# EVALUATION OF A MONTHLY WATER BALANCE MODEL CONSIDERING RAINFALL STATION WEIGHTS AND PHYSICAL PARAMETERS IN NILWALA BASIN SRI LANKA

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Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Water Resources Engineering and Management

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## DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgment is made in text.

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Date

The above candidate has carried out research for the Master's thesis under my supervision.

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Professor N.T.S.Wijesekera

Date

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## ABSTRACT

Water Resources Management is key for economic growth and sustainable development. Monthly Water Balance Models are widely applied for its easy and simple structure characteristics. Many research efforts have been carried out using Two Parameter Monthly Water Balance Model for water resources management in Sri Lanka in which model estimation are influenced by rainfall and the approach for the selection of parameters which can be performed using rainfall station weights optimization ;on the contrary, the non-availability of gauged streamflow data in hydrological modelling for optimization remains one of the major challenges where many modelers suggests parameter estimation using physical characteristic of a watershed as solution.

The objective of the study is to evaluate monthly water balance model incorporating optimization of rainfall station weights and physical parameters of the catchment for water resources planning and development. Two parameter model was used for monthly water resource estimation of Nilwala Ganga basin in Sri Lanka. The model was calibrated and verified for Pitabeddara (324km2) watershed using 24 years' monthly rainfall, pan evaporation and streamflow data successfully. Initially, the model parameters values C and Sc estimated with Thiessen method later rainfall stations weights were optimized while keeping the model parameters C and Sc unchanged for calibration and verification. Secondly C and Sc parameters of two parameters monthly water balance model with station weights were optimized simultaneously where parameters were estimated using physical characteristics of the catchment taking into account rainfall, pan evaporation and landuse variables. Rainfall and pan evaporation relationship was utilized for estimation of C and Sc parameter was estimated using correlation of curve number (CN). After Two Parameter Monthly Water Balance Model Applied using Thiessen method on Pitabeddara watershed.

The value for C and Sc were 1.5 and 1700 respectively with average MRAE of 0.22 and 0.31 during calibration and verification periods. Rainfall station weights optimization only resulted in values of 1.3 and 1600 for C and Sc parameters respectively with average MRAE of 0.22 during calibration and 0.27 during verification, stations weights of (0.47, 0.31, 0.07, 0.12, 0.03) for Deniyaya, Dampahala, Anningkanda, Goluwawatta, Kirama stations respectively. Obtained C and Sc values of 1.41 and 1550 while station weights are parameters are optimized simultaneously with average MRAE of 0.19 and 0.25 for calibration and verification respectively, stations weights of (0.12, 0.22, 0.32, 0.22,0.12) for mentioned stations respectively. Also, value of C and Sc parameters were 1.40 and 1500 were retrieved by accounting physical characteristics of catchment and MRAE of 0.23 and 0.28 for calibration and verification. The station weights optimization improved the MRAE results of model by (10%) which is significant with indication of better MRAE than conventional rainfall averaging method. Estimation using physical characteristics of model resulted in (5%) superior results than empirical approach.

This research effort concludes that rainfall station weights optimization method results are superior then Thiessen Method and parameters estimation using physical characteristics of the catchment can be useful for ungauged catchments and it can provide acceptable results.

**Keywords:** Ungauged streamflow estimation, Physical catchment characteristics, Spatial Variability of Rainfall, Water balance modelling,

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# LIST OF ABBREVIATIONS

| Abbreviation | Description |
|---|---|
| c | Parameter c |
| C | Runoff Coefficient |
| DSD | Divisional Secretary Divisions |
| E | Nash–Sutcliffe coefficient |
| E (t) | Actual Evapotranspiration |
| EP (t) | Pan Evaporation |
| IPCC | Intergovernmental Panel on Climate Change |
| K | Pan Coefficient |
| MAR | Mean Annual Rainfall |
| MRAE | Mean Ratio of Absolute Error |
| MSE | Mean Square Error |
| NEM | North East Monsoon |
| P (t) | Rainfall |
| Q (t) | Runoff |
| RAEM | Ratio of Absolute Error to Mean |
| RE | Relative Error |
| RMSE | Root Mean Square Error |
| S (t) | Soil Moisture Content |
| SC | Field capacity of the catchment |
| SWM | South West Monsoon |
| TPMWBM | Two Parameter Monthly Water Balance Model |
| WMO | World Meteorological Organization |

# EVALUATION OF A MONTHLY WATER BALANCE MODEL CONSIDERING RAINFALL STATION WEIGHTS AND PHYSICAL PARAMETERS IN NILWALA BASIN SRI LANKA

## 1 INTRODUCTION

### 1.1 General

Water resources are scarce and vulnerable. Management of water resources can be considered as a very important issue from different angles such as development and expansion of water bodies according to current and future requirements, protecting existing water bodies from contamination and over utilization in order to prevent future conflicts (Loucks, 2000). Having a proper water resource management in a basin requires to understand the dynamic and availability of water for various uses such as water for drinking, water supply, irrigation and hydropower generation (Popovska, 2015).

Water balance functions as base for management and policy making in some critical issues Associated to water resource management such as water supply systems design, flood forecasting, water usage and distribution, storm water and wastewater management in urban areas, aquatic ecosystems management, in all these mentioned areas, watershed managers and policy makers require information about the volume of water resources, demands and changes in storage of the catchment (Ghandhari & Moghaddam, 2011).

Water balance modelling can give us a better understanding of the components of the hydrologic cycle which is useful for developing a perfect management options. Similarly, these models can be considered as a set of equations designed to represent the processes of the hydrological cycle, the main advantages of these models are that they have a clear conceptual basis and use available data (Zhang, Walker, & and Dawes, 2002).

These models can find the variations between estimation and problems related to assumptions that can provide possibilities for watershed managers to closely examine the performance of the system, data collection, data recording and data extraction (Wijesekera & Lanka, 2001).

Xu and Singh (1998) found two practical reasons for using monthly resolution in a model. Firstly, the monthly variation of discharge may be sufficient for planning of water resources and climatic change impacts in a catchment. Secondly, monthly data are most easily available.

Mouelhi et al. (2006) explained about the importance of models with monthly data input that, these models are essential tools in managing water resources, basin runoff simulation, drought assessment and predicting the effect of climate change on water resources.

Several types of monthly water balance models are available in hydrology. Xu and Singh (1998) in their study of a review on monthly water balance models for Water Resources Investigations mentioned four types such as monthly models using only precipitation as input, monthly models using precipitation and temperature as input, monthly models using precipitation and potential evapotranspiration as input, monthly output models using daily input data.

Monthly water balance models have been developed with various number of parameters, ranging from complex models with 12 parameters to a simple model with 6,4, and 2 parameters such as (Xiong & Guo, 1999) applied monthly water model using two parameters, Servat and Dezetter (1993) developed two rainfall- runoff models (CREC) water balance model with seven parameters and (GR3) model with three parameters, Xu (2000) applied 6-parameter monthly water model, Abulohom et al. (2001) Developed 5 parameter monthly water balance model, Hughes and Metzler (2010) applied two monthly water balance models Pitman with 12 parameters and Namrom with five parameters respectively.

Two parameters monthly water balance model (TWBM), developed by Xiong and Guo (1999) has been widely used, for monthly runoff simulation and forecast, considering less number of parameters and using available data the model performed well in several catchments (Guo et al.,2002; Xiong and Guo, 2012; Zhang et al., 2013; Xiong et al., 2014). Moreover, this model is very important because of their inherent parsimony, can be used for regionalization purpose, can be applied further in ungagged catchment and this can be very easy and simple tool in the hand of watershed manager for water resource management (Mouelhi, Michel, Perrin, & Andre, 2006).

Catchments where observed data is not available are termed ungauged catchment hence for managing water resources in these catchments, there are both operational and academic drivers for pursuing rainfall-runoff modeling to calculate runoff and other variables (Unter & Oschl, 2005). One of the important objectives in the development of water balance models has always been in applying them to ungauged catchments (F. Sharifi, 1996).

Application of water balance models depends on physical interpretations of the model parameters related to the characteristics of the catchment, this allows model parameters to be estimated from the catchment properties even when observed data is not available (F. Sharifi, 1996).

Model estimations are influenced by rainfall because rainfall is the main driver of runoff, reliable measurements of rainfall are critical for successfully calibrating of rainfall-runoff model to a catchment (Vaze, Jordan, Beecham, Frost, & Summerell, 2011).Average rainfall can be considered as a main input in hydrologic modelling for a catchment, specifically for those models which are used for surface runoff, because in general rainfall is known as first climatic variable which can give fast increasing flow (Barbalho, Silva, & Formiga, 2014).

A long with the development of watershed modelling several methods has been used for rainfall distribution over an area such as isohyet reciprocal distance method Thiessen Polygon Method, Reciprocal Distance Squared Method, Kriging Method, Multiqua-dric Equations method, while Thiessen average rainfall is the most common method used in rainfall- runoff modelling (Barbalho, Silva, & Formiga, 2014).

Rainfall stations within or close proximity is a difficult operation it is important to identify the influence of stations and this can be done by optimization of Rainfall stations weight (Musiake & Wijesekera, 1990). The other problem is non availability of streamflow data to optimize model parameters, since the development of rainfall-runoff models most of the modelers used trial and error method which is time consuming and needs observed data (Wijesekera, 2000). This can be solved if parameters can be estimated using physical characteristics of a watershed.

## 1.2 Problem identification

To assess potential of monthly water balance model by means of optimizing rainfa station weights and physical parameters for water resources management.

## 1.3 Study Objectives

### 1.3.1 Overall Objective

The overall objective of the study is to evaluate monthly water balance model incorporating optimization of rainfall station weights and physical parameters of the catchment for water resources planning and development.

### 1.3.2 Specific Objectives

1. To review the state of art of water balance models with physical parameters
2. To collect data, perform data checking and divide the data set into calibration and verification data sets.
3. Develop, calibrate and verify the model for Thiessen Rainfall in Nilwala gaga river basin.
4. Optimize Rainfall station weights with model parameters C and Sc Calibration and verification
5. Parameter identification from physical characteristics of the catchment.
6. Evaluation of results and comparison of optimized parameters with discussions.
7. Conclude results and give recommendations for application potential of the model in evaluating water resources.

## 1.4 Study Area Selection

Considering the availability of five rain gauge stations, and one streamflow and evaporation station within the catchment of Pitabeddra at Nilwala ganga river basin was selected for present study. Pitabeddra watershed is a sub watershed of Nilwala Ganga River Basin in Mattara district. Drainage area of the Pitabeddra watershed is 291 km$^2$ this catchment has one stream gauge station and five rain gauge stations, two stations are inside the catchment and other three stations are located outside the boundary of the watershed. Deniyaya Evaporation station was selected for evaporation .the study area is shown in Figure 1-1 below .

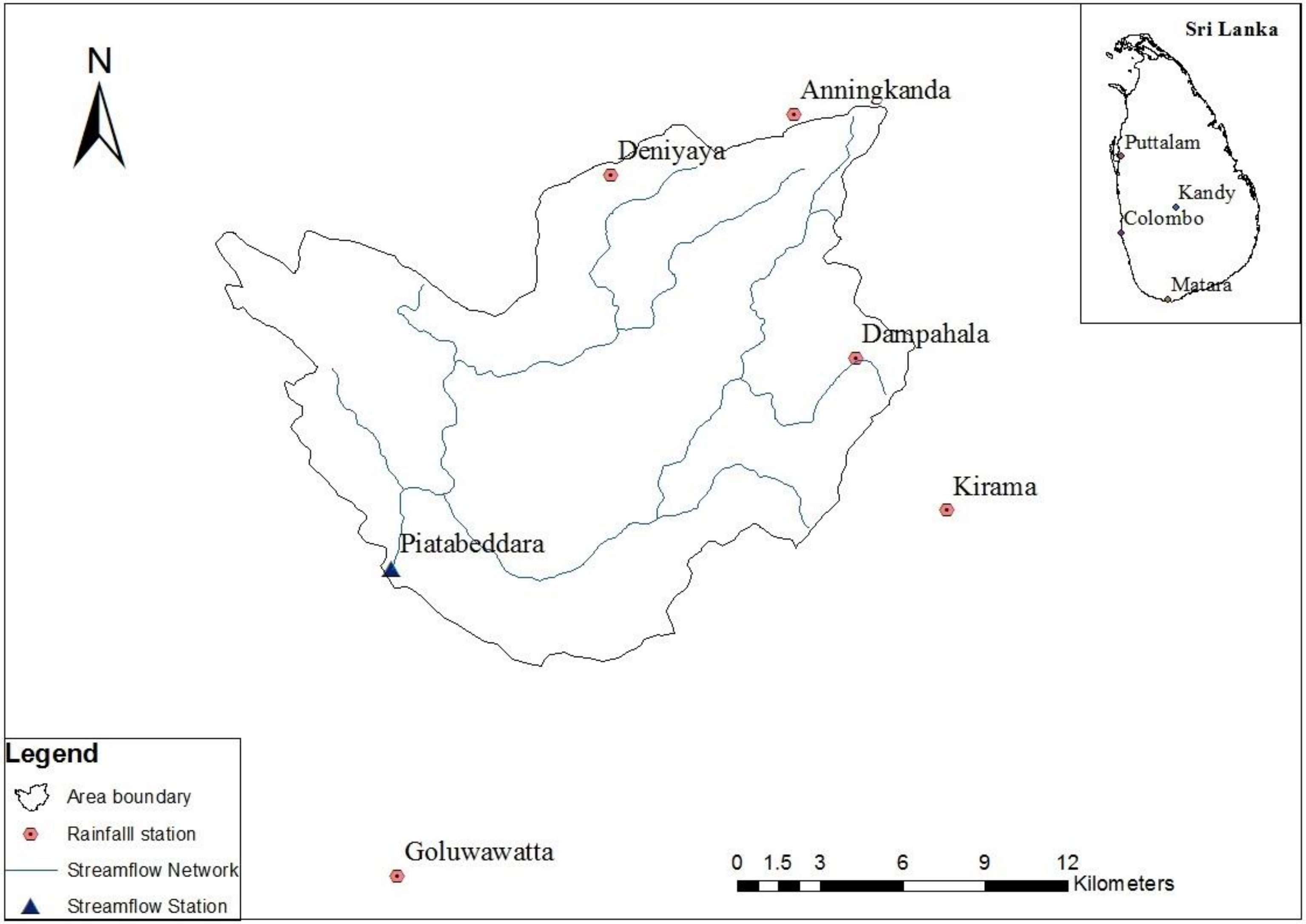


Figure 1-1: Pitabeddara watershed

# 2 LITERATURE REVIEW

## 2.1 General

Why we are doing Modelling? there are several reasons behind this theory, or what is the need for modelling the rainfall-runoff processes of hydrology. The main reason can be the result of the limitations of hydrological measurement techniques. Because we want to know about all hydrological systems which are not able to measure, in reality, only a restricted range of measuring methods and a restricted range of space and time. Therefore, we need a resources to extrapolate from those present measurements in both space and time, especially to ungauged watersheds where measurements are not accessible and into the future where measurements are not possible to evaluate the probable influence of future hydrological change (Beven. Keith, 2001).

Hydrological models have become an essential tool for the evaluation, management, and use of water resources. These models can be used as best mechanisms for prediction of watershed behavior and assess the effects of population growth and natural changes in the future. For watershed managers , such models are especially useful to assess the assumptions and concepts about the main hydrologic processes in a catchment (Al-lafta, Al-tawash, & Al-baldawi, 2013).

## 2.2 Current state of water balance model

Water balance models were originally introduced to assess the significance of various hydrological parameters under a variety of hydrological circumstances but its current application showed that its widely used for water resource management (Ghandhari & Moghaddam, 2011).

Water balance is the most accepted, logical and a critical concept that needs to be in a streamflow estimation model. Water balance model was introduced for the first time in the 1940s by Thornthwaite (1948) and later reviewed by Thornthwaite & Mather (1957).

Water balance models are basically bookkeeping procedures which approximate the balance among the income of water from precipitation, snowmelt and outflow of water by streamflow, evapotranspiration and groundwater recharge (Alley, 1984).these models have been developed at different time scales(hourly, daily, monthly and yearly) (Xu & Singh, 1998).

On a monthly time scale The inter-relationship between rainfall, evapotranspiration and runoff, seems to be very close because of the mutual effects and continuous response of all types of water movements in the soil–plant–atmosphere continuum (M. B. Sharifi, 2015).

Since the development of monthly water balance models these were used to evaluate the importance of the several hydrologic process under various hydrologic circumstances. Presently, monthly water balance models are mainly applicable in three major areas i.e. reconstruction of hydrology of watershed, climate change impact assessment, the evaluation of seasonal and geo-graphical patterns of water supply and irrigation demand (Xu & Singh, 1998).

Several types of monthly water balance model have been used by modelers in the world with different types of input data, such as precipitation as Input, precipitation and, Temperature, precipitation and potential evapotranspiration, precipitation; temperature and relative humidity (Xu & Vandewiele, 1995).in addition, the number of parameters also differentiate the types of models from each other, from simple two, four, six parameters to relatively complex conceptual models with ten to twelve parameters.

Hughes (1998) evaluated the results of three monthly water balance models (Pitman) with 12 parameters, (Nampit) with 13 parameters and (Namrom) with 5 parameters in his study for semi-arid watersheds in Namibia with area ranging from 212 to 5463 km² using 20 years precipitation and observed streamflow data, and found that the calibration results of the models were not much different.

Jazim (2006) applied 6 parameters monthly water balance model to simulate monthly runoff at arid and semiarid catchments in the Middle East located at Yemen and Jordan in Wadi Wala and Wadi Zabid catchments with the area ranging from 1800 to 4750 km² using 29 years' data the simulation results showed that model had good match between simulated and observed streamflow, based on application results the model further suggested for efficient planning and management of water resources and assessment of climatic change impacts.

Abulohom et al. (2001) developed 5 parameters rainfall- runoff model using monthly precipitation and potential evapotranspiration data as input for simulation of monthly runoff in four watersheds Hub (9391 km$^{2)}$, Khost (1320 km$^2$), Wadi Surdud (3820 km$^2$), Brandu (598 km$^2$ ) in Pakistan. They have indicated in their study that model performed relatively well.

Monthly water balance models are valuable tools for water resources management, reservoir simulation, drought assessment or long term drought forecasting (Kumari & Dissanayake, 2017).

Gleick (1987) developed a monthly water balance model specifically for climate impact assessment and addressed the advantages for water balance type models in practice (e.g. Schaake and Liu, 1989; Arnell, 1992).

Fennessey (2002) determined that a monthly time step provides accurate reservoir-yield estimates. Monthly water balance can be used for planning and managing of reservoir water effectively, through rational correction of poor quality data (Wijesekera & Lanka, 2001).

## 2.3 Monthly water balance models comparison

The main factor to be considered for monthly water balance models, is the purpose for which the model is going to be developed. Since the development of monthly water balance models they have been applied for different purposes such as water resource management, climate change impact studies, flood forecast, water supply and irrigation demand.

Though various water balance models are available in hydrology, but watershed mangers need to select a suitable model for a particular hydrological practice. numerous model comparisons have been conducted with many types of water balance models, in order to prepare a systematic guideline on the application of water balance models (Bai, Liu, Liang, & Liu, 2015).

Xu and Singh (1998) conducted a very good review of monthly water balance models for water resource investigation considering their application ,types of input data and number of parameters, they found two practical reasons for using these models. Firstly, the monthly variation of discharge may be sufficient for planning of water resources and climatic change impacts in a catchment. Secondly, monthly data are most easily available.

Vandewiele and Xu (1992) compared several monthly water balance models in 79 catchments with area up to 4000 km$^2$ in Belgium, Burma and China. precipitation and potential evapotranspiration was used as input data in these models.as a result, they indicated that their new proposed model showed good performance then other existing models.

Jiang et al. (2007) compared  six monthly water balance models and applied in humid catchments in the Dongjiang Basin, South China. And they stated in their study that the performance of all models was comparable instead of large range of model complexity.

Twelve monthly water balance models were compared with different structures and different degree of complexity, in 153 watersheds having various climatic situations in China. They evaluated the relationship of catchment physical characteristics and model performance and they found that the physical characteristics as a very important factor which effects model performance.in addition, they investigated the model complexity and found that simple model can achieve similar even better results than complex models, as a result they suggested a simple two parameters monthly   water balance model for monthly water resources estimation (Bai, Liu, Liang, & Liu, 2015).

Makhlouf and Michel (1994) compared a two-parameter monthly water balance model with other four mostly used monthly water balance models in 91 catchments With the  area ranging   from 315 to 5560 km$^2$  in France. and found that the simple two parameter model can achieve similar results with other four models for the water resource assessment.

## 2.4 Two parameter water balance model

Two parameters monthly water balance model (TWBM), developed by Xiong and Guo (1999), which has been broadly used for monthly runoff simulation and forecast

(Guo et al.,2002; Xiong and Guo, 2012; Zhang et al., 2013; Xiong et al., 2014). The model inputs were monthly precipitation and monthly evaporation. they all concluded in their studies that the model results were satisfactory.

Xiong and Guo (1999) developed a two parameter monthly water balance model for the first time and they applied in 70 sub catchments in the Dongjiang, Ganjiang and Hanjiang Basins in the south of China with the area ranging from 243 to 4660 km$^2$ using seventy years monthly precipitation, evaporation and observed runoff data, for monthly runoff simulation, the model application showed good results both in calibration and verification periods and they suggested this model can be used efficiently for water resource management and climate impact studies.

Two parameter water balance model was already tested on several catchments in Sri Lanka such as Sharifi (2015) calibrated and verified two parameters monthly water balance model for evaluating the water resources of Kalu and Mahaweli with area ranging almost from 1490 km$^2$ to 542 km$^2$ rivers using 30 years rainfall, evaporation and streamflow data, the model performed well for water resource management. Khandu (2015) applied two parameter model for evaluating the climate change impacts on the streamflow of Gin ganga (368km$^{2)}$ and Kelani (182km$^{2)}$ Ganga basins using 40 & 48 years monthly precipitation, evaporation and streamflow data. The model results were satisfactory in both calibration and verification periods, Kumari and Dissanayake (2017) evaluated the capability of two parameter model with daily data set about 10 and 15 years for daily runoff simulation of d Kalu and Gin river basins. The application results showed that the model performance was successful for the for both catchments.

Considering less number of parameters, availability data of Two parameter monthly water balance model was selected for the current study (Kim et al., 2016).

## 2.5 Model components

### 2.5.1 Rainfall

Several factors such as elevation, slope, orientation and Exposure, have impact on Spatial distribution of precipitation falling on the ground (Spreen, 1386). Average precipitation can be considered as a main input in hydrologic modelling for a catchment, specifically for those models which are used for surface runoff, because in general rainfall is known as first climatic variable which can give fast flow increasing flow (Barbalho et al., 2014).

Since rainfall has been used as main input data in to the system, here we can define the amount of rainfall as an accumulated total volume for any selected period (Khandu, 2015). A long with the development of watershed modelling several methods has been used for rainfall distribution over an area such as isohyet reciprocal distance method Thiessen Polygon Method, Reciprocal Distance Squared, Method Kriging Method. Multiqua-dric Equations method. (Barbalho et al., 2014) compared all the above methods for rainfall distribution in Brazilian catchments, and they indicated that the results of Thiessen Polygon Reciprocal Distance Squared was satisfactory.

Singh and Chowdhury (1986) carried out a study for the comparison of 13 various methods of estimating mean areal precipitation using daily, monthly , yearly rainfall data in different catchments of Mexico ,Britain and U.S.A. they stated that almost all methods are giving similar results but Among these methods Thiessen polygon method is simple and most used method which showed good results than others.

### 2.5.2 Actual Monthly evapotranspiration

Hydrologists categorized evaporation under these three terms (1) the term free water evaporation, ET0 it shows the amount of evaporation from water surface, in this case water goes back into the atmosphere from lakes and reservoirs and, in some cases, from streams in the catchment(2) the term actual evapotranspiration Eta, explains all mechanisms by which water becomes atmospheric vapor under natural conditions at or near the earth's surface (3) the term potential evapotranspiration ETp (Singh, 2008).

The term ETp was introduced for the first time by PENMAN (1948) and it was defined "the amount of water transpired in a given time by a short green crop, completely shading the ground, of uniform height and with adequate water status in the soil profile". Evaporation includes a highly complex set of processes, which is affected by various factors such as land use, vegetation covers and climatic variables (Khandu, 2015).

Monthly average rainfall and potential evapotranspiration had been used as the main input data to most monthly water balance models which widely used for monthly runoff simulation and forecast in a catchmen (Vandewiele et al., 1992; Guo, 1995; Hughes & Metzler, 1998; Vandewiele & Ni-Lar-Win, 1998; Xiong & Guo, 1999).

Since the development of water balance models several methods has been used by modelers for the calculation of evapotranspiration. Lang et al. (2017) compared various methods for the finding the realistic value of evapotranspiration in a catchment in china and they found that (Thornthwaite ,1948) and (PENMAN, 1948) methods are the most physical and reliable methods. In case of two parameter water balance model.

Xiong and Guo (1999) suggested the following equation.

$E(t) = c * EP(t) * \tanh [P(t) / EP(t)]$

Where, E(t) is used for monthly evapotranspiration, EP(t) for monthly pan evaporation value, P(t) for monthly precipitation and C is considered as first model parameter the new coefficient, this parameter C is used for the representing the effect of change in time scale from year to month.

### 2.5.3 Streamflow

The monthly runoff *Q* is closely related to the soil water storage S. In the water balance models (Xiong & Guo, 1999). the regulating effect of a watershed on precipitation is assumed to operate as a linear or a non-linear reservoir (Shaw, 1994). In the current study the runoff *Q* is also considered as a hyperbolic tangent function of the soil water content *S*, in following equation.

$Q(t) = S(t) * \mathrm{Tanh} [S(t) / SC]$

where $Q(t)$ is the monthly runoff, $S(t)$ is the water content in soil, and SC is used to represent field capacity of catchments. Thus, SC is the second, parameter used in the present model, having the unit of millimeter.

### 2.5.4 Soil water content

The initial value of the soil water content S(0) needs to be accurate because it has direct effect on the model performance. Specially, in the case where the used data set is not long enough (Xiong & Guo, 1999). They concluded that the value of S(0) should not be very distinct from the soil water content of the month with the same rank within one year. Such as S (12), S (24) because one year can be considered as a reasonable cycle period. Hence, this study had found that choosing S(0) as the mean value of soil water content S over all months having the same rank within a year can be reasonable ,i,e,

$(S)=\sum_{j=1}^{m} S(j*12)/m$

Hence, m is the number of years of the calibration data set, i.e. m =Nc/12. They recommended S (0) value from 150 to 200 mm for primary run of the two parameter water balance model which they tested on more than 100s catchment

## 2.6 Model Calibration and Verification

Model calibration is a method to optimize or systematically adjust the parameter values of the model to obtain a set of parameters that provide the best estimate of the observed streamflow. Whilst model validation is a method of using the obtained values of parameters from calibration period to simulate streamflow over an independent period apart from calibration period (Vaze et al., 2011).

Rainfall – runoff models calibration can be performed by two methods, manual and automatic method, or a combination of these two methods. In manual calibration, the definition of "goodness of fit" is generally formed as a combination of statistical indices and visual assessment of the observed and simulated hydrographs. Whilst, in automatic calibration, the definition of "goodness of fit" is generally formed using an objective function which translates the observed and simulated flow in to a single number. Therefore, automatic calibration practice use a defined algorithm which runs the model several times (Boyle, Gupta, & Sorooshian, 2000).

The modelers have been developed the monthly water balance models in last 70 years and they are still complicated for the analysis of physical based issues and different application. However, these complicated models have still more difficulties regarding calibration, error correction and parameter estimation (Moradkhani & Sorooshian, 2009).

### 2.6.1 Objective Functions

All hydrologic models need calibration and verification before applying in the area, these models are calibrating by comparing the calculated and observed data with each other, the comparison is made an optimization procedure using an objective function which is adopted for that purpose and a set of data which is a subset of all data available or observable. The choice of the set of data and of the objective function to be used for any given model is a subjective decision which influences the values of the model such as a model performance and parameters, the data set used should be comparable to the engineering application for which the model is intended the objective function can be chosen by outlined procedure in the article (Diskin & Simon, 1977).

Objective functions can be defined as mathematical measurements of how well the simulated flow by model can fit the observed flow (Beven. Keith, 2001) .Generally, several objective functions mainly deal with a summation of the error term (difference between the simulated and the observed variable at each time step) normalized by a measure of the variability in the observation. In order to prevent the cancellation of errors of the opposite sign, the summation of the absolute or squared error is often applied for different objective function. As a result, it can be an emphasis to place on larger errors while smaller errors tend to be ignored (Krause & Boyle, 2005).

Diskin and Simon (1977) showed in their study that choosing the data set and objective functions that can be used for any given model is a subjective decision which effects the values of the model parameters and the performance of the model. In their study they outlined some procedures for choosing objective functions.

Madsen (2000) had mentioned in his study of automatic calibration of a conceptual rainfall-runoff model using multiple objective that some objectives have to be considered for proper assessment of the calibrated model which listed as below (1) A good agreement between the average simulated and observed streamflow for catchment for example a good water balance (2) A good entire agreement of the shape of the hydrograph.(3) A good agreement of the peak flows with respect to timing, rate and volume. (4) A good agreement for low flows.

Taylor et al. (2009) carried out a comparative study about various objective function, 21 numbers of objective functions were listed for comparison with different procedures .as a result, they recommended 12 numbers of objective functions.

These objective functions are mostly used in the watershed modelling simulations by several modelers such as the sum of squared deviations (Diskin & Simon, 1977), considering equation below:

$$R2 = \sum(q_o - q_s)^2 \qquad (1)$$

Where, ($q_{o)}$ is observed streamflow and t ($q_s$) is simulated streamflow

Green & Stephenson (2009); Stephenson (1979) accepted the sum of absolute Error of residuals as a goodness of fit criterion in their study of regarding optimization.

