Cécile , P. (2015). *Hydrology A Science for Engineers.* 6000 Broken Sound Parkway NW, Suite 300: CRC Press Taylor & Francis Group.

Asati, S., & Rathore, S. (2012). Comparative Study of Stream Flow Prediction Models.

Aubert, D., Loumagne, C., & Oudin, L. (2003). Sequential assimilation of soil moisture and streamflow data in a conceptual rainfall -Runoff model. *Journal of Hydrol., 280,* 145–161.

Berthet, L., Andréassian, V., Perrin, C., & Javelle, P. (2011). How crucial is it to account for the antecedent moisture conditions in flood forecasting? Comparison of event-based and continuous approaches on 178 catchments. *Hydrol. Earth Syst. Sci,13,* 819–831.

Burt, T., & Weerasinghe, K. (2014). Rainfall Distributions in Sri Lanka in Time and Space. *An Analysis Based on Daily Rainfall Data. Climate, 2(4).*, 242-263.

Caldera, H., Piyathisse, V., & Nandalal, K. (2016). A Comparison of Methods of Estimating Missing Daily Rainfall Data. *ENGINEER - Vol. XLIX, No. 04,* 1-8.

Campozano, L., Sanchez, E., Aviles, A., & Samaniego, E. (2014). Evaluation of infilling methods for time series of daily precipitation and temperature: The case of the Ecuadorian Andes.

Castillo, V., Gomez-Plaza, A., & Martınez-Mena, M. (2003). The role of antecedent soil water content in the runoff response of semiarid catchments: a simulation approach. *Journal of Hydrol. 284 (1),* 114–130.

Chow, V., Maidment, D., & Mays, L. (1988). *Applied Hydrology.* McGraw Hill.

Cooray, P. (1984). *An Introduction to the Geology of Sri Lanka (Ceylon),2nd revised edition.* Colombo.

Daggupati, P., Haw, Y., Michael, J. W., Raghavan, S., Jaffrey, G. A., Conor, S. K., & Scott , P. S. (2015). Impact of Model Development,Calibration and Validation decisions on Hydrological Simulation in West Lake Erie Basin.

Daggupati, P., Pai, N., Ale, S., Douglas, Zeckoski, K., Jeong, J., . . . Youssef, M. (2014). A Recommended Calibration and Validation Strategy for Hydrologic and Water Quality models. *American Society of Agricultural and Biological Engineers, Vol. 58(6),* 1705-1719.

De Silva, M., Weerakoon, S., & Shrikantha, H. (2014). *Journal of Hydrology*.

De Silva, M., Weerakoon, S., Srikantha, H., & Ratnayake, U. (2012). Event Based Flood Modeling in Lower Kelani Basin. *SAITM Research Symposium on Engineering Advancements*.

De Silva, M., Weerakoon, S., Srikantha, H., Ratnayake, U., & Mahanama, S. (2012). *Flood Inundation Mapping along the Lower Reach of Kelani River Basin under the Impact of Climatic Change.*

Dharmasena, G. T. (1997). *Application of mathematical models for flood forecasting in Sri Lanka.* Colombo: Hydrology Division, Irrigation Department of Sri Lanka.

Duhan, S., & Kumar, M. (2017). Event and Continuous Hydrological Modeling with HEC-HMS. *International Journal of Engineering Technology Science and Research 4*, 2394–3386.

Gamagea, S., Hewaa, G., & Beechama, S. (2015). Modelling hydrological losses for varying rainfall and moisture conditions in South Australian catchments. *Journal of Hydrology, 4*, 1-21.

Gayathri, K., Ganasri, B., & Dwarakish, G. (2015). *A Review on Hydrological Models.*

Georgakakos, K. P. (2006). Analytical results for operational flash flood guidance. *Journal of Hydrol. 317*, 81–103.

Getachew, T., Dong, K. P., & Young-Oh, K. (2017). Comparison of hydrological models for the assessment of water resources in a data-scarce region, the Upper Blue Nile River Basin. *Journal of Hydrology,14*, 49-66.

Hay, L., & Clark, M. (2003). Use of statistically and dynamically downscaled atmospheric model output for hydrologic simulations in three mountainous basins in the western United States. *Journal of Hydrology, 282*, 56–75.

Hlavcova, H., Kohnova, S., Kubes, R., Szolgay, J., & Zvolensky, M. (2005). An empirical method for estimating future flood risks for flood warnings. *Hydrol. Earth Syst.Sci.,9*, 431–448.

Hossein, M., Samani, & Shamasipour, G. (2004). Hydrologic flood routing in branched river systems via nonlinear optimization. *Journal of Hydraulic Research, 42*, 55-59.

HRS-Report-No-06. (1999). *Rainfall Antecedent to Large and Extreme Rainfall Bursts Over Southeast Australia.* Bureau of Meteorology, Australia.

Hunukumbura, P., Weerakoon, S., & Herath, S. (2004a). Estimation of Flow Duration Curves for Mini Hydropower Plant Design in Ungauged Streams using Measurements during a Short Period. *Proceedings of the International*

Conference on Sustainable Water Resources Management in the Changing Environment of the Monsoon Region. Colombo: National Water Resources Secretariat.

IFM-Tool Series-No.19. (2013). *Integrated Flood Management ,Flood Forecasting and Early Warning.* World Meteorological Organization.

Jonathan, J., Gourley, & Robert, A. C. (2018). Real-Time Flash Flood Forecasting. *Oxford Research Encyclopedia of Natural Hazard Science*.

Kachroo, R., & Liang, G. (1992). River flow forecasting: Algebraic development of linearmodelling techniques. *Journal of Hydrology, 133(1-2)*, 17-40.

Keith Beven. (2012). *Rainfall-Runoff Modelling.* Chichester, West Sussex, PO19 8SQ, UK: John Wiley & Sons, Ltd.

Kopmann, R., & Schmidt, A. (2010). *Comparison of different reliability analysis methods for a 2D morphodynamic numerical model of River Danube.*

Krishan P. Singh. (1982). *Runoff Conditions for Converting Strom Rainfall to Runoff with SCS Curve Numbers.* SWS Contract Report.

Lijalem, Z., Jackson, R., & Dilnesaw, A. (2007). Calibration and validation of SWAT Hydrologic Model for Meki Watershed Ethiopia.

Mallawatantri, A., Rodrigo, A., & De Silva, K. (2016). *Medium to Long-term Multi-Stakeholder Strategy and Action Plan for Management and Conservation of Kelani River Basin.* Colombo: Central Environment Authority and International Union for the Conservation of Nature.

Matthew, C., & Myles, R. A. (2002). Assessing the Relative Roles of Initial and Boundary Conditions in Inter annual to Decadal Climate Predictability.

Mishra, S., Jain, M., & Singh, V. (2004). Evaluation of the SCSCN-based model incorporating antecedent moisture. *Water Resour.Manag.18 (6),* 567–589.

Mohsen, S., & Mehdi, D. (2012). Comparison of Flood Routing Models (Case Study: Maroon River, Iran). *World Applied Sciences Journal 16 (5),* 769-775.

Montesarchio, V., Lombardo, F., & Napolitano, F. (2009). Rainfall thresholds and flood warning: an operative case study. *Hazards Earth Syst. Sci., 9*, 135–144.

Moriasi, D., Arnold, J., Van Liew, M., Bingner, R., Harmel, R., & Veith, T. (2007). *Model evaluation guidline for systematic quantification of accuracy in watershed simulations.*

Mu, J., & Zhang, X. (2007). Real-time flood forecasting method with 1-D unsteady flow model. *Journal of Hydrodynamics, 19(2)*, 150-154.

Nandakumar, N., Mein, R., & Siriwardena, L. (1994). *Loss Modeling for Flood Estimation.* Cooperative Reserch Centerfor Catchment Hydrology.

Nanseer, N., & Rajkumar, S. (2006). Kelani Ganga Conservation Barrage and Results of Model Studies. *ENGINEER - Vol. XXXIX, No. 02,* 42-49.

Neal, J., Atkinson, P., & Hutton, C. (2007). Flood inundation model updating using an ensemble Kalman filter and spatially distributed measurements. *Journal of Hydrology, 336(3-4),* 401-415.

Owe, M., De Jeu, R., & Walker, J. (2001). A methodology for surface soil moisture and vegetation optical depth retrieval using the microwave polarization difference index. *IEEE Trans. Geosci. Remote Sens., 39(8),* 1643-1654.

Panabokke, C. R. (1996). *Soils and Agro-Ecological Environments of Sri Lanka.* Colombo.

Parasuraman, K., & Elshorbagy, A. (2008). *Toward improving the reliability of hydrologic prediction: Model structure uncertainty and its quantification using ensemble-based genetic programming framework.* Water Resources Research, 44.

Parkin, G., O'Donnell, G., Ewen, J., Bathurst, J., O'Connell, P., & Lavabre, J. (1996). Validation of catchment models for predicting land-use and climate change impacts: 2. Case study for a Mediterranean catchment. *Journal of Hydrology, 175*, 595–613.

Raghunath, H. M. (2006). *Hydrology (2nd ed.).* New Delhi: New Age International (Pvt) Ltd.

Sakazume, R., Masahiro, R., & Oliver, S. (2015). Consideration of Antecedent Soil Moisture for Predicting Flood Characteristics. *Journal of Japan Society of Civil Engineers,71,* 97-102.

Sampath, D., Weerakoon, S., & Herath, S. (2015). HEC-HMS Model for Runoff Simulation in a Tropical Catchment with Intra-Basin Diversions – Case Study of the Deduru Oya River Basin, Sri Lanka. *ENGINEER - Vol. XLVIII, No. 01,* 1-9.

Sivapalan, M., Blöschl, G., Merz, R., & Gutknecht, D. (2005). Linking flood frequency to long-term water balance:Incorporating effects of seasonality. *Water Resour. Res., 41*, 1-17.

Thea, T., Korbinian, B., Janneke, E., Dinand, A., & Victor, J. (2016). A new flood type classification method for use in climate change impact studies. *Weather and Climate Extremes,14*, 1-16.

Tramblay, Y., Bouaicha, R., Brocca, L., Dorigo, W., Bouvier, C., Camici, S., & Servat, E. (2012). Estimation of antecedent wetness conditions for flood modelling in northern Morocco. *Hydrol. Earth Syst. Sci,16*, 4375–4386.

USGS- TR No. W-10. (2007). *Improving Flood Forecasting and Early Warning in Somalia.* U.S. Geological Survey.

Vaze, J., Jorden, P., Beecham, R., Forst, A., & Summerell, G. (2012). *Guidelines for rainfall-runoff modeling.* e Water Cooperative Research Center.

Vel´azquez, J., Anctil, F., & Perrin, C. (2010). Performance and reliability of multimodel hydrological ensemble simulations based on seventeen lumped models and a thousand catchments. *Hydrol. Earth Syst. Sci., 14*, 2303–2317.

Vrugt, J., Gupta, H., Bouten, W., & Sorooshian, S. (2003). A shuffled complex evolution metropolis algorithm for optimization and uncertainty assessment of hydrologic model parameters. *Water Resour. Res., 39(8)*, 1201.

Wijesekera , N., & Ghanapala, P. (2003). *Engineer Journal of the Institution of Engineers*.

Wijesekera, N. (2000b). A Comparison of Peak Flow Estimates for Small Ungauged Urban Watersheds. *Annual Sessions of the Institution of Engineers Sri Lanka*.

Wijesekera, N. (2010a). National Science Foundation,(Ministry of Irrigation and water resources management, Sri Lanka).

Wilby, R. L. (2005). Uncertainty in water resource model parameters used for climate change impact assessment,. *Hydrol. Processes, 19,*, 3201-3219.

William, A., Scharffenberg, & Matthew, J. (2009). *Hydrologic Modeling system HEC-HMS User's Manual US Army Crop Engineers.* 609,Second Street , Davis CA 95616 USA: Institute of water resources,Hydrologic Engineering Centre.

WMO-168-Vol-I. (2008). *Guide to Hydrological Practices Volume I Hydrology – From Measurement to Hydrological Information.* World Meteorological Organization.

WMO-168-Vol-II. (2009). *Guide to Hydrological Practices Volume II Management of Water Resources and Application of Hydrological Practices.* World Meteorological Organization .

WMO-No.1095. (2012). *Technical Material for Water Resources Assessment.* World Meteorological Organization.

WMO-No-100. (2011). *Guide to Climatological Practice.* World Meteorological Organization.

WMO-No-1072. (2011). *Manual on Flood Forecasting and Warning.* World Meteorological Organization.

World Disasters Report. (2003).

Yeou-Koung, T., & Chi-Leung, W. (2016). Sensitivity and Uncertainty Analysis of Hydrologic/Hydraulic Model for Shenzhen River and Northern New Territory Basin in Hong Kong.

Zakwan, M., & Muzzammil, M. (2016). Optimization approach for hydrologic channel Routing.

APPENDICES

APPENDIX 01: - Runoff Curve Numbers According to Antecedent Moisture Class, Antecedent Precipitation Index and The Antecedent Precipitation Index to Estimate Rainfall-Runoff

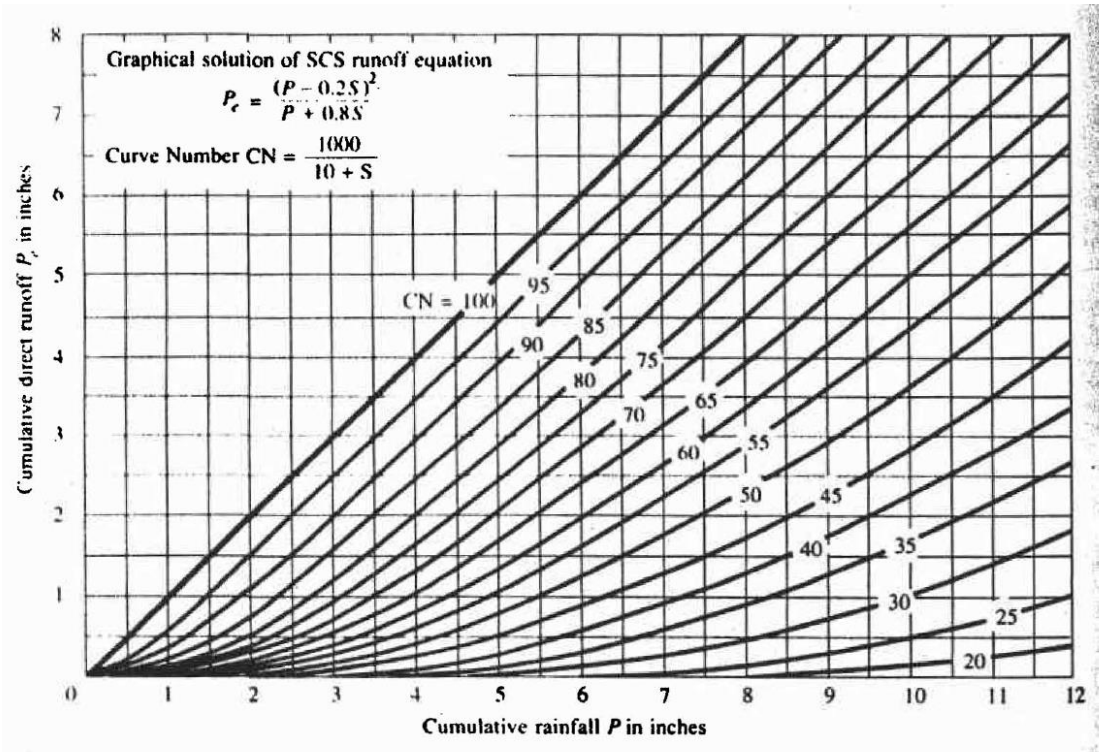


Figure A1-1: Graphical Solution of SCS Runoff Coefficients

Source: Applied Hydrology Book Ven Te Chow, 1988; Figure 5.5.2, page 148.

Where S (inches) is potential maximum retention after runoff begins. The curve numbers shown above apply for normal antecedent moisture conditions (AMC II). Dry condition (AMC I) and wet condition (AMC III) equivalent curve numbers calculated using the following equation. The range of antecedent moisture conditions for each class is shown below.

$$\text{CN(I)} = \frac{4.2\text{CN(II)}}{10 - 0.058CN\text{(II)}}$$

$$\text{CN(III)} = \frac{23\text{CN(II)}}{10 + 0.13\text{CN(II)}}$$

Table A1-1: Classification of antecedent moisture classes (AMC) for the SCS method of rainfall abstractions

AMC group	Total 5-day antecedent rainfall (In)	
	Dormant Season	Growing Season
I	Less than 0.5	Less than 1.4
II	0.5 to 1.1	1.4 to 2.1
III	Over 1.1	Over 2.1

Source: Applied Hydrology Book Ven Te Chow, 1988; Figure 5.5.2, page 149.

Curve numbers have been tabulated by the soil conservation service on the basis of soil type and land use. Four soil groups are defined as follows.

Group A: Deep sand, deep loess, aggregated silts

Group B: Shallow loess, sandy loam

Group C: Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay.

Group D: Soils that swell significantly when wet, heavy plastic clays, and certain saline soils

The values of CN for various land uses on these soil types as follows. For a watershed made up of several soil types and land uses, a composite CN can be calculated.

Table A1-2: Runoff curve numbers for selected agricultural, suburban and urban land use (AMCII, and $I_a = 0.25$)

Land-use description		Hydrological soil group A	B	C	D
Cultivated land[a]					
Without conservation treatment		72	81	88	91
With conservation treatment		62	71	78	81
Pasture or rangeland					
Poor condition		68	79	86	89
Good condition		39	61	74	80
Meadow					
Good condition		30	58	71	78
Wood or forest land					
Thin stand, poor cover, no mulch		45	66	77	83
Good cover[b]		25	55	70	77
Open spaces: lawns, parks, golf courses and so forth					
Good condition: grass cover = 75% or more		39	61	74	80
Fair condition: grass cover = 50–75%		49	69	79	84
Commercial and business areas (85% impervious)		89	92	94	95
Industrial districts (72% impervious)		81	88	91	93
Residential[c]					
Average lot size	Average % impervious[d]				
1/8 acre[e] or less	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
Paved parking lots, roofs, driveways and so forth[f]		98	98	98	98
Streets and roads					
Paved with curbs and storm sewers[f]		98	98	98	98
Gravel		76	85	89	91
Dirt		72	82	87	89

[a] For a more detailed description of agricultural land-use curve numbers, please refer to *National Engineering Handbook* (Natural Resources Conservation Service, 1972).
[b] Good cover is protected from grazing and litter and brush cover soil.
[c] Curve numbers are computed assuming that the runoff from the house and driveway is directed toward the street with a minimum of roof water directed to lawns where additional infiltration could occur.
[d] The remaining pervious areas (lawns) are considered to be in good condition for these curve numbers.
[e] 1 ha = 0.404687 acre
[f] In some warmer climates of the country a curve number of 95 may be used.

Source: Guide to Hydrological Practices Volume II WMO-No. 168 Sixth edition 2009; Table II.5.8., page 202.