Sum of Absolute Error,

$$SAE = \sum_{i=1}^{n} Abs(q_o - q_s) \qquad (2)$$

Where, $q_o$ is observed streamflow and the $q_s$ is simulated streamflow.

The Nash Sutcliffe objective function Firstly, suggested by.Nash in (1969) and then by Nash & Sutcliffe in (1970),this objective function is formulated by (Servat.E & Dezetter.A.,1991).

$$\boldsymbol{D} = \mathbf{1} - \frac{\sum(q_c - \mathrm{q}_s)^2}{\sum(\mathrm{q}_o - q_s)^2} \qquad (3$$

Where ,qc is the mean observed runoff , qo is the observed runoff and qs is the simulated runoff . in order to improves model, fit the D should reach unity. This efficiency criterion can be a formula for normalizing the least squares objective function. While the good agreement between simulated streamflow and observed streamflow yields the efficiency of 1.0. therefore, the negative efficiency means weakness of agreement, however, the initial variation of the observed flow record has strong effect on the efficiency value. Consequently, it is not valid to use for model performance comparison between basins but it can be used for single basin optimization (Servat.E & Dezetter.A.,1991).

Patry and Mariño (2008) carried a study for evaluating the performance of a nonlinear functional rainfall-runoff model modified the root mean square error as a criterion for hydrographs comparisons .

$$RMSE = (\frac{1}{n}\sum_{i=1}^{n}(q_o - (q_s)^2))^{1/2} \qquad (4)$$

Where, qo is observed runoff and qs is the simulated runoff and n is the number of points in the hydrograph. this objective function has used by Several modelers for checking the model efficiency (Patry & Mariño, 2008).

Considering the mean of observed flows, it can compare the errors within the mean of observed discharges. This objective function mostly deals with characteristics of the observed flow records. especially, when there are high and low peaks. therefore, the errors might not allow to do simple comparisons and mean of observed discharge does not reflect the real mean value of the runoff series (Kumari & Dissanayake, 2017) (World Meteorological Organization, 1975).

Wijesekera ( 2000), Wijesekara.N.T.S. & Ghanapala.P.P. (2003) adopted that Mean Ratio of Absolute Error (MRAE) objective function is the difference between simulated and observed streamflow regarding specific observation. This objctive function recommended by WMO (1975). And it is calculating by following equation.

$$MRAE = \frac{1}{n}[\sum\frac{|Qo-Qs|}{Qo}] \qquad (5)$$

Where Qo is the observed streamflow, and Qs is the modeled streamflow and n is the number of observation series.

Makridakis.S.S.(1993), Hyndman.R.J.et.al.,(2006) and Tofallis.C.,(2014) defined Mean Average Percentage Error (MAPE) as a percentage of MRAE.

The least squares objective function (e.g. Dawdy & O'Donnell, 1965) has been used to optimize the parameters in a conceptual model developed by Bari,M.A., et.al in 2006. The objective function is described as below.

$$OBJ\ (LS) = \frac{\sum_{i=1}^{N}(Qobsi - Qsimi)}{N} \qquad (6)$$

where $Q_{obs}$, is the observed flow on day i, $Q_{sim}$, is the simulated flow on day i, and N is the total number of days.

$$RE = \sum(Qi - Qi')/\sum Qi * 100\% \qquad (7)$$

Where, $Q_i$ and $Q_i'$ represent the observed maximum monthly runoff and the simulated runoff, respectively.

Sonam Tobgay (2014) developed an event based rainfall – runoff model model for stremflow simulation using Curve number and unit hydrogaph methods.it was demonstred in this study that different objective functions would yield different paramters from the same model.

Jain and Sudheer (2009) carried a study about the Effect of time-scale on the calibration of objective functions in hydrological models performance.as as result they indicated in their study that model have to evaluate considering their behavior in different aspects of simulations, such as characteristics of hydrograph, predictive uncertainty, capability to reserve statistical properties of the flow data series.

In hydrologic models, different objective functions can be used according to the purpose of the study such as water resource management, flood management, environmental flows, and the combinations (Kumari & Dissanayake, 2017).

Thapa.G.,2016,(unpubl) optimized the flood model with MRAE and RAEM and had indicated in the results that MRAE performed well for all flows, especially for high flows. with the MRAE & RAEM. Muthumala.P.,2016, (unpuble) applied a HEC-HMS model for daily streamflow simulation,MRAE value was used as objective function which performed well both for high flows and intermediate flows.

Moreover, Sonam Tobgay (2014) confirmed that the RAEM are not performing well for long term hydrological time records. Also Wijesekera ( 2000),Wijesekera & Perera (2016) showed that high flows and low flows are matching reasonably with MRAE objecvive function . whilst, it can match intermediate flows perfectly.

According to the research by Xion & Guo, (1999), (David A. Post, 1999) and (Nandalal.H.K. and Ratnayake.U.R.,2010) Nash sutcliffe is performing very well for high flow and medium flow conditions. Also it has observed an underestimation during low flow conditions (Krause et al., 2005).

Many of comparisions studies WMO,1975, Diskin.M.H., & Simon.E.,1977, Servat.E. & Dezetter.A.,1991, Houhton.H.A.,1999, Krause.P.et.al,2005 have investigated the interms of various objective functions. Furthermore, Khandu (2015) evaluated Nash Sutcliffe, RAEM, MRAE, RMSE, BIAS and RE and then MRAE was selected as most suitable objective function.

A daily steramflow modeling study of Kalu river basin in Sri Lanka using HEC-HMS (Jayadeera, 2016) evaluated the suitability of Nash-Sutcliffe, MRAE and RAEM. In this work it was recognized that the Nash-Sutcliffe efficiency was a better objective function to easily match the high flows. The MRAE and RAEM demonstrate advantages over the Nash-Sutcliffe when the intermediate and low flows are matched. RAEM and MRAE Comparison had shown that MRAE clearly reflects the convergence on parameters when modellers perform peak and low flow region matching.

Xiong and Guo (1999) were used two objective functions to evaluate the model efficency in Two Parameter MonthlyWater Balance. They were Nash–Sutcliffe efficiency criterion and Relative Error (RE).

Qo is the observed streamflow , Qs is the calculated streamflow, Qo is the average observed streamflow and n is the number of observations used for comparison. This objective function indicates the ratio between observed and calculated discharge with (RMSE) is used as an error criterion between the observed and simulated runoffs, and (NSE) criterion of Nash and Sutcliffe (1970) is used for the model efficiency as objective functions (Kim et al., 2016; Sharifi, 2015; Khandu, 2015).

### 2.6.2 Parameter Optimization

Model optimization consist of two important steps, i.e. Calibration and verification. Similarly, the entire data records are divided into two parts, i.e. the calibration period and the verification period. In Calibration first p art of data set utilized for finding the optimum value for model parameters, whilst in verification the second part of dataset is used in order to validate the value which obtained from calibration period, only when the model performed well both in calibration and verification, then the model can be applied further for objective purpose (Xiong & Guo, 1999).

A Model needs the use of an objective function in its parameter optimization process, it aids calibration of parameters for evaluating the verification. Their formulations are made for the purpose of achieving specific influence on the shape and values of the simulated series by the model.one objective function may have significant effect on flood level peak, while another would influence on low levels of flow. Objective functions are functioning as an indicator for the suitability of the model estimation. Finally, the value of the objective functions enables either to eliminate or reject some solutions, these can evaluate the quality of model results as whole (Taylor et al., 2009).

### 2.6.3 Warm up period

A warm up period prepare the model to run for an appropriate period of time before simulation period to initialize key model variables or permit essential processes to reach a dynamic equilibrium (Daggupati, Pai, & Ale, 2015).

While using short warm up periods may result in biased simulated response, specifically in the starting years when the results of model may be dominated by uncertainty in characterization of the primary state rather than uncertainty in parameters or model (Huard & Mailhot, 2008), for example Muthuwatta and Rientjes (2009) stated that an inadequate warm-up period is the main cause of the difference between the simulated and observed graphs in both calibration and verification periods. Especially, in the initial years of simulation which can reduce the model performance largely.

Stewart Robinson (2007) carried out comparative study on the comparison of methods for estimating warm-up period which have been suggested within the past 40 years. They categorized the warm up period under five main headings that are concisely named as following (heuristic approaches, graphical methods, statistical methods, hybrid methods and initialization bias test).as a result a new SPC method was proposed Which have been tested on 7 datasets and the obtained results are showing good accuracy. Moreover, this approach was discussed about its easiness of application simplicity, generality of use and its parameter estimation requirements.

Warm-up periods Length can be varied for different watershed-scale processes. Warm-up periods for various hydrologic studies may range from months to decades, from one to four years being common for hydrologic modeling (Daggupati et al., 2015).

However, in watershed scale modeling the modelers suggested the length for warm up period ranging from 2 to 3 years for hydrological processes and 5 to 10 years for nutrient related sediment (Raghavan Srinivasan, Texas A&M University; Jeffrey Arnold, USDA-ARS; James Almendinger, St. Croix Watershed Research Station, Minnesota, personnel communication, 20 January 2014).

There are 5 important methods according to (Stewart Robinson, 2007) which deal with initialization bias Such as (1) Run the model for a warm-up period till it reaches a realistic condition (steady state for nonterminating simulations) and then Delete the collected data during warm-up period (2) Fixed initial conditions in the model so that the simulation begins in a realistic condition (3) Set a part of initial conditions then run the model for warm-up period and delete warm- up period data (4) Run the model for longer time period to make the bias effect minor (5) Estimate the steady state parameters from a short transient simulation run (S. Robinson, 2003; Voss & Willemain, 1996).

## 2.7 Rainfall Spatial Variability

Various water balance models have been developed over the years based on temporal resolution, intended use, number of parameters, input data, data resolution etc (Mouelhi et al., 2006; Xu & Singh., 1998) . and are known for their importance in hydrological modelling (Jayatilaka, Sakthivadivel, Shinogi, Makin, & Witharana., 2003; Bai, Liu, Liang, & Liu., 2015; Chen, et al., 2017) because of their accuracy and applicability with limited data.

### 2.7.1 Methods of areal averaging rainfall

Rainfall being one of the most important input in a hydrological model, therefore it is of utmost importance to select a suitable areal averaging method to compute the applicable rainfall by considering all the rain gauge stations of the catchment area (Bhavani, 2013).

Most commonly used methods are Thiessen polygon, arithmetic mean, and isohyetal method because of their simplicity (Akin, 1971; Bhavani, 2013; Barbalho Silva, & Formiga, 2014; Edwards, 1972; Shaw & Lynn, 1972).

**Arithmetic Mean Method** - This is the simplest method of computing the average rainfall over a basin. The resultant rainfall is obtained by the division of the sum of rain depths recorded at different rain gauge stations of the basin by the number of the stations.

$$P_{av} = \frac{P_1+P_2+\cdots+P_n}{n} \qquad 8$$

Where $P_{av}$ is average rainfall, $P_i$ is the station rainfall and n is the total number of stations.

**Thiessen Polygon Method** - The amount of rain recorded at any station should represent the amount for only that region enclosed by a line midway between the station under consideration and surrounding stations (Thiessen & Alter, 1911).

$$Q = \frac{A_a R_a + A_b R_b + \cdots + A_n R_n}{A_a + A_b + \cdots + A_n} \qquad 9$$

Where Q is the average rainfall, $R_i$ is rainfall of a station and $A_i$ is the area represented by corresponding rainfall station.

**Isohyetal Method** - An isohyetal is a line joining places where the rainfall amounts are equal on a rainfall map of a basin. An isohyetal map showing contours of equal rainfall is more accurate picture of the rainfall over the basin. This method is suitable for hilly are, large basins with area over 5000 km$^2$ and rainfall station density is high.

$$P_{av} = \frac{A_1\frac{P_1+P_2}{2} + A_2\frac{P_2+P_3}{2} + \cdots + A_{n-1}\frac{P_{n-1}+P_n}{2}}{A_1+A_2+\cdots+A_n} \qquad 10$$

Where $P_i$ is the value of isohyet lines, $A_i$ is the area between the pair of isohyet lines and $P_{av}$ is the areal averaged rainfall.

### 2.7.2 Importance of rainfall spatial variability

There are various methods developed over the years for areal estimation of rainfall such as Thiessen polygon, arithmetic average method, isohyetal method, grid method etc. Whereas accuracy of these methods is not verified with the observed streamflow. Musiake and Wijesekera (1990) discussd about the method of optimizing rainfall station weights for incorporation of rainfall spatial variability by comparing it with the observed streamflow.

Rainfall accuracy not only depends upon the geometric method of areal averaging but also depends on the density and distribution of rain gauge stations over a region. "Considering 8 rain gauges as a standard representative of rainfall over the region, absolute error increases from 15% to 64% as gauge numbers are decreased from 7 to 1" (Mishra, 2013).

"Regression analysis showed that the computed runoff agreed with the observed runoff with R2 values of 0.80, 0.78 and 0.83 for Kalu Ganga, Kelani Ganga and Attanagalu Oya basin respectively. Averaged runoff coefficients, for basins with the spatial variation were calculated as 0.52, 0.49 and 0.51 for Kelani Ganga, Kalu Ganga and Attanagalu Oya sub basin respectively" as calculated by (Perera & Wijesekera, 2011) in their study on runoff as a function of catchment characteristics.

"The amount of rain recorded at any station should represent the amount for only that region enclosed by a line midway between the station under consideration and surrounding stations" (Thiessen & Alter, 1911).

# 3 Methodology:

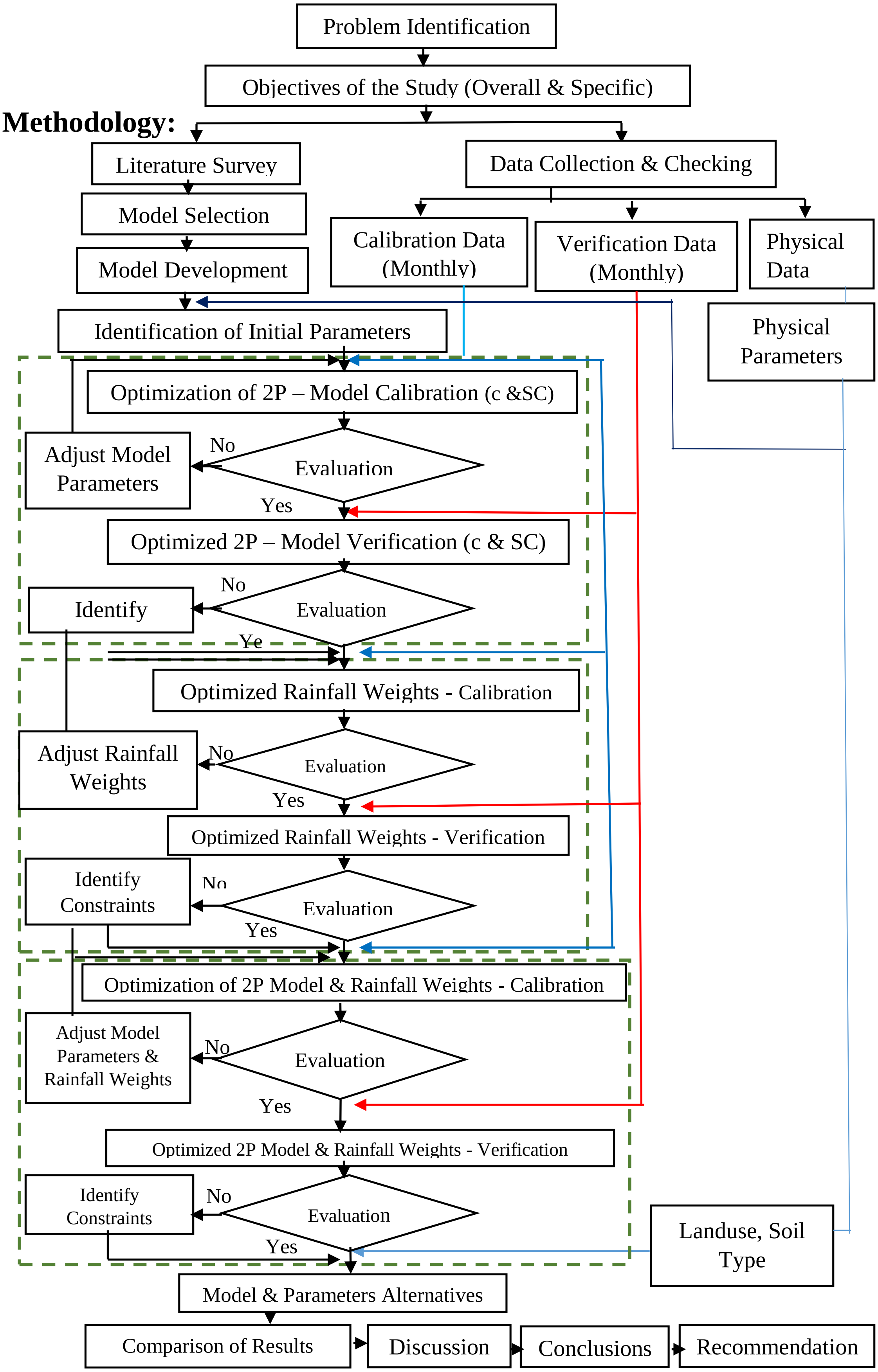


Figure 3-1:Methodology flow chart

# 4 Data collection

Rainfall, streamflow, pan evaporation, land use map, topographic map and soil map data are the main data used in this study.

Irrigation and Meteorology Department are responsible agencies for data collection in Sri Lanka. Similarly, survey department is valued source for land use, soil map, topographic map.

Streamflow data for Pitabeddara station were collected from the Department of Irrigation and rainfall data for five rain gauge stations and pan evaporation data were collected from Meteorology Department of Sri Lanka. Sources and resolutions of data are indicated in the table 4-1

Table 4-1:Data source and Data Resolution of Nilwala ganga at Pitabeddara

| **Data types** | **Spatial Resolution** | **Station Name** | **Data period** | **Source** |
|---|---|---|---|---|
| Rainfall | Monthly | Kirama | 1993-2017 | Department of Meteorology |
| | | Dampahala | | |
| | | Goluwawatta | | |
| | | Deniyaya | | |
| | | Annigkanda | | |
| Streamflow | Monthly | Pitabeddara | 1993-2017 | Department of Irrigation |
| Pan evapoation | Monthly | Deniyaya | 1993-2017 | Department of Meteorology |
| Land use map | 1:50,000 | | | Department of Survey |
| Topographic | 1:50,000 | | | Department of Survey |
| Soil Map | 1:50,000 | | | Department of Survey |

## 4.1 Rainfall and Streamflow

Monthly streamflow, rainfall and evaporation data were used in this study for the purpose of collection monthly rainfall data the locations of rain gauging stations were identified, coordinates and location of each station is mentioned in table 4-2.

Table 4-2:Rain Gauging Station Details of Nilwala ganga at Pitabeddara

| Rain gauging stations | Location Details | | |
|---|---|---|---|
| | Co-ordinates | | Location Relative to the Catchment Boundary |
| | Latitude | Longitude | |
| Deniyaya | 6.33 N | 80.55 E | Inside the boundary |
| Dampahala | 6.27 N | 80.63 E | Inside the boundary |
| Kirama | 6.22 N | 80.67 E | outside the boundary |
| Goluwawatta | 6.1 N | 80.48 E | outside the boundary |
| Anningkanda | 6.35 N | 80.61 E | outside the boundary |

## 4.2 Data Checking

spatial distribution of rainfall and streamflow gauging stations were checked according to the guideline of World Meteorological Organization (WMO,1975).

Table 4-3:Distribution of Gauging Stations in Pittabeddara at Nilwala gaga

| Gauging Station | Number of Stations | Station Density (km2/station) | WMO Standards (km2/station) |
|---|---|---|---|
| Rainfall | 5 | 58 | 575 |
| Streamflow | 1 | 291 | 1875 |

The rainfall data of all the stations were checked, missing data were marked.in addition, no missing data was found during checking the streamflow data for selected period for Nilwala ganga basin at Pitabeddara. Visual data checking was performed for rainfall, streamflow and evaporation data to check for inconsistencies. Double mass curve was used to check the consistency of data. The response of streamflow against rainfall were plotted for three years the results showed in graphs below.

## 4.3 Filling the missing data

Missing data is a critical problem in many meteorological time series. Monthly rainfall and streamflow datasets without missing values are essential for environment friendly estimation for application purposes. In order to estimate any missing observations in data, interpolation methods are presently used (Wan Ismail & Wan Zin @ Wan Ibrahim, 2017).

Caldera (2016) studied and investigated seven various available interpolation methods for filling gaps in rainfall data records in order to suggest a suitable method for a catchment located in a mountainous area of Sri Lanka. They found that for target stations which have only one neighboring station with a high correlation coefficient, the Linear Regression meth and Probabilistic method provide good results. For those stations that have quite low correlation coefficients with the neighboring stations, the Inverse Distance Squared method and the Normal Ratio method performed better than others.

Dayawansa (2007) carried out a study about four interpolation methods in Sri Lanka. Such as Arithmetic Mean (Local Mean) method, Normal Ratio method, Inverse Distance and newly introduced method authors is named as Aerial Precipitation Ratio method. they indicate in Their study that Aerial Precipitation Ratio method is more suitable for Mid part of the Country Wet Zone.

El and Soussi (2018) thoroughly examined the accuracy of five methods of filling in missing data ,such as simple arithmetic averaging (AA), inverse distance interpolation (ID), normal ration (NR), Thiessen polygons and multiple imputation(MI).as result they recommended Thiessen polygon method as best method for filling missing data.

Considering the location of Pitabeddara catchment in Nilwala Ganga river basin in wet zone, areal precipitation method was used for filling missing data. In this method This method was developed based on spatial distribution of monthly rainfall without accounting for the historical recurrence. The method leads the extension of point rainfall records to Thiessen Polygon areas. The APR method assumes the contribution of rainfall from surrounding stations is proportionate to the aerial contribution of each sub catchment (Thiessen polygon area claimed by each station without considering the missing gauge), when the station of missing values is excluded (P, 1997).

Table 4-4:Missing value for each month

| Data Type | Station names | Years | Missing Months |
|---|---|---|---|
| Rainfall | Deniyaya | 2014/15 | October, November |
| | Dampahala | 2011/12 | April |
| | Kirama | 1993/94 | March |
| | | 2004/05 | May |
| | | 2010/11 | September |
| | Goluwawatta | 1999/00 | November |
| | | 2002/03 | June |
| | | 2008/09 | August |
| | | 2016/17 | June |
| | Anningkanda | 1995/96 | November |
| | | 2003/04 | December |
| | | 2015/16 | June |
| Streamflow | Pitabeddara | No missing | |
| Evaporation | Deniyaya | No missing | |

## 4.4 Thiessen Rainfall

Different Systematic averaging methods such as Thiessen polygon, isohyet and reciprocal distance methods can be used to account for variations in space. ArcGIS software has been used to estimate the Thiessen average rainfall of for chosen catchments, Parallel Thiessen polygon areas and weights was used to calculate the catchment average rainfall, Thiessen polygon was developed for the Pitabeddra catchment the Thiessen area and Thiessen weights are mentioned in table 4-5

Table 4-5:Each station Thiessen polygon area and Thiessen weight

| Rain gauging stations | Area (km2) | Thiessen Weight |
|---|---|---:|
| Deniyaya | 137.985 | 0.47 |
| Dampahala | 90.3852 | 0.31 |
| Anningkanda | 20.2844 | 0.07 |
| Goluwawatta | 35.1994 | 0.12 |
| Kirama | 7.45223 | 0.03 |

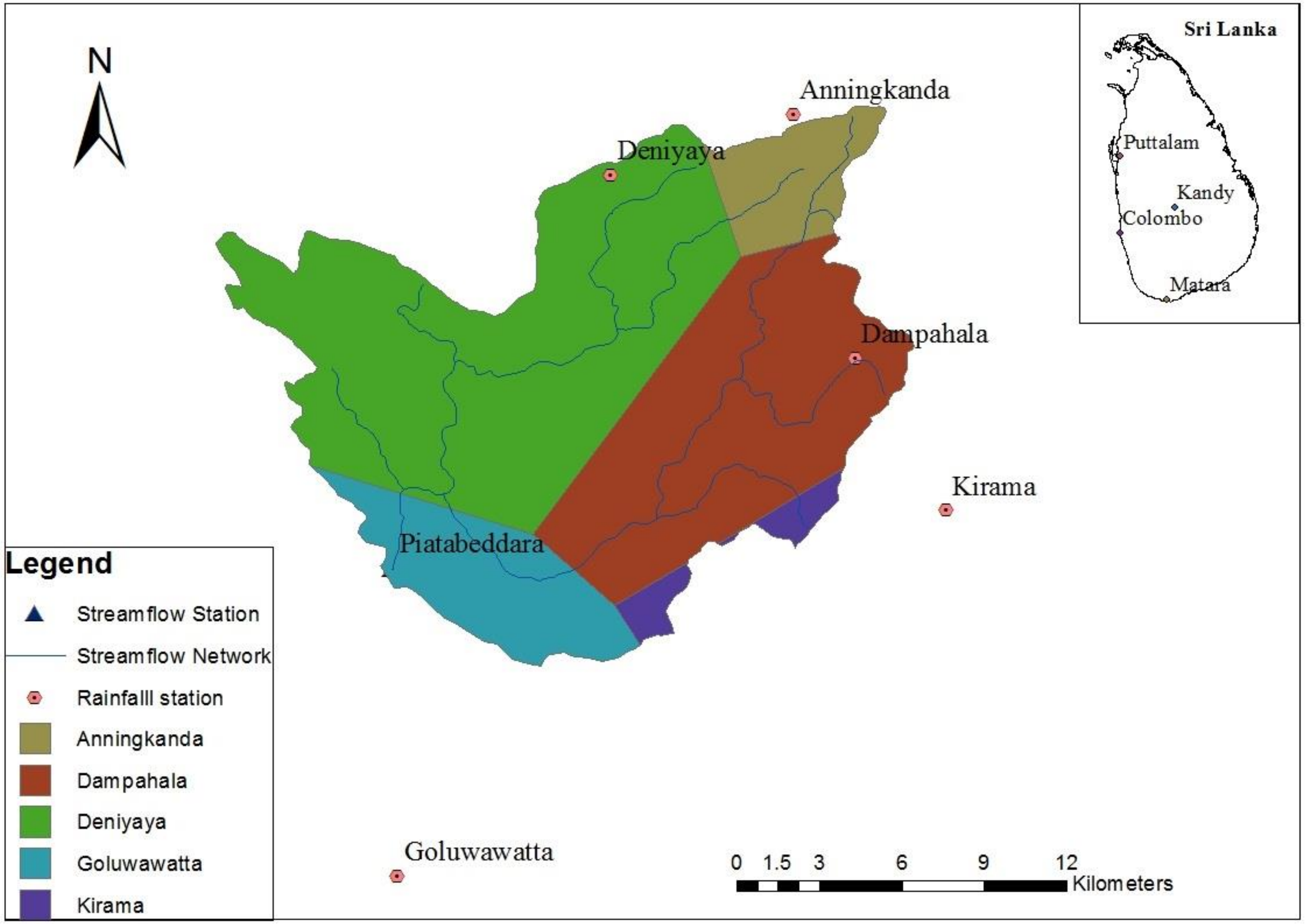


Figure 4-1:Thiessen polygon Pitabeddara watershed

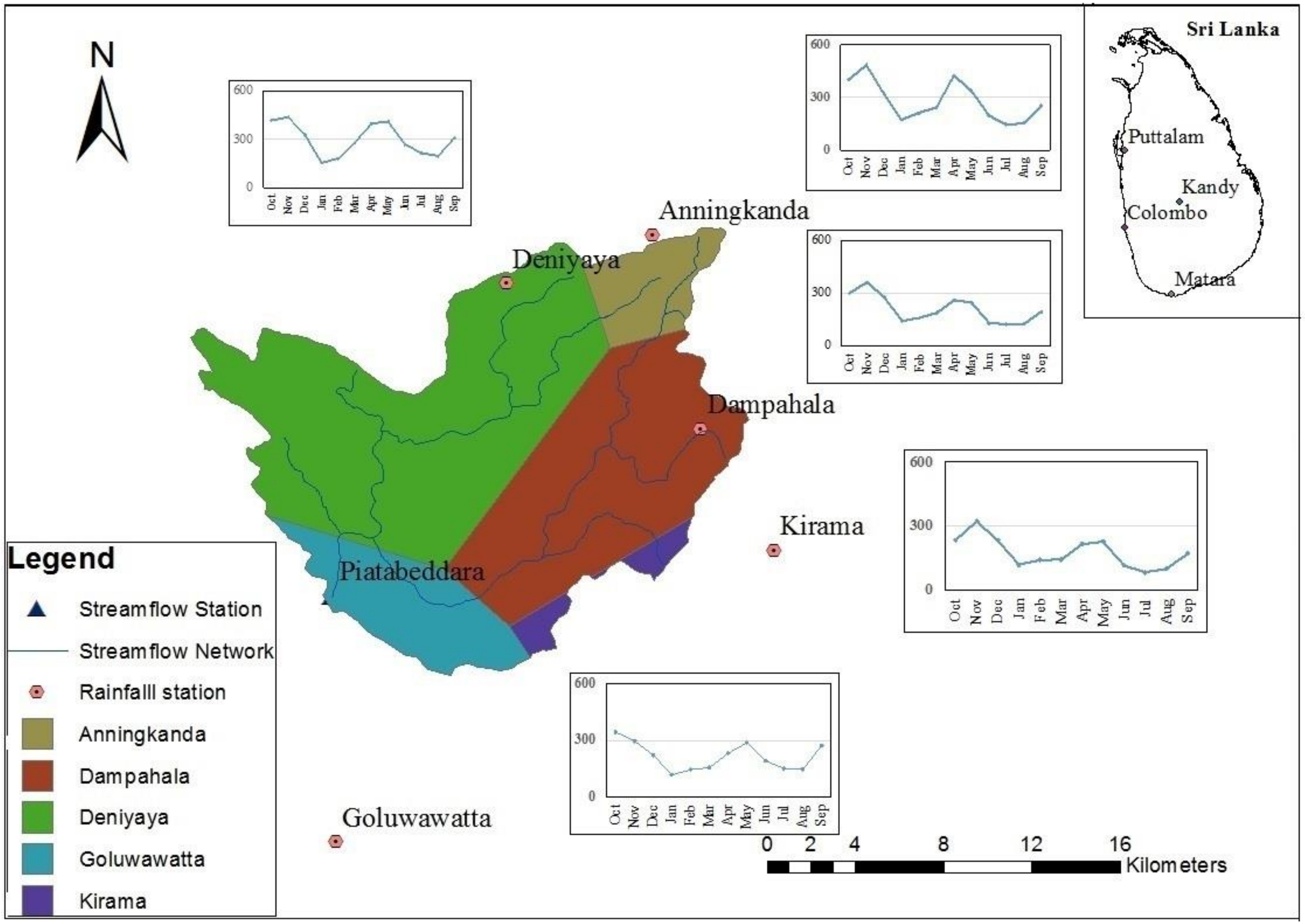


Figure 4-2: Thiessen polygon and Monthly rainfall variation

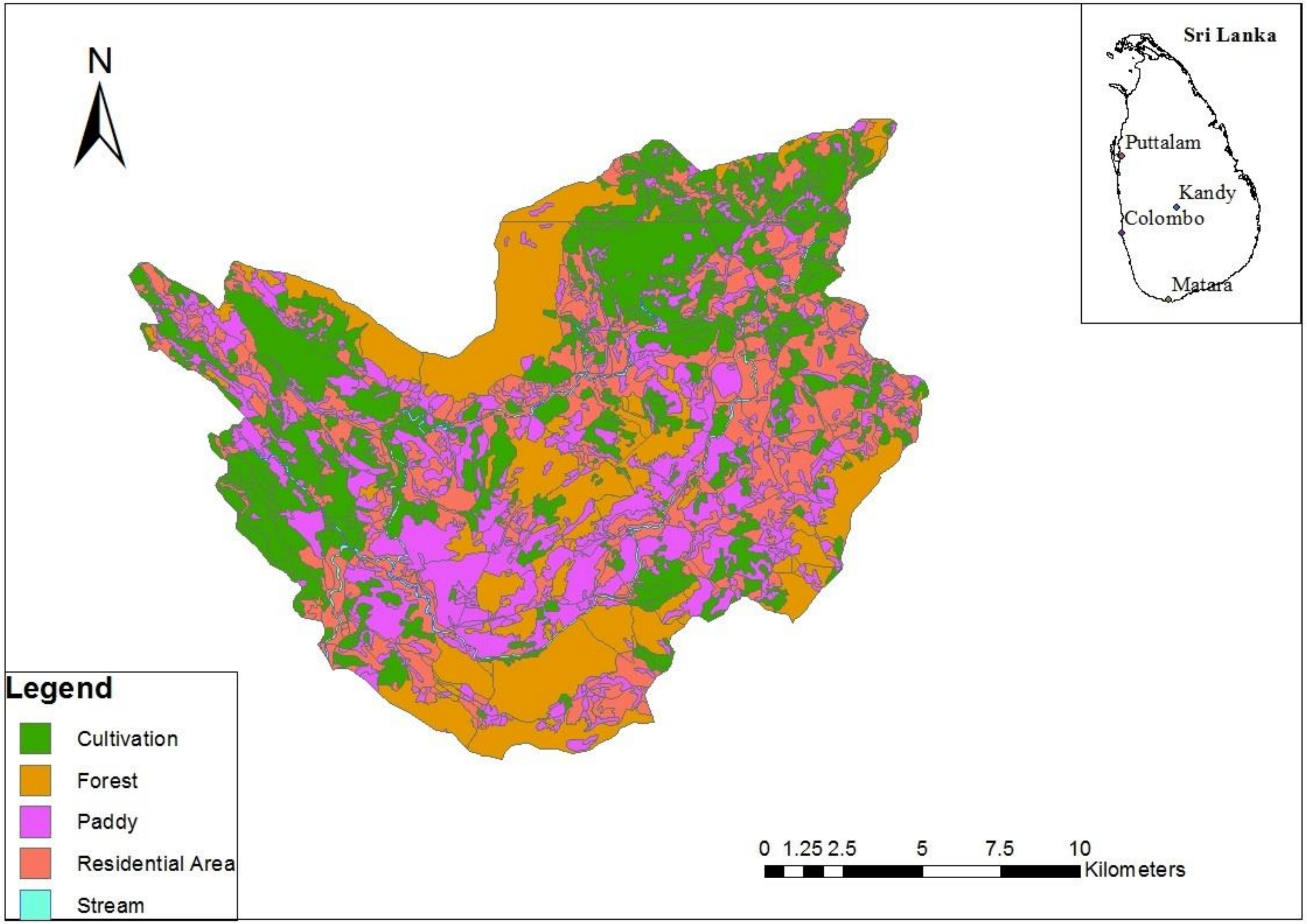


Figure 4-2:Land use Map of Pitabeddara watershed

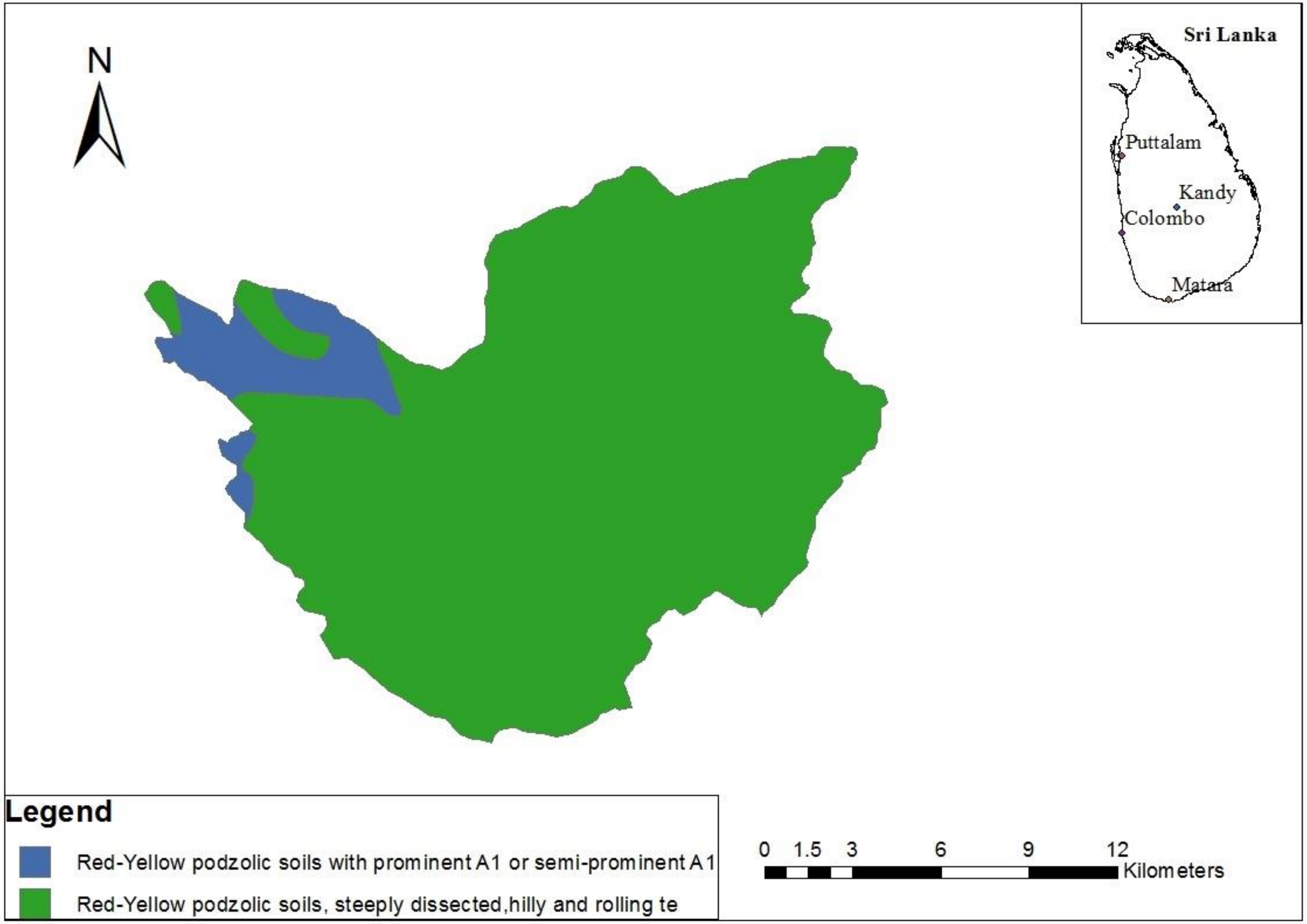


Figure 4-3:Soil Map Pitabeddara watershed

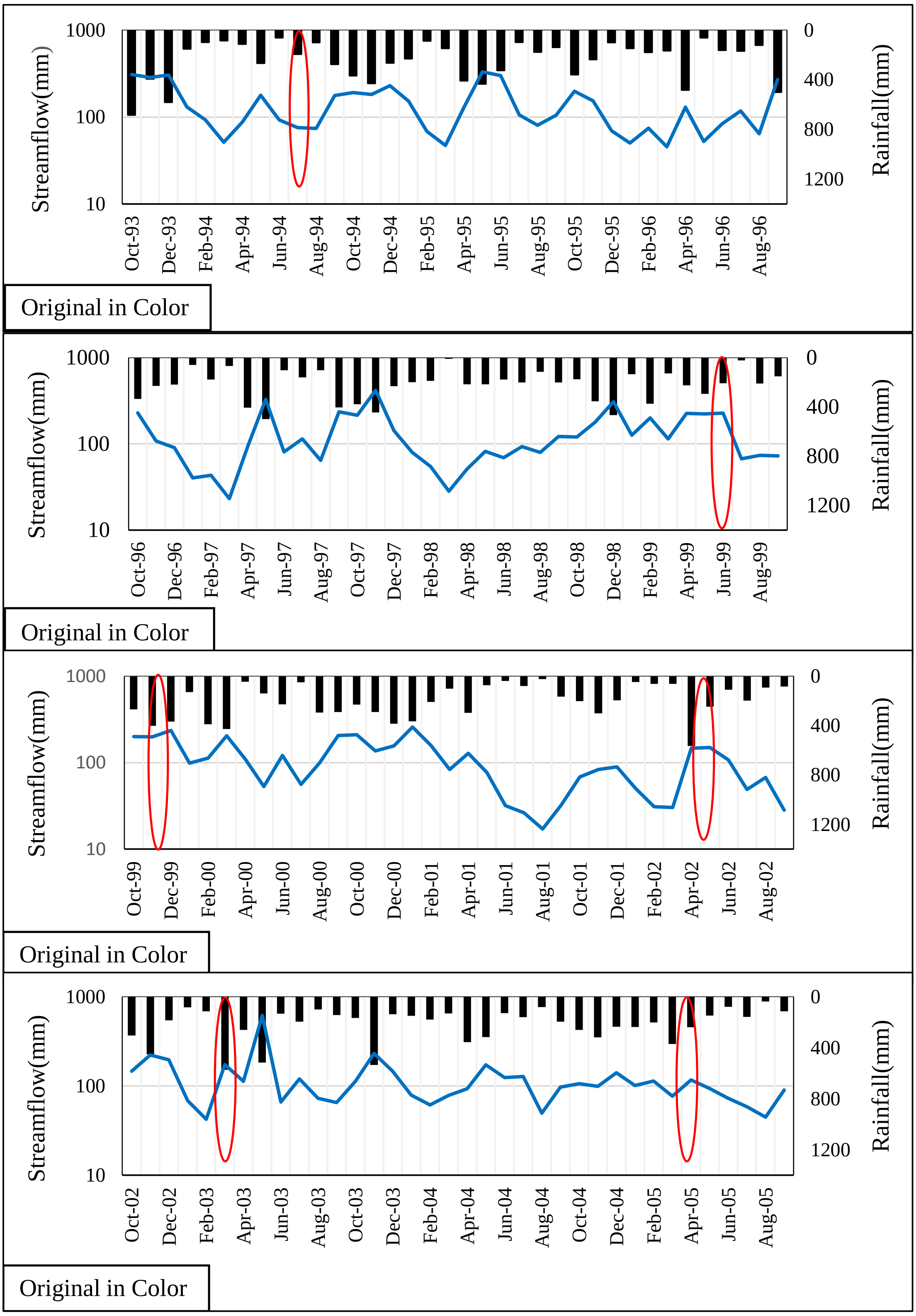


Figure 4-4:Dampahala Streamflow response to rainfall from(1993-2005

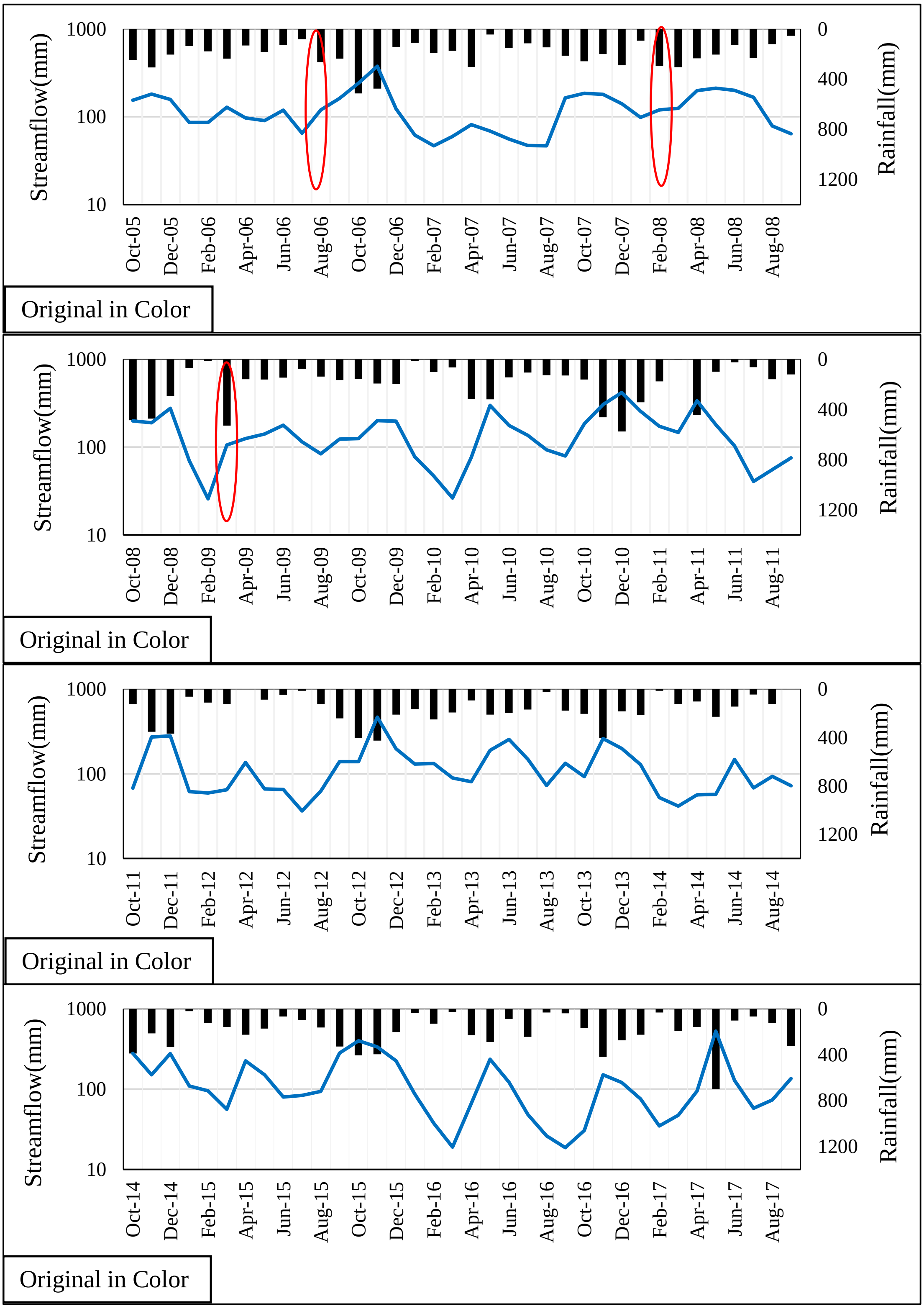


Figure 4-5:Dampahala Streamflow response to rainfall from (2005-2017)

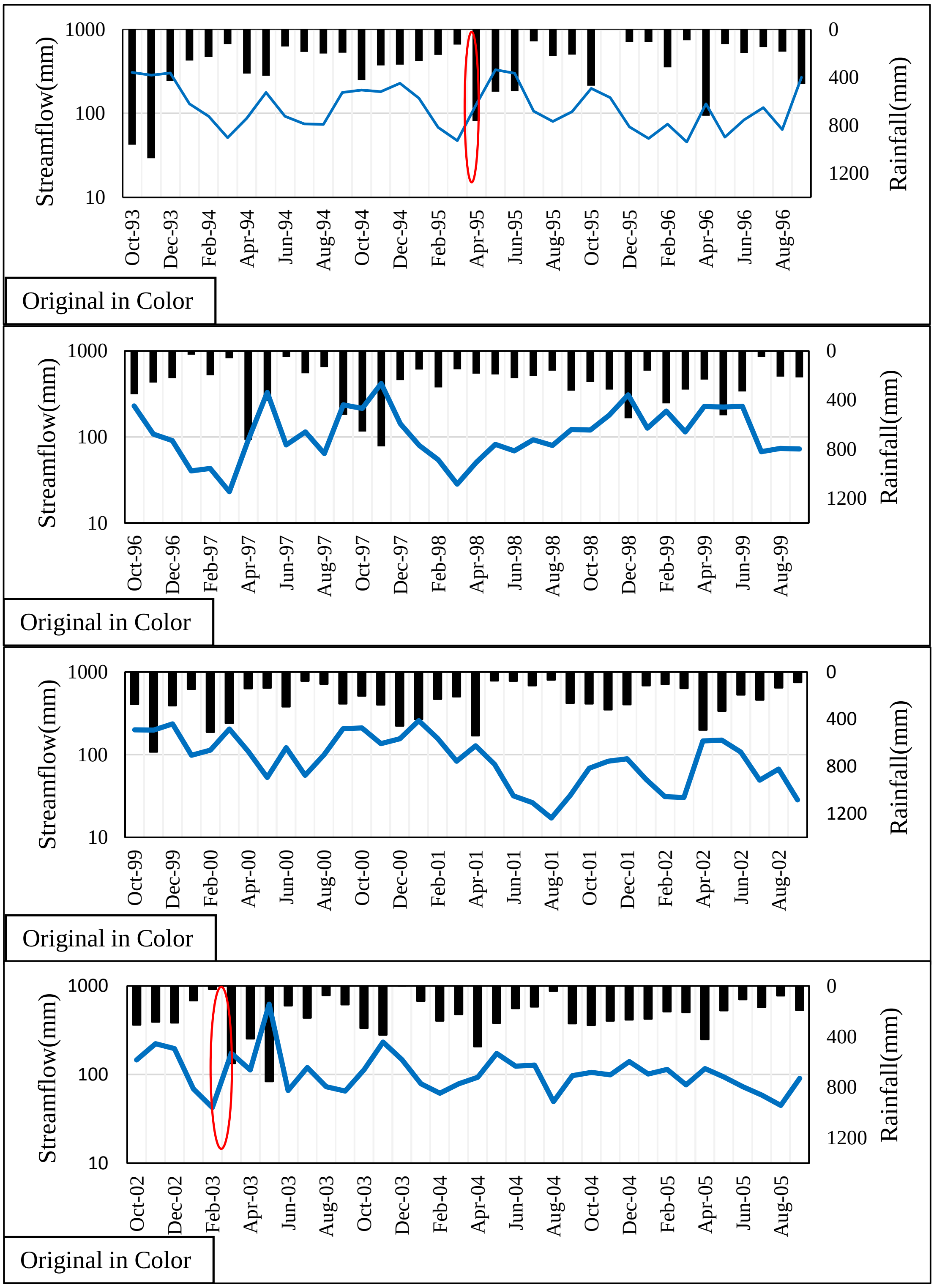


Figure 4-6:Anningkanda Streamflow response to rainfall from (1993-2005)

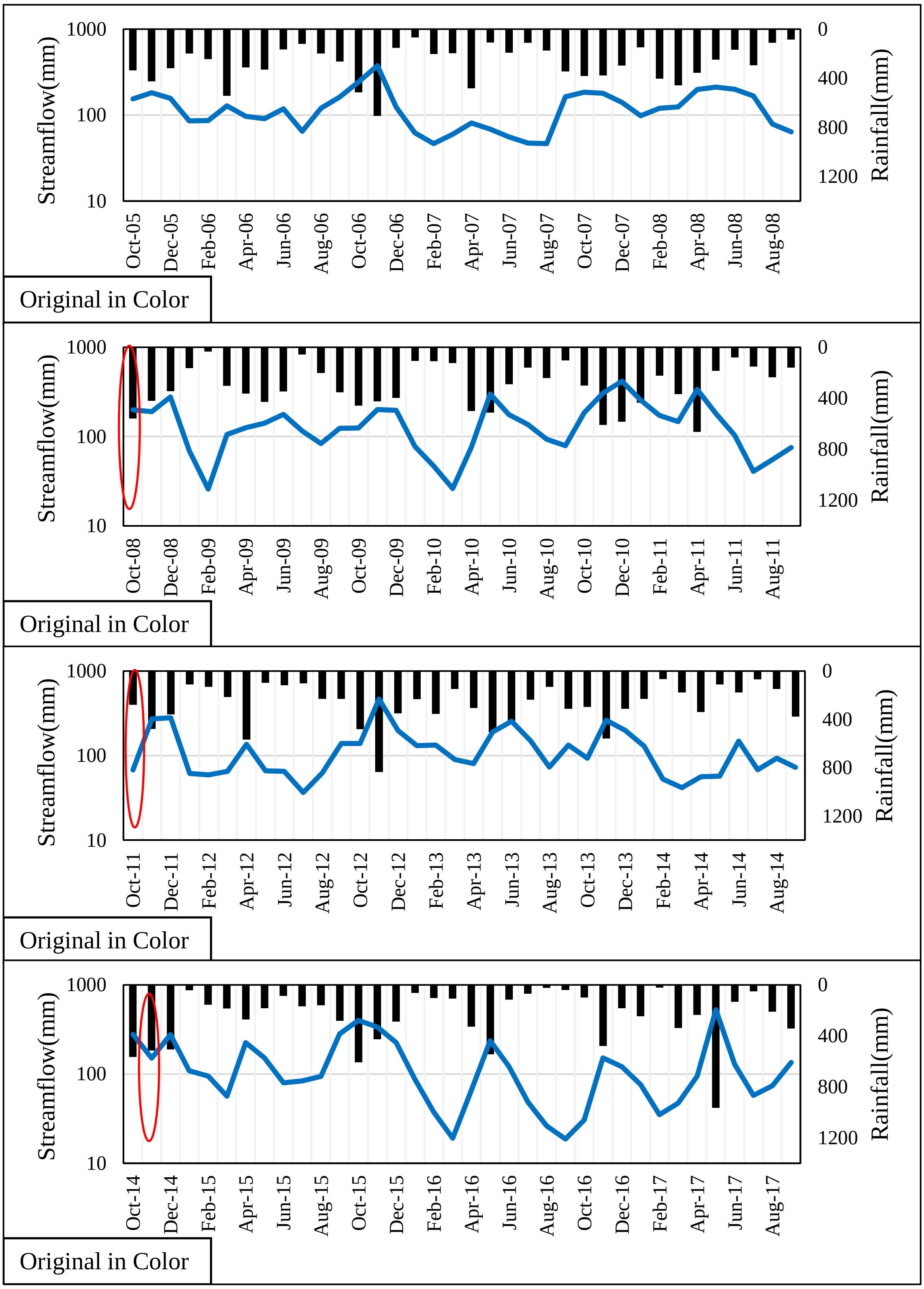


Figure 4-7:Anningkanda Streamflow response to rainfall from (2005-2017)

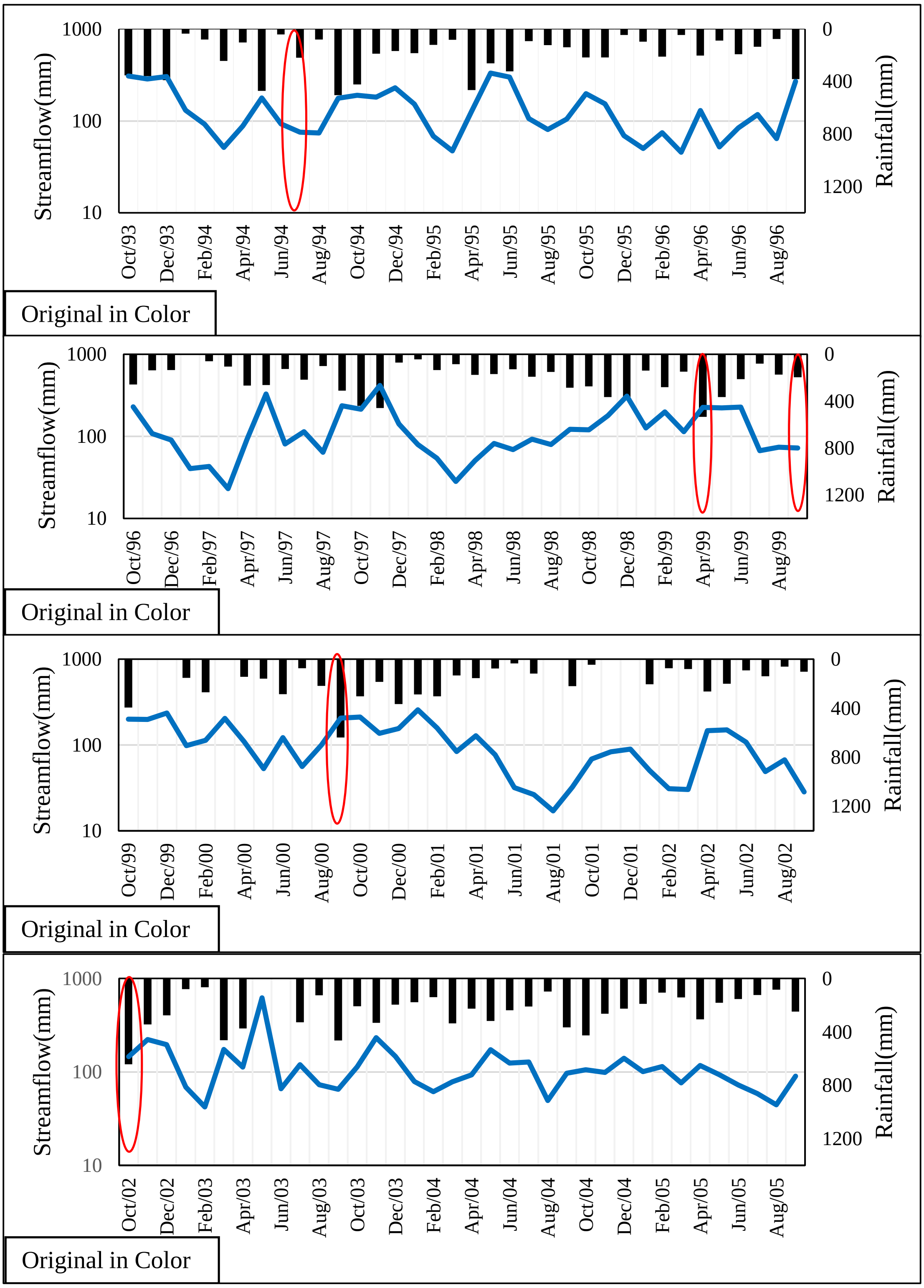


Figure 4-8:Goluwawtta streamflow response rainfall from (1993-2005)