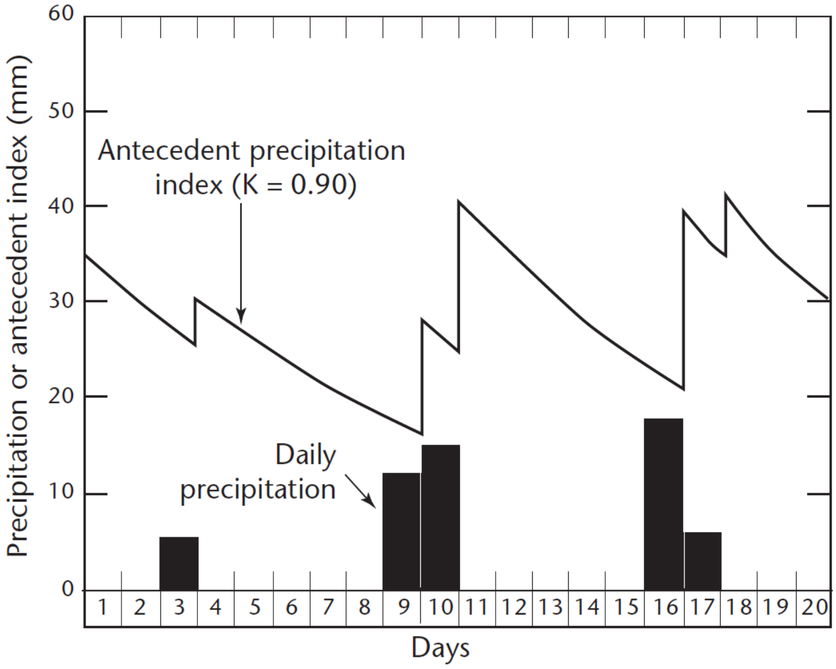


Figure A1-2: Antecedent precipitation index

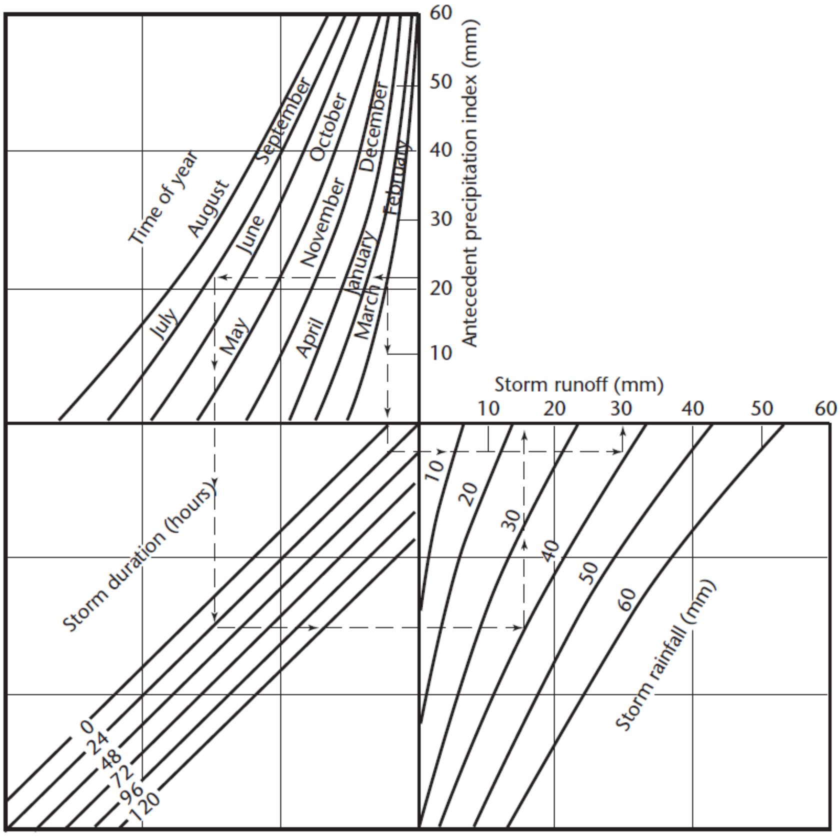


Figure A1-3: The antecedent precipitation index to estimate rainfall runoff

Source: Guide to Hydrological Practices Volume II WMO-No. 168 Sixth edition 2009; Figure II.6.6, Figure II.6.7., page 232.

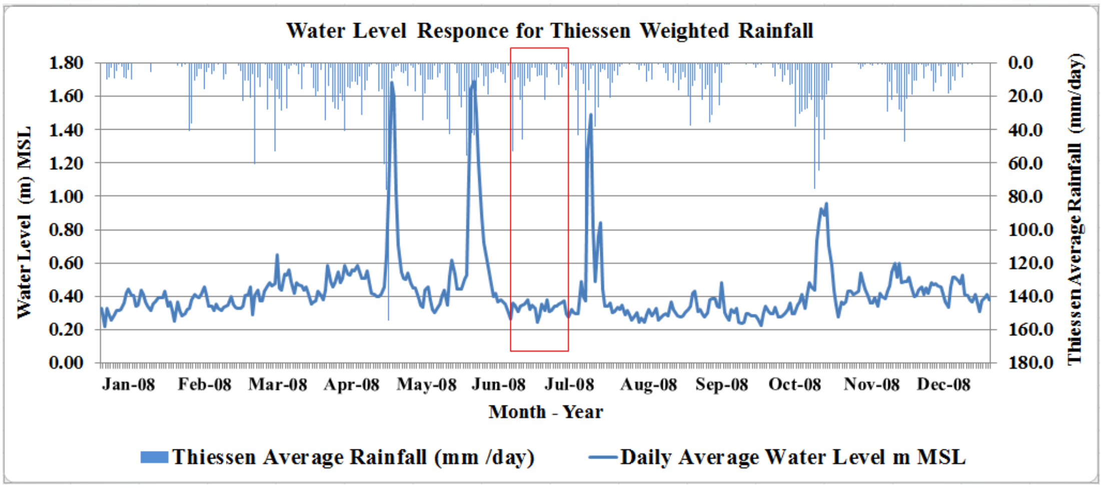
APPENDIX 02: - Mathematical Expressions for several Objective Functions

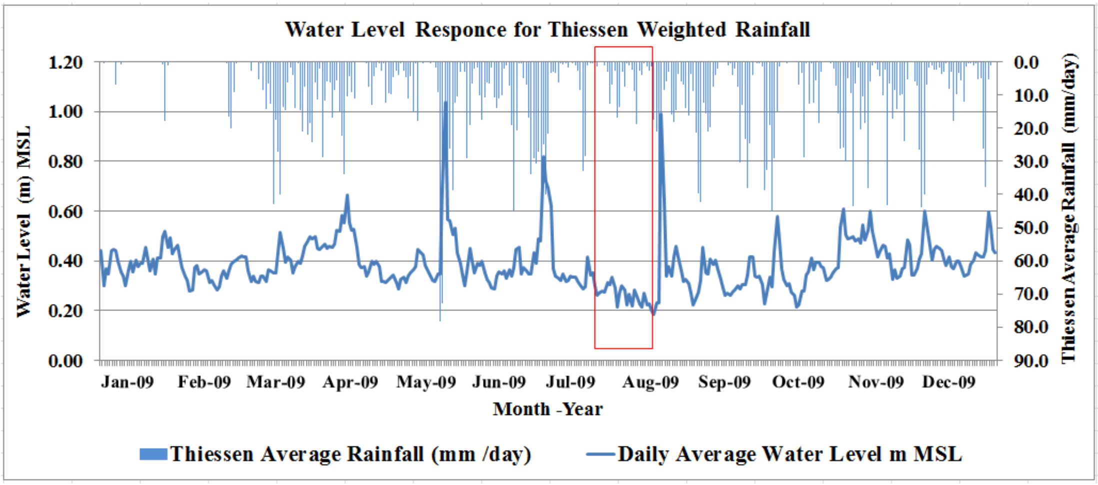
Table A2-1: Mathematical expressions for a number of objective functions with discharge Q at the outlet of the considered basin

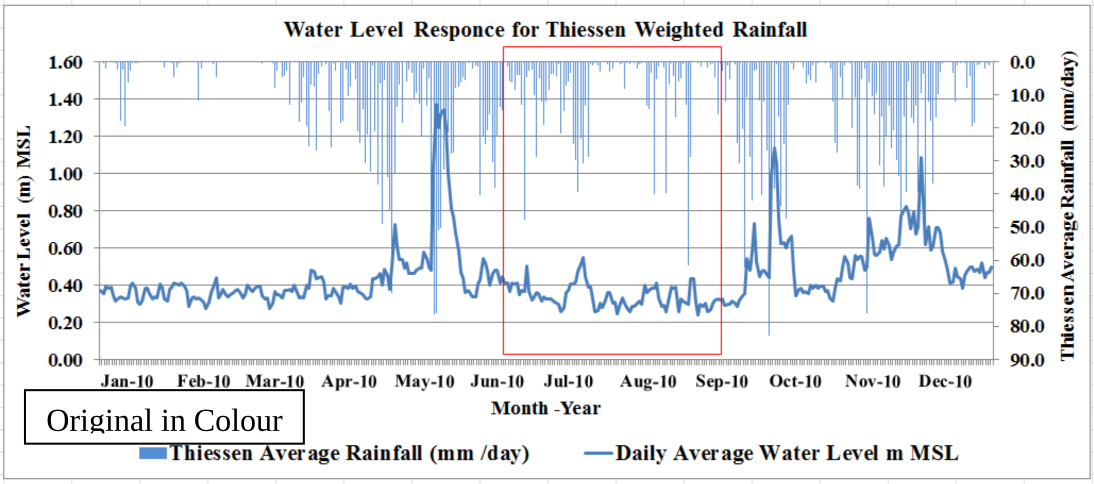
Criterion	Expression
Bias	$F = \frac{1}{n}\sum_{i=1}^{n}\left(Q_o(i) - Q_s(i)\right)$
Squared correlation coefficient	$F = \frac{\left[\sum_{i=1}^{n}(Q_o(i)-\overline{Q}_o)(Q_s(i)-\overline{Q}_s)\right]^2}{\sum_{i=1}^{n}(Q_o(i)-\overline{Q}_o)^2 \cdot \sum_{i=1}^{n}(Q_s(i)-\overline{Q}_s)^2}$
Least squares	$F = \sum_{i=1}^{n}\left(Q_o(i) - Q_s(i)\right)^2$
Nash-Sutcliffe	$F = 1 - \frac{\sum_{i=1}^{n}\left(Q_o(i) - Q_s(i)\right)^2}{\sum_{i=1}^{n}\left(Q_o(i) - \overline{Q}_o\right)^2}$
Nash-Sutcliffe with logarithms	$F = 1 - \frac{\sum_{i=1}^{n}\left(\ln(Q_o(i)+\eta) - \ln(Q_s(i)+\eta)\right)^2}{\sum_{i=1}^{n}\left(\ln(Q_o(i)+\eta) - \ln(\overline{Q}_o+\eta)\right)^2}$
Clabour-Moore	$F = \frac{\sum_{i=1}^{n}\left\|Q_o(i) - Q_s(i)\right\|}{\sum_{i=1}^{n}Q_o(i)}$
Peak flood discharges	$F = Q_{po}(k) - Q_{ps}(k)$

Source: Hydrology, A Science for Engineers by Professor Andre Musy.2015; Table 3.1., page 89.

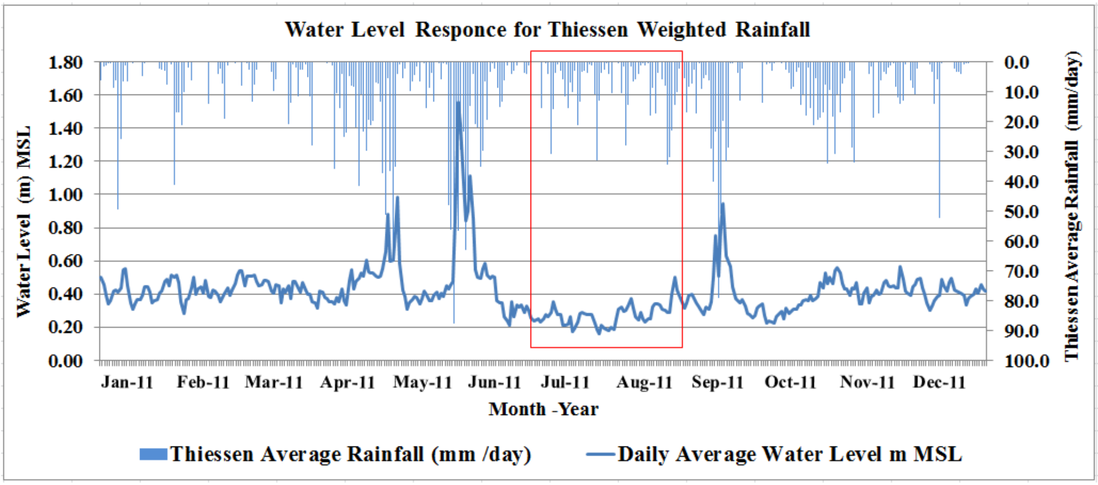
APPENDIX 03: - Thiessen Weighted Rainfall and Water Level Comparison (Visual Checking – Nagalagam Street Watershed)

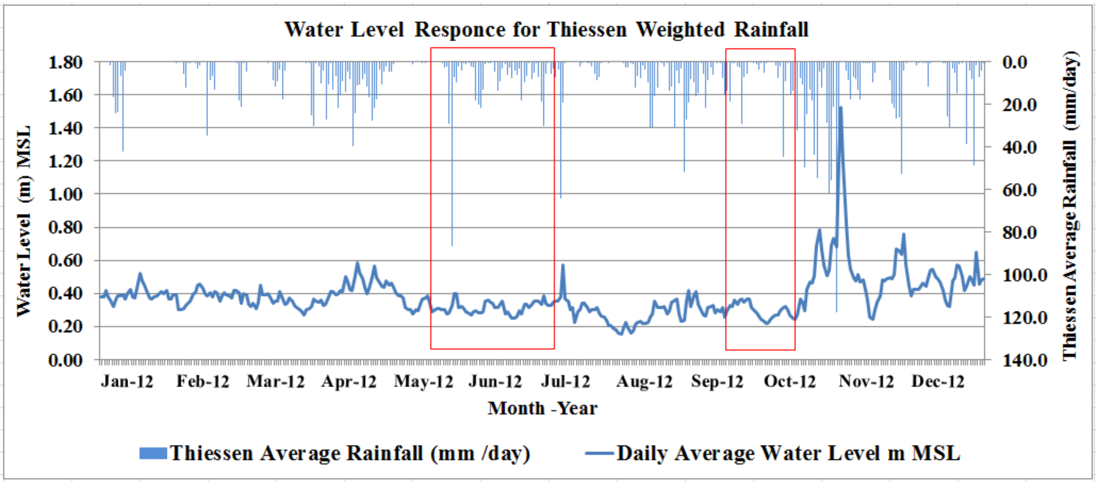


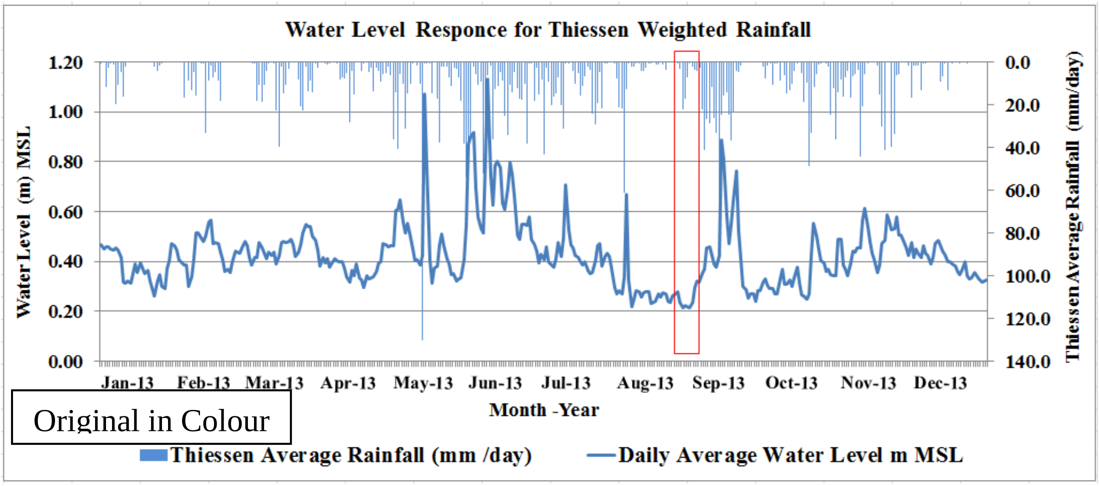




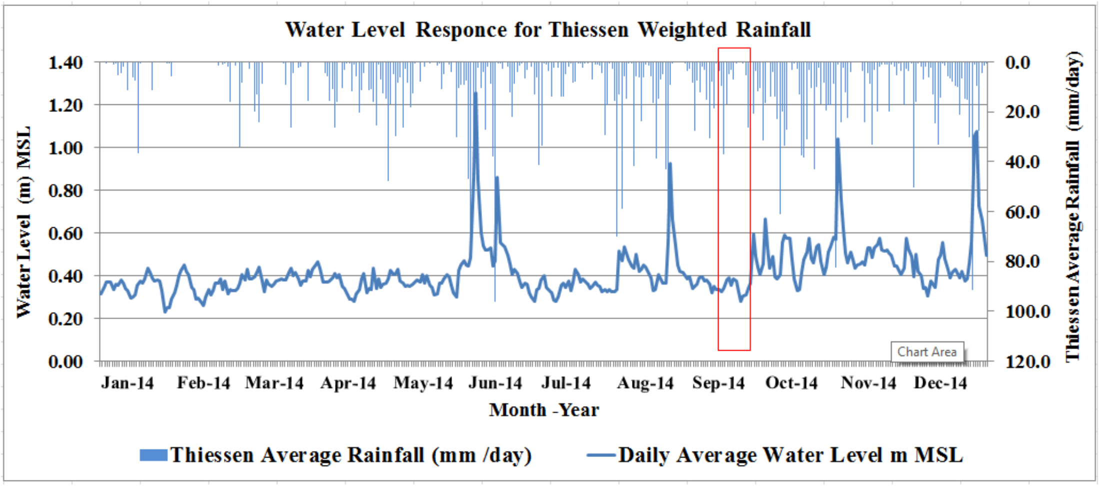
Appendix 03 - 1 Water level response for Thiessen average rainfall of Nagalagam Street Catchment (2008-2010)

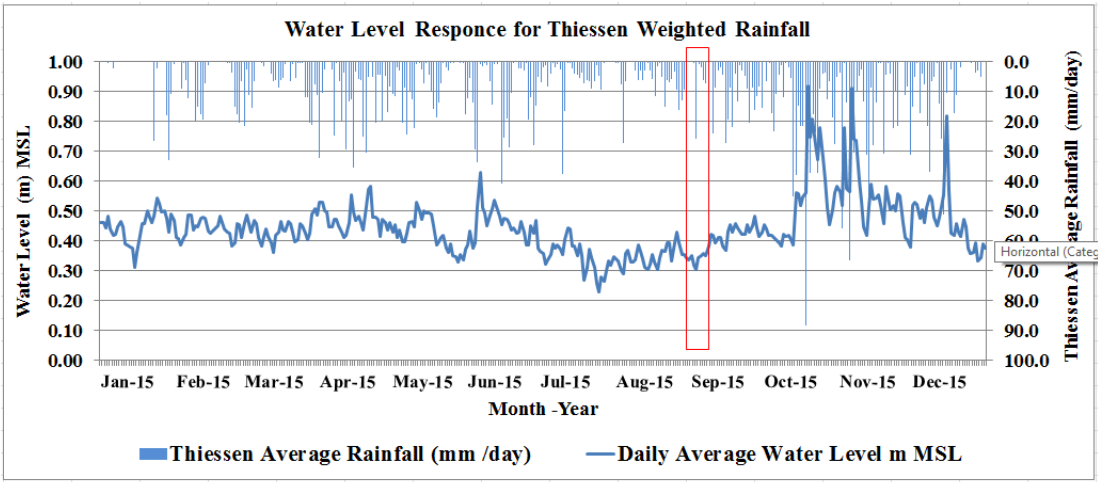


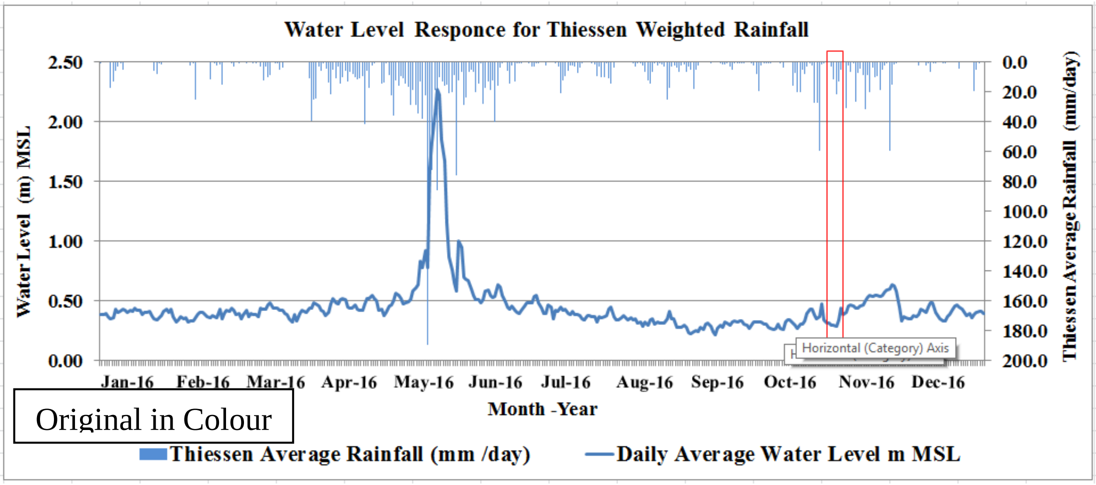




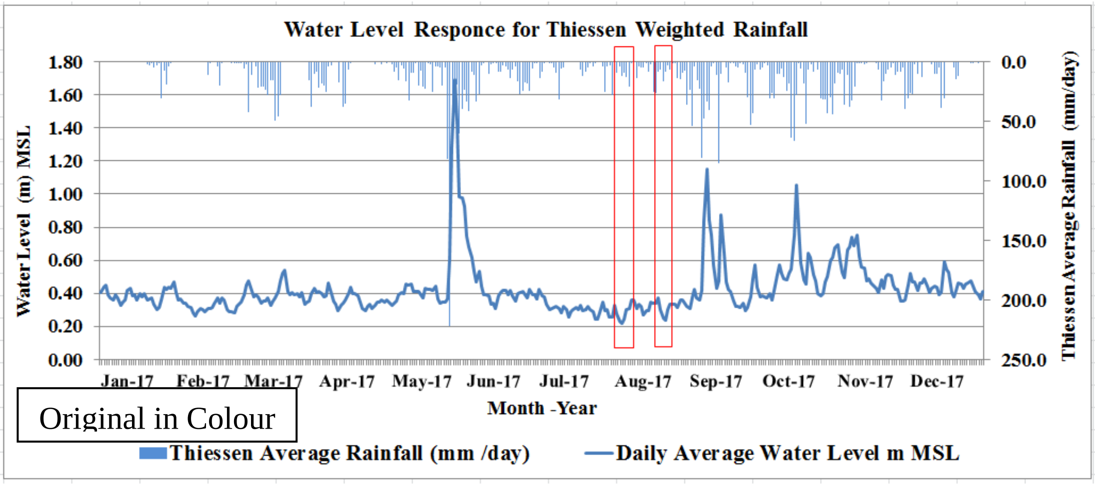
Appendix 03 - 2 Water level response for Thiessen average rainfall of Nagalagam Street Catchment (2011-2013)