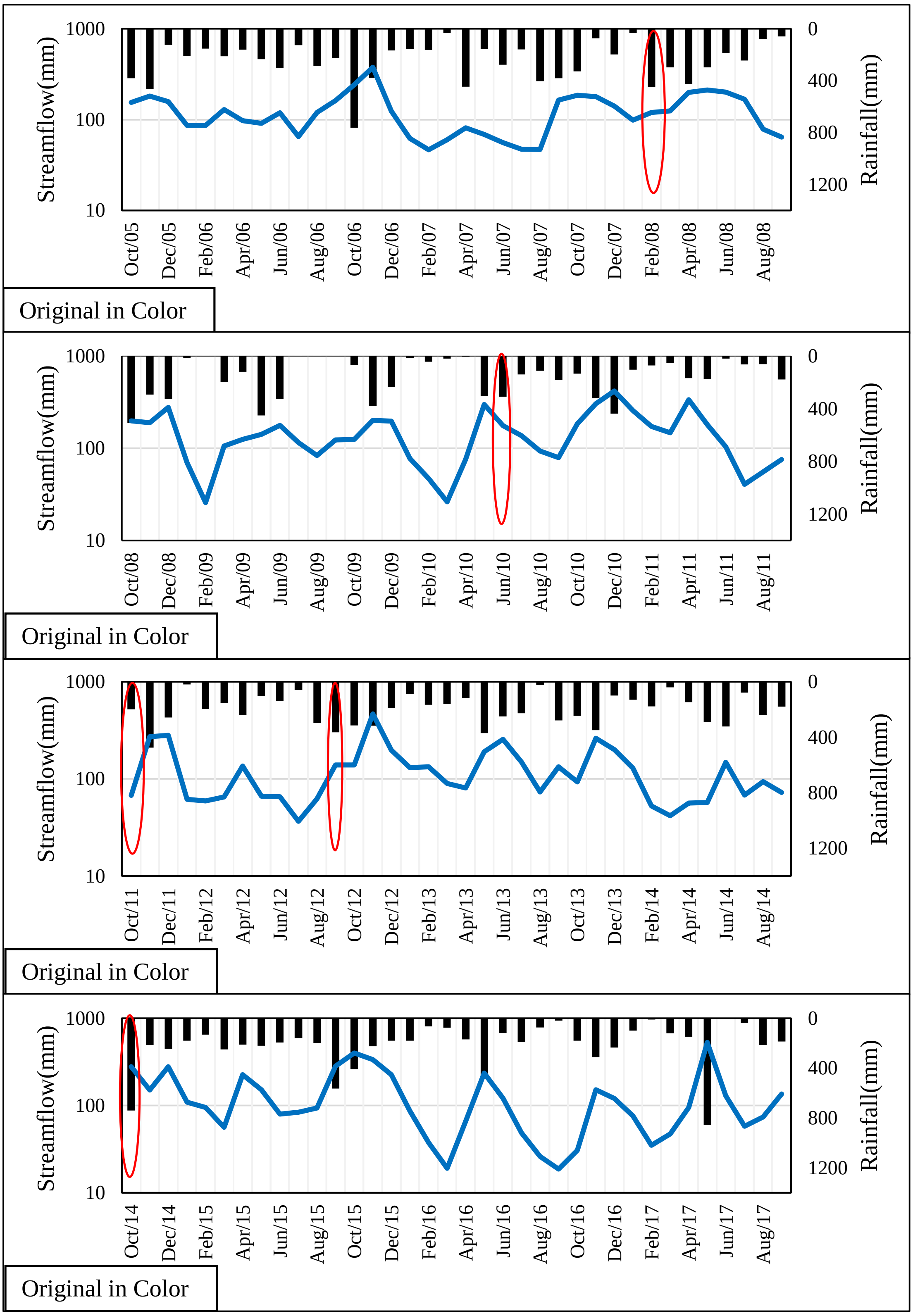
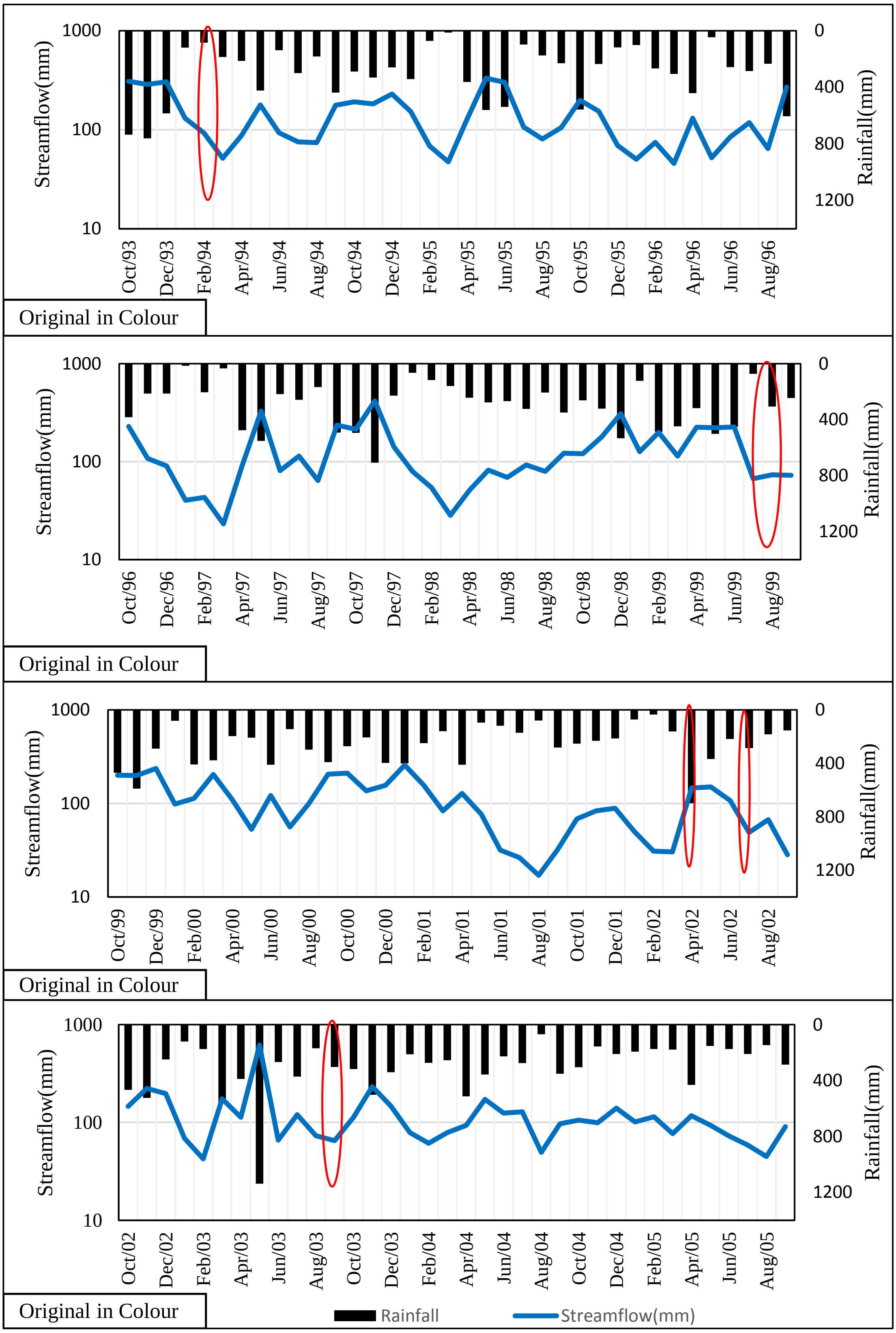


Figure 4-9:Goluwawatta Streamflow response to rainfall (2005-2017



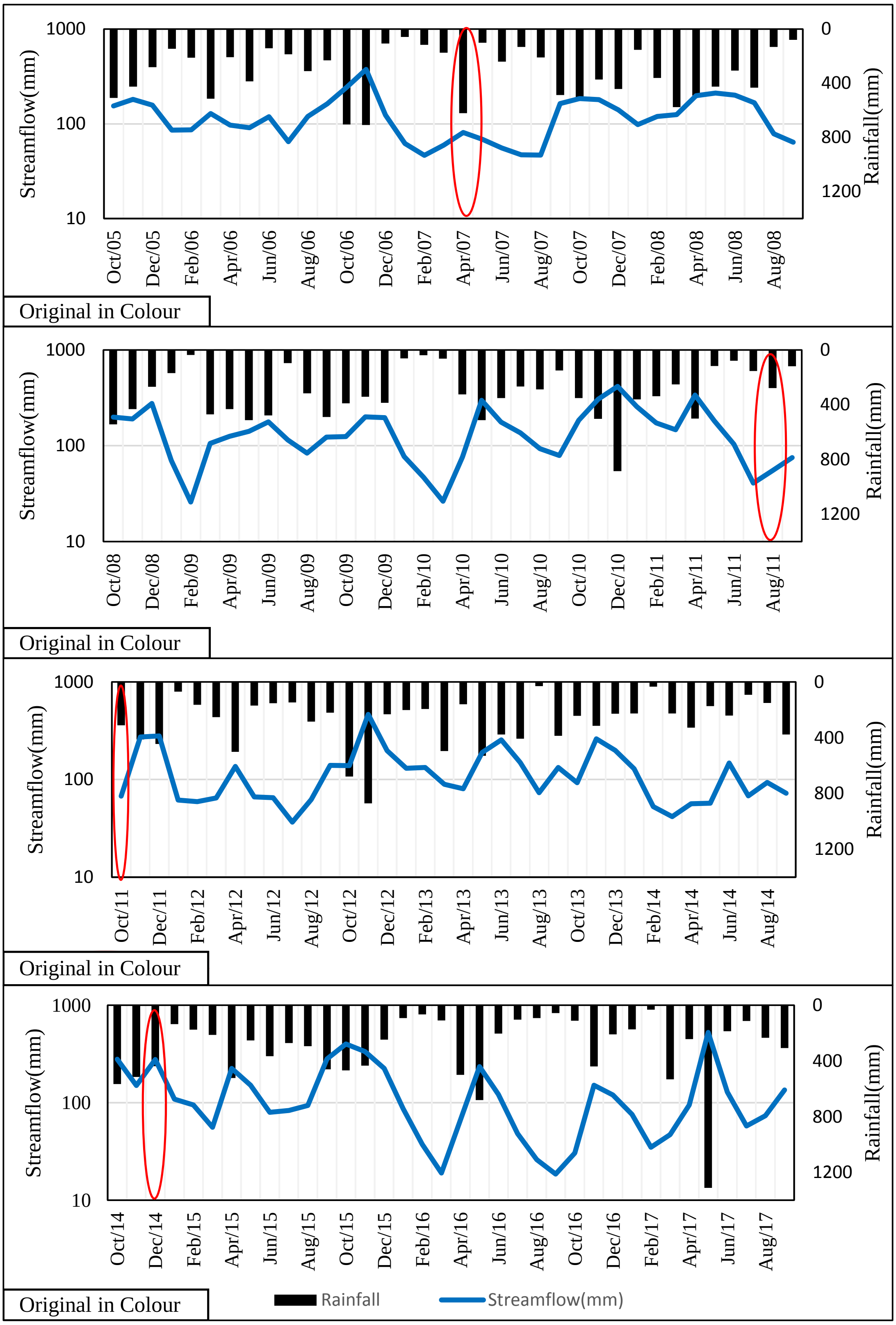
Original in Colour

Original in Colour

Original in Colour

Original in Colour

Figure 4-10:Deniyaya Streamflow response to rainfall from (1993-2005)



Original in Colour

Original in Colour

Original in Colour

Original in Colour

Figure 4-11:Deniyaya Streamflow response to rainfall from (2005-2017)

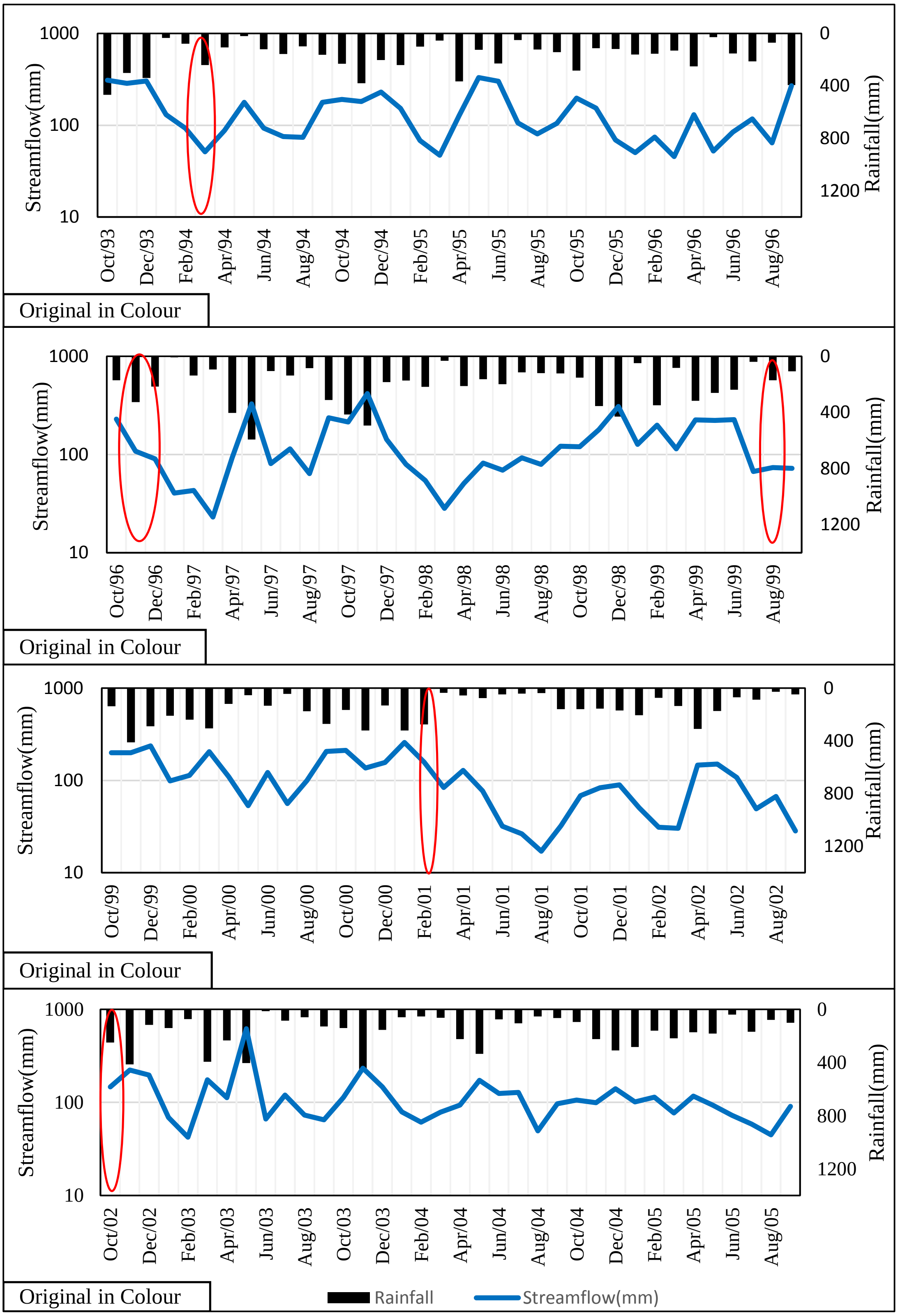


Figure 4-12:Kirama Streamflow response to rainfall from (1993-2005)

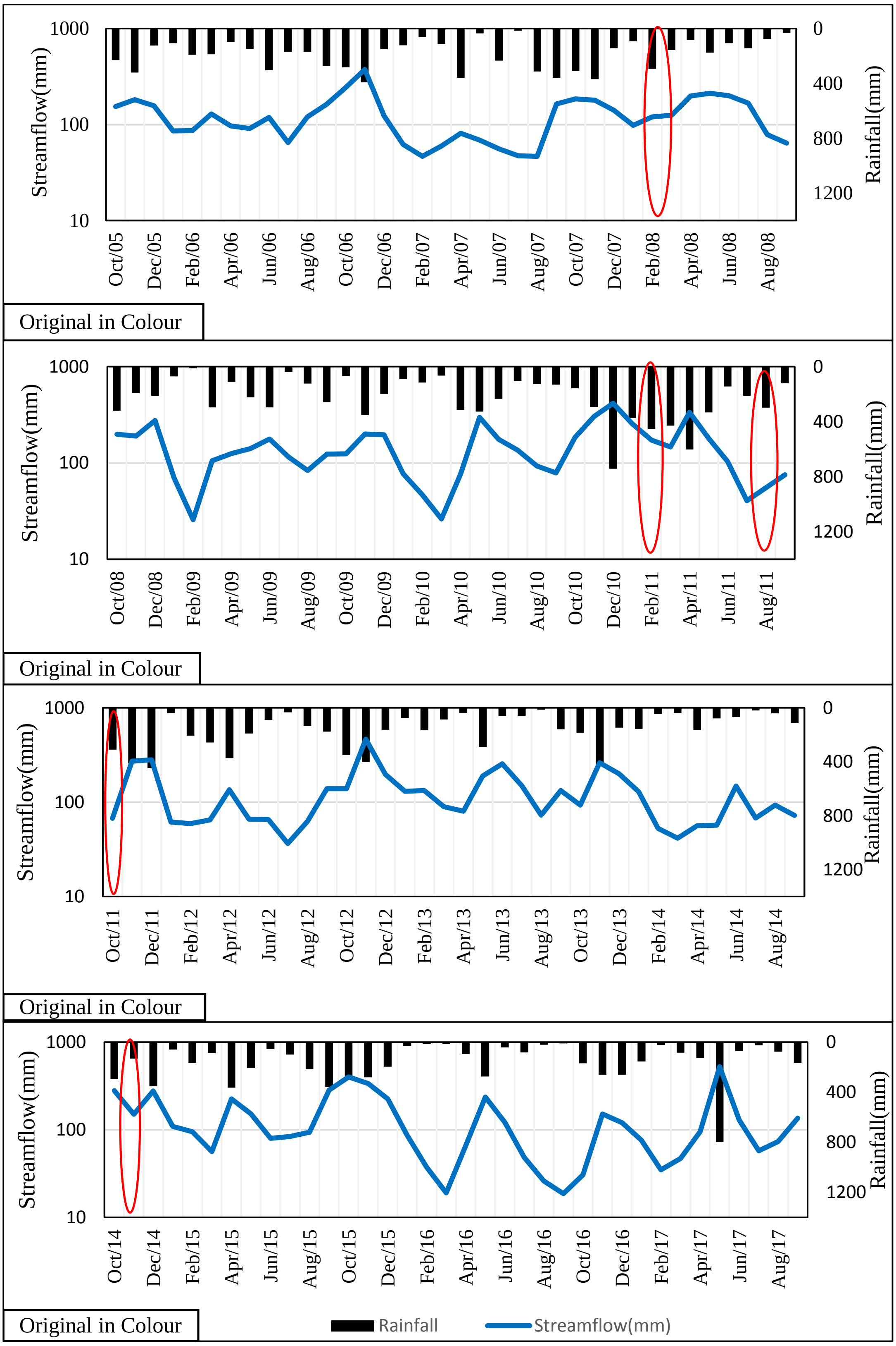


Figure 4-13:Kirama Streamflow response to rainfall from (2005-2017)

## 4.5 Double Mass Curve

Double mass curves of cumulative rainfall data of one rainfall station with cumulative of other stations.

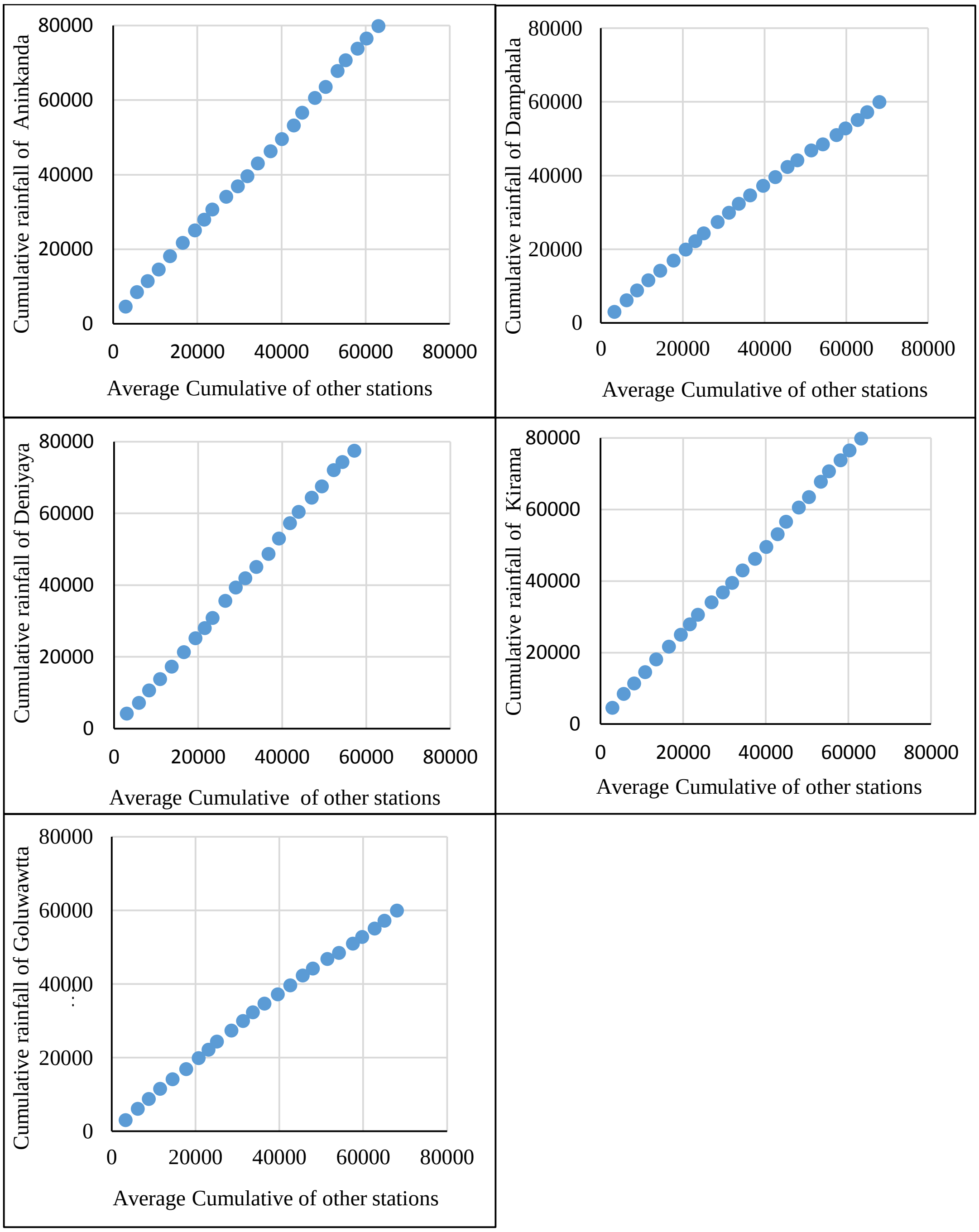


Figure 4-14:Double Mass Curve for Rainfall Data of Pittabeddara

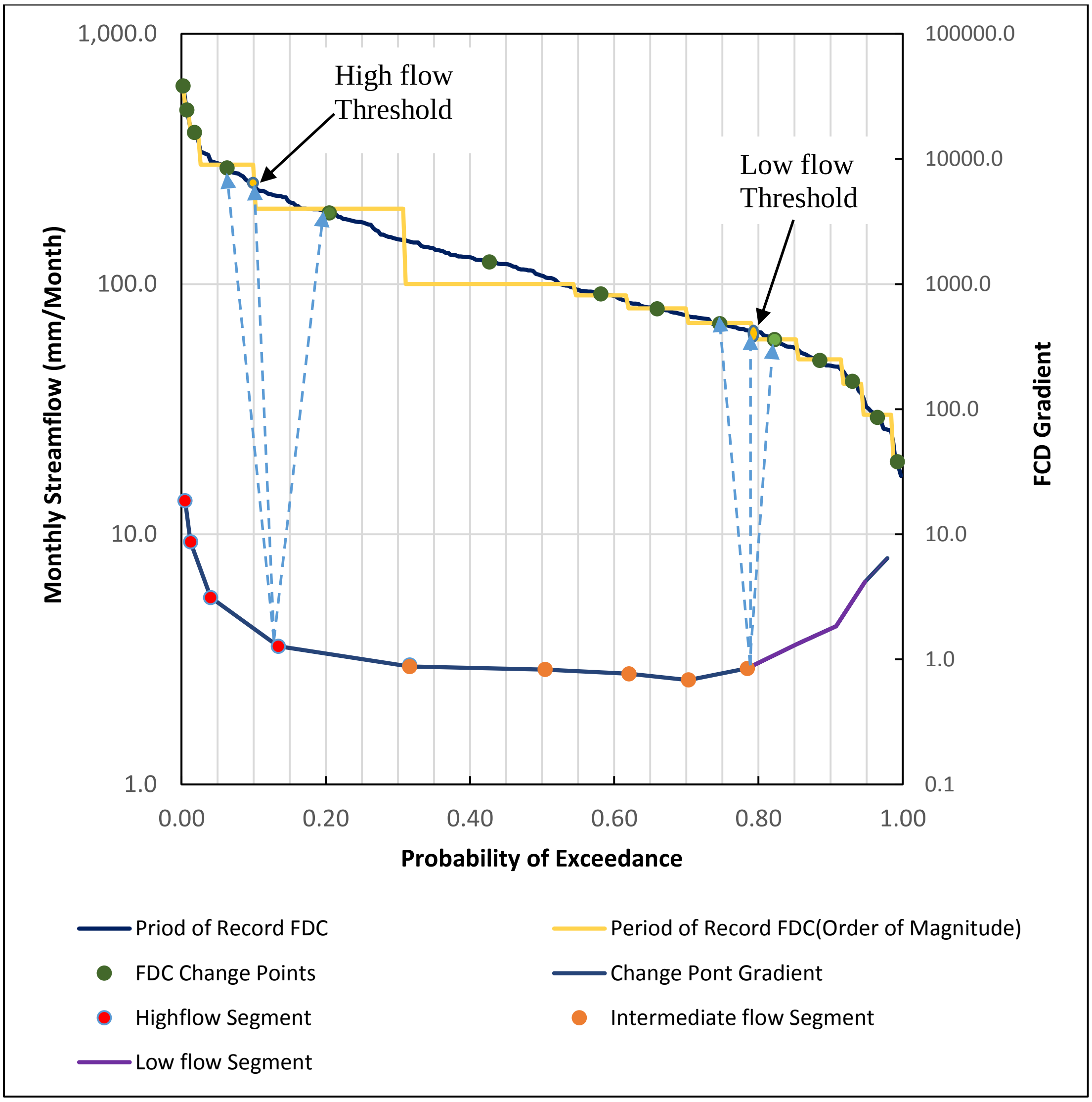


Figure 4-15::Monthly Flow Duration Curve

High, Medium and Low flow limits with Monthly data

| Percentage of Exceedance | |
|---|---|
| | Pitabeddara (1993-2017) Monthly |
| High | <14 |
| Medium | >14 & < 79 |
| Low | <79 |

## 4.6 Annual Data Comparison

### 4.6.1 Annual monthly rainfall comparison

Rainfall pattern was compared for the year 1993 to 2017 for all rain gauge stations the results shown in graph below.

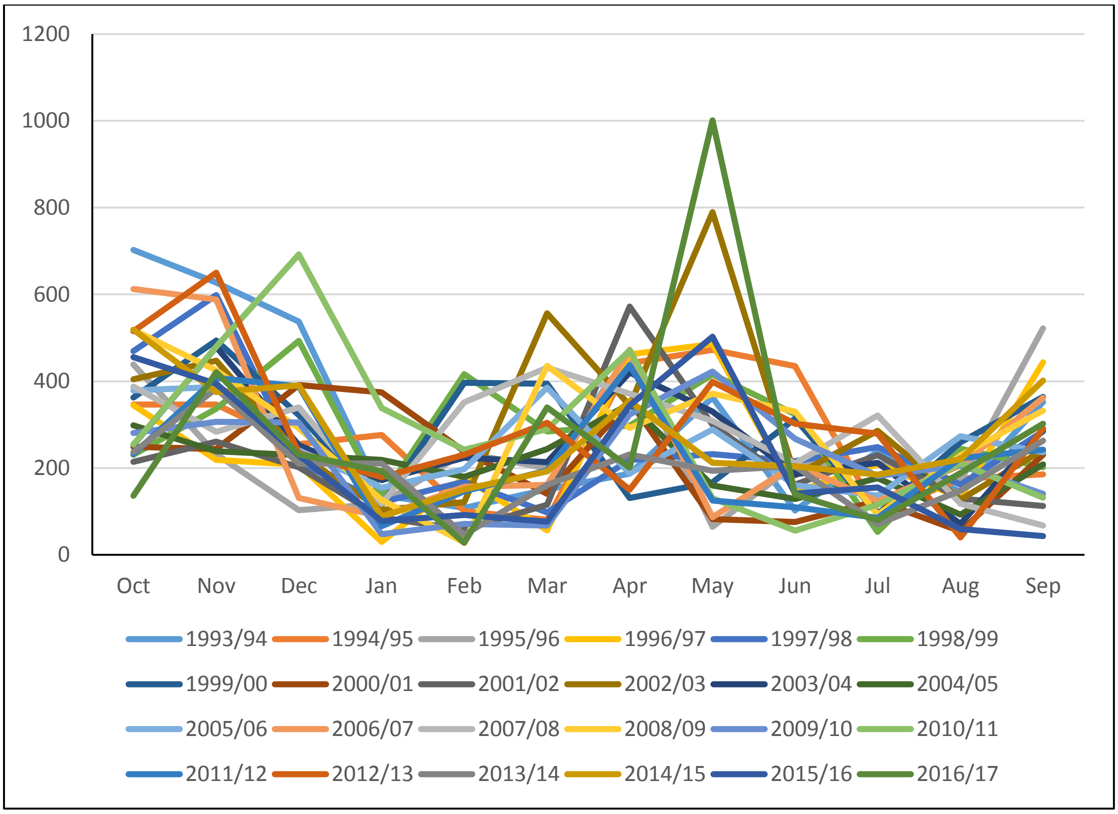


Figure 4-16:Annual Rainfall Pattern

From above comparison the rainfall pattern can be observed similar in the considered period except for years 2002/2003,2010/2011, 2016/2017.Moreover, from observation there is a significant deviation in the rainfall pattern from the month November to march and June to September and of the years 2009/2010, 2010/2011.while during the month April to July the rainfall pattern was observed different showing heavy rains occurred in this period of time. overall the rainfall pattern was observed similar for all rain gauge stations.

### 4.6.2 Annual Water Balance

Annual water balance was developed for Pittabeddara catchment in Nilwala ganga basin, for the purpose of comparison the annual volume of rainfall, streamflow and evaporation. Annual water balance of Pittabeddara catchment showed in table 4-6.

Table 4-6:Annul water balance for Pittabeddara watershed

| year | Annual RF(mm/year) | Annual SF(mm/year) | Annual Evp(mm/year) | Annual Water Balance | Runoff Coefficient |
|---|---|---|---|---|---|
| 1993/1994 | 3640.3 | 1857.4 | 1154.02 | 1782.9 | 0.5 |
| 1994/1995 | 3099.6 | 1920.8 | 1123.42 | 1178.7 | 0.6 |
| 1995/1996 | 2932.8 | 1309.3 | 1182.75 | 1623.5 | 0.4 |
| 1996/1997 | 2912.7 | 1450.8 | 1205.6 | 1461.9 | 0.5 |
| 1997/1998 | 3028.7 | 1431.8 | 1126.53 | 1596.9 | 0.5 |
| 1998/1999 | 3420.8 | 1934.7 | 1135.45 | 1486.1 | 0.6 |
| 1999/2000 | 3321.4 | 1698.0 | 959.09 | 1623.4 | 0.5 |
| 2000/2001 | 2552.7 | 1315.3 | 1062.8 | 1237.4 | 0.5 |
| 2001/2002 | 2407.3 | 901.6 | 1031.26 | 1505.7 | 0.4 |
| 2002/2003 | 3784.9 | 1907.2 | 999.653 | 1877.7 | 0.5 |
| 2003/2004 | 3056.3 | 1376.5 | 1023.72 | 1679.9 | 0.5 |
| 2004/2005 | 2514.9 | 1114.4 | 1054.16 | 1400.5 | 0.4 |
| 2005/2006 | 2840.6 | 1449.1 | 823.42 | 1391.5 | 0.5 |
| 2006/2007 | 3192.5 | 1375.1 | 863.99 | 1817.4 | 0.4 |
| 2007/2008 | 3299.9 | 1771.0 | 475.99 | 1528.9 | 0.5 |
| 2008/2009 | 3384.8 | 1632.9 | 871.335 | 1752.0 | 0.5 |
| 2009/2010 | 2585.0 | 1532.6 | 890.34 | 1052.4 | 0.6 |
| 2010/2011 | 3284.4 | 2276.8 | 869.18 | 1007.6 | 0.7 |
| 2011/2012 | 2531.6 | 1312.2 | 994.01 | 1219.4 | 0.5 |
| 2012/2013 | 3573.1 | 2037.1 | 870.27 | 1536.0 | 0.6 |
| 2013/2014 | 2166.4 | 1273.2 | 898.86 | 893.2 | 0.6 |
| 2014/2015 | 2852.7 | 1882.1 | 897.63 | 970.6 | 0.7 |
| 2015/2016 | 2571.8 | 1619.3 | 847.75 | 952.4 | 0.6 |
| 2016/2017 | 3161.9 | 1476.6 | 876.246 | 1685.3 | 0.5 |

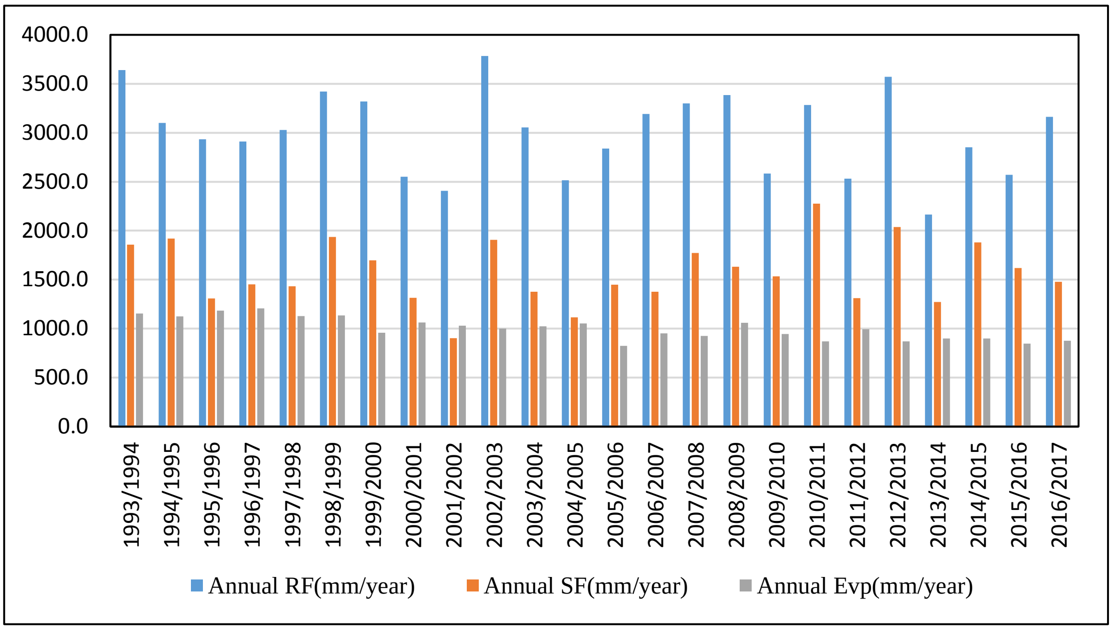


Figure 4-17:Annual water balance

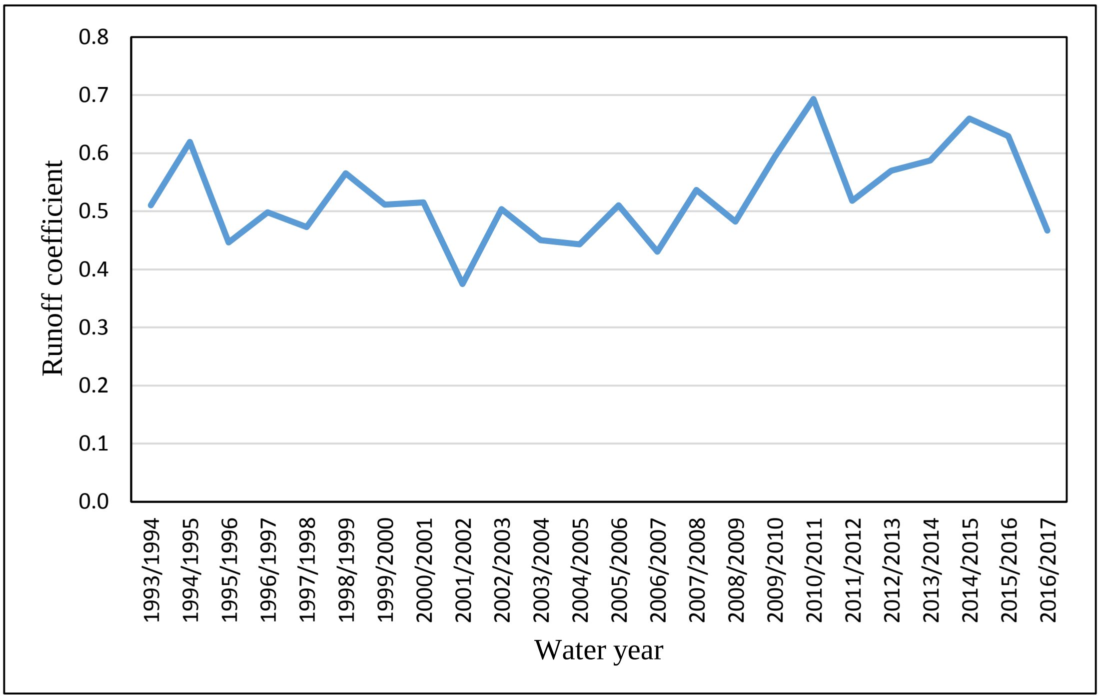


Figure 4-18:Runoff coefficient

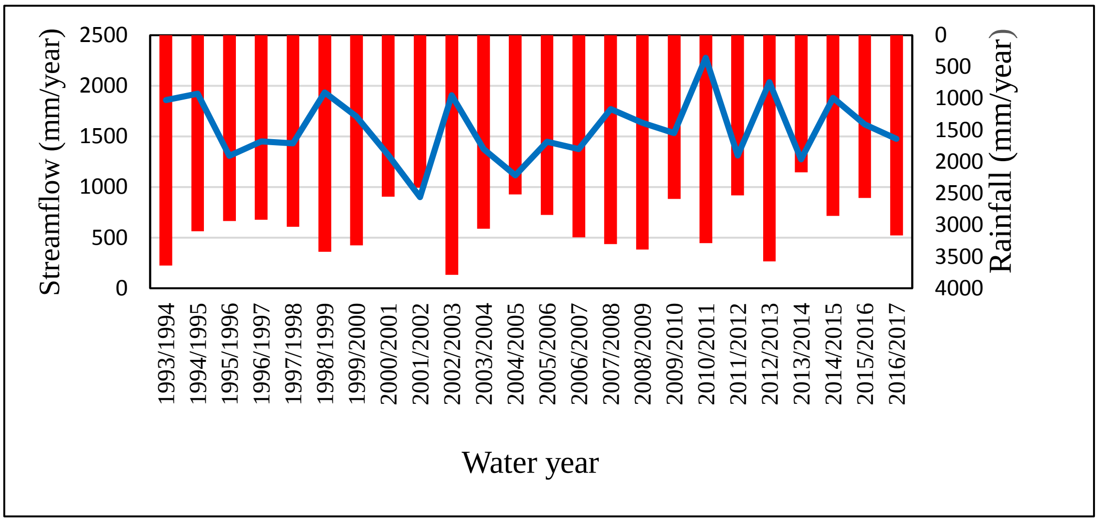


Figure 4-19:Stream flow response vs rainfall

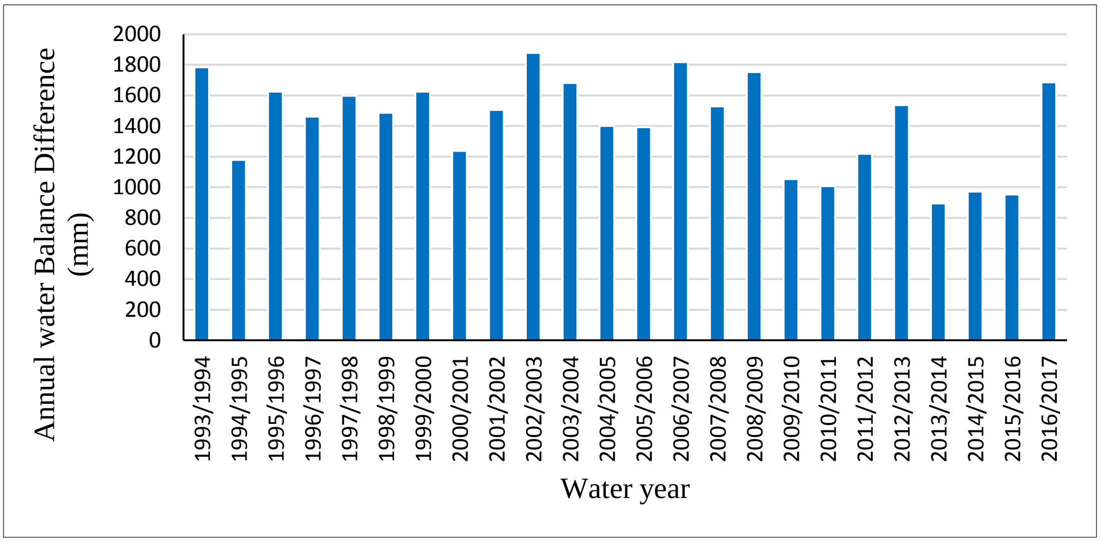


Figure 4-20:Annual water balance difference

It is found from annual water balance comparison that, the minimum annual rainfall during the selected period of water year 2013/2014 was (2166.4 mm). while minimum streamflow (1273.2 mm) was received in the same water year recorded in Pitabeddara gauging station data. During the water year 2001/2002 the annual rainfall was high (2407.3mm). whilst, the annual streamflow was very low (901.6mm) in the same water year. The maximum rainfall was observed (3784.9mm) in the water year (2002/2003) similarly, the maximum streamflow (2276.8mm) was occurred in the year 2010/2011 with high runoff coefficient 0.7 in the same year. However lowest runoff coefficient i.e. 0.4 in the year 1995/1996.

## 4.7 Identification of Missing Data

During checking the rainfall, evaporation and stream flow data almost 12 points missing data were found only for rainfall data set from the year 1993 to 2017 such as two months' data October and November in the water year of 2014/2015, April in the year 2011/2012, march in the year 1993/1994 may 2004/ 2005, September in year 2010/2011, November in year 1999/2000, June in 2002/2003, August in 2008/2009, June 2016/2017, November in 1995/1996, December in 2003/2004 and June. Whilst, evaporation data from 1993 to 2000 was replaced from nearby evaporation station and streamflow data were free of missing data for considered data set. The full details of the missing data mentioned in table below.

| **Data Type** | **Station names** | **Years** | **Missing Months** |
|---|---|---|---|
| Rainfall | Deniyaya | 2014/15 | October ,November |
| | Dampahala | 2011/12 | April |
| | Kirama | 1993/94 | March |
| | | 2004/05 | May |
| | | 2010/11 | September |
| | Goluwawatta | 1999/00 | November |
| | | 2002/03 | June |
| | | 2008/09 | August |
| | | 2016/17 | June |
| | Anningkanda | 1995/96 | November |
| | | 2003/04 | December |
| | | 2015/16 | June |
| Streamflow | Pitabeddara | --- | --- |
| Evaporation | Deniyaya | --- | --- |

# 5 ANALYSIS AND RESULTS

## 5.1 Introduction

Two parameter monthly water balance proposed by Xiong and Guo (1999) is a simple water balance model with less number of parameters which can estimates streamflow and soil moisture content very easily, this model has been already applied in Sri Lankan catchments such as (M. B. Sharifi, 2015) for evaluating the water resources of Kalu and Mahaweli rivers . (Khandu, 2015) used for evaluating the climate change impacts on the streamflow of Gin ganga and Kelani Ganga basins. Kumari and Dissanayake (2017) applied for simulation of daily rainfall runoff of Kalu and Gin river basins and they stated in their results that the model performance was satisfactory both in calibration and verification periods. Kim et al. (2016) used this model for monthly runoff simulation in Korea they introduced the new method for parameters estimation using physical characteristics of the catchment. After comparing the results of the both methods, trial and error physical parameters, the model achieve better results with physical parameters. Musiake and Wijesekera, (1990). applied tank model developed by (Sugawara ,1961) to Sri Lankan catchment for streamflow simulation. They initially optimized the model parameters assuming a uniform spatial variation of rainfall, then station weights were optimized while keeping model parameters constant, as a result the optimized weighted parameters values was reasonable. Therefore, in this study the model parameters C and Sc were first optimized using Thiessen rainfall in the model likewise the rainfall station weights were optimized and the model parameters were optimized using the optimized rainfall in the model. Secondly, the parameters C and Sc identified from physical characteristics of the catchment, the parameter C was estimated using rainfall and evaporation data while parameter Sc were estimated using soil and land use variables, finally the parameter values from all these mentioned methods were compared, to find the good match of simulated and observed hydrograph. The overall objective of the study is to evaluate monthly water balance model incorporating optimization of rainfall station weights and physical parameters of the catchment for water resources planning and development, this method will provide valuable information for watershed mangers when selecting rainfall data and a reliable method for parameter estimated without observed data, it will become a new strength for two parameter water balance model to apply further to ungauged catchments.

## 5.2 Model Development

A two parameter monthly water balance model suggested by (Xiong, 1999). Generally, Consist of three main equations.

$E(t)/ EP(t) = C\times \text{Tanh} [P(t)/ EP(t)]$ ( 1)

$Q(t) = S(t-1) + \text{Tanh}\{(S(t-1) +P(t)-E(t)/Sc)\}$ (2)

$S(t) = S(t-1) +P(t)-E(t)-Q(t)$ (11) ( 3)

Where, E(t) – Evapotranspiration Estimation of Model

EP(t) – Pan evaporation

P(t) – Average rainfall

C – Monthly evaporation coefficient

Q(t) – Estimated runoff

S(t-1) – Soil water content at the end of (t-1) month

S(t) - Soil water content at the end of (t) month

For the purpose of estimating accurate values as a model output, following conditions are compulsory to be in the computation process.

**First Condition**; the obtained evapotranspiration E(t) from model must be greater or equal to zero at any given time.

Therefore, $E(t) \geq 0$ (4)

**Second Condition**; the obtained evapotranspiration E(t) from model must be less than or equal to potential evaporation at that specific period.

Therefore, $E(t) \leq EP(t)$ (5)

**Third Condition;** Streamflow estimated by the model must be greater or equal to zero at any time period

Therefore, $Q(t) \geq 0$ (6)

**Forth condition**;

Soil moisture storage of watershed must be non-negative at any time.

$St \geq 0$ (7)

## 5.3 Warm up period

According to literature a warm up period prepare the model to run for an appropriate period of time using value of initial soil water content (S) which has its own influence on monthly streamflow, Q(t), specifically for limited observed data accurate value of soil water content S(o) has special impact on model performance. Particularly, when the used date set is enough long. similarly, here for this study the initial soil water content was selected after five times model runs over the calibration period data set from the year 1393 to 2005. After the five times model run the initial soli water storage value was found 165.06(mm).

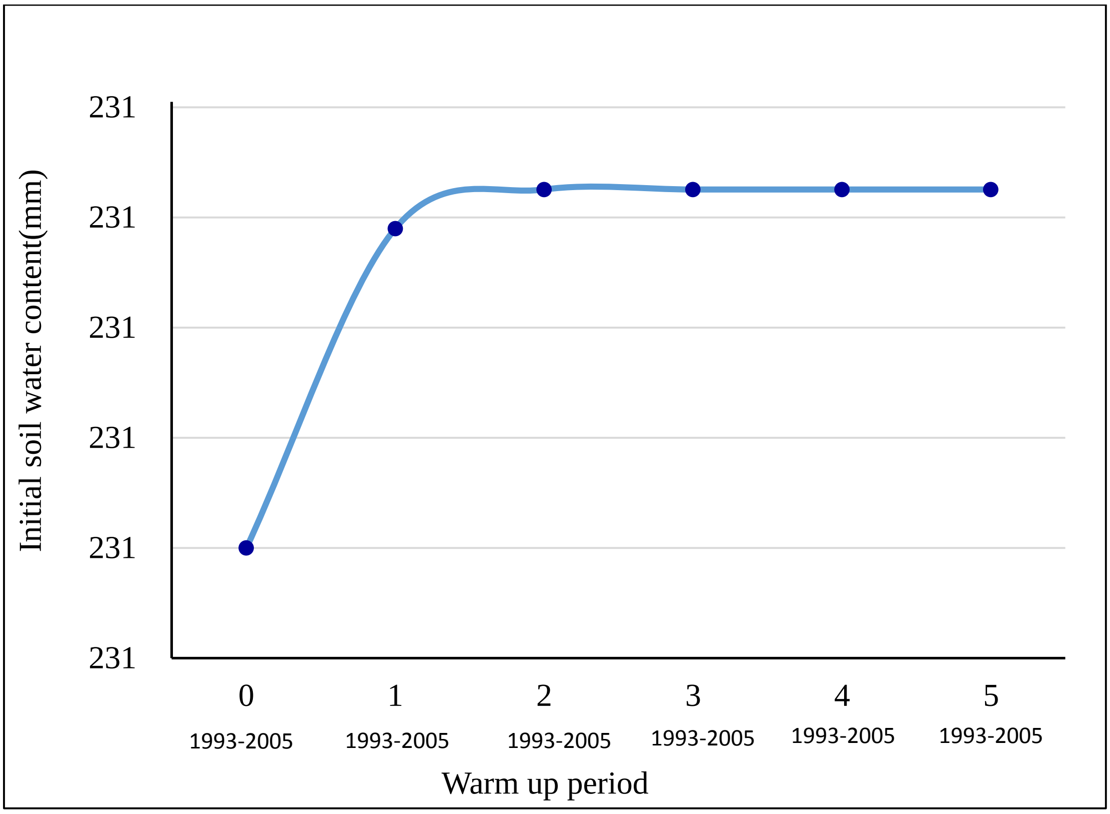


Figure 5-1:Model Warm-up Period for Initial Soil Water Content

## 5.4 Model Calibration and Model Verification (Thiessen Rainfall)

24 years' data were used for model calibration and verification as whole data set which is ranging from (1993-2017) further the total data series is divided in to two separate parts 12 years for calibration ranging from (1393-2005) and 12 years for verification ranging from (2005-2017) for Pittabeddara watershed respectively.

## 5.5 Selection of Objective function

Two parameter monthly water balance model was developed for Pittabeddara catchment. According to literature two objective functions were selected such as Mean ratio of absolute error (MRAE) and Nash-Sutcliffe(NS). considering optimization rules they were used as primary and secondary objective functions. Mean ratio of absolute error (MRAE) which is widely used and proposed by modelers for water resource management because it giving Very good results for all flows high, low and medium flow, means this objective function can match all points of both simulated and observed hydrograph at each point. From other hand, this has performed well for series with having high low variations. Nash-Sutcliffe(NS) which is mostly used for flood management is giving good results for high flow matching. The (MRAE) was found (0.221) and for calibration period and (0.297) for verification period respectively.

The second objective function which matches the peaks of both simulated and observed hydrographs Nash-Sutcliffe was found 80% for calibration period and 65.85% for verification period respectively.

## 5.6 parameter optimization

Parameter optimization was done by Xiong and Guo (1999) in two steps for two parameters monthly water balance model. Both parameters C and Sc were optimized simultaneously using single objective function. Then they keep the parameter c constant. the parameter Sc was optimized respect to second objective function. according to this procedure they in primarily optimized C value using objective function of RE (Relative Error) while they optimized the Sc value with (NS)Nash-Sutcliffe. Here in this study for fining the optimum values of parameter C and Sc for Pittabeddara watershed Excel solver tool was used for parameter optimization, this process was conducted at two different resolutions, such as Coarser and finer search ranges. Trial and error method was used for finding the optimum values of C and Sc. This optimization method contains the following two steps. Firstly, model parameters C and Sc were optimized with (MRAE) objective function in or order to achieve a good simulated runoff volume at a Coarser search range. Secondly, the value of parameters C and Sc were optimized according to (MRAE) objective function in near minimum range for finding the finer optimum values of both parameters respectively.

### 5.6.1 Determination of Global Minimum

According to literature the range of parameter C fluctuates between (0.2 to 1.5) and the parameter Sc rages varies between (300 to 2000). in this study for capturing global minimum of objective function value several trails were attempted while changing C and Sc values. After optimization the value of parameter C was found 1.5 and the value of parameter Sc was found 1700 in both and calibration and verification period respectively and the (MRAE) value was found (0.221) in calibration period and (0.297) in verification period. The Nash-Sutcliffe was found 80% for calibration period and 65.85% for verification period respectively.

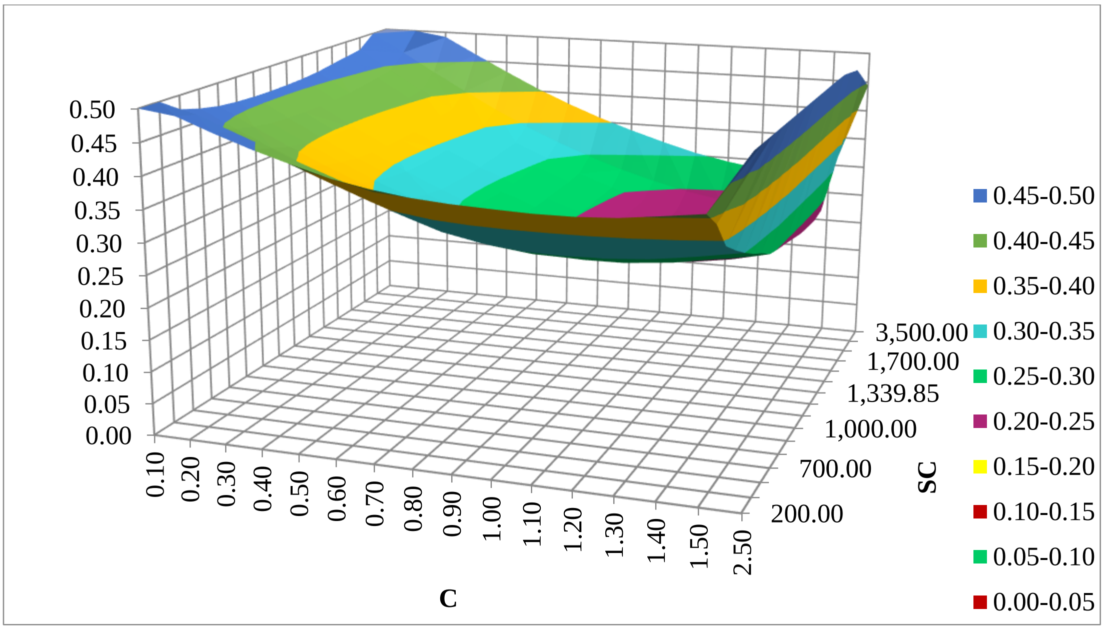


Figure 5-2:Coarser Resolution Surface for Pitabeddara

Table 5-1:Comparison of Model Performance Calibration (Thiessen Rainfall)

| Model Performance | 2 Parameter Monthly Water Balance Model - Calibration |
|---|---|
| C | 1.50 |
| SC | 1700 |
| MRAE - Overall | 0.22 |
| MRAE - High | 0.09 |
| MRAE - Intermediate | 0.05 |
| MRAE - Low | 0.07 |
| Soil Water Storage - Beginning | 230.24 |
| Soil Water Storage - End | 230.24 |
| Maximum Storage | 473.37 |
| Minimum Storage | 163.33 |
| Data Period | 1993-2005 |
| Maximum Flow | 603.91 |
| Minimum Flow | 19.61 |

Table 5-2:Comparison of Model Performance Calibration (Thiessen Rainfall)

| Model Performance | 2 Parameter Monthly Water Balance Model - Verification |
|---|---|
| C | 1.50 |
| SC | 1700.00 |
| MRAE - Overall | 0.31 |
| MRAE - High | 0.14 |
| MRAE - Intermediate | 0.15 |
| MRAE - Low | 0.16 |
| Soil Water Storage - Beginning | 361.29 |
| Soil Water Storage - End | 361.29 |
| Maximum Storage | 473.13 |
| Minimum Storage | 189.85 |
| Data Period | 1993-2005 |
| Maximum Flow | 745.66 |
| Minimum Flow | 27.69 |

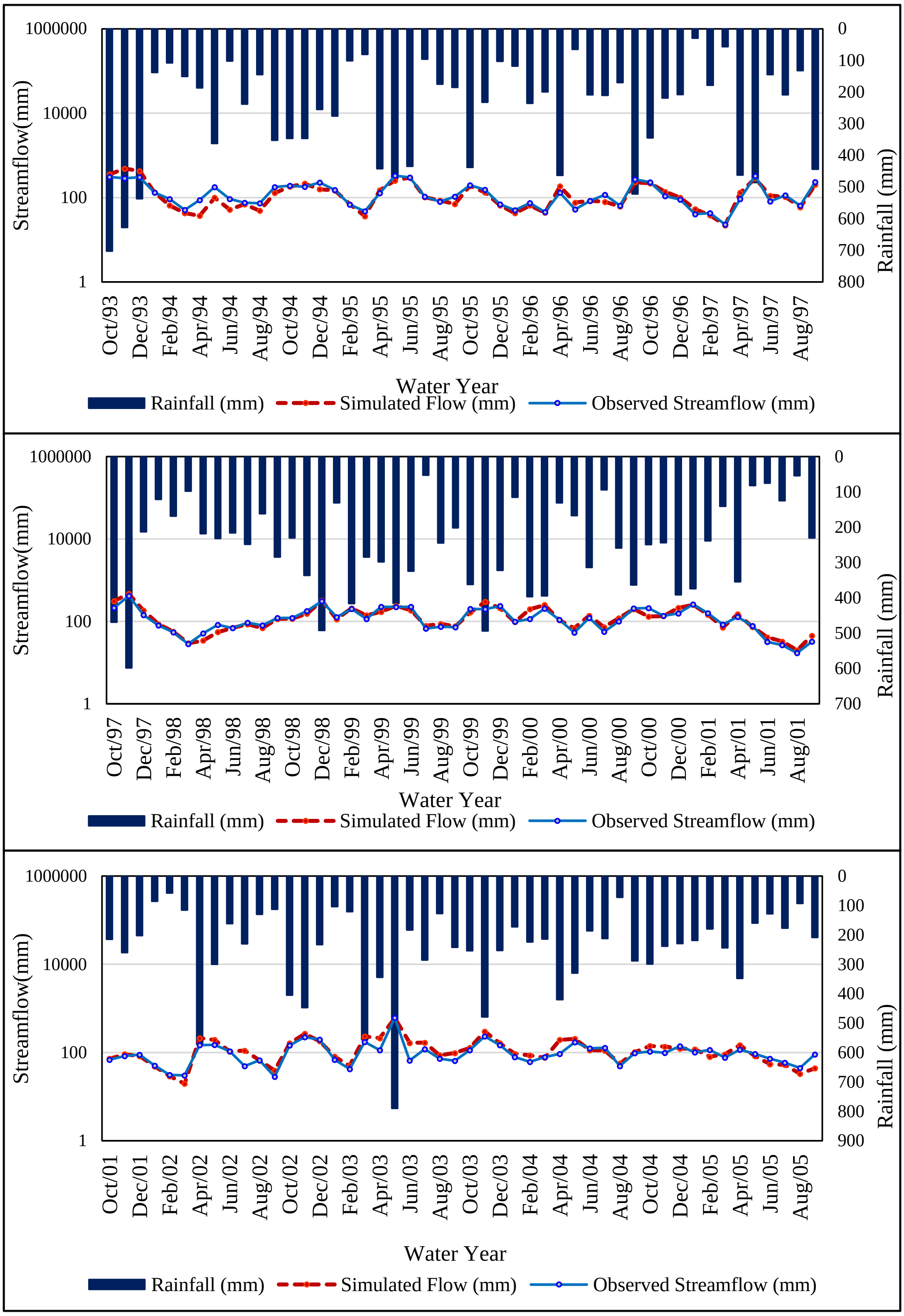


Figure 5-3:Hydrographs from Model calibration -Thiessen rainfall (1993-2005)