Appendix 03 - 3 Water level response for Thiessen average rainfall of Nagalagam Street Catchment (2014-2016)



Appendix 03 - 4 Water level response for Thiessen average rainfall of Nagalagam Street Catchment 2017

APPENDIX 04: - The Land Use Categories in Sub Catchment

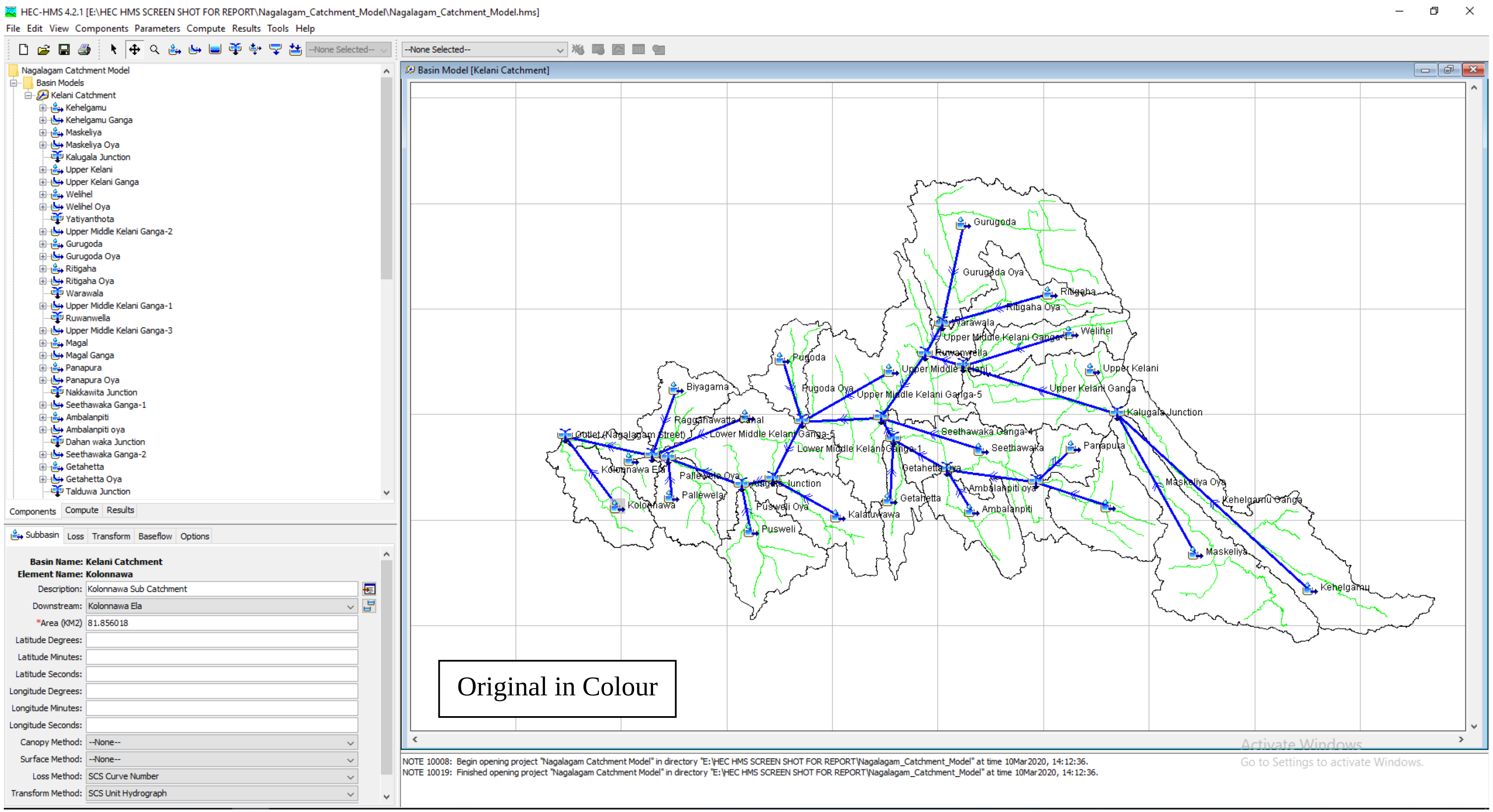
Name of the Sub Catchment	Area (km²)	Land Use Category	Area (km²)	Name of the Sub Catchment	Area (km²)	Land Use Category	Area (km²)
Lower Kelani Ganga	38.010	Cultivated Land (With CT)	6.768	Getahetta Oya	41.432	Cultivated Land (With CT)	3.229
		Cultivated Land (Without CT)	28.855			Cultivated Land (Without CT)	35.944
		Meadow	1.094			Forest Land (Good Cover)	0.868
		Water Surface	1.291			Meadow	1.011
Kehelgamu Ganga	212.186	Cultivated Land (With CT)	0.892			Rock	0.051
		Cultivated Land (Without CT)	160.853			Water Surface	0.329
		Forest Land (Good Cover)	36.698	Seethawaka Ganga	140.603	Cultivated Land (With CT)	3.353
		Meadow	7.816			Cultivated Land (Without CT)	133.214
		Pasture (Good)	2.862			Forest Land (Good Cover)	0.333
		Rock	1.186			Meadow	1.455
		Water Surface	1.879			Rock	0.193
Maskeliya Oya	199.409	Cultivated Land (With CT)	0.651			Water Surface	2.055
		Cultivated Land (Without CT)	108.135	Pugoda Oya	51.062	Cultivated Land (With CT)	12.408
		Forest Land (Good Cover)	72.432			Cultivated Land (Without CT)	37.781
		Meadow	6.968			Meadow	0.385
		Pasture (Good)	4.735			Rock	0.183
		Rock	4.084			Water Surface	0.304
		Water Surface	2.404	Upper Middle Kelani Ganga	244.113	Cultivated Land (With CT)	18.773
Magal Ganga	111.357	Cultivated Land (With CT)	0.772			Cultivated Land (Without CT)	213.762
		Cultivated Land (Without CT)	37.387			Forest Land (Good Cover)	2.296
		Forest Land (Good Cover)	58.077			Meadow	4.688
		Meadow	8.905			Rock	0.653
		Rock	4.737			Water Surface	3.940
		Water Surface	1.478	Wak Oya / Kalatuwawa	88.243	Cultivated Land (With CT)	3.400
Original in Colour Panapura Oya	42.821	Cultivated Land (With CT)	0.916			Cultivated Land (Without CT)	60.096
		Cultivated Land (Without CT)	38.833			Forest Land (Good Cover)	20.953
		Forest Land (Good Cover)	1.289			Meadow	1.261
		Meadow	0.719			Pasture (Good)	2.131
		Rock	0.545			Water Surface	0.402
		Water Surface	0.519				

Name of the Sub Catchment	Area (km²)	Land Use Category	Area (km²)
Upper Kelani Ganga	136.049	Cultivated Land (With CT)	1.892
		Cultivated Land (Without CT)	104.445
		Forest Land (Good Cover)	23.633
		Meadow	2.204
		Rock	1.604
		Water Surface	2.271
Welihel Oya	82.140	Cultivated Land (With CT)	1.709
		Cultivated Land (Without CT)	67.559
		Forest Land (Good Cover)	7.648
		Meadow	2.154
		Rock	1.733
		Water Surface	1.337
Ritigaha Oya	98.200	Cultivated Land (With CT)	4.903
		Cultivated Land (Without CT)	82.181
		Forest Land (Good Cover)	6.552
		Meadow	2.516
		Rock	0.799
		Water Surface	1.250
Gurugoda Oya	235.760	Cultivated Land (With CT)	23.166
		Cultivated Land (Without CT)	194.016
		Forest Land (Good Cover)	7.015
		Meadow	9.384
		Rock	0.385
		Water Surface	1.795
Ambalanpiti Oya	71.840	Cultivated Land (With CT)	0.866
		Cultivated Land (Without CT)	68.396
		Forest Land (Good Cover)	0.444
		Meadow	1.146
		Rock	0.299
		Water Surface	0.689

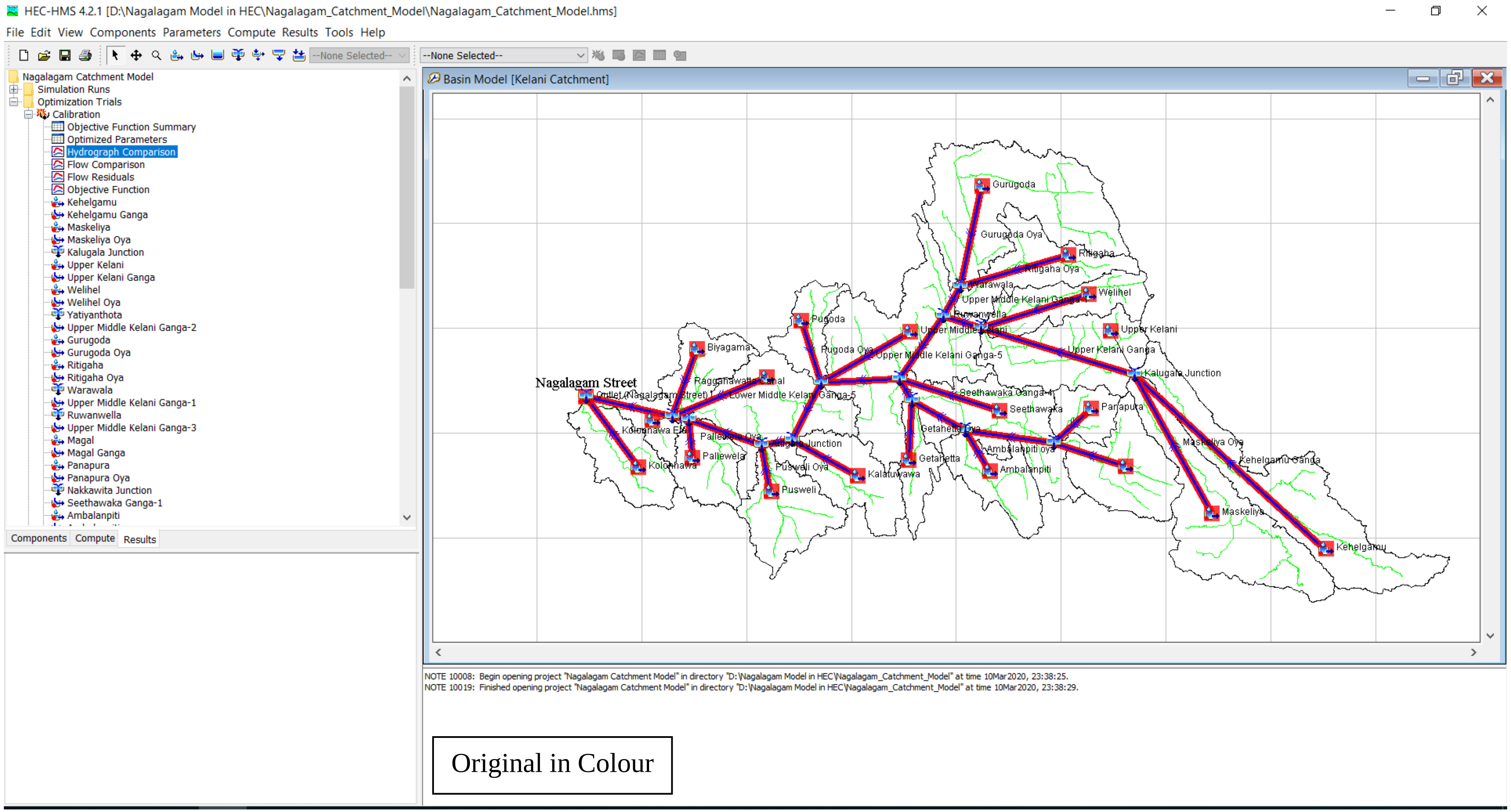
Name of the Sub Catchment	Area (km²)	Land Use Category	Area (km²)
Pusweli Oya	94.207	Cultivated Land (With CT)	19.404
		Cultivated Land (Without CT)	71.382
		Meadow	3.063
		Water Surface	0.358
Pallewela Oya / Maha Ela	62.133	Cultivated Land (With CT)	13.218
		Cultivated Land (Without CT)	46.705
		Meadow	1.699
		Water Surface	0.511
Lower Middle Kelani Ganga	151.986	Cultivated Land (With CT)	24.316
		Cultivated Land (Without CT)	119.524
		Meadow	4.720
		Water Surface	3.426
Biyagama	60.828	Cultivated Land (With CT)	12.317
		Cultivated Land (Without CT)	47.734
		Meadow	0.377
		Water Surface	0.399
Kolonnawa Ela	81.856	Cultivated Land (With CT)	10.846
		Cultivated Land (Without CT)	59.790
		Meadow	6.468
		Residential (1/8) arce or less	2.599
		Sand	0.360
		Water Surface	1.793

Original in Colour

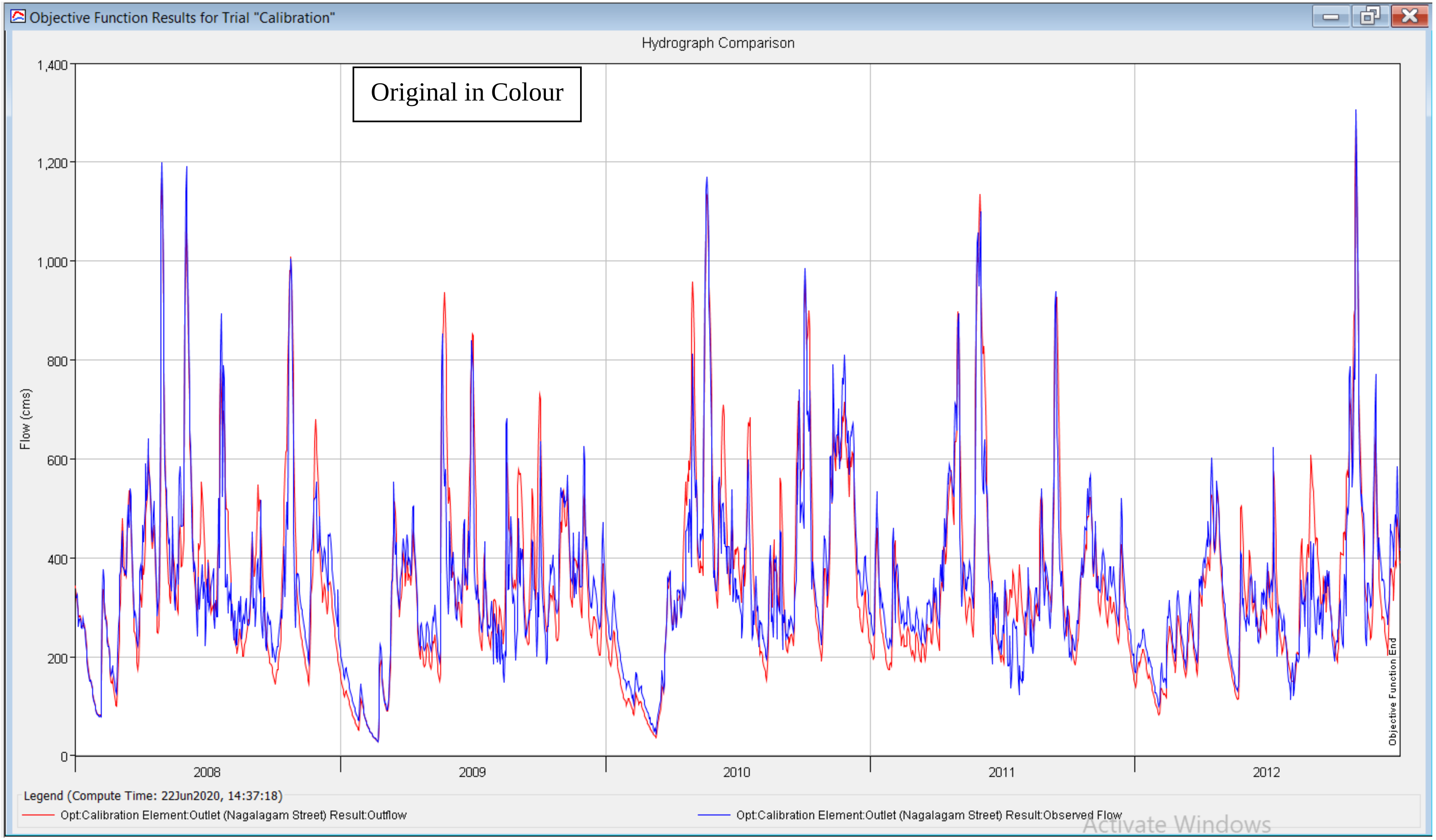
APPENDIX 05: - Screen Shots of HEC-HMS Model, Calibration and Validation Stages