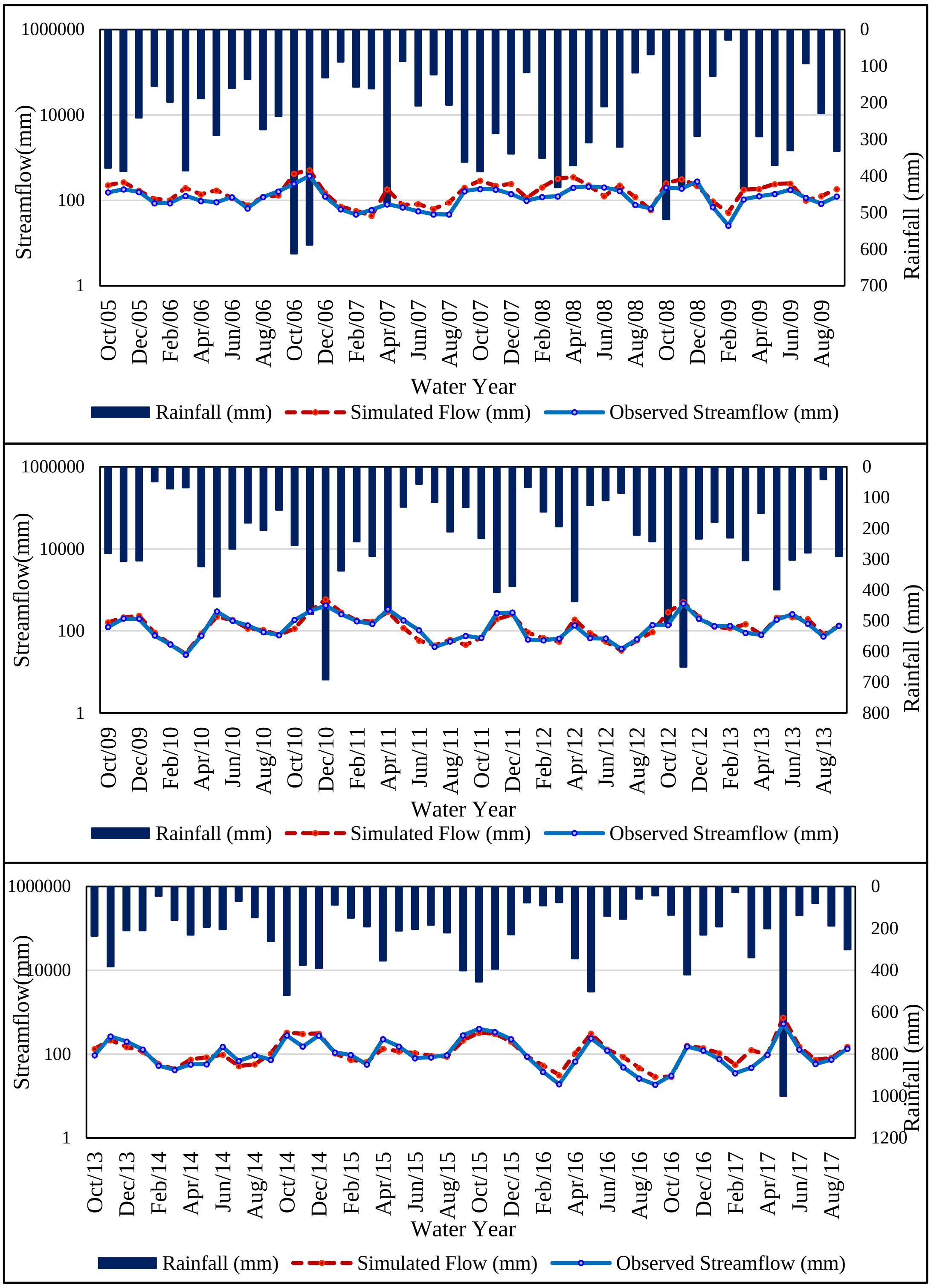


Figure 5-4:Hydrographs from model verification -Thiessen rainfall (2005-2017)

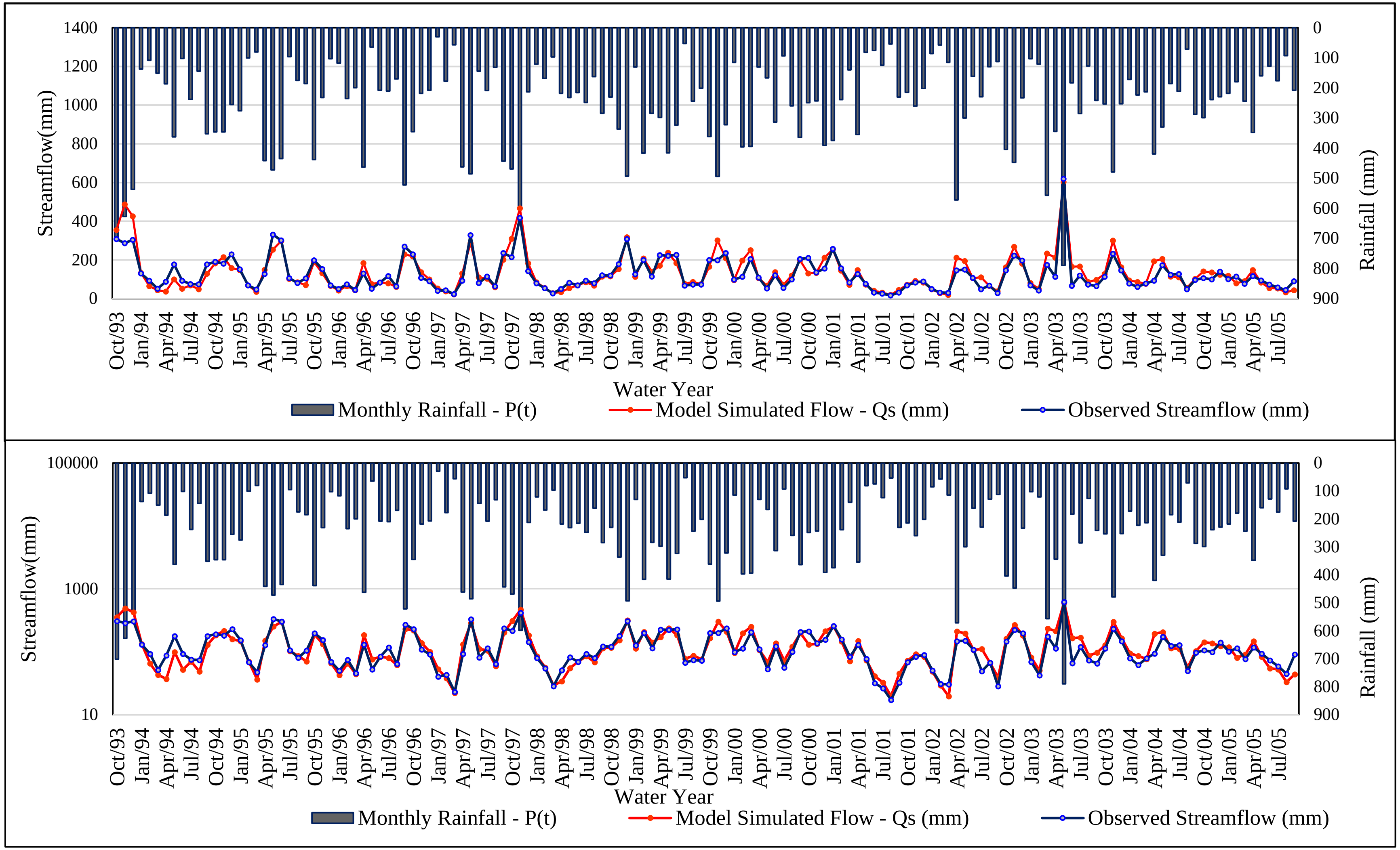


Figure 5-5:Hydrographs from model calibration  (Thiessen rainfall) on both normal and log scale

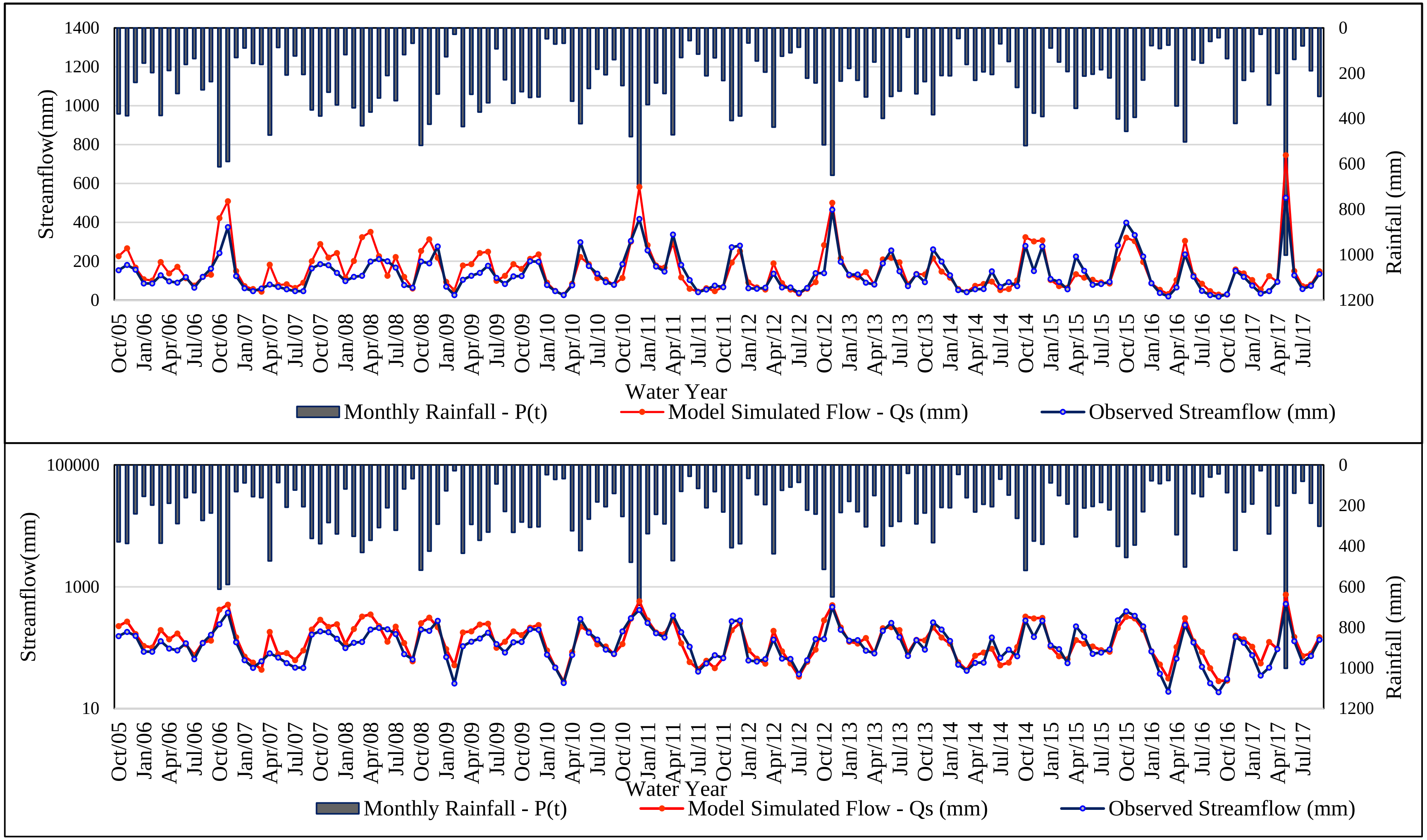


Figure 5-6:Hydrographs from model verification (Thiessen rainfall) on both normal and log scale

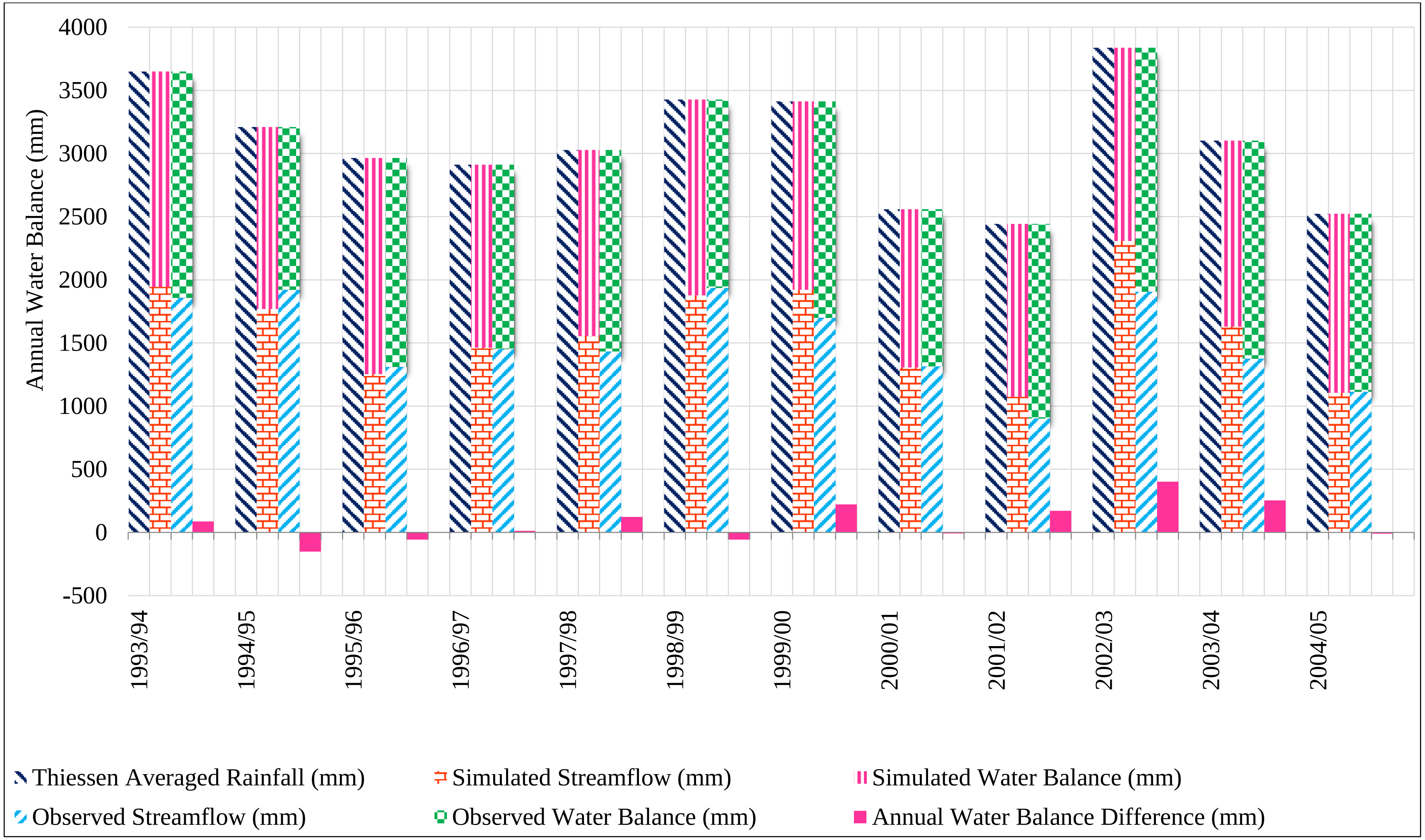


Figure 5-7:Annual Water Balance comparison calibration (Thiessen rainfall)

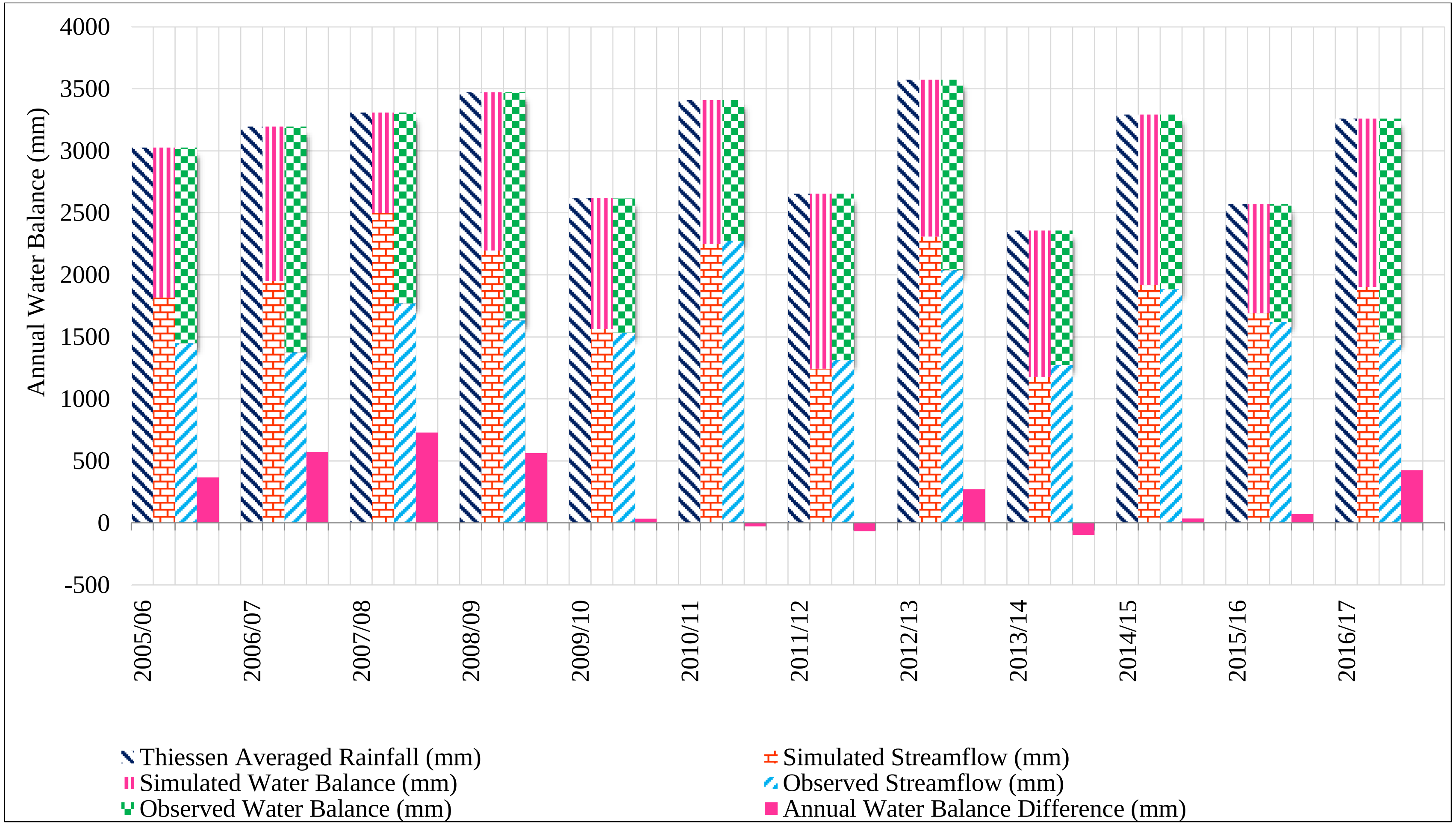


Figure 5-8:Annual Water Balance comparison verification (Thiessen rainfall)

Table 5-3:Water Balance Estimation Calibration Period (Thiessen rainfall)

| Water Year | Thiessen Average Rainfall (mm) | Simulated Streamflow | Simulated Water Balance | Observed Streamflow | Observed Water Balance | Annual Water Balance Difference |
|---|---|---|---|---|---|---|
| 1993/94 | 3650.2 | 1943.8 | 1706.4 | 1857.4 | 1792.8 | 86.37 |
| 1994/95 | 3210.4 | 1768.0 | 1442.5 | 1920.8 | 1289.6 | (152.88) |
| 1995/96 | 2964.1 | 1252.7 | 1711.4 | 1309.3 | 1654.8 | (56.56) |
| 1996/97 | 2912.7 | 1462.9 | 1449.8 | 1450.8 | 1461.9 | 12.11 |
| 1997/98 | 3028.7 | 1554.9 | 1473.8 | 1431.8 | 1596.9 | 123.11 |
| 1998/99 | 3428.3 | 1877.1 | 1551.3 | 1934.7 | 1493.6 | (57.64) |
| 1999/00 | 3412.6 | 1921.0 | 1491.6 | 1698.0 | 1714.6 | 222.94 |
| 2000/01 | 2558.9 | 1306.4 | 1252.4 | 1315.3 | 1243.6 | (8.84) |
| 2001/02 | 2442.3 | 1072.7 | 1369.5 | 901.6 | 1540.6 | 171.10 |
| 2002/03 | 3837.4 | 2307.9 | 1529.5 | 1907.2 | 1930.2 | 400.68 |
| 2003/04 | 3101.2 | 1629.3 | 1471.9 | 1376.5 | 1724.8 | 252.88 |
| 2004/05 | 2522.3 | 1104.4 | 1418.0 | 1114.4 | 1408.0 | (9.99) |

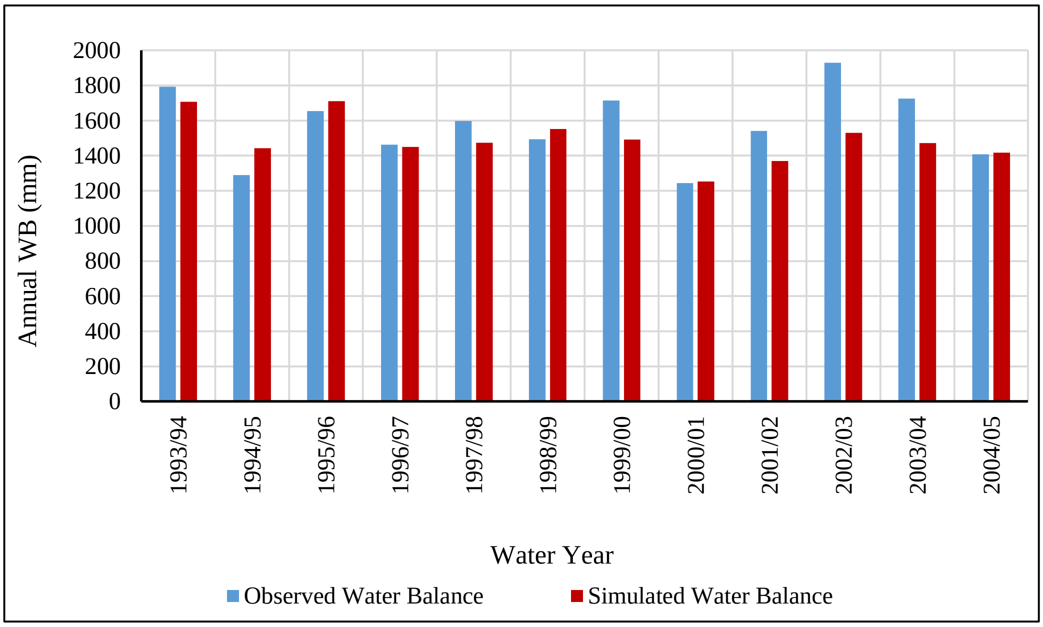


Figure 5-9:Water Balance for Calibration period (Thiessen rainfall)

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Table 5-4:Water Balance Estimation Verification Period (Thiessen rainfall)

| Water Year | Thiessen Average Rainfall (mm) | Simulated Streamflow | Simulated Water Balance | Observed Streamflow | Observed Water Balance | Annual Water Balance Difference |
|---|---|---|---|---|---|---|
| 2005/06 | 3027.12 | 1816.45 | 1210.66 | 1449.11 | 1578.01 | 367.34 |
| 2006/07 | 3195.11 | 1948.16 | 1246.96 | 1375.10 | 1820.01 | 573.06 |
| 2007/08 | 3308.08 | 2498.86 | 809.23 | 1771.02 | 1537.06 | 727.84 |
| 2008/09 | 3472.42 | 2197.30 | 1275.12 | 1632.87 | 1839.54 | 564.42 |
| 2009/10 | 2619.37 | 1565.52 | 1053.85 | 1532.65 | 1086.72 | 32.87 |
| 2010/11 | 3410.40 | 2248.88 | 1161.53 | 2276.83 | 1133.58 | (27.95) |
| 2011/12 | 2656.40 | 1243.80 | 1412.60 | 1312.16 | 1344.24 | (68.36) |
| 2012/13 | 3573.07 | 2309.87 | 1263.20 | 2037.11 | 1535.96 | 272.76 |
| 2013/14 | 2358.16 | 1176.59 | 1181.57 | 1273.22 | 1084.94 | (96.62) |
| 2014/15 | 3293.25 | 1917.58 | 1375.67 | 1882.08 | 1411.17 | 35.50 |
| 2015/16 | 2571.76 | 1691.31 | 880.45 | 1619.32 | 952.44 | 71.98 |
| 2016/17 | 3260.05 | 1902.05 | 1358.00 | 1476.59 | 1783.46 | 425.45 |

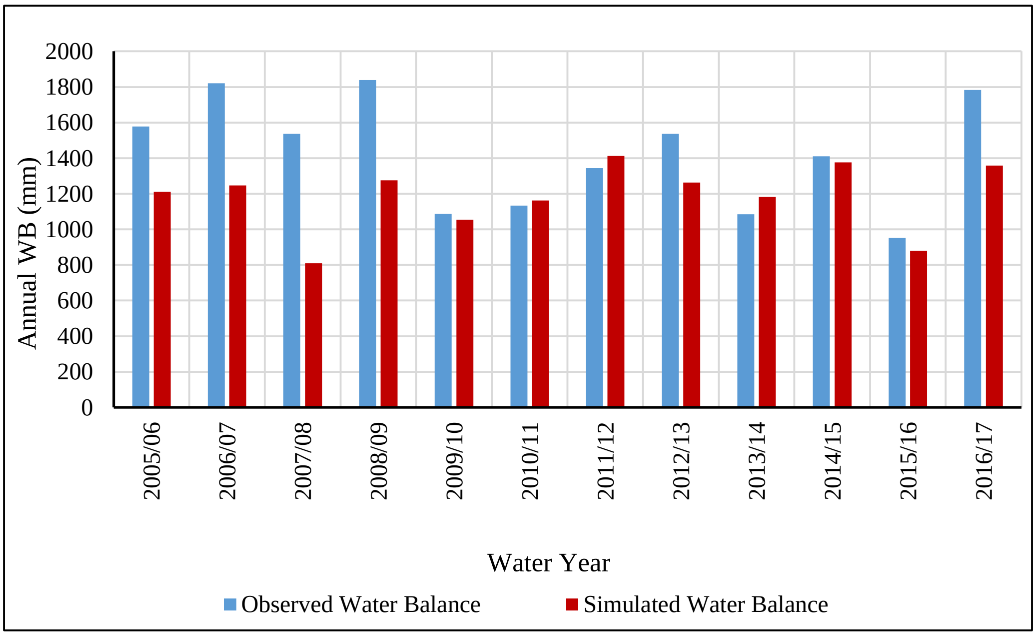


Figure 5-10:Water Balance for Verification period (Thiessen rainfall)

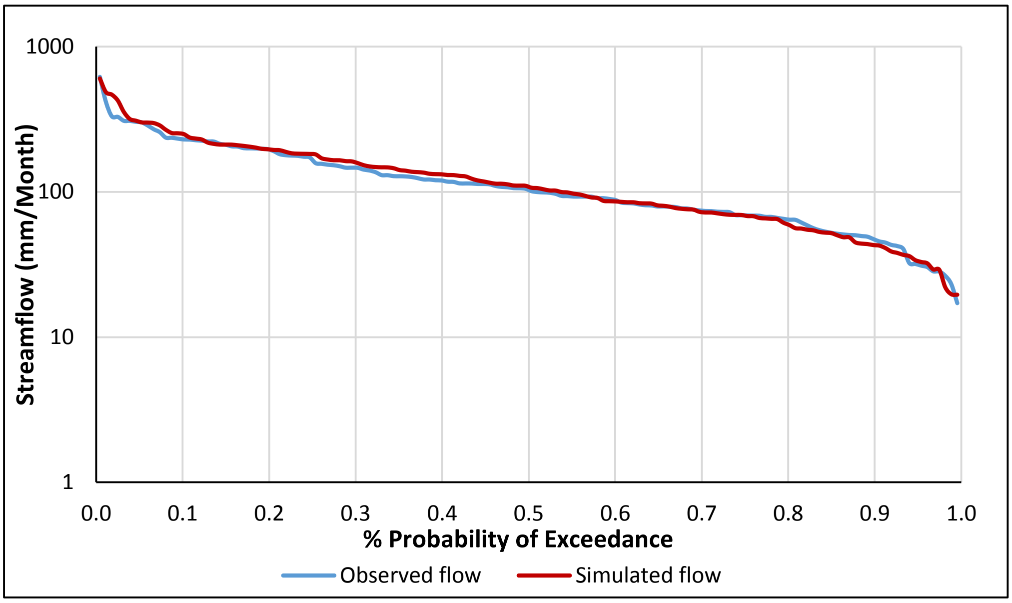


Figure 5-11:Flow duration curve – calibration period (Thiessen rainfall)

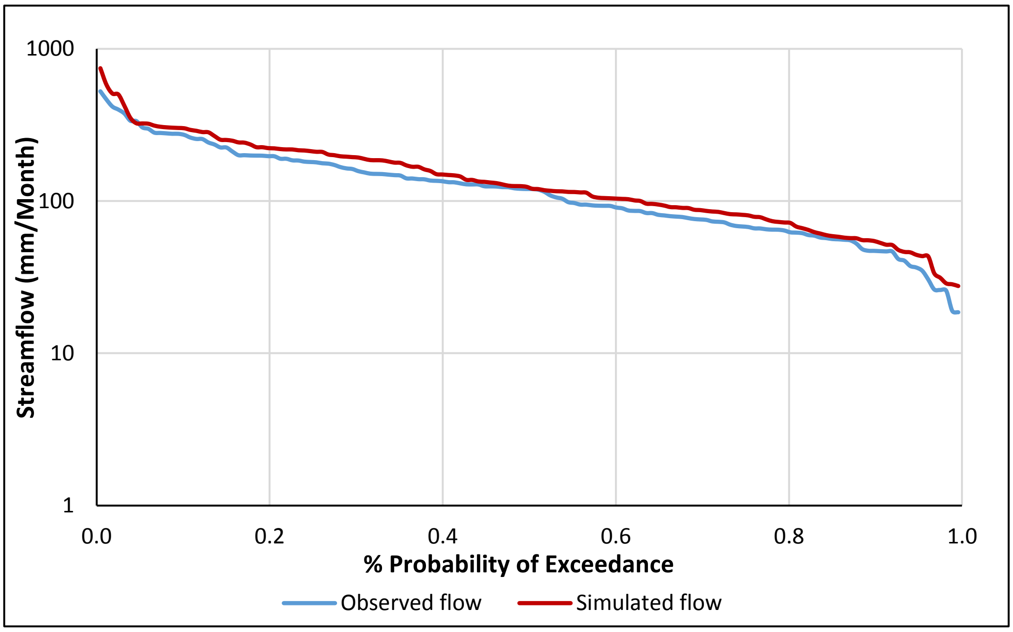


Figure 5-12:Flow duration curve – Verification  period (Thiessen rainfall)

## 5.7 Model Calibration and Model Verification (Optimized Rainfall)

There are various methods developed over the years for areal estimation of rainfall such as Thiessen polygon, arithmetic average method, Isohyetal method, grid method etc. Whereas accuracy of these methods is not verified with the observed streamflow. Musiake and Wijesekera (1990) used the method of optimizing rainfall station weights for incorporation of rainfall spatial variability by comparing it with the observed streamflow.in this method first the tank parameters were optimized while spatial variation of rainfall was assumed, then station weights were optimized while keeping the tank parameters constant (Musiake & Wijesekera, 1990). Same method was used here first the parameters values of C and Sc of two parameters monthly water balance model was optimized by using Thiessen rainfall in the model then station weights were optimized keeping the two parameters constant. The optimized station weights are mentioned in table 5- 11 as below.