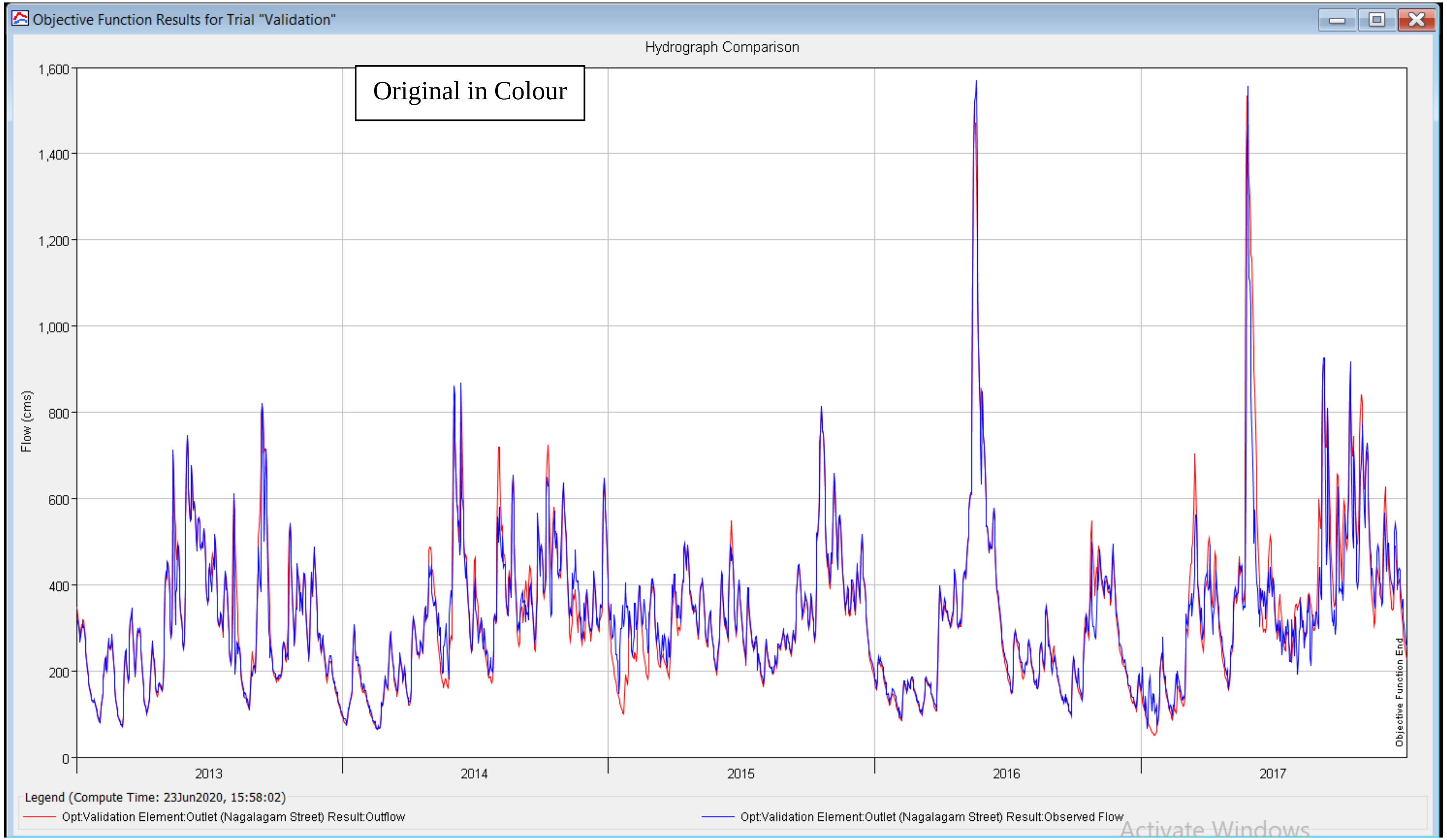
River flow Simulation Model



River flow Model Calibration



Hydrograph comparison at the Calibration stage



Hydrograph comparison at the Validation stage

APPENDIX 06: - Calculation of Parameter Values for HEC-HMS Model

Name of the Sub Catchment	Area (km²)	Land Use Category	Area (km²)	%	Hydrological Soil Group A	Hydrological Soil Group B	Hydrological Soil Group C	Hydrological Soil Group D	Area % Group A	Area % Group B	Area % Group C	Area % Group D	CN Group A	CN Group B	CN Group C	CN Group D	Product A	Product B	Product C	Product D	Total A	Total B	Total C	Total D	Weighted CN	Impervious %
Lower Kelani Ganga	38.010	Cultivated Land (With CT)	6.768	17.81	2.2982	_	4.4703	_	6.05	_	11.76	_	72	_	88	_	435.33	_	1,034.97	_	2861.95	_	4,441.77	_	73.04	0.00
		Cultivated Land (Without CT)	28.855	75.92	12.3946	_	16.4608	_	32.61	_	43.31	_	62	_	78	_	2,021.76	_	3,377.94	_						
		Meadow	1.094	2.88	1.0241	_	0.0702	_	2.69	_	0.18	_	30	_	71	_	80.83	_	13.12	_						
		Water Surface	1.291	3.40	1.2316	_	0.0598	_	3.24	_	0.16	_	100	_	100	_	324.03	_	15.74	_						
Kehelgamu Ganga	212.186	Cultivated Land (With CT)	0.892	0.42	_	_	0.8921	_	_	_	0.42	_	_	_	88	_	_	_	37.00	_	_	_	7,666.44	_	76.66	0.56
		Cultivated Land (Without CT)	160.853	75.81	_	_	160.8528	_	_	_	75.81	_	_	_	78	_	_	_	5,912.97	_						
		Forest Land (Good Cover)	36.698	17.30	_	_	36.6984	_	_	_	17.30	_	_	_	70	_	_	_	1,210.67	_						
		Meadow	7.816	3.68	_	_	7.8163	_	_	_	3.68	_	_	_	71	_	_	_	261.54	_						
		Pasture (Good)	2.862	1.35	_	_	2.8619	_	_	_	1.35	_	_	_	74	_	_	_	99.81	_						
		Rock	1.186	0.56	_	_	1.1855	_	_	_	0.56	_	_	_	100	_	_	_	55.87	_						
		Water Surface	1.879	0.89	_	_	1.8795	_	_	_	0.89	_	_	_	100	_	_	_	88.58	_						
Maskeliya Oya	199.409	Cultivated Land (With CT)	0.651	0.33	_	_	0.5656	0.0855	_	_	0.28	0.04	_	_	88	91	_	_	24.96	3.90	_	_	5,880.64	1,775.17	76.56	2.05
		Cultivated Land (Without CT)	108.135	54.23	_	_	88.9978	19.1372	_	_	44.63	9.60	_	_	78	81	_	_	3,481.20	777.35						
		Forest Land (Good Cover)	72.432	36.32	_	_	54.8889	17.5431	_	_	27.53	8.80	_	_	70	77	_	_	1,926.80	677.41						
		Meadow	6.968	3.49	_	_	6.2728	0.6953	_	_	3.15	0.35	_	_	71	78	_	_	223.34	27.20						
		Pasture (Good)	4.735	2.37	_	_	0.5601	4.1746	_	_	0.28	2.09	_	_	74	80	_	_	20.78	167.48						
		Rock	4.084	2.05	_	_	1.7952	2.2888	_	_	0.90	1.15	_	_	100	100	_	_	90.03	114.78						
		Water Surface	2.404	1.21	_	_	2.2637	0.1405	_	_	1.14	0.07	_	_	100	100	_	_	113.52	7.05						
Magal Ganga	111.357	Cultivated Land (With CT)	0.772	0.69	_	_	0.7655	0.0065	_	_	0.69	0.01	_	_	88	91	_	_	60.49	0.53	_	_	6,295.51	1,255.76	75.51	4.25
		Cultivated Land (Without CT)	37.387	33.57	_	_	37.1121	0.2752	_	_	33.33	0.25	_	_	78	81	_	_	2,599.52	20.02						
		Forest Land (Good Cover)	58.077	52.15	_	_	43.3341	14.7428	_	_	38.91	13.24	_	_	70	77	_	_	2,724.02	1,019.42						
		Meadow	8.905	8.00	_	_	8.6940	0.2115	_	_	7.81	0.19	_	_	71	78	_	_	554.32	14.81						
		Rock	4.737	4.25	_	_	2.5658	2.1716	_	_	2.30	1.95	_	_	100	100	_	_	230.41	195.01						
		Water Surface	1.478	1.33	_	_	1.4115	0.0665	_	_	1.27	0.06	_	_	100	100	_	_	126.75	5.97						
Panapura Oya	42.821	Cultivated Land (With CT)	0.916	2.14	_	_	0.9163	_	_	_	2.14	_	_	_	88	_	_	_	188.30	_	_	_	7,840.24	_	78.40	1.27
		Cultivated Land (Without CT)	38.833	90.69	_	_	38.8333	_	_	_	90.69	_	_	_	78	_	_	_	7,073.59	_						
		Forest Land (Good Cover)	1.289	3.01	_	_	1.2890	_	_	_	3.01	_	_	_	70	_	_	_	210.71	_						
		Meadow	0.719	1.68	_	_	0.7185	_	_	_	1.68	_	_	_	71	_	_	_	119.13	_						
		Rock	0.545	1.27	_	_	0.5449	_	_	_	1.27	_	_	_	100	_	_	_	127.26	_						
		Water Surface	0.519	1.21	_	_	0.5192	_	_	_	1.21	_	_	_	100	_	_	_	121.24	_						
Upper Kelani Ganga	136.049	Cultivated Land (With CT)	1.892	1.39	_	_	1.8327	0.0590	_	_	1.35	0.04	_	_	88	91	_	_	118.54	3.95	_	_	7,589.58	146.43	77.36	1.18
		Cultivated Land (Without CT)	104.445	76.77	_	_	103.8309	0.6146	_	_	76.32	0.45	_	_	78	81	_	_	5,952.85	36.59						
		Forest Land (Good Cover)	23.633	17.37	_	_	22.0257	1.6077	_	_	16.19	1.18	_	_	70	77	_	_	1,133.26	90.99						
		Meadow	2.204	1.62	_	_	2.2037	0.0001	_	_	1.62	0.00	_	_	71	78	_	_	115.01	0.01						
		Rock	1.604	1.18	_	_	1.4015	0.2026	_	_	1.03	0.15	_	_	100	100	_	_	103.01	14.89						
		Water Surface	2.271	1.67	_	_	2.2707	_	_	_	1.67	_	_	_	100	100	_	_	166.90	_						
Welihel Oya	82.140	Cultivated Land (With CT)	1.709	2.08	_	_	1.6625	0.0462	_	_	2.02	0.06	_	_	88	91	_	_	178.11	5.12	_	_	7,072.59	770.01	78.43	2.11
		Cultivated Land (Without CT)	67.559	82.25	_	_	61.6637	5.8952	_	_	75.07	7.18	_	_	78	81	_	_	5,855.61	581.34						
		Forest Land (Good Cover)	7.648	9.31	_	_	6.3878	1.2601	_	_	7.78	1.53	_	_	70	77	_	_	544.38	118.13						
		Meadow	2.154	2.62	_	_	2.1544	_	_	_	2.62	_	_	_	71	_	_	_	186.22	_						
		Rock	1.733	2.11	_	_	1.2842	0.4485	_	_	1.56	0.55	_	_	100	100	_	_	156.34	54.60						
		Water Surface	1.337	1.63	_	_	1.2480	0.0889	_	_	1.52	0.11	_	_	100	100	_	_	151.93	10.82						
Ritigaha Oya	98.200	Cultivated Land (With CT)	4.903	4.99	_	_	4.9025	_	_	_	4.99	_	_	_	88	91	_	_	439.33	_	_	_	7,435.56	404.86	78.40	0.81
		Cultivated Land (Without CT)	82.181	83.69	_	_	78.0902	4.0906	_	_	79.52	4.17	_	_	78	81	_	_	6,202.69	337.41						
		Forest Land (Good Cover)	6.552	6.67	_	_	6.0726	0.4796	_	_	6.18	0.49	_	_	70	77	_	_	432.87	37.61						
		Meadow	2.516	2.56	_	_	2.5156	_	_	_	2.56	_	_	_	71	_	_	_	181.88	_						
		Rock	0.799	0.81	_	_	0.5060	0.2931	_	_	0.52	0.30	_	_	100	100	_	_	51.53	29.84						
		Water Surface	1.250	1.27	_	_	1.2497	_	_	_	1.27	_	_	_	100	_	_	_	127.26	_						
Gurugoda Oya	235.760	Cultivated Land (With CT)	23.166	9.83	_	_	16.1471	7.0191	_	_	6.85	2.98	_	_	88	91	_	_	602.71	270.93	_	_	5,823.56	2,128.51	79.52	0.16
		Cultivated Land (Without CT)	194.016	82.29	_	_	145.3327	48.6832	_	_	61.64	20.65	_	_	78	81	_	_	4,808.25	1,672.60						
		Forest Land (Good Cover)	7.015	2.98	_	_	5.6824	1.3323	_	_	2.41	0.57	_	_	70	77	_	_	168.72	43.51						
		Meadow	9.384	3.98	_	_	5.9185	3.4650	_	_	2.51	1.47	_	_	71	78	_	_	178.24	114.64						
		Rock	0.385	0.16	_	_	0.2910	0.0939	_	_	0.12	0.04	_	_	100	100	_	_	12.34	3.98						
		Water Surface	1.795	0.76	_	_	1.2566	0.5385	_	_	0.53	0.23	_	_	100	100	_	_	53.30	22.84						

Original in Colour

Name of the Sub Catchment	Area (km²)	Land Use Category	Area (km²)	%	Hydrological Soil Group A	Hydrological Soil Group B	Hydrological Soil Group C	Hydrological Soil Group D	Area % Group A	Area % Group B	Area % Group C	Area % Group D	CN Group A	CN Group B	CN Group C	CN Group D	Product A	Product B	Product C	Product D	Total A	Total B	Total C	Total D	Weighted CN	Impervious %
Ambalanpiti Oya	71.840	Cultivated Land (With CT)	0.866	1.21	_	_	0.8660	_	_	_	1.21	_	_	_	88	_	_	_	106.08	_	–	–	7,826.20	_	78.26	0.42
		Cultivated Land (Without CT)	68.396	95.21	_	_	68.3957	_	_	_	95.21	_	_	_	78	_	_	_	7,426.04	_						
		Forest Land (Good Cover)	0.444	0.62	_	_	0.4444	_	_	_	0.62	_	_	_	70	_	_	_	43.30	_						
		Meadow	1.146	1.59	_	_	1.1458	_	_	_	1.59	_	_	_	71	_	_	_	113.24	_						
		Rock	0.299	0.42	_	_	0.2992	_	_	_	0.42	_	_	_	100	_	_	_	41.64	_						
		Water Surface	0.689	0.96	_	_	0.6889	_	_	_	0.96	_	_	_	100	_	_	_	95.90	_						
Getahetta Oya	41.432	Cultivated Land (With CT)	3.229	7.79	_	_	3.2295	_	_	_	7.79	_	_	_	88	_	_	_	685.92	_	–	–	7,864.26	_	78.64	0.12
		Cultivated Land (Without CT)	35.944	86.75	_	_	35.9441	_	_	_	86.75	_	_	_	78	_	_	_	6,766.82	_						
		Forest Land (Good Cover)	0.868	2.09	_	_	0.8677	_	_	_	2.09	_	_	_	70	_	_	_	146.59	_						
		Meadow	1.011	2.44	_	_	1.0114	_	_	_	2.44	_	_	_	71	_	_	_	173.32	_						
		Rock	0.051	0.12	_	_	0.0509	_	_	_	0.12	_	_	_	100	_	_	_	12.28	_						
		Water Surface	0.329	0.79	_	_	0.3287	_	_	_	0.79	_	_	_	100	_	_	_	79.33	_						
Seethawaka Ganga	140.603	Cultivated Land (With CT)	3.353	2.39	_	_	3.3534	_	_	_	2.39	_	_	_	88	_	_	_	209.88	_	–	–	7,849.88	_	78.50	0.14
		Cultivated Land (Without CT)	133.214	94.74	_	_	133.2138	_	_	_	94.74	_	_	_	78	_	_	_	7,390.06	_						
		Forest Land (Good Cover)	0.333	0.24	_	_	0.3335	_	_	_	0.24	_	_	_	70	_	_	_	16.60	_						
		Meadow	1.455	1.03	_	_	1.4551	_	_	_	1.03	_	_	_	71	_	_	_	73.48	_						
		Rock	0.193	0.14	_	_	0.1930	_	_	_	0.14	_	_	_	100	_	_	_	13.73	_						
		Water Surface	2.055	1.46	_	_	2.0546	_	_	_	1.46	_	_	_	100	_	_	_	146.12	_						
Pugoda Oya	51.062	Cultivated Land (With CT)	12.408	24.30	0.3545	_	12.0534	_	0.69	_	23.61	_	72	_	88	_	49.99	_	2,077.27	_	182.70	_	7,818.68	_	80.01	0.36
		Cultivated Land (Without CT)	37.781	73.99	0.8998	_	36.8816	_	1.76	_	72.23	_	62	_	78	_	109.26	_	5,633.87	_						
		Meadow	0.385	0.75	0.2244	_	0.1609	_	0.44	_	0.32	_	30	_	71	_	13.18	_	22.38	_						
		Rock	0.183	0.36	_	_	0.1828	_	_	_	0.36	_	_	_	100	_	_	_	35.80	_						
		Water Surface	0.304	0.60	0.0525	_	0.2520	_	0.10	_	0.49	_	100	_	100	_	10.27	_	49.36	_						
Upper Middle Kelani Ganga	244.113	Cultivated Land (With CT)	18.773	7.69	0.6498	_	18.1234	_	0.27	_	7.42	_	72	_	88	_	19.17	_	653.33	_	129.97	_	7,734.45	_	78.64	0.27
		Cultivated Land (Without CT)	213.762	87.57	3.7275	_	210.0344	_	1.53	_	86.04	_	62	_	78	_	94.67	_	6,711.11	_						
		Forest Land (Good Cover)	2.296	0.94	_	_	2.2963	_	_	_	0.94	_	_	_	70	_	_	_	65.85	_						
		Meadow	4.688	1.92	0.2512	_	4.4369	_	0.10	_	1.82	_	30	_	71	_	3.09	_	129.05	_						
		Rock	0.653	0.27	_	_	0.6534	_	_	_	0.27	_	_	_	100	_	_	_	26.77	_						
		Water Surface	3.940	1.61	0.3185	_	3.6215	_	0.13	_	1.48	_	100	_	100	_	13.05	_	148.35	_						
Kalatuwawa	88.243	Cultivated Land (With CT)	3.400	3.85	0.0212	_	3.3792	_	0.02	_	3.83	_	72	_	88	_	1.73	_	336.98	_	12.90	_	7,617.15	_	76.30	0.00
		Cultivated Land (Without CT)	60.096	68.10	0.0863	_	60.0092	_	0.10	_	68.00	_	62	_	78	_	6.07	_	5,304.34	_						
		Forest Land (Good Cover)	20.953	23.75	_	_	20.9534	_	_	_	23.75	_	25	_	70	_	_	_	1,662.16	_						
		Meadow	1.261	1.43	0.1492	_	1.1121	_	0.17	_	1.26	_	30	_	71	_	5.07	_	89.48	_						
		Pasture (Good)	2.131	2.41	_	_	2.1306	_	_	_	2.41	_	39	_	74	_	_	_	178.67	_						
		Water Surface	0.402	0.46	0.0003	_	0.4017	_	0.00	_	0.46	_	100	_	100	_	0.04	_	45.52	_						
Pusweli Oya	94.207	Cultivated Land (With CT)	19.404	20.60	_	1.2312	18.1729	_	_	1.31	19.29	_	72	81	88	_	_	105.86	1,697.56	_	87.96	544.00	7,257.58	_	78.90	0.00
		Cultivated Land (Without CT)	71.382	75.77	1.0119	3.5849	66.7851	_	1.07	3.81	70.89	_	62	71	78	_	66.60	270.18	5,529.59	_						
		Meadow	3.063	3.25	0.4142	2.2488	0.3998	_	0.44	2.39	0.42	_	30	58	71	_	13.19	138.45	30.13	_						
		Water Surface	0.358	0.38	0.0770	0.2780	0.0029	_	0.08	0.30	0.00	_	100	100	100	_	8.17	29.51	0.31	_						
Pallewela Oya	62.133	Cultivated Land (With CT)	13.218	21.27	0.7427	_	12.4751	_	1.20	_	20.08	_	72	_	88	_	86.06	_	1,766.86	_	372.93	_	7,548.80	_	79.22	0.00
		Cultivated Land (Without CT)	46.705	75.17	2.6980	_	44.0072	_	4.34	_	70.83	_	62	_	78	_	269.22	_	5,524.52	_						
		Meadow	1.699	2.73	0.0208	_	1.6783	_	0.03	_	2.70	_	30	_	71	_	1.00	_	191.77	_						
		Water Surface	0.511	0.82	0.1034	_	0.4079	_	0.17	_	0.66	_	100	_	100	_	16.64	_	65.65	_						
Lower Middle Kelani Ganga	151.986	Cultivated Land (With CT)	24.316	16.00	5.0376	0.0252	19.2535	_	3.31	0.02	12.67	_	72	81	88	_	238.65	1.34	1,114.78	_	1,499.16	18.31	6,092.30	_	76.10	0.00
		Cultivated Land (Without CT)	119.524	78.64	25.4698	0.2521	93.8025	_	16.76	0.17	61.72	_	62	71	78	_	1,039.00	11.77	4,813.99	_						
		Meadow	4.720	3.11	2.0194	0.1359	2.5643	_	1.33	0.09	1.69	_	30	58	71	_	39.86	5.19	119.79	_						
		Water Surface	3.426	2.25	2.7610	_	0.6648	_	1.82	_	0.44	_	100	_	100	_	181.66	_	43.74	_						
Biyagama	60.828	Cultivated Land (With CT)	12.317	20.25	0.2971	_	12.0195	_	0.49	_	19.76	_	72	_	88	_	35.17	_	1,738.87	_	99.41	_	7,891.14	_	79.91	0.00
		Cultivated Land (Without CT)	47.734	78.47	0.5405	_	47.1937	_	0.89	_	77.59	_	62	_	78	_	55.09	_	6,051.70	_						
		Meadow	0.377	0.62	_	_	0.3774	_	_	_	0.62	_	30	_	71	_	_	_	44.05	_						
		Water Surface	0.399	0.66	0.0557	_	0.3438	_	0.09	_	0.57	_	100	_	100	_	9.15	_	56.52	_						
Kolonnawa Ela	81.856	Cultivated Land (With CT)	10.846	13.25	1.5092	4.8696	4.4674	_	1.84	5.95	5.46	_	72	81	88	_	132.74	481.87	480.27	_	519.60	2,708.76	4,308.07	_	75.36	2.06
		Cultivated Land (Without CT)	59.790	73.04	4.7147	19.8588	35.2168	_	5.76	24.26	43.02	_	62	71	78	_	357.10	1,722.51	3,355.79	_						
		Meadow	6.468	7.90	0.5598	4.2578	1.6500	_	0.68	5.20	2.02	_	30	58	71	_	20.52	301.69	143.12	_						
		Residential (1/8) arce or less	2.599	0.02	0.0230	_	2.5756	_	0.03	_	3.15	_	77	_	90	_	2.16	_	283.19	_						
		Sand	0.360	0.44	_	0.1015	0.2583	_	_	0.12	0.32	_	_	77	85	_	_	9.55	26.82	_						
		Water Surface	1.793	2.19	0.0579	1.5809	0.1546	_	0.07	1.93	0.19	_	100	100	100	_	7.07	193.14	18.89	_						

Original in Colour

Name of the Sub Catchment	Area (km²)	Weighted CN	Potential Storage (S)	Flow length (m)	Flow Length (ft) L	Elevation of Hydraulically Most Remort Point (m)	Elevation of Outlet of Watershed (m)	Difference in Elevation (ft) H	Time of Concentration T_c	Lag Time (min)	Average WS Slope (%) y
Lower Kelani Ganga	38.01	73.04	93.77	13,657.78	44,808.45	-4.100	-6.34	7.35	852.94	511.76	0.02
Kehelgamu Ganga	212.19	76.66	77.31	47,971.63	157,385.33	1,565.694	105.53	4,790.52	300.36	180.22	3.04
Maskeliya Oya	199.41	76.56	77.77	43,471.49	142,621.27	1,520.000	105.53	4,640.61	271.36	162.82	3.25
Magal Ganga	111.36	75.51	82.37	17,669.56	57,970.31	1,187.550	76.75	3,644.33	105.29	63.17	6.29
Panapura Oya	42.82	78.40	69.97	8,034.62	26,359.97	264.300	76.75	615.33	84.04	50.42	2.33
Upper Kelani Ganga	136.05	77.36	74.33	23,081.00	75,724.15	105.525	17.29	289.50	380.08	228.05	0.38
Welihel Oya	82.14	78.43	69.87	24,537.68	80,503.21	788.255	17.29	2,529.40	177.07	106.24	3.14
Ritigaha Oya	98.20	78.40	69.96	24,073.51	78,980.36	652.659	15.54	2,090.28	186.40	111.84	2.65
Gurugoda Oya	235.76	79.52	65.41	41,047.33	134,668.10	855.555	15.54	2,755.94	310.38	186.23	2.05
Ambalanpiti Oya /Gonmala Oya	71.84	78.26	70.55	15,282.88	50,140.06	101.025	17.35	274.52	240.97	144.58	0.55
Getahetta Oya	41.43	78.64	68.98	13,049.17	42,811.73	33.255	12.53	68.01	343.56	206.14	0.16
Maha Oya /Seethawaka Ganga	140.60	78.50	69.57	27,551.24	90,390.10	76.745	9.75	219.80	518.48	311.09	0.24
Pugoda Oya	51.06	80.01	63.44	14,505.82	47,590.68	28.973	4.53	80.21	364.34	218.60	0.17
Upper Middle Kelani Ganga	244.11	78.64	68.97	27,536.75	90,342.57	17.285	4.53	41.86	981.17	588.70	0.05
Wak Oya / Kalatuwawa	88.24	76.30	78.89	17,427.67	57,176.71	83.755	0.02	274.71	280.36	168.22	0.48
Pusweli Oya	94.21	78.90	67.95	17,995.17	59,038.55	18.255	-1.55	64.99	506.77	304.06	0.11
Pallewela Oya / Maha Ela	62.13	79.22	66.64	14,252.02	46,758.03	12.585	-3.44	52.59	419.99	251.99	0.11
Lower Middle Kelani Ganga	151.99	76.10	79.78	27,893.40	91,512.65	4.525	-4.10	28.30	1,157.94	694.76	0.03
Biyagama	60.83	79.91	63.88	11,111.59	36,454.90	8.525	-4.10	41.42	345.38	207.23	0.11
Kolonnawa Ela	81.86	75.36	83.03	18,556.83	60,881.26	6.155	-4.98	36.54	655.37	393.22	0.06
** Note:Elevation taken by Time_weight layer and Maximum Hydraulic flow length taken from Flow_Length layer.											

Lag time calculation by using the Kirpich Method

Name of the Sub Catchment	Area (A) (km^2)	Lag Time tp (min)	Base Time T (day)	Base Time T (hrs)	After Peak N (days)	After Peak N (hrs)	Peak Discharge Qp (Cumec)	q_p (Cumec/km)	W_{50} (hr)	W_{75} (hr)	Q_N Flow	Ratio to Peak
Lower Kelani Ganga	38.010	511.76	4.07	97.59	1.74	41.73	8.91	0.23	26.82	15.33	6.75	0.76
Kehelgamu Ganga	212.186	180.22	3.38	81.01	2.45	58.86	141.29	0.67	8.69	4.96	30.00	0.21
Maskeliya Oya	199.409	162.82	3.34	80.14	2.42	58.14	146.97	0.74	7.79	4.45	32.00	0.22
Magal Ganga	111.357	63.17	3.13	75.16	2.16	51.74	211.53	1.90	2.80	1.60	50.00	0.24
Panapura Oya	42.821	50.42	3.11	74.52	1.78	42.74	101.91	2.38	2.20	1.25	71.00	0.70
Upper Kelani Ganga	136.049	228.05	3.48	83.40	2.24	53.86	71.59	0.53	11.20	6.40	22.00	0.31
Welihel Oya	82.140	106.24	3.22	77.31	2.03	48.69	92.78	1.13	4.91	2.81	27.00	0.29
Ritigaha Oya	98.200	111.84	3.23	77.59	2.10	50.46	105.36	1.07	5.19	2.97	30.00	0.28
Gurugoda Oya	235.760	186.23	3.39	81.31	2.50	60.12	151.92	0.64	9.00	5.14	33.00	0.22
Ambalanpiti Oya /Gonmala Oya	71.840	144.58	3.30	79.23	1.97	47.40	59.63	0.83	6.85	3.91	19.00	0.32
Getahetta Oya	41.432	206.14	3.43	82.31	1.77	42.46	24.12	0.58	10.05	5.74	10.00	0.41
Maha Oya /Seethawaka Ganga	140.603	311.09	3.65	87.55	2.26	54.21	54.24	0.39	15.67	8.95	17.00	0.31
Pugoda Oya	51.062	218.60	3.46	82.93	1.84	44.27	28.03	0.55	10.70	6.12	10.00	0.36
Upper Middle Kelani Ganga	244.113	588.70	4.23	101.44	2.52	60.54	49.76	0.20	31.20	17.83	20.00	0.40
Wak Oya / Kalatuwawa	88.243	168.22	3.35	80.41	2.06	49.39	62.95	0.71	8.07	4.61	20.00	0.32
Pusweli Oya	94.207	304.06	3.63	87.20	2.08	50.04	37.18	0.39	15.29	8.73	14.00	0.38
Pallewela Oya / Maha Ela	62.133	251.99	3.52	84.60	1.92	46.04	29.59	0.48	12.48	7.13	11.00	0.37
Lower Middle Kelani Ganga	151.986	694.76	4.45	106.74	2.29	55.06	26.25	0.17	37.31	21.32	14.50	0.55
Biyagama	60.828	207.23	3.43	82.36	1.91	45.85	35.22	0.58	10.10	5.77	13.00	0.37
Kolonnawa Ela	81.856	393.22	3.82	91.66	2.03	48.65	24.98	0.31	20.18	11.53	10.50	0.42
Concider Cp	2											
$T = 3+3+\left(\frac{t_p}{24}\right)$	$N = 0.84A^{0.2}$	$Q_P = C_P \frac{A}{t_p}$	$W_{50} = \frac{5.6}{q_p^{1.08}}$	$W_{75} = \frac{W_{50}}{1.75}$								

Original in Colour

Ratio to Peak of each Sub catchment

Name of the Sub Catchment	Area (km²)	Weighted CN	Potential Storage (S) Milimeters $S = 25.4\left[\frac{1000}{CN} - 10\right]$	Initial Abstraction (I_a) $I_a = 0.2S$
Lower Kelani Ganga	38.010	73.04	93.768	18.754
Kehelgamu Ganga	212.186	76.66	77.314	15.463
Maskeliya Oya	199.409	76.56	77.774	15.555
Magal Ganga	111.357	75.51	82.367	16.473
Panapura Oya	42.821	78.40	69.970	13.994
Upper Kelani Ganga	136.049	77.36	74.335	14.867
Welihel Oya	82.140	78.43	69.872	13.974
Ritigaha Oya	98.200	78.40	69.962	13.992
Gurugoda Oya	235.760	79.52	65.414	13.083
Ambalanpiti Oya /Gonmala Oya	71.840	78.26	70.551	14.110
Getahetta Oya	41.432	78.64	68.980	13.796
Maha Oya /Seethawaka Ganga	140.603	78.50	69.572	13.914
Pugoda Oya	51.062	80.01	63.445	12.689
Upper Middle Kelani Ganga	244.113	78.64	68.973	13.795
Wak Oya / Kalatuwawa	88.243	76.30	78.894	15.779
Pusweli Oya	94.207	78.90	67.945	13.589
Pallewela Oya / Maha Ela	62.133	79.22	66.637	13.327
Lower Middle Kelani Ganga	151.986	76.10	79.782	15.956
Biyagama	60.828	79.91	63.875	12.775
Kolonnawa Ela	81.856	75.36	83.030	16.606

Initial Abstraction of each Sub catchment

Name of the Sub Catchment	Initial Discharge (Cumec)
Lower Kelani Ganga	0.45
Kehelgamu Ganga	0.45
Maskeliya Oya	7.06
Magal Ganga	10.58
Panapura Oya	5.10
Upper Kelani Ganga	7.35
Welihel Oya	4.64
Ritigaha Oya	5.27
Gurugoda Oya	7.60
Ambalanpiti Oya /Gonmala Oya	2.98
Getahetta Oya	1.21
Maha Oya /Seethawaka Ganga	2.71
Pugoda Oya	1.40
Upper Middle Kelani Ganga	2.49
Wak Oya / Kalatuwawa	3.15
Pusweli Oya	1.86
Pallewela Oya / Maha Ela	1.48
Lower Middle Kelani Ganga	1.31
Biyagama	1.76
Kolonnawa Ela	1.25

Original in Colour

Initial Discharge of each Sub catchment

Name of the Sub Catchment	Area (km²)	Name of Related Rain Gauge	Area (km²)	Depth Weight	Name of Junction	Length from Juncton to End (m)	Length from Juncton to Thiessen Line (m)	Time Weight
Lower Kelani Ganga	38.010	Colombo	38.010	1.000	Nagalagam Street	_	_	1.000
Kehelgamu Ganga	212.186	Annfield	146.522	0.691	Kalugala	47,971.396	22,284.829	0.465
		Laxapana	60.254	0.284		22,284.829	1,737.372	0.457
		Weweltalawa	5.410	0.025		_	_	0.078
Maskeliya Oya	199.409	Annfield	77.411	0.388	Kalugala	43,488.259	25,596.241	0.589
		Laxapana	121.073	0.607		25,596.241	628.190	0.387
		Weweltalawa	0.925	0.005		_	_	0.025
Magal Ganga	111.357	Laxapana	109.888	0.987	Nakkawita	17,669.564	1,950.877	0.890
		Weweltalawa	1.469	0.013		_	_	0.110
Panapura Oya	42.821	Laxapana	12.162	0.284	Nakkawita	6,608.824	4,768.716	0.722
		Weweltalawa	30.659	0.716		_	_	0.278
Upper Kelani Ganga	136.049	Weweltalawa	107.607	0.791	Yatiyantota	23,064.235	8,617.787	0.010
		Laxapana	0.490	0.004		23,777.892	23,411.653	0.985
		Dunedin	27.952	0.205		_	_	0.006
Welihel Oya	82.140	Weweltalawa	66.968	0.815	Yatiyantota	24,537.678	6,305.100	0.743
		Dunedin	15.172	0.185		_	_	0.257
Ritigaha Oya	98.200	Dunedin	26.667	0.272	Warawala	_	_	0.006
		Vincit	0.056	0.001		18,323.139	18,206.859	0.761
		Weweltalawa	71.477	0.728		24,067.010	9,116.260	0.232
Gurugoda Oya	235.760	Dunedin	8.451	0.036	Warawala	_	_	0.039
		Vincit	98.384	0.417		19,027.295	734.541	0.425
		Weweltalawa	128.925	0.547		41,047.335	19,027.295	0.536
Ambalanpiti Oya /Gonmala Oya	71.840	Dunedin	55.926	0.778	Dahanwaka	_	_	0.036
		Hanwella Group	3.677	0.051		5,945.578	5,731.154	0.070
		Laxapana	12.236	0.170		16,891.511	15,092.125	0.893
Getahetta Oya	41.432	Dunedin	3.977	0.096	Talduwa	_	_	0.272
		Hanwella Group	37.455	0.904		13,047.114	3,545.621	0.728
Maha Oya /Seethawaka Ganga	140.603	Dunedin	108.236	0.770	Kudagama	_	_	0.088
		Hanwella Group	0.733	0.005		12,531.389	12,223.589	0.154
		Laxapana	17.558	0.125		34,942.559	29,018.844	0.405
		Weweltalawa	14.077	0.100		27,551.236	25,652.595	0.354
Pugoda Oya	51.062	Vincit	33.542	0.657	Pugoda	14,505.817	5,071.914	0.650
		Hanwella Group	17.520	0.343		_	_	0.350

Name of the Sub Catchmment	Area (km²)	Name of Related Rain Gauge	Area (km²)	Depth Weight	Name of Junction	Length from Juncton to End (m)	Length from Juncton to Thiessen Line (m)	Time Weight
Upper Middle Kelani Ganga	244.113	Dunedin	76.918	0.315	Pugoda	27,536.749	7,432.301	0.365
		Hanwella Group	54.924	0.225		_	_	0.255
		Vincit	112.270	0.460		24,474.420	5,897.136	0.380
Wak Oya / Kalatuwawa	88.243	Hanwella Group	88.243	1.000	Kaluaggala			1.000
Pusweli Oya	94.207	Hanwella Group	94.207	1.000	Artigala			1.000
Pallewela Oya / Maha Ela	62.133	Colombo	20.748	0.334	Kaduwela	_	_	0.174
		Hanwella Group	41.386	0.666		14,252.020	2,485.280	0.826
Lower Middle Kelani Ganga	151.986	Colombo	5.163	0.034	Raggahawatta	_	_	0.152
		Hanwella Group	146.823	0.966		27,893.396	4,227.039	0.848
Biyagama	60.828	Colombo	36.843	0.606	Raggahawatta	_	_	0.109
		Hanwella Group	23.985	0.394		11,122.227	9,906.836	0.891
Kolonnawa Ela	81.856	Colombo	81.856	1.000	Nagalagam Street	_	_	1.000