Figure 5-13:Optimized station weights

| Rain gauging stations | Optimized weights |
|---|---:|
| Deniyaya | 0.12 |
| Dampahala | 0.22 |
| Kirama | 0.32 |
| Goluwawatta | 0.12 |
| Anningkanda | 0.22 |
| total | 1.0 |

Table 5-5:Comparison of Model Performance Calibration (Optimized Rainfall)

| Model Performance Optimized Rainfall | 2 Parameter Monthly Water Balance Model - Calibration |
|---|---|
| C | 1.30 |
| SC | 1600.00 |
| MRAE - Overall | 0.22 |
| MRAE - High | 0.08 |
| MRAE - Intermediate | 0.06 |
| MRAE - Low | 0.09 |
| Soil Water Storage - Beginning | 213.05 |
| Soil Water Storage - End | 213.05 |
| Maximum Storage | 441.00 |
| Minimum Storage | 157.91 |
| Data Period | 1993-2017 |
| Maximum Flow | 456.96 |
| Minimum Flow | 19.62 |

Table 5-6:Comparison of Model Performance Verification (Optimized Rainfall)

| Model Performance Optimized Rainfall | 2 Parameter Monthly Water Balance Model – Verification |
|---|---|
| C | 1.30 |
| SC | 1600.00 |
| MRAE - Overall | 0.27 |
| MRAE - High | 0.05 |
| MRAE - Intermediate | 0.08 |
| MRAE - Low | 0.15 |
| Soil Water Storage - Beginning | 326.70 |
| Soil Water Storage - End | 326.70 |
| Maximum Storage | 445.26 |
| Minimum Storage | 182.62 |
| Data Period | 1993-2017 |
| Maximum Flow | 620.97 |
| Minimum Flow | 27.41 |

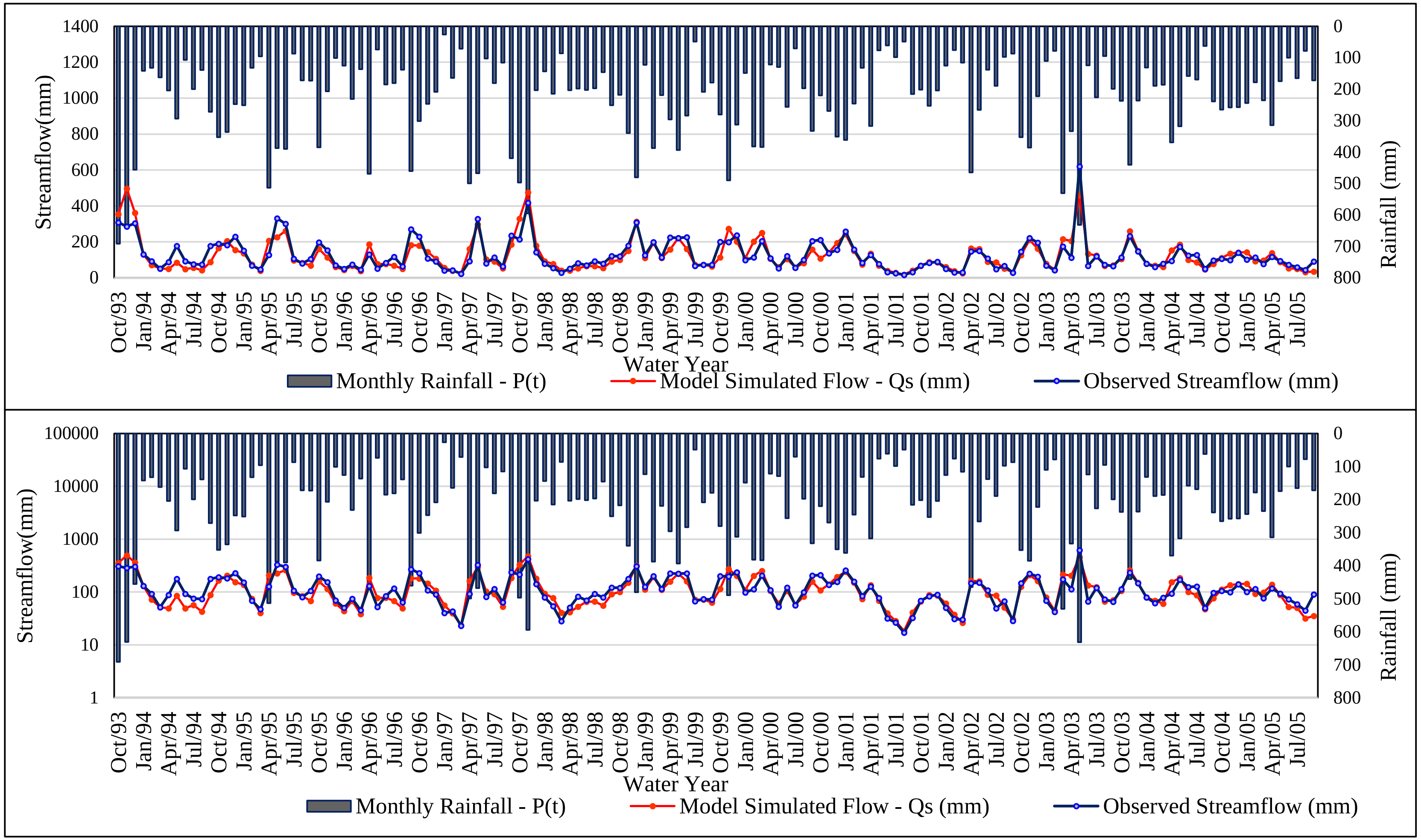


Figure 5-14:Hydrographs from model calibration using Optimized rainfall on both normal and log scale

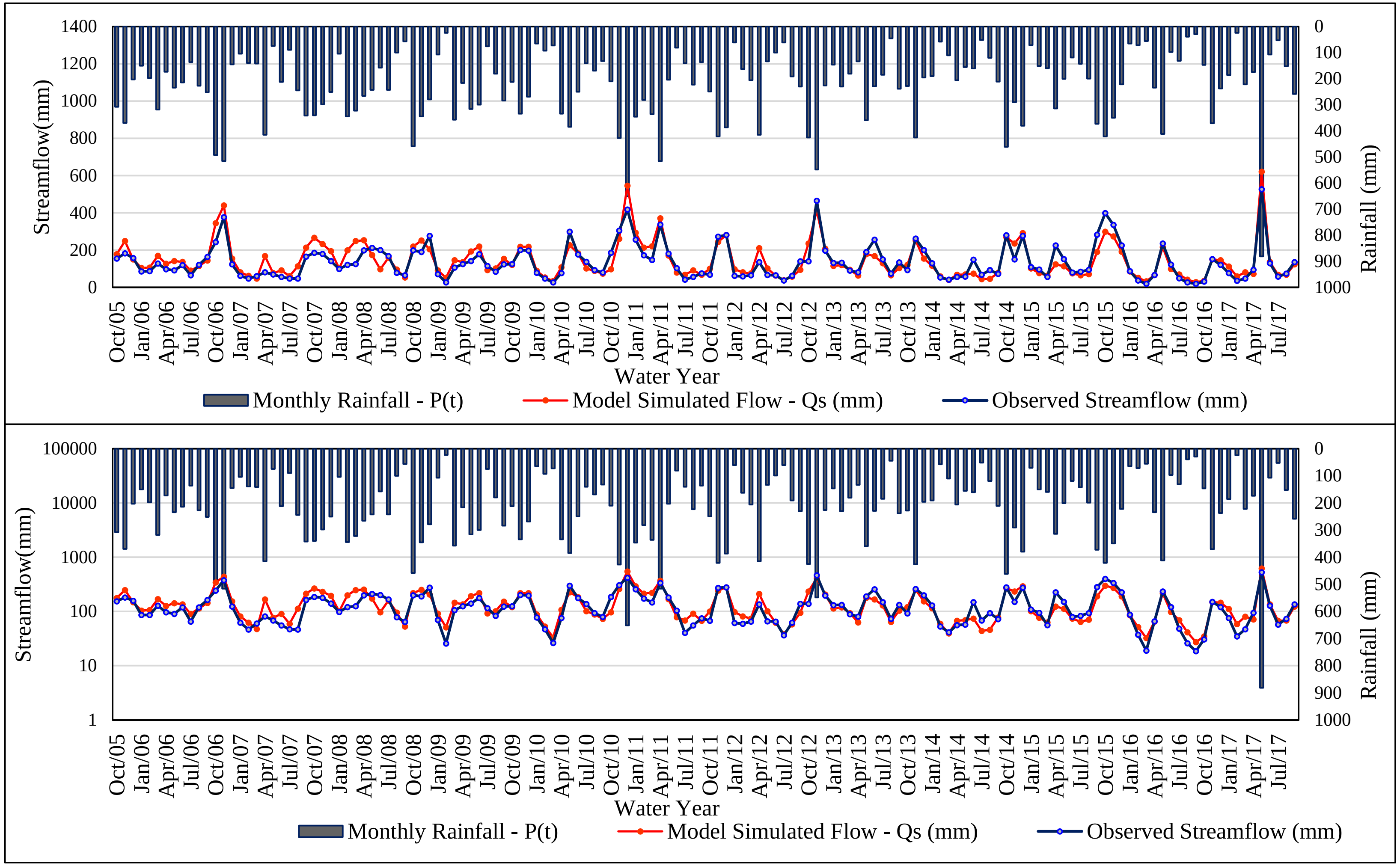


Figure 5-15: Hydrographs from model Verification using Optimized rainfall on both normal and log scale

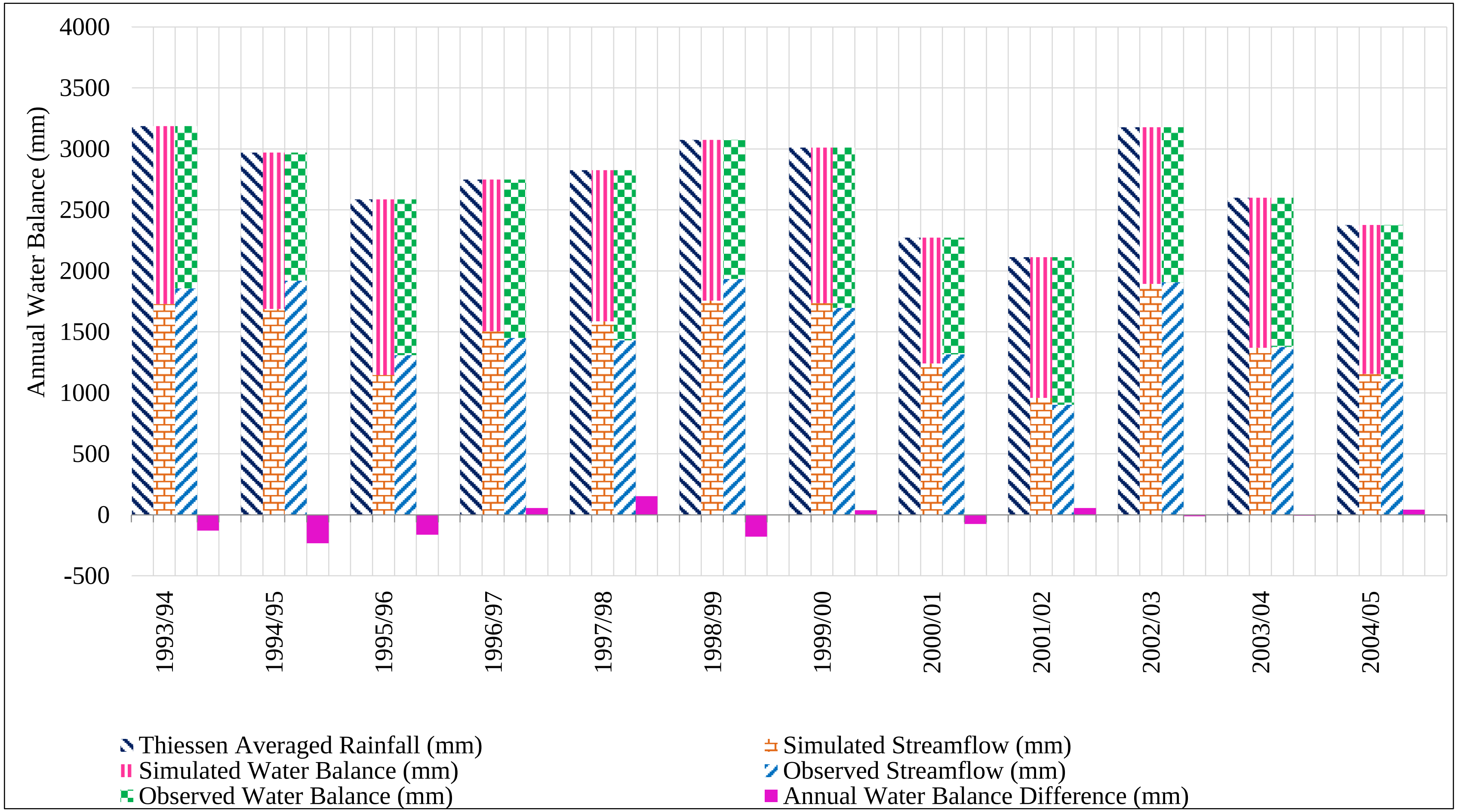


Figure 5-16:Annual Water Balance Comparison Calibration (Optimized Rainfall)

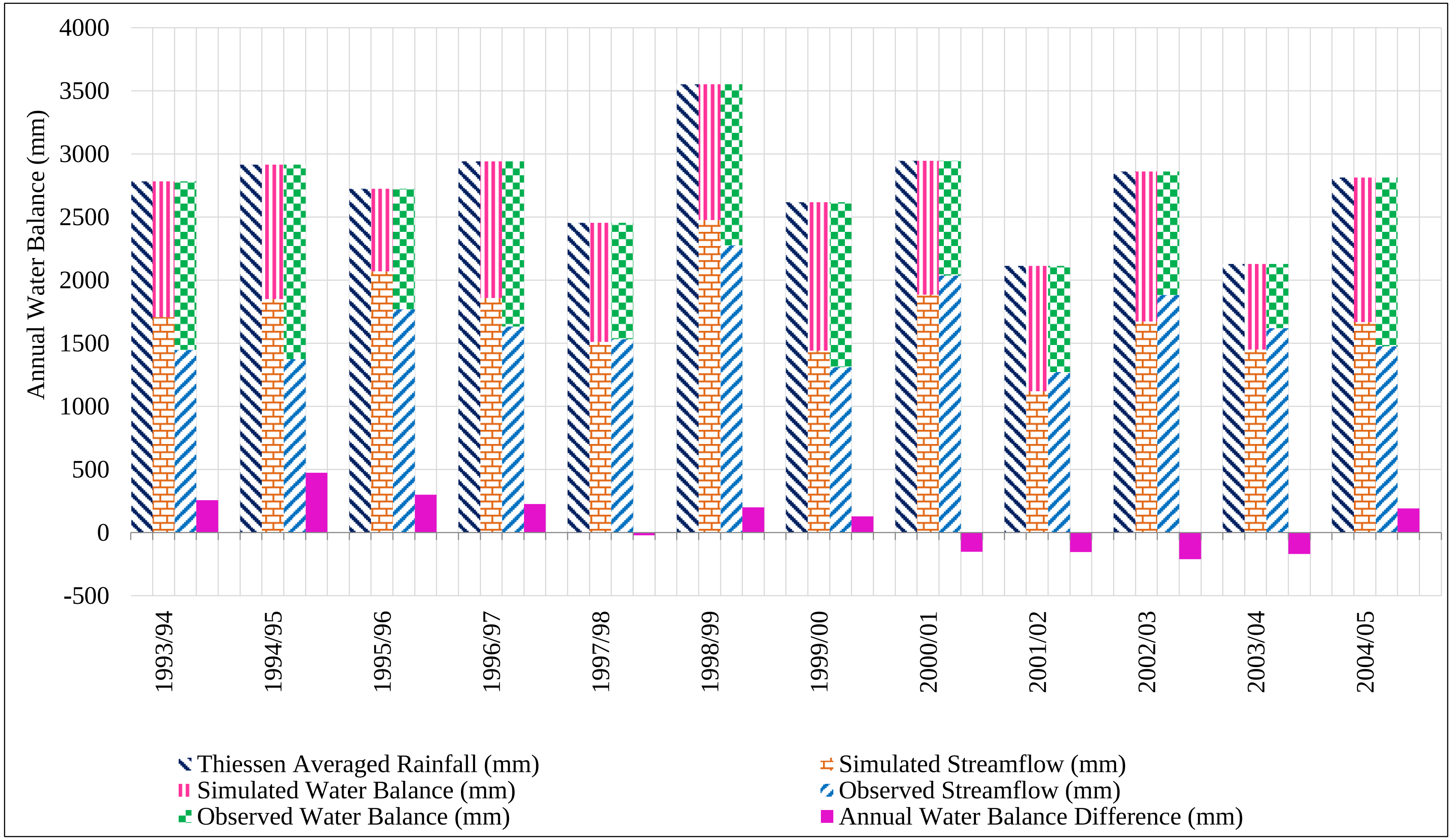


Figure 5-17:Annual Water Balance Comparison Verification (Optimized Rainfall)

Table 5-7:Water Balance Estimation Calibration Period (Optimized Rainfall)

| Water Year | Thiessen Average Rainfall (mm) | Simulated Streamflow | Simulated Water Balance | Observed Streamflow | Observed Water Balance | Annual Water Balance Difference |
|---|---|---|---|---|---|---|
| 1993/94 | 3188.06 | 1727.96 | 1460.10 | 1857.40 | 1330.66 | (129.44) |
| 1994/95 | 2970.21 | 1688.59 | 1281.62 | 1920.85 | 1049.36 | (232.26) |
| 1995/96 | 2586.87 | 1145.87 | 1441.00 | 1309.30 | 1277.57 | (163.43) |
| 1996/97 | 2750.18 | 1506.36 | 1243.82 | 1450.79 | 1299.39 | 55.57 |
| 1997/98 | 2826.23 | 1585.90 | 1240.33 | 1431.83 | 1394.40 | 154.07 |
| 1998/99 | 3074.77 | 1755.80 | 1318.97 | 1934.71 | 1140.05 | (178.91) |
| 1999/00 | 3011.76 | 1735.76 | 1276.00 | 1698.03 | 1313.73 | 37.72 |
| 2000/01 | 2273.34 | 1241.06 | 1032.28 | 1315.29 | 958.05 | (74.23) |
| 2001/02 | 2111.69 | 958.21 | 1153.48 | 901.64 | 1210.05 | 56.57 |
| 2002/03 | 3178.06 | 1894.67 | 1283.39 | 1907.18 | 1270.87 | (12.51) |
| 2003/04 | 2601.23 | 1369.77 | 1231.47 | 1376.47 | 1224.76 | (6.70) |
| 2004/05 | 2376.82 | 1155.61 | 1221.21 | 1114.36 | 1262.45 | 41.24 |

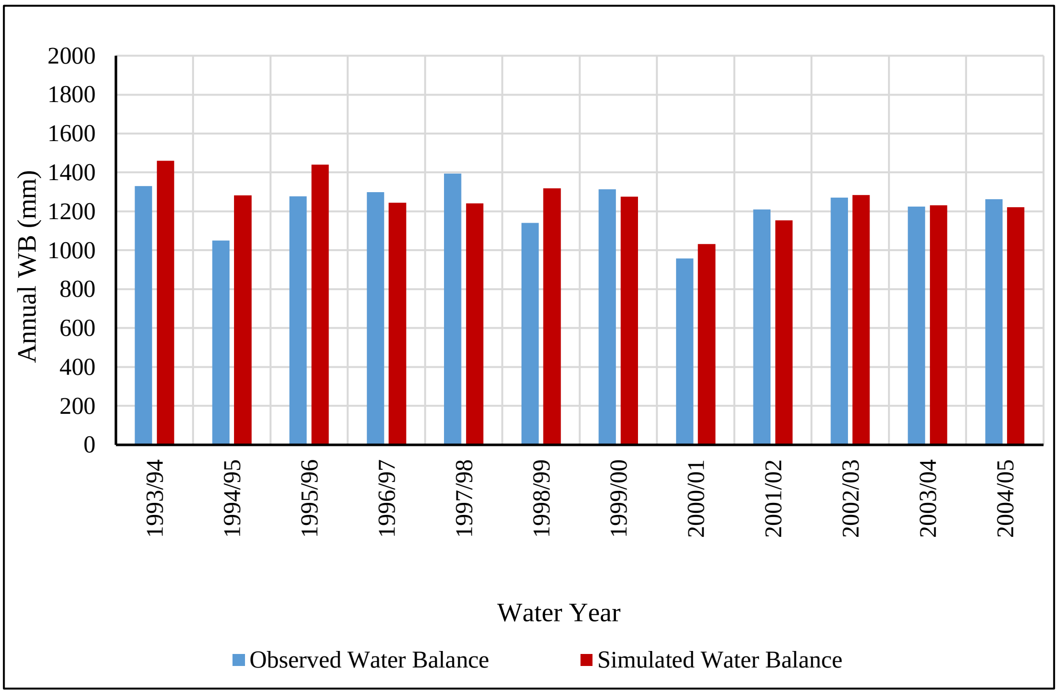


Figure 5-18:Annual Water Balance Comparison Calibration (Optimized Rainfall)

Table 5-8:Water Balance Estimation Verification Period (Optimized Rainfall)

| Water Year | Thiessen Average Rainfall (mm) | Simulated Streamflow | Simulated Water Balance | Observed Streamflow | Observed Water Balance | Annual Water Balance Difference |
|---|---|---|---|---|---|---|
| 1993/94 | 2783.51 | 1706.21 | 1077.30 | 1449.11 | 1334.41 | 257.10 |
| 1994/95 | 2916.86 | 1850.49 | 1066.37 | 1375.10 | 1541.76 | 475.39 |
| 1995/96 | 2724.28 | 2070.99 | 653.29 | 1771.02 | 953.26 | 299.97 |
| 1996/97 | 2942.72 | 1858.46 | 1084.25 | 1632.87 | 1309.85 | 225.59 |
| 1997/98 | 2455.90 | 1512.23 | 943.68 | 1532.65 | 923.26 | (20.42) |
| 1998/99 | 3553.42 | 2476.83 | 1076.60 | 2276.83 | 1276.59 | 200.00 |
| 1999/00 | 2618.04 | 1441.78 | 1176.26 | 1312.16 | 1305.88 | 129.62 |
| 2000/01 | 2947.30 | 1885.99 | 1061.31 | 2037.11 | 910.19 | (151.12) |
| 2001/02 | 2113.79 | 1119.29 | 994.50 | 1273.22 | 840.57 | (153.93) |
| 2002/03 | 2862.44 | 1671.84 | 1190.59 | 1882.08 | 980.36 | (210.23) |
| 2003/04 | 2129.35 | 1451.16 | 678.18 | 1619.32 | 510.03 | (168.16) |
| 2004/05 | 2814.20 | 1668.96 | 1145.24 | 1476.59 | 1337.61 | 192.36 |

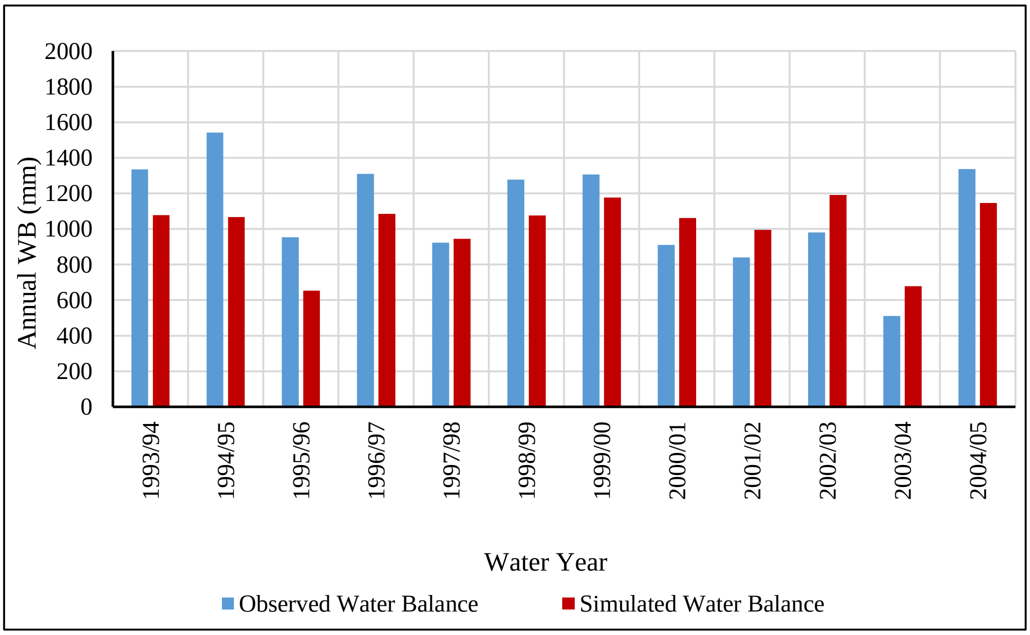


Figure 5-19:Annual Water Balance Comparison Verification (Optimized Rainfall)

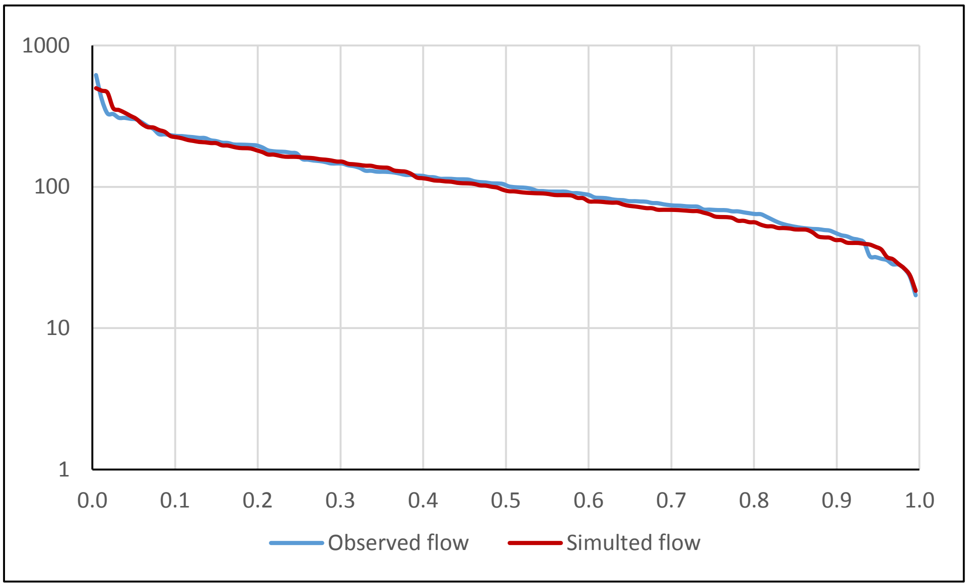


Figure 5-20:Flow duration curve – Calibration period (Optimized rainfall)