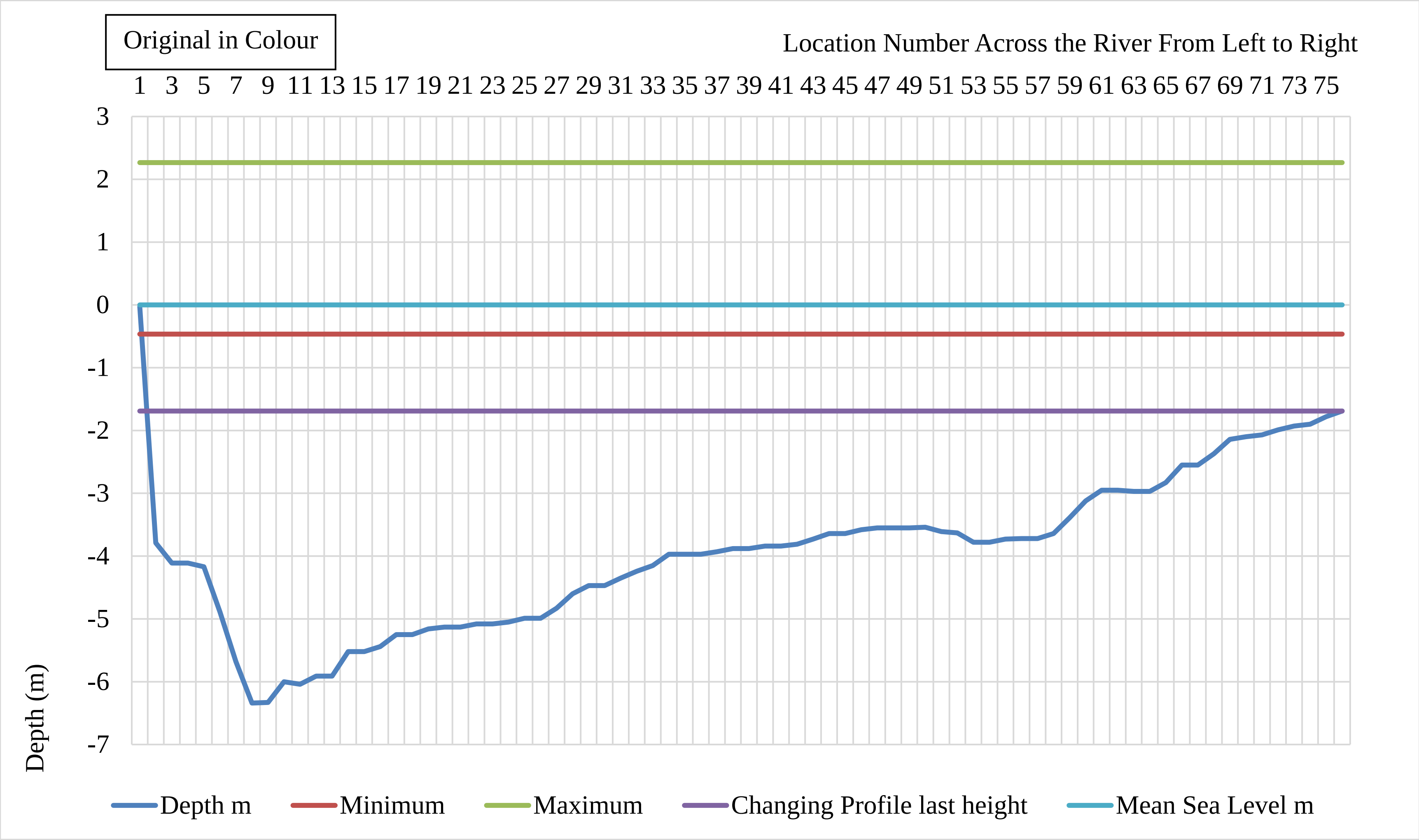
Original in Colour

Depth weight and Time weight for Metrologic model

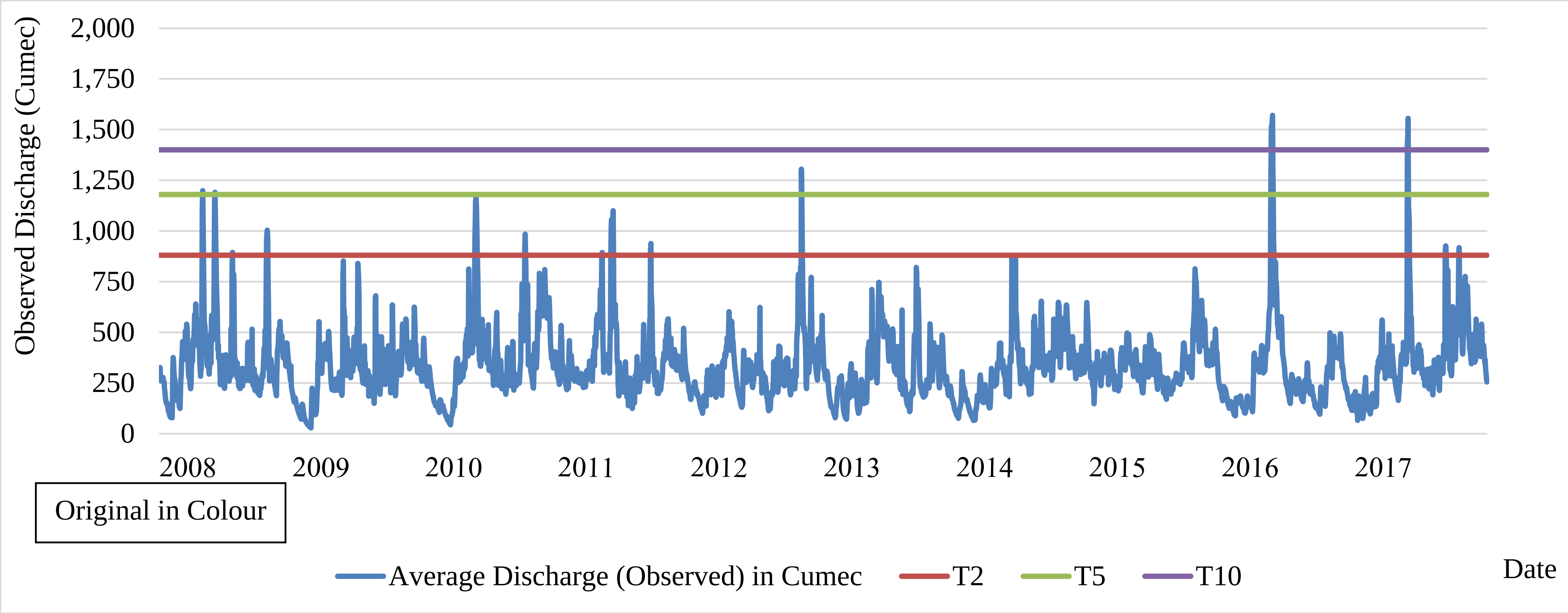
Name of the River	Flow length (m)	Elevation of Most Remort Point in river	Elevation of Outlet of River	Slope (m/m)	Manning's n	Bottom Width	Number of Subreaches
Lower Kelani Ganga	13,657.78	-4.100	-6.340	0.000164	0.035	98.56	2
Kehelgamu Ganga	47,971.63	1565.694	105.525	0.030438	0.035	25.13	4
Maskeliya Oya	43,471.49	1518.570	105.525	0.032505	0.035	19.79	3
Magal Ganga	17,669.56	1187.550	76.745	0.062865	0.035	34.45	4
Panapura Oya	8,034.62	264.300	76.745	0.023343	0.035	21.85	2
Upper Kelani Ganga	23,081.00	105.525	17.285	0.003823	0.035	40.98	4
Welihel Oya	24,537.68	788.255	17.285	0.031420	0.035	16.54	5
Ritigaha Oya	24,073.51	652.659	15.535	0.026466	0.035	14.88	4
Gurugoda Oya	41,047.33	855.555	15.535	0.020465	0.035	22.11	6
Ambalanpiti Oya /Gonmala Oya	15,282.88	101.025	17.350	0.005475	0.035	20.34	4
Getahetta Oya	13,049.17	33.255	12.525	0.001589	0.035	8.50	4
Maha Oya /Seethawaka Ganga-4	27,551.24	76.745	9.750	0.002432	0.035	37.28	6
Seethawaka Ganga-1	13,693.36	76.745	17.350	0.004338	0.035	37.33	2
Seethawaka Ganga-2	9,713.27	17.350	12.525	0.000497	0.035	39.74	2
Seethawaka Ganga-3	4,144.61	12.525	9.750	0.000670	0.035	34.76	2
Pugoda Oya	14,505.82	28.973	4.525	0.001685	0.035	5.47	4
Upper Middle Kelani Ganga-5	27,536.75	17.285	4.525	0.000463	0.035	52.36	8
Upper Middle Kelani Ganga-1	4,337.40	15.535	13.655	0.000433	0.035	32.04	2
Upper Middle Kelani Ganga-2	7,384.72	17.285	13.655	0.000492	0.035	54.16	2
Upper Middle Kelani Ganga-3	9,854.25	13.655	9.750	0.000396	0.035	51.13	2
Upper Middle Kelani Ganga-4	10,297.78	9.750	4.525	0.000507	0.035	72.11	2
Wak Oya / Kalatuwawa	17,427.67	83.755	0.023	0.004805	0.035	14.69	3
Pusweli Oya	17,995.17	18.255	-1.554	0.001101	0.035	9.72	4
Pallewela Oya / Maha Ela	14,252.02	12.585	-3.444	0.001125	0.035	12.59	3
Lower Middle Kelani Ganga-5	27,893.40	4.525	-4.100	0.000309	0.035	79.63	8
Lower Middle Kelani Ganga-1	9,105.33	4.525	0.023	0.000494	0.035	71.53	2
Lower Middle Kelani Ganga-2	4,621.38	0.023	-1.554	0.000341	0.035	81.68	2
Lower Middle Kelani Ganga-3	12,051.28	-1.554	-3.444	0.000157	0.035	83.77	2
Lower Middle Kelani Ganga-4	2,115.41	-3.444	-4.100	0.000310	0.035	81.54	2
Biyagama	11,111.59	8.525	-4.100	0.001136	0.035	13.65	2
Kolonnawa Ela	18,556.83	6.155	-4.984	0.000600	0.035	24.10	3
Kolonnawa Ela Junction to Outlet	32.90	-4.984	-6.340	0.041216	0.035	116.34	2

Input Parameter values for kinematic wave river routing method in HEC-HMS model

APPENDIX 07: - River Cross Section at Nagalagam Street and Observed Discharge for the Period of 2008 January to 2017 December

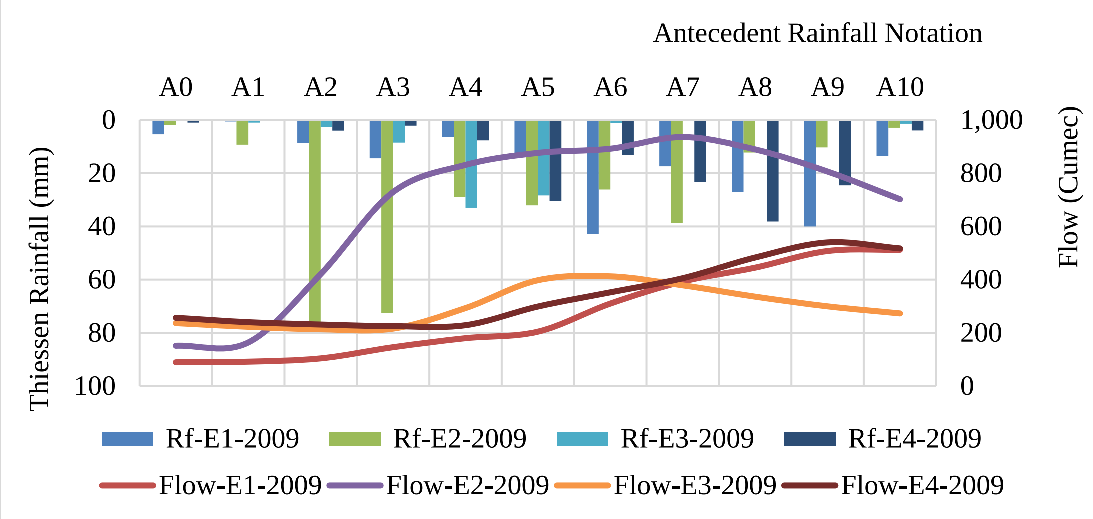


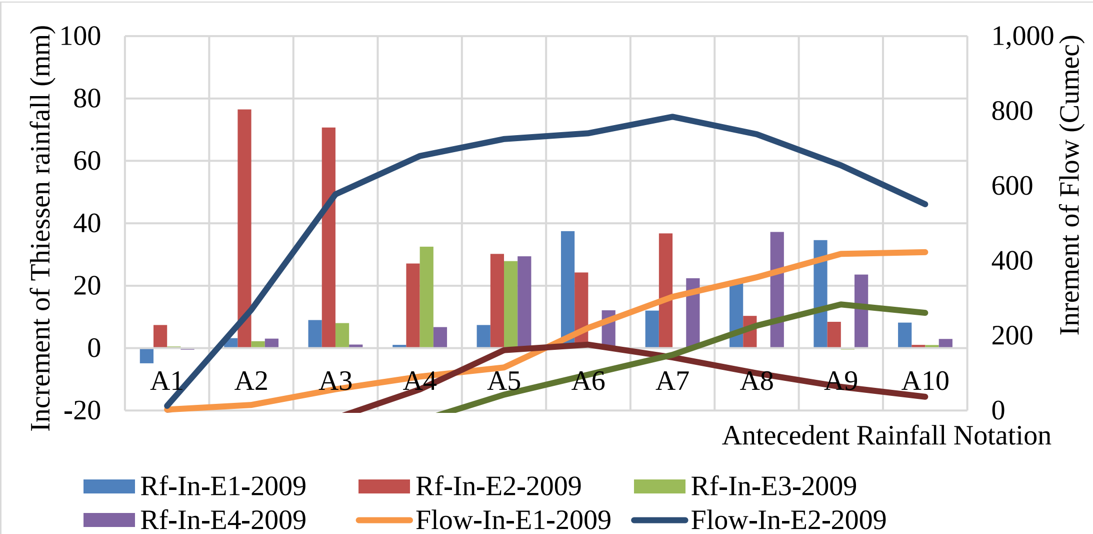
Nagalagam Street River Cross Section

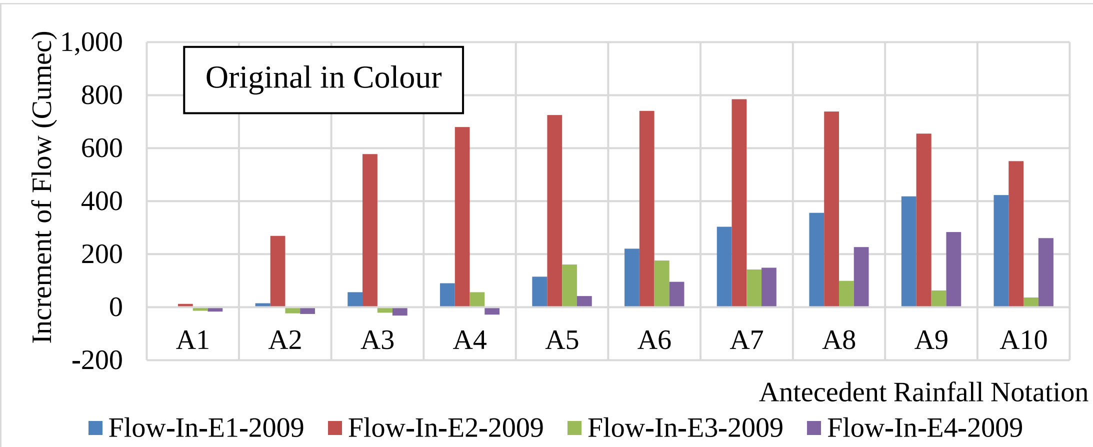


Observed Discharge for the Period of 2008 Jan. to 2017 Dec.

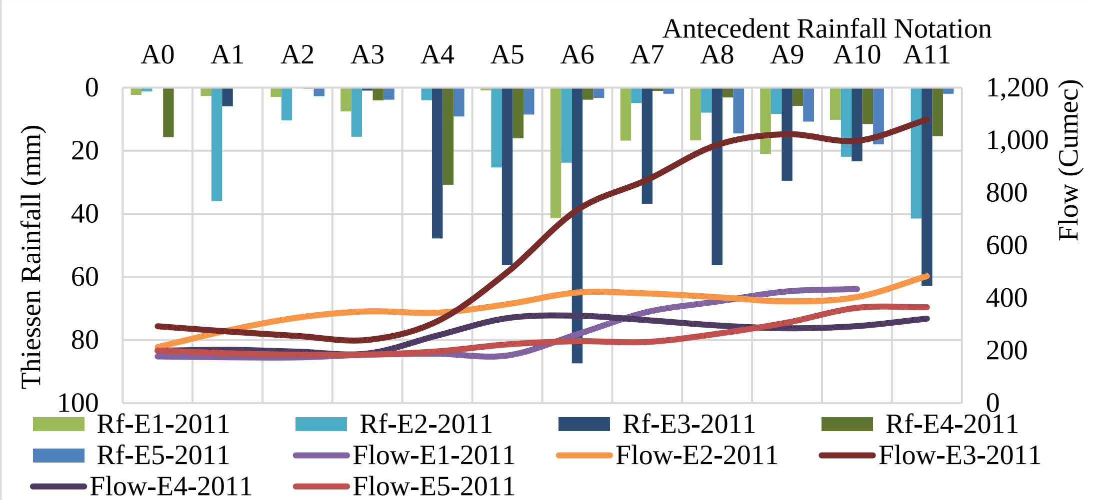
APPENDIX 08: - HEC-HMS Model Flow with Thiessen Rainfall for Antecedent Rainfall Scenario

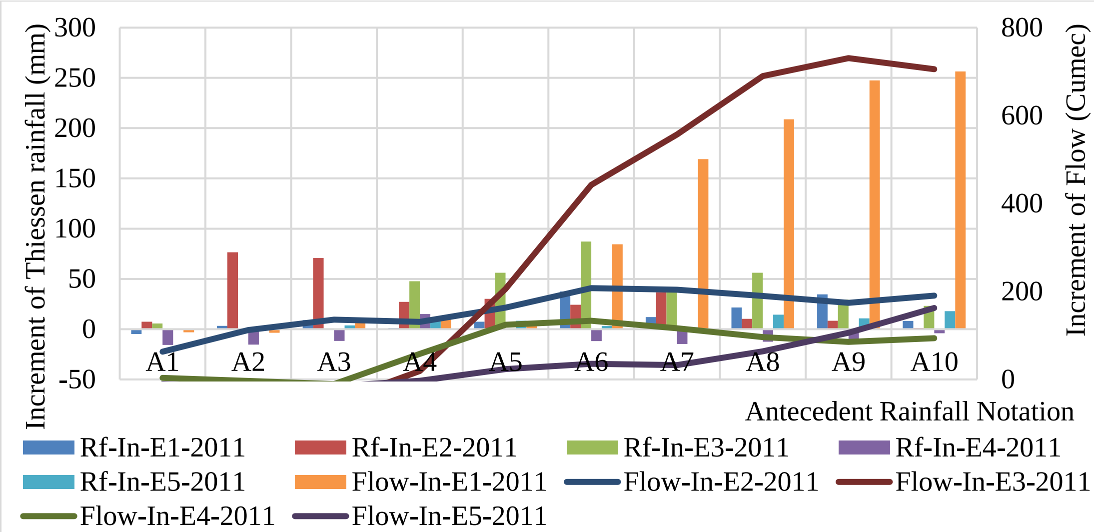


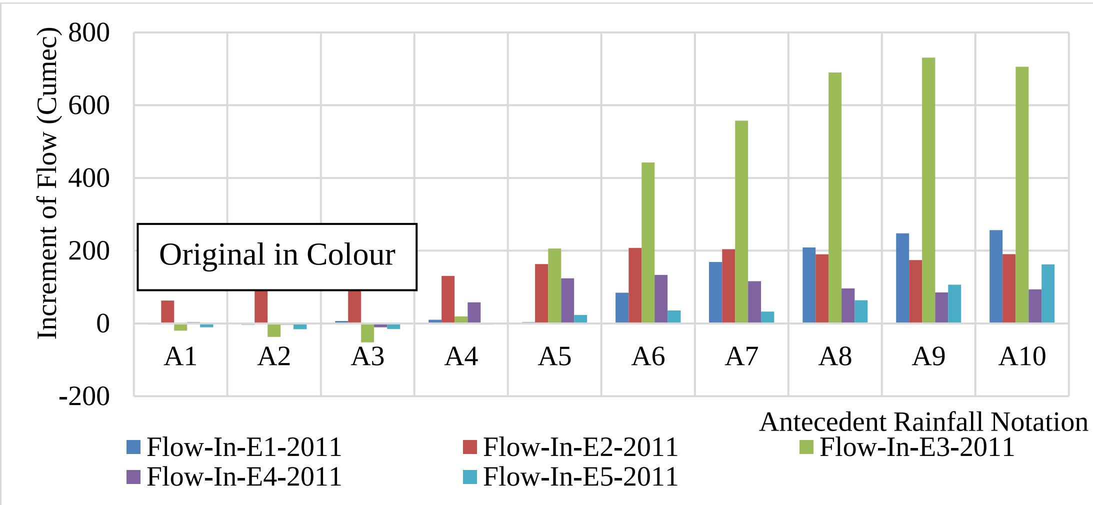




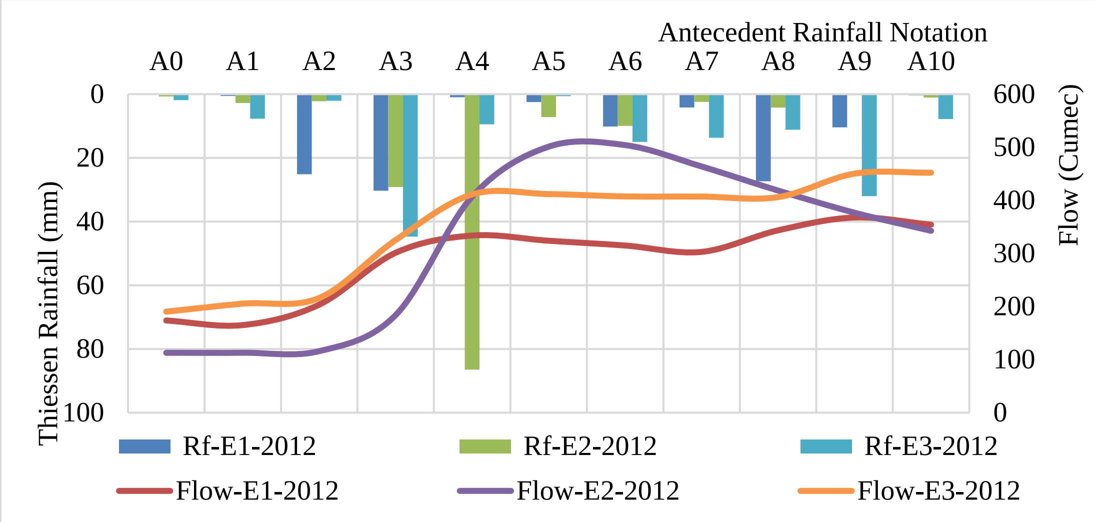
Appendix 08 – 1-Antecedent Rainfall Scenario for the Year 2009

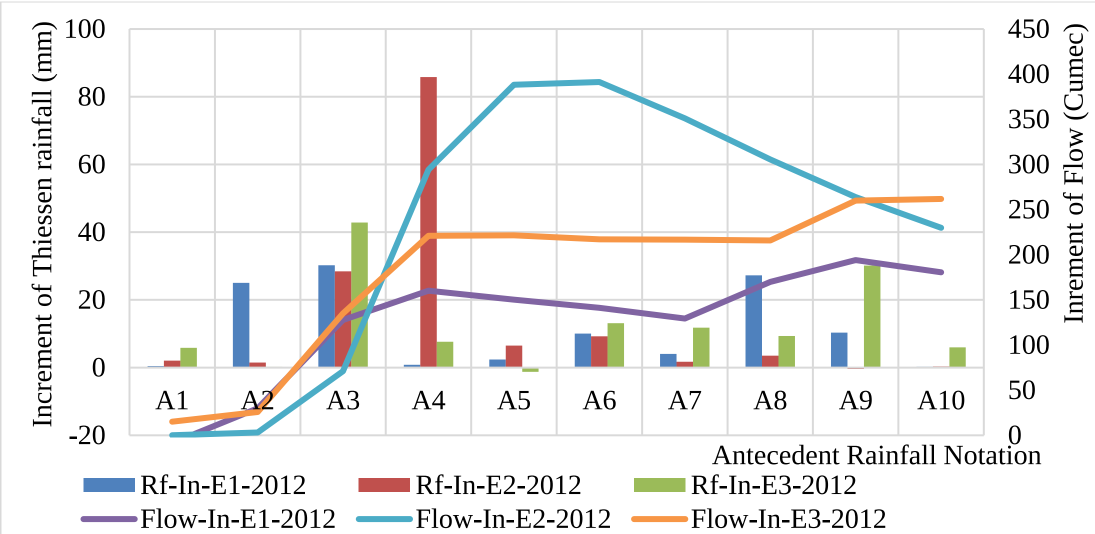


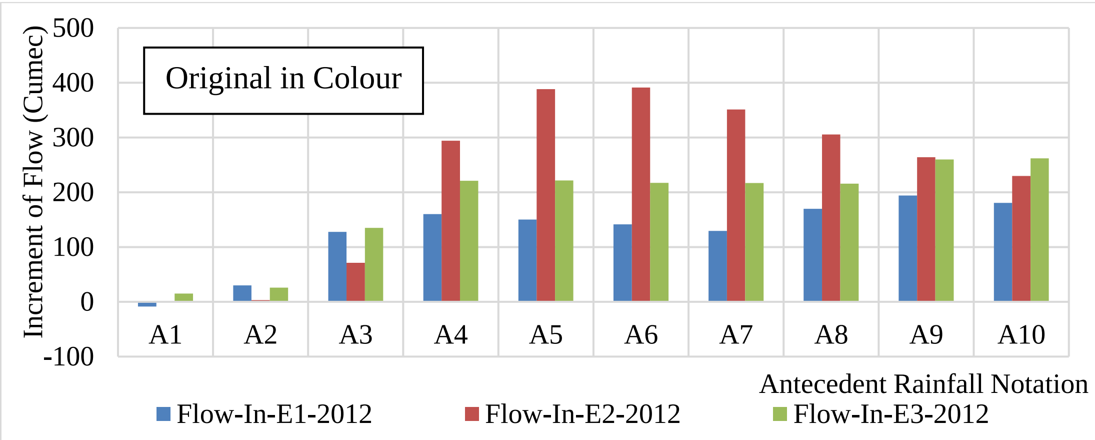




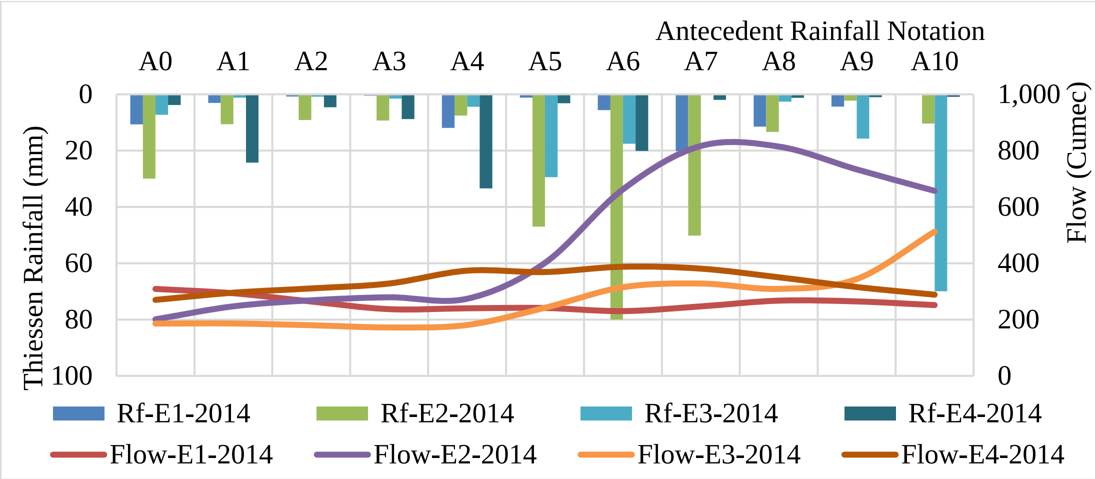
Appendix 08 – 2-Antecedent Rainfall Scenario for the Year 2011

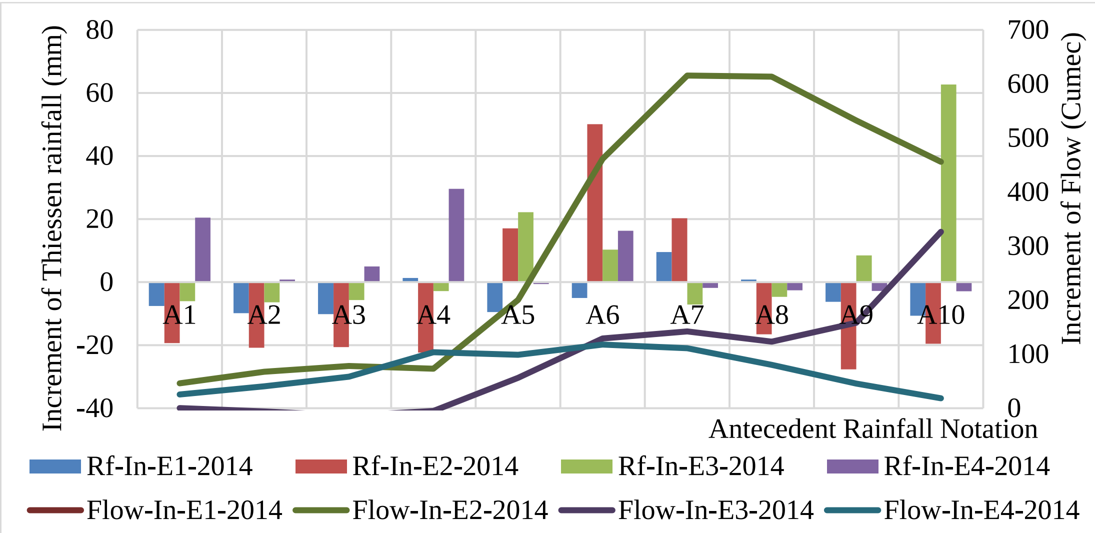


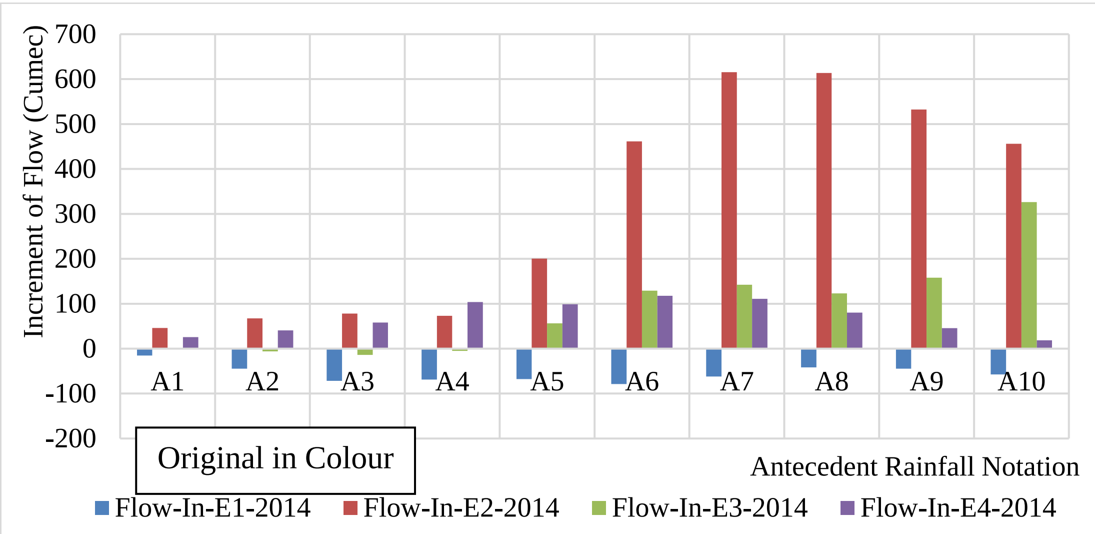




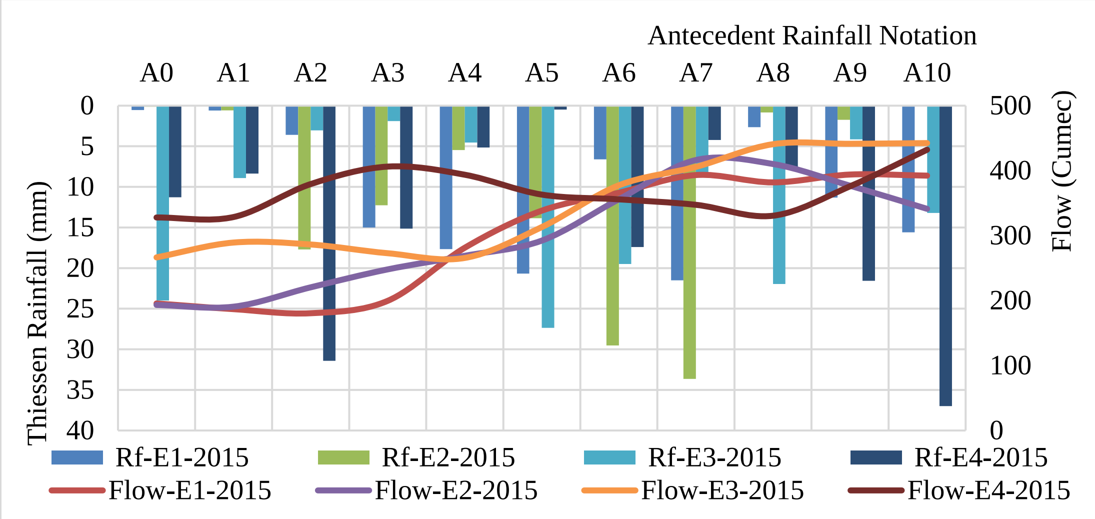
Appendix 08 – 3-Antecedent Rainfall Scenario for the Year 2012

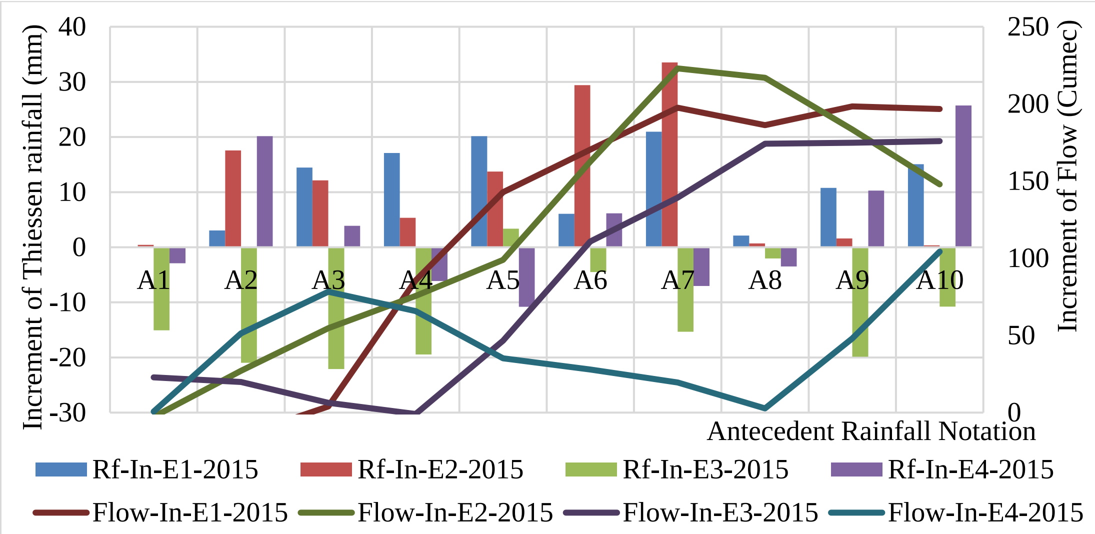


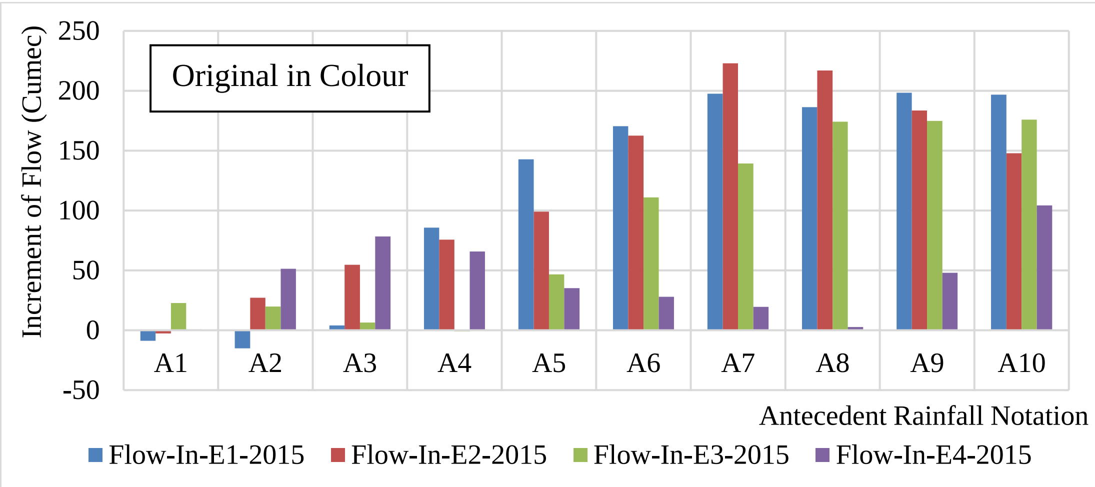




Appendix 08 – 4-Antecedent Rainfall Scenario for the Year 2014







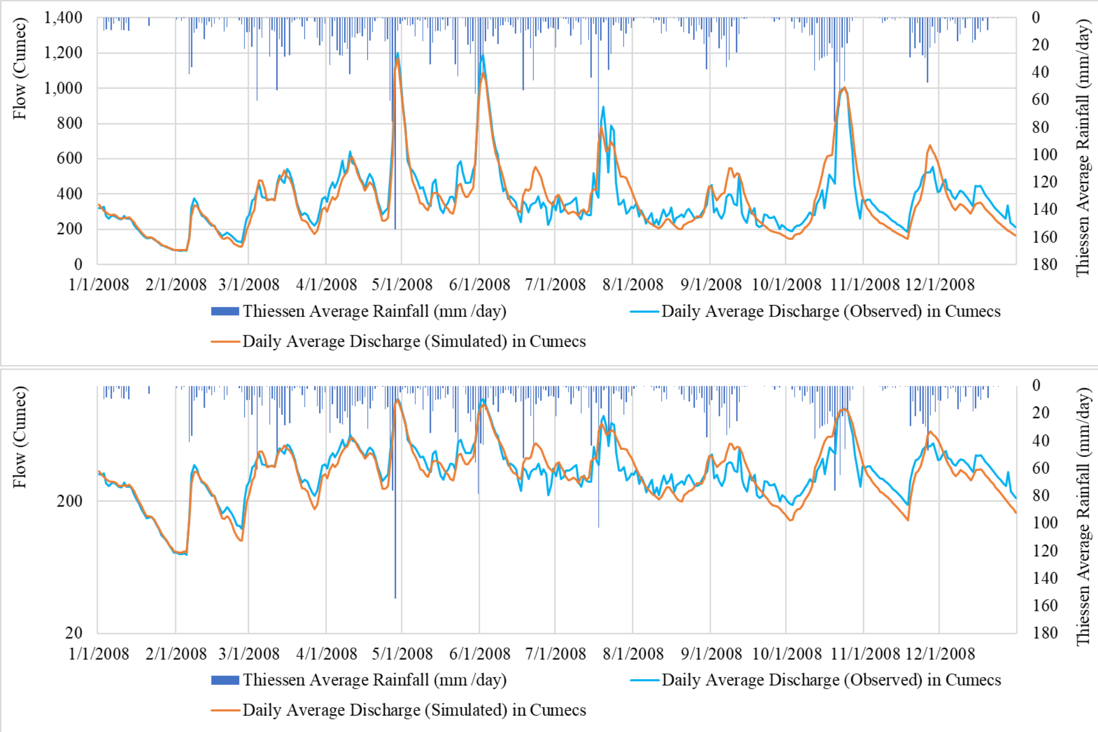
Appendix 08 – 5-Antecedent Rainfall Scenario for the Year 2015

Scenario No	Event No	5- Antecedent Rainfall (mm) {A0 to A5}	AMC Season	AMC Group	5-Antecedent Rainfall (mm) Increment %	5-Antecedent Rainfall (mm) Increment	10-Antecedent Rainfall (mm) Increment	5-Antecedent Flow (Cumec) Increment	10-Antecedent Flow (Cumec) Increment	5-Antecedent Flow (Cumec) Increment %	10-Antecedent Flow (Cumec) Increment %
1	E1_2008	99.73	Growing	AMC III	-91	-37	-37	142	74	98	51
2	E2_2008	50.58	Growing	AMC II	19	20	-2	290	427	184	319
3	E3_2008	169.18	Growing	AMC III	806	155	6	852	391	341	157
4	E4_2008	69.67	Growing	AMC III	785	56	9	184	519	44	124
5	E5_2008	27.44	Dormant	AMC II	624	14	14	13	490	5	169
6	E6_2008	26.05	Dormant	AMC II	152	4	1	63	247	43	171
7	E1_2009	35.30	Dormant	AMC III	138	7	8	115	423	129	473
8	E2_2009	89.70	Growing	AMC III	1624	30	1	725	551	478	364
9	E3_2009	26.68	Dormant	AMC II	6195	28	1	161	37	68	15
10	E4_2009	15.14	Dormant	AMC II	3063	29	3	42	261	16	102
11	E1_2010	80.10	Growing	AMC III	-63	-11		190		125	
12	E2_2010	145.56	Growing	AMC III	3789	74	20	536	622	141	163
13	E3_2010	52.64	Growing	AMC II	827	15	59	77	139	26	46
14	E4_2010	107.19	Growing	AMC III	940	5	15	257	303	86	101
15	E1_2011	15.44	Dormant	AMC II	-64	-1	8	4	257	2	145
16	E2_2011	48.79	Growing	AMC II	1987	24	21	163	190	77	89
17	E3_2011	40.80	Growing	AMC II	36999	56	23	206	706	70	241
18	E4_2011	50.78	Growing	AMC II	2	0	-4	124	94	62	47
19	E5_2011	27.44	Dormant	AMC II	10386	8	18	23	163	12	81
20	E1_2012	57.06	Growing	AMC III	2254	2	0	150	181	87	104
21	E2_2012	121.32	Growing	AMC III	926	6	0	388	230	344	204
22	E3_2012	65.78	Growing	AMC III	-67	-1	6	222	262	116	138
23	E1_2013	28.24	Dormant	AMC III	94	5	32	17	85	12	58
24	E2_2013	46.95	Growing	AMC II	52	2	15	3	99	1	31
25	E3_2013	50.78	Growing	AMC II	-20	0	21	126	138	113	124
26	E4_2013	74.66	Growing	AMC III	14591	14	17	151	82	52	28
27	E1_2014	26.94	Dormant	AMC II	-89	-9	-11	-68	-57	-22	-19
28	E2_2014	66.53	Growing	AMC III	57	17	-20	201	456	100	227
29	E3_2014	15.24	Dormant	AMC II	306	22	63	56	326	30	176
30	E4_2014	74.90	Growing	AMC III	-16	-1	-3	99	18	37	7
31	E1_2015	37.40	Growing	AMC II	3669	20	15	143	197	73	101
32	E2_2015	36.13	Growing	AMC II	10690	14	0	99	148	51	77
33	E3_2015	21.39	Dormant	AMC II	14	3	-11	47	176	17	66
34	E4_2015	71.36	Growing	AMC III	-96	-11	26	35	104	11	32
35	E1_2016	102.84	Growing	AMC III	-42	-5	-5	246	220	190	170
36	E2_2016	60.58	Growing	AMC III	141	21	0	89	116	29	38
37	E3_2016	14.84	Dormant	AMC II	275	9	-3	29	56	17	33
38	E4_2016	68.98	Growing	AMC III	-47	-7	11	163	217	101	135
39	E1_2017	15.16	Dormant	AMC II	-72	-2	-1	48	175	95	351
40	E2_2017	90.24	Growing	AMC III	641	24	24	169	421	60	149
41	E3_2017	39.88	Growing	AMC II	680	18	15	-60	1027	-14	240
42	E4_2017	64.23	Growing	AMC III	221	8	9	135	141	62	65

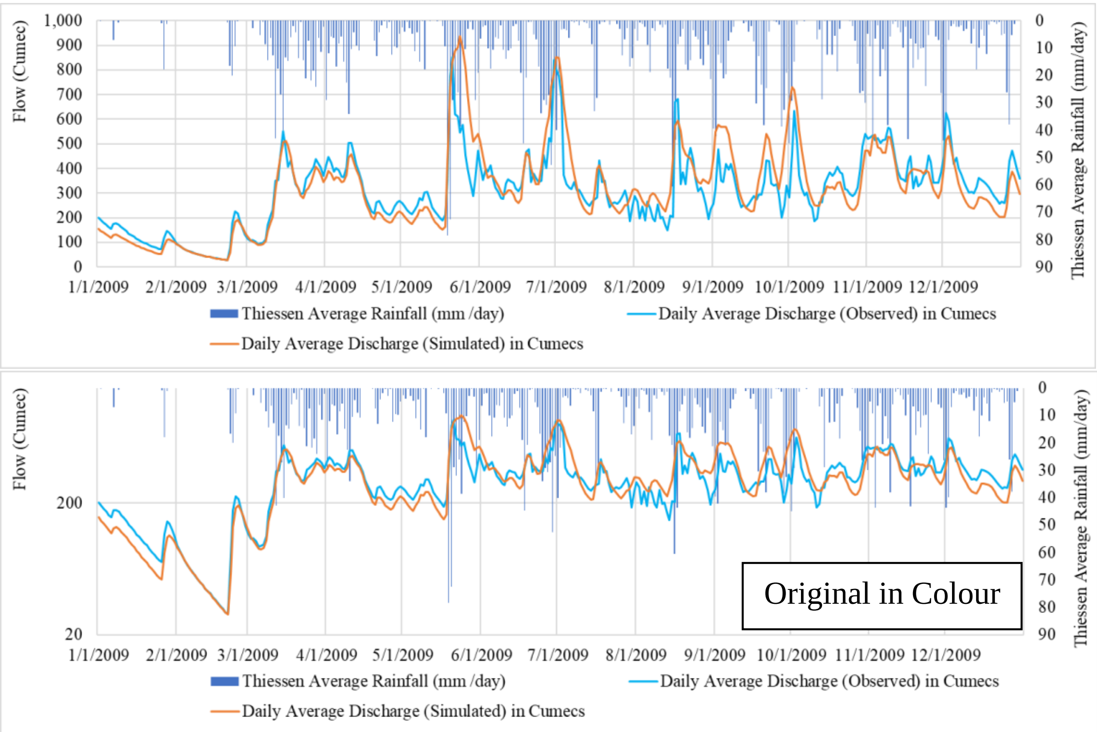
Original in Colour

The season of AMC and group of AMC for all scenario with details of 5-Day,10-Day increment of rainfall and discharge with respect to the A0.

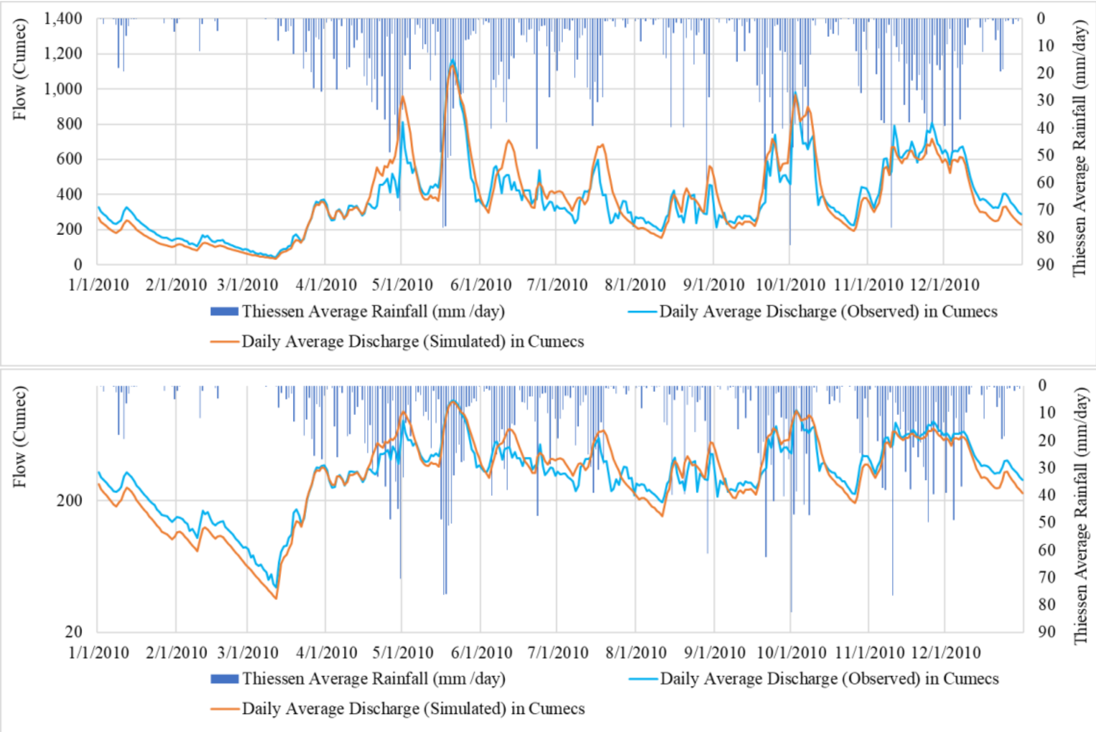
APPENDIX 09: - The daily average discharge observed and simulated with Thiessen rainfall in the Calibration stage and Validation stage for year 2008 to 2017.



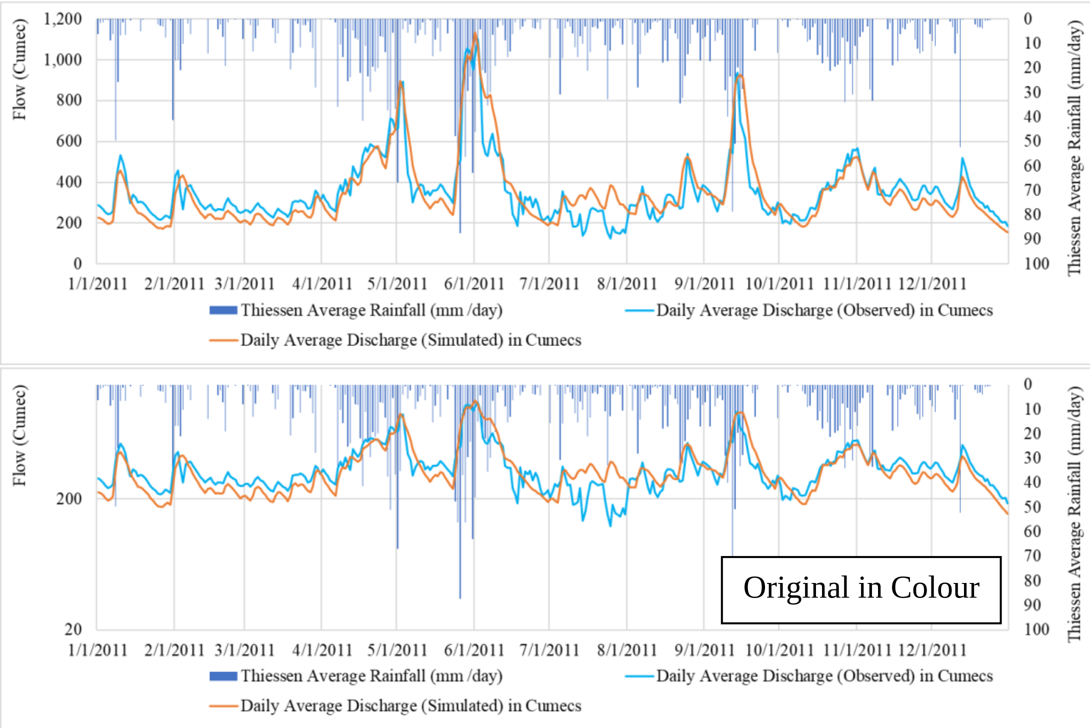
APPENDIX 09 – (a) The daily average discharge observed and simulated hydrograph with Thiessen rainfall for year 2008.



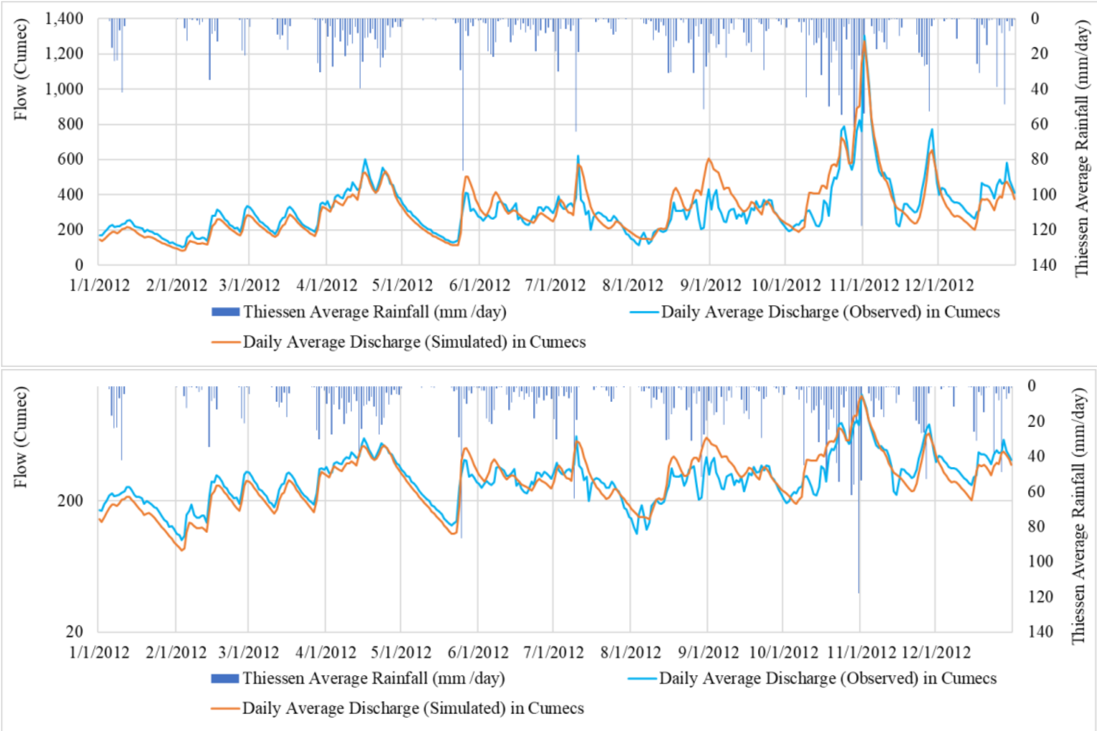
APPENDIX 09 – (b) The daily average discharge observed and simulated hydrograph with Thiessen rainfall for year 2009.



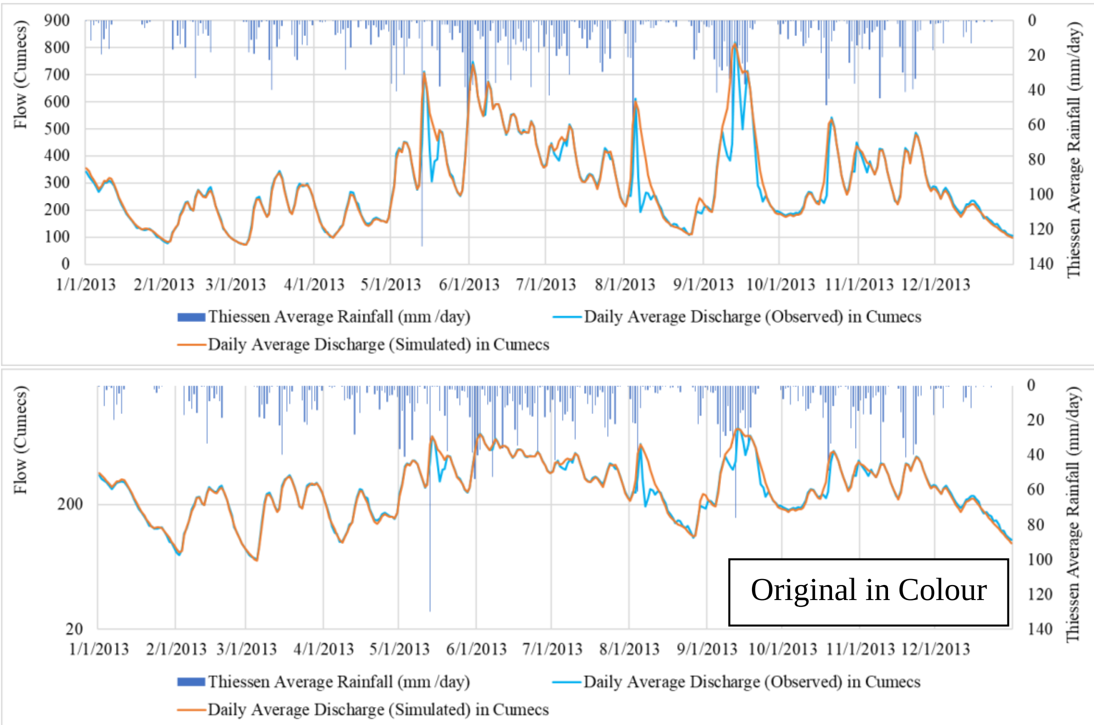
APPENDIX 09 – (c) The daily average discharge observed and simulated hydrograph with Thiessen rainfall for year 2010.



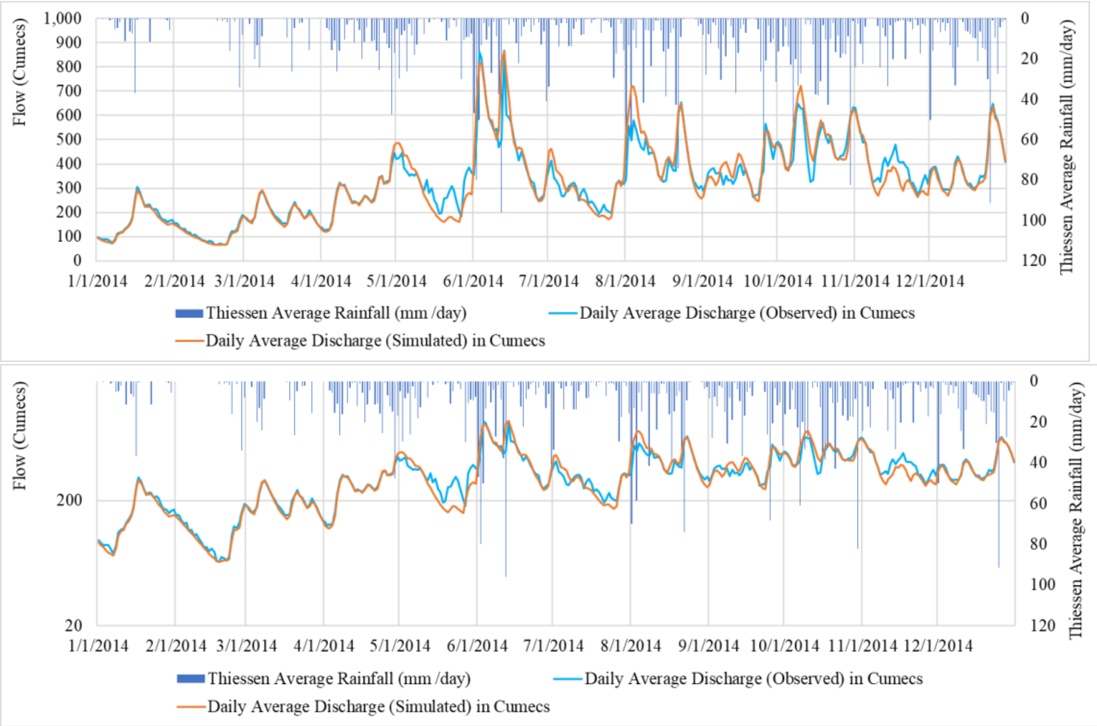
APPENDIX 09 – (d) The daily average discharge observed and simulated hydrograph with Thiessen rainfall for year 2011.



APPENDIX 09 – (e) The daily average discharge observed and simulated hydrograph with Thiessen rainfall for year 2012.

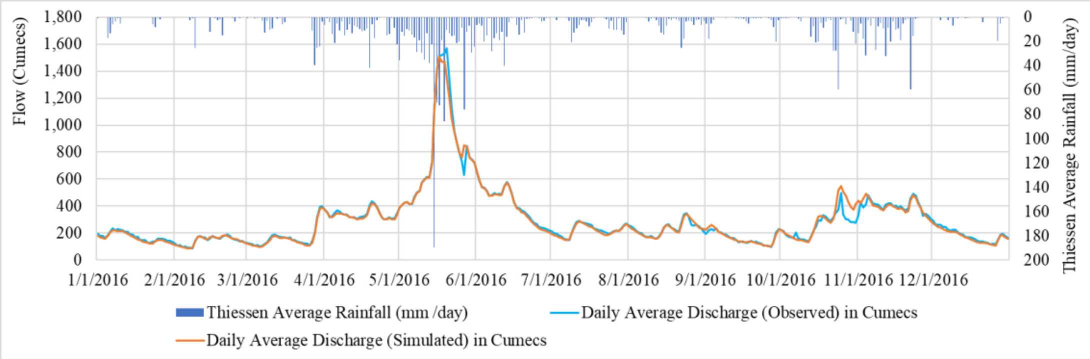


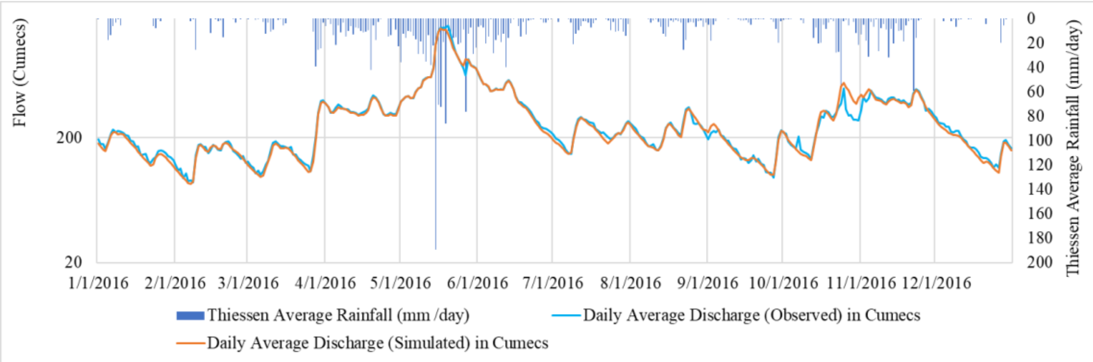
APPENDIX 09 – (f) The daily average discharge observed and simulated hydrograph with Thiessen rainfall for year 2013.



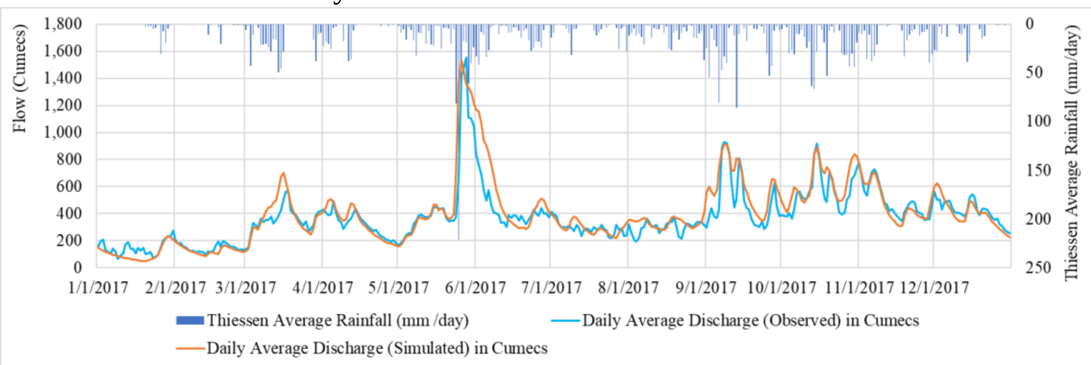
APPENDIX 09 – (g) The daily average discharge observed and simulated hydrograph with Thiessen rainfall for year 2014.

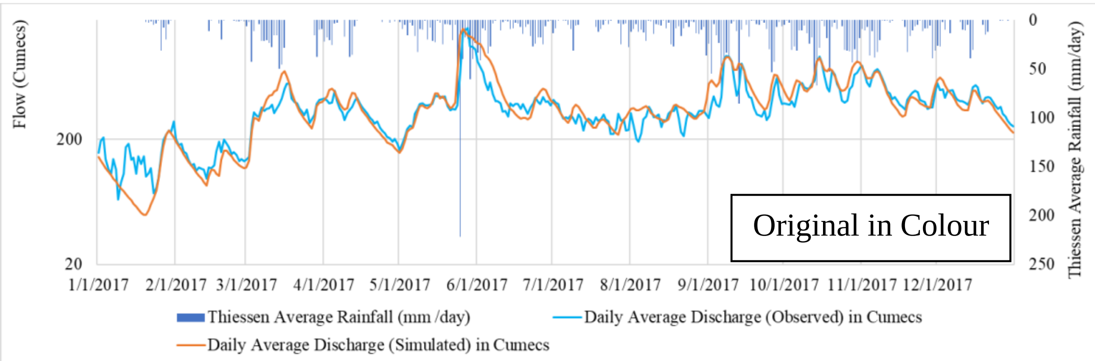
APPENDIX 09 – (h) The daily average discharge observed and simulated hydrograph with Thiessen rainfall for year 2015.





APPENDIX 09 – (i) The daily average discharge observed and simulated hydrograph with Thiessen rainfall for year 2016.





APPENDIX 09 – (j) The daily average discharge observed and simulated hydrograph with Thiessen rainfall for year 2017.

The findings, interpretations and conclusions expressed in this thesis/dissertation are entirely based on the results of the individual research study and should not be attributed in any manner to or do neither necessarily reflect the views of UNESCO Madanjeet Singh Centre for South Asia Water Management (UMCSAWM), nor of the individual members of the MSc panel, nor of their respective organizations.