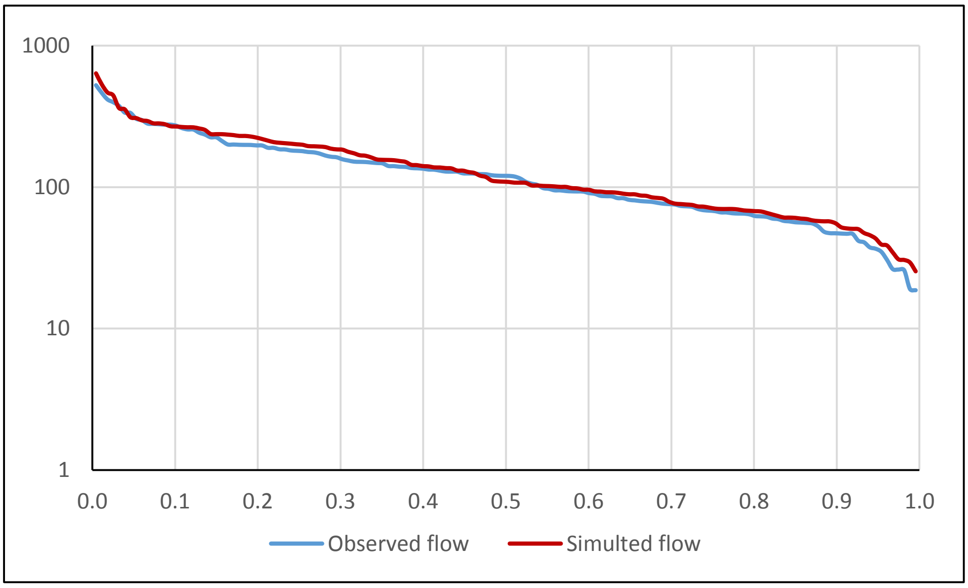


Figure 5-21:Flow duration curve – Verification period (Optimized rainfall)

## 5.8 Model Calibration and Model Verification with two parameters and station weights and optimization

Musiake and Wijesekera (1990) used the method of optimizing rainfall station weights for incorporation of rainfall spatial variability by comparing it with the observed streamflow.in this method first the tank parameters were optimized while spatial variation of rainfall was assumed, then station weights were optimized while keeping the tank parameters constant (Musiake & Wijesekera, 1990). Then they optimized both parameters of tank model and station weights simultaneously. Same method applied here in this study both the two parameters values of C and Sc of two parameter monthly water balance model and station weights of five rain gauges were optimized at the same time using Excel Solver tool. The optimization summary table is below

Table 5-9:Two parameters and station weights optimization

| | |
|---|---|
| C | 1.41 |
| Sc | 1550 |
| Deniyaya | 0.27 |
| Dampahala | 0.20 |
| Kirama | 0.26 |
| Goluwawatta | 0.17 |
| Anningkanda | 0.10 |

Table 5-10:Comparison of Model Performance Calibration with two parameter and station weights

| Model Performance with two parameters and station weights | 2 Parameter Monthly Water Balance Model - Calibration |
|---|---|
| C | 1.41 |
| SC | 1550 |
| MRAE - Overall | 0.19 |
| MRAE - High | 0.06 |
| MRAE - Intermediate | 0.08 |
| MRAE - Low | 0.10 |
| Soil Water Storage - Beginning | 211.47 |
| Soil Water Storage - End | 211.47 |
| Maximum Storage | 427.40 |
| Minimum Storage | 161.89 |
| Data Period | 1993-2005 |
| Maximum Flow | 444.96 |
| Minimum Flow | 21.63 |

Table 5-11:Comparison of Model Performance Verification with two parameter and station weights

| Model Performance | 2 Parameter Monthly Water Balance Model – Verification |
|---|---|
| C | 1.41 |
| SC | 1550 |
| MRAE - Overall | 0.26 |
| MRAE - High | 0.06 |
| MRAE - Intermediate | 0.08 |
| MRAE - Low | 0.12 |
| Soil Water Storage - Beginning | 316.95 |
| Soil Water Storage - End | 316.95 |
| Maximum Storage | 431.58 |
| Minimum Storage | 179.43 |
| Data Period | 2005-2017 |
| Maximum Flow | 689.74 |
| Minimum Flow | 27.45 |

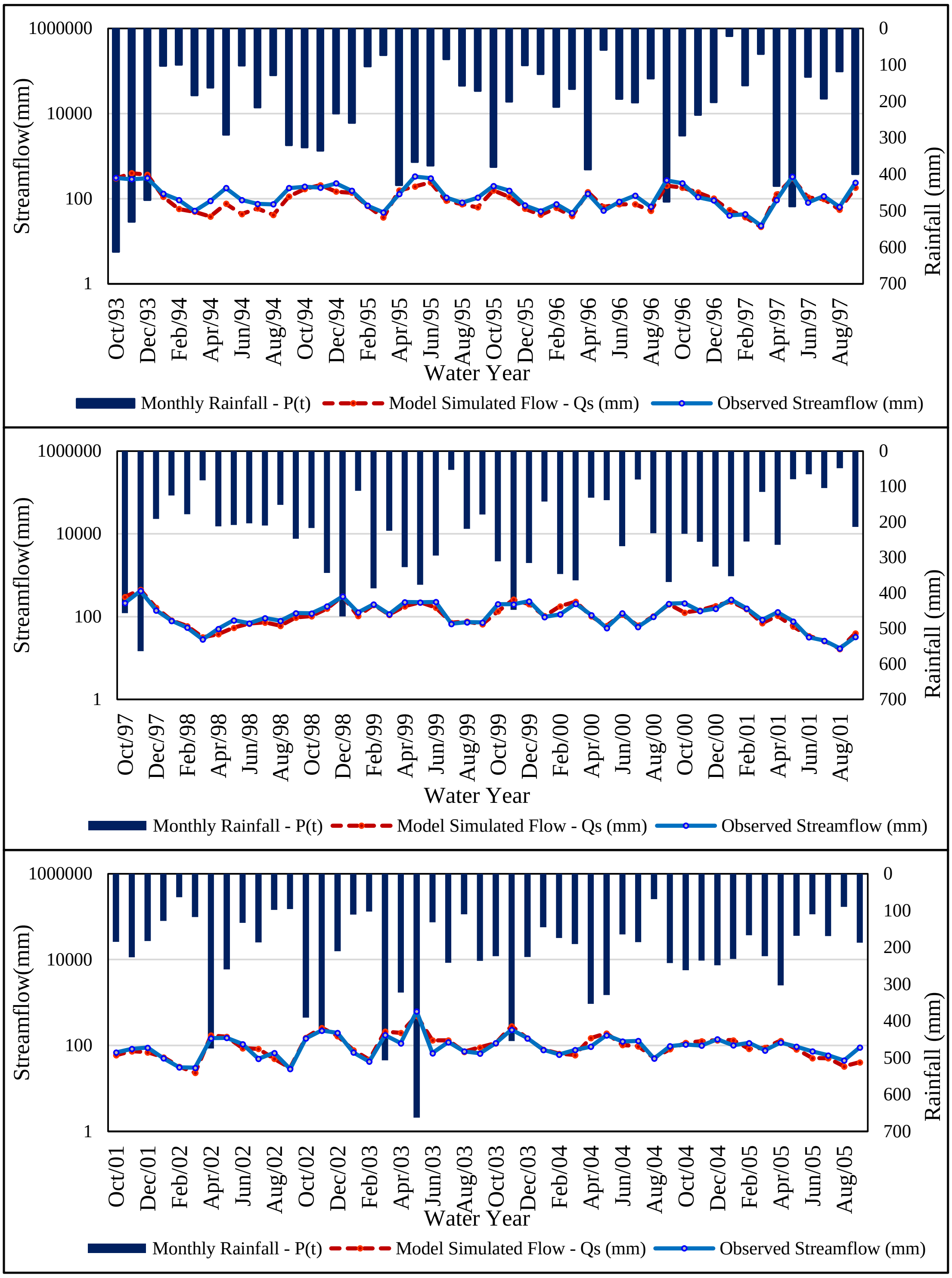


Table 5-12:Hydrographs from Model calibration –two parameter & station weights optimization (1993-2005)

Table 5-13:Water Balance Estimation Calibration Period two parameters- station weights

| Water Year | Thiessen Average Rainfall (mm) | Simulated Streamflow | Simulated Water Balance | Observed Streamflow | Observed Water Balance | Annual Water Balance Difference |
|---|---|---|---|---|---|---|
| 1993/94 | 3222.28 | 1650.56 | 1571.72 | 1857.40 | 1364.88 | (206.84) |
| 1994/95 | 2919.37 | 1578.69 | 1340.68 | 1920.85 | 998.53 | (342.16) |
| 1995/96 | 2645.07 | 1072.77 | 1572.30 | 1309.30 | 1335.77 | (236.53) |
| 1996/97 | 2744.23 | 1397.75 | 1346.48 | 1450.79 | 1293.44 | (53.04) |
| 1997/98 | 2830.47 | 1469.96 | 1360.51 | 1431.83 | 1398.64 | 38.13 |
| 1998/99 | 3200.08 | 1757.73 | 1442.35 | 1934.71 | 1265.37 | (176.99) |
| 1999/00 | 3145.87 | 1743.51 | 1402.35 | 1698.03 | 1447.83 | 45.48 |
| 2000/01 | 2314.34 | 1183.17 | 1131.17 | 1315.29 | 999.05 | (132.12) |
| 2001/02 | 2155.34 | 891.93 | 1263.41 | 901.64 | 1253.69 | (9.71) |
| 2002/03 | 3457.27 | 2024.76 | 1432.51 | 1907.18 | 1550.09 | 117.58 |
| 2003/04 | 2762.45 | 1416.69 | 1345.76 | 1376.47 | 1385.98 | 40.22 |
| 2004/05 | 2398.81 | 1063.11 | 1335.70 | 1114.36 | 1284.45 | (51.25) |

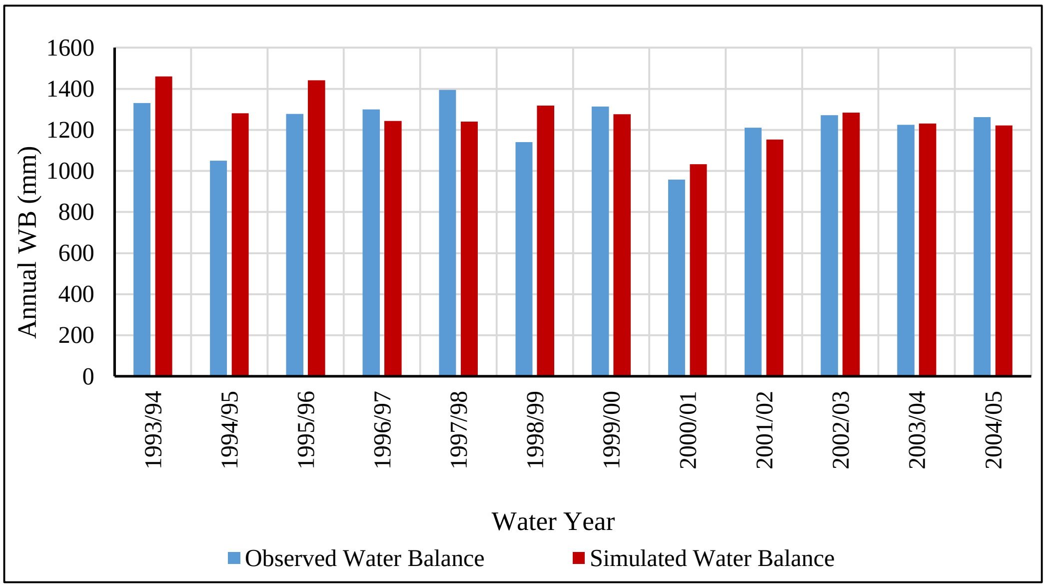


Figure 5-22:Annual Water Balance Comparison calibration two parameter- station weights

Table 5-14:Water Balance Estimation Verification Period two parameters- station weights

| Water Year | Thiessen Average Rainfall (mm) | Simulated Streamflow | Simulated Water Balance | Observed Streamflow | Observed Water Balance | Annual Water Balance Difference |
|---|---|---|---|---|---|---|
| 1993/94 | 2858.22 | 1376.39 | 1481.82 | 1449.11 | 1409.11 | (72.72) |
| 1994/95 | 3050.62 | 1886.63 | 1163.99 | 1375.10 | 1675.52 | 511.53 |
| 1995/96 | 2934.68 | 2211.56 | 723.13 | 1771.02 | 1163.66 | 440.53 |
| 1996/97 | 3118.40 | 1931.39 | 1187.01 | 1632.87 | 1485.52 | 298.52 |
| 1997/98 | 2451.93 | 1453.06 | 998.87 | 1532.65 | 919.28 | (79.59) |
| 1998/99 | 3444.05 | 2301.85 | 1142.20 | 2276.83 | 1167.22 | 25.03 |
| 1999/00 | 2660.34 | 1363.16 | 1297.18 | 1312.16 | 1348.18 | 51.01 |
| 2000/01 | 3076.16 | 1934.19 | 1141.97 | 2037.11 | 1039.05 | (102.93) |
| 2001/02 | 2152.11 | 1059.69 | 1092.43 | 1273.22 | 878.90 | (213.53) |
| 2002/03 | 3094.34 | 1781.33 | 1313.00 | 1882.08 | 1212.26 | (100.74) |
| 2003/04 | 2245.91 | 1476.42 | 769.50 | 1619.32 | 626.59 | (142.90) |
| 2004/05 | 2936.60 | 1698.72 | 1237.87 | 1476.59 | 1460.01 | 222.13 |

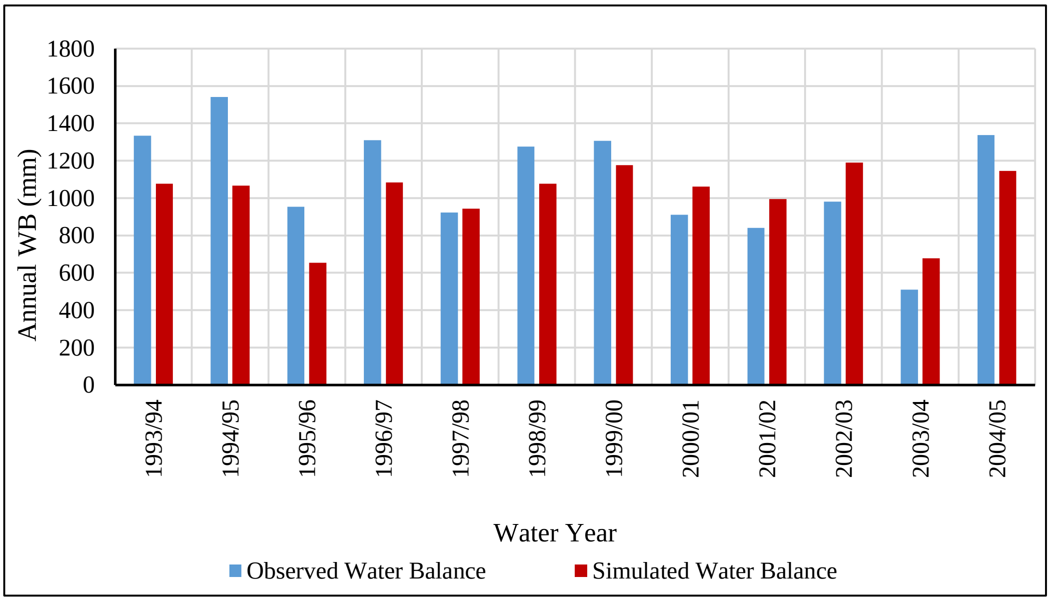


Figure 5-23:Annual Water Balance Comparison two parameter verification two parameter - station weights

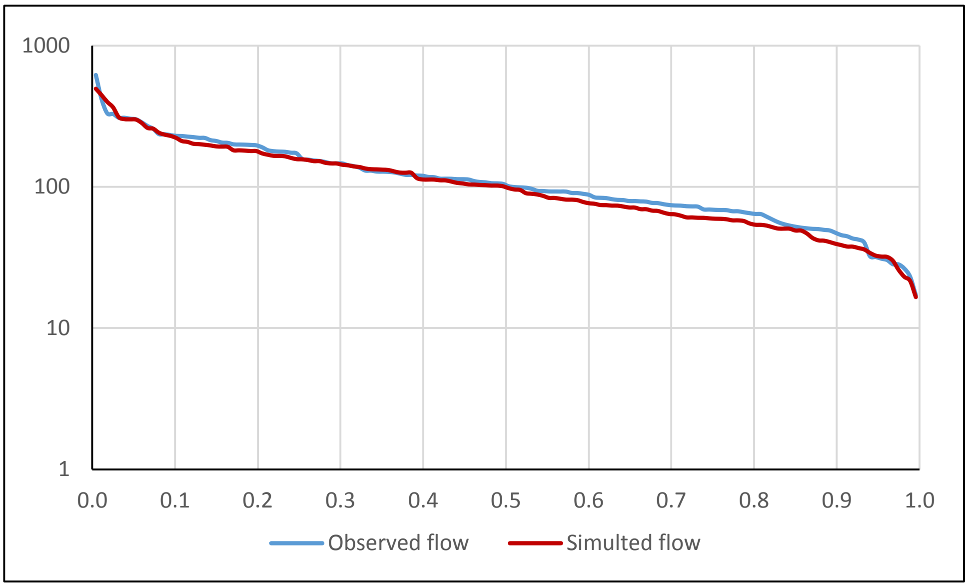


Figure 5-24:Flow duration curve – Calibration period two parameters and station weights

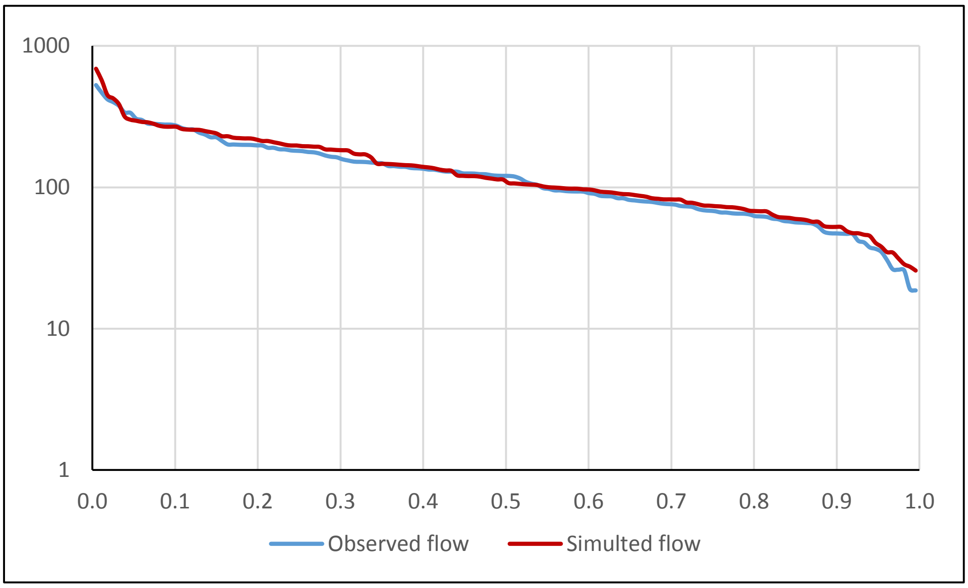


Figure 5-25:Flow duration curve – Verification period two parameters and station weights

## 5.9 Parameters estimation from physical characteristics of the catchment

Since the development of two parameters monthly water model balance model several modelers used trial and error method for parameters estimation and most of them applied in gauged catchment by comparing the simulated and with observed. However, it is difficult to estimate the parameters without observed data, hence there is a need to estimate the parameters from physical characteristics of the catchment. For this purpose, here in this method we consider various variables of the catchment such as rainfall, evaporation, landuse and soil type.

A common method which is widely used for converting pan evaporation in to actual evaporation to use the reduction factor K, i.e. $E(t) = K^* EP(t)$ hence the equation of which used in two parameters monthly water balance model for actual evaporation calculation as below.

$E(t) = C \times EP(t) \times \tanh [\, P(t)/EP(t)] = k \times EP(t)$

Then parameter C can calculate as below

$$C = \frac{k}{\tanh[P(t)/EP(t)]}$$

While the k value is known as 0.8 for May to August, 0.6 for November to February, and 0.7 for March, April, September and October from the table suggested by (Kim, Hong, Kang, Noh, & Kim, 2016), then the parameter C can estimated from monthly rainfall and evaporation data collected from the related departments.

Sc parameter is defined as the soil moisture content or field capacity of the catchment, it is the variable which includes spatial meaning and it may have a same value in a catchment (Xiong & Guo, 1999). Therefore, in this method we consider that the field capacity is related to curve number (CN), which has direct relationship with soil type and landuse, and the parameter Sc has a linear relationship with (CN) of AMC- II (Antecedent soil Moisture Condition II)(Kim et al., 2016). As below.

$$Sc = (a_1 \times CN) + a_2$$

where $a_1$ and $a_2$ are constants:

$$Sc = (-19.808 \times CN) + 2274.1$$

Table 5-14: Weighted curve number calculation for Pitabaddara Watershed

| **Land Use Type** | **Area(%)** | **CN value** | **weighted CN** |
|---|---|---|---|
| Abandoned paddy | 0.36 | 88 | 0.31 |
| Barren land | 0.06 | 91 | 0.05 |
| Cocoanut | 0.25 | 82 | 0.2 |
| Forest | 18.03 | 77 | 13.89 |
| Forest plantation | 0.31 | 77 | 0.24 |
| Grass land | 0.04 | 79 | 0.03 |
| Homesteads/home gardens | 24.58 | 80 | 19.66 |
| Industry | 0.03 | 91 | 0.02 |
| Marsh | 0.03 | 88 | 0.03 |
| Mixed tree | 0.84 | 73 | 0.61 |
| Open forest | 5.44 | 73 | 3.97 |
| Other crops | 0.18 | 84 | 0.16 |
| Other plantation | 0.27 | 81 | 0.22 |
| Paddy | 6.28 | 88 | 5.53 |
| Plantation crop | 0.01 | 88 | 0.01 |
| Play ground | 0.03 | 79 | 0.02 |
| Rubber | 1.13 | 82 | 0.93 |
| Scrub | 3.06 | 74 | 2.26 |
| Tea | 38.43 | 79 | 30.36 |
| Vacant land | 0.02 | 77 | 0.01 |
| Water bodies | 0.62 | 100 | 0.62 |
| Weighted curve number | 79.33 | | |

$$Sc = (-10.808 \times CN) + 2274.1$$

$$Sc = (-10.808 \times 75.55) + 2274.1$$

$$Sc = 1500$$

Table 5-16:C parameter value calculation

| 1993/2017 | Oct(0.7) | Nov(0.6) | Dec(0.6) | Jan(0.6) | Feb(0.6) | Mar(0.7) |
|---|---|---|---|---|---|---|
| Mean Rainfall | 368.34 | 400.95 | 296.73 | 148.85 | 173.57 | 232.16 |
| Mean Eva | 73.06 | 70.86 | 73.26 | 85.52 | 90.79 | 103.51 |
| C | 0.70 | 0.60 | 0.60 | 0.64 | 0.63 | 0.72 |
| 1993/2017 | Apr(0.7) | May(0.8) | Jun(0.8) | Jul(0.8) | Aug(0.8) | Sep(0.7) |
| Mean Rainfall | 336.47 | 329.22 | 200.47 | 166.71 | 161.85 | 260.29 |
| Mean Eva | 87.11 | 82.38 | 80.47 | 79.64 | 77.86 | 76.44 |
| **C** | 1.1 | 1.9 | 0.9 | 1.82 | 0.9 | 1.9 |

C = 1.40

Table 5-15:Comparison of Model Performance Calibration (Physical based parameters)

| Model Performance | 2 Parameter Monthly Water Balance Model - Calibration |
|---|---|
| C | 1.40 |
| SC | 1500 |
| MRAE - Overall | 0.23 |
| MRAE - High | 0.66 |
| MRAE - Intermediate | 0.52 |
| MRAE - Low | 0.48 |
| Soil Water Storage - Beginning | 229.52 |
| Soil Water Storage - End | 229.52 |
| Maximum Storage | 417.17 |
| Minimum Storage | 144.32 |
| Data Period | 1993-2005 |
| Maximum Flow | 667.99 |
| Minimum Flow | 17.36 |

Table 5-16:Comparison of Model Performance Verification (Physical based parameters)

| Model Performance | 2 Parameter Monthly Water Balance Model - Verification |
|---|---|
| C | 1.40 |
| SC | 1500.00 |
| MRAE - Overall | 0.28 |
| MRAE - High | 0.52 |
| MRAE - Intermediate | 0.52 |
| MRAE - Low | 0.28 |
| Soil Water Storage - Beginning | 178.10 |
| Soil Water Storage - End | 178.10 |
| Maximum Storage | 417.59 |
| Minimum Storage | 170.12 |
| Data Period | 1993-2005 |
| Maximum Flow | 792.05 |
| Minimum Flow | 25.32 |

Table 5-17:Water Balance Estimation Calibration Period (Physical Parameters)

| Water Year | Thiessen Average Rainfall (mm) | Simulated Streamflow | Simulated Water Balance | Observed Streamflow | Observed Water Balance | Annual Water Balance Difference |
|---|---|---|---|---|---|---|
| 1993/94 | 3650.2 | 2060.5 | 1589.6 | 1857.4 | 1792.8 | 203.12 |
| 1994/95 | 3210.4 | 1787.2 | 1423.3 | 1920.8 | 1289.6 | (133.68) |
| 1995/96 | 2964.1 | 1325.6 | 1638.6 | 1309.3 | 1654.8 | 16.27 |
| 1996/97 | 2912.7 | 1489.3 | 1423.5 | 1450.8 | 1461.9 | 38.47 |
| 1997/98 | 3028.7 | 1557.8 | 1470.9 | 1431.8 | 1596.9 | 125.93 |
| 1998/99 | 3428.3 | 1861.8 | 1566.6 | 1934.7 | 1493.6 | (72.92) |
| 1999/00 | 3412.6 | 1912.0 | 1500.6 | 1698.0 | 1714.6 | 213.97 |
| 2000/01 | 2558.9 | 1411.4 | 1147.5 | 1315.3 | 1243.6 | 96.11 |
| 2001/02 | 2442.3 | 1087.1 | 1355.2 | 901.6 | 1540.6 | 185.47 |
| 2002/03 | 3837.4 | 2459.7 | 1377.7 | 1907.2 | 1930.2 | 552.53 |
| 2003/04 | 3101.2 | 1811.6 | 1289.7 | 1376.5 | 1724.8 | 435.09 |
| 2004/05 | 2522.3 | 1323.2 | 1199.2 | 1114.4 | 1408.0 | 208.80 |

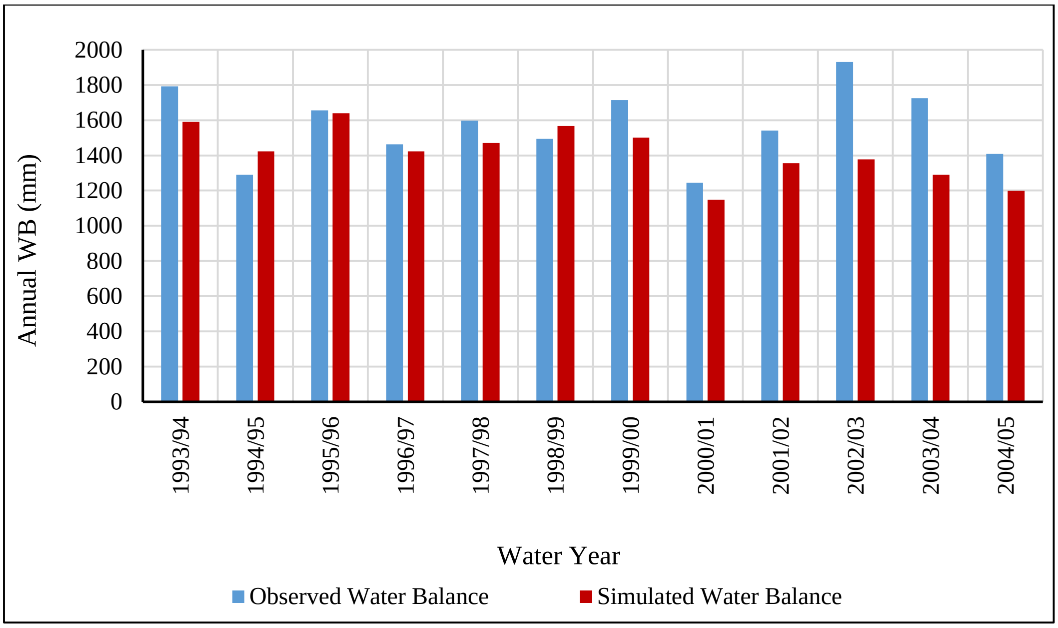


Figure 5-26*:*Annual Water Balance Comparison Calibration (Physical Parameters)

Table 5-18*:*Water Balance Estimation Verification Period (Physical Parameters)

| Water Year | Thiessen Average Rainfall (mm) | Simulated Streamflow | Simulated Water Balance | Observed Streamflow | Observed Water Balance | Annual Water Balance Difference |
|---|---|---|---|---|---|---|
| 2005/06 | 3027.12 | 1583.48 | 1443.63 | 1449.11 | 1578.01 | 134.38 |
| 2006/07 | 3195.11 | 1921.81 | 1273.30 | 1375.10 | 1820.01 | 546.71 |
| 2007/08 | 3308.08 | 2257.45 | 1050.63 | 1771.02 | 1537.06 | 486.43 |
| 2008/09 | 3472.42 | 1993.08 | 1479.34 | 1632.87 | 1839.54 | 360.21 |
| 2009/10 | 2619.37 | 1503.47 | 1115.90 | 1532.65 | 1086.72 | (29.18) |
| 2010/11 | 3410.40 | 2170.74 | 1239.66 | 2276.83 | 1133.58 | (106.09) |
| 2011/12 | 2656.40 | 1318.28 | 1338.12 | 1312.16 | 1344.24 | 6.12 |
| 2012/13 | 3573.07 | 2319.43 | 1253.64 | 2037.11 | 1535.96 | 282.32 |
| 2013/14 | 2358.16 | 1091.18 | 1266.98 | 1273.22 | 1084.94 | (182.04) |
| 2014/15 | 3293.25 | 1976.75 | 1316.50 | 1882.08 | 1411.17 | 94.67 |
| 2015/16 | 2571.76 | 1668.31 | 903.45 | 1619.32 | 952.44 | 48.99 |
| 2016/17 | 3260.05 | 1967.50 | 1292.55 | 1476.59 | 1783.46 | 490.91 |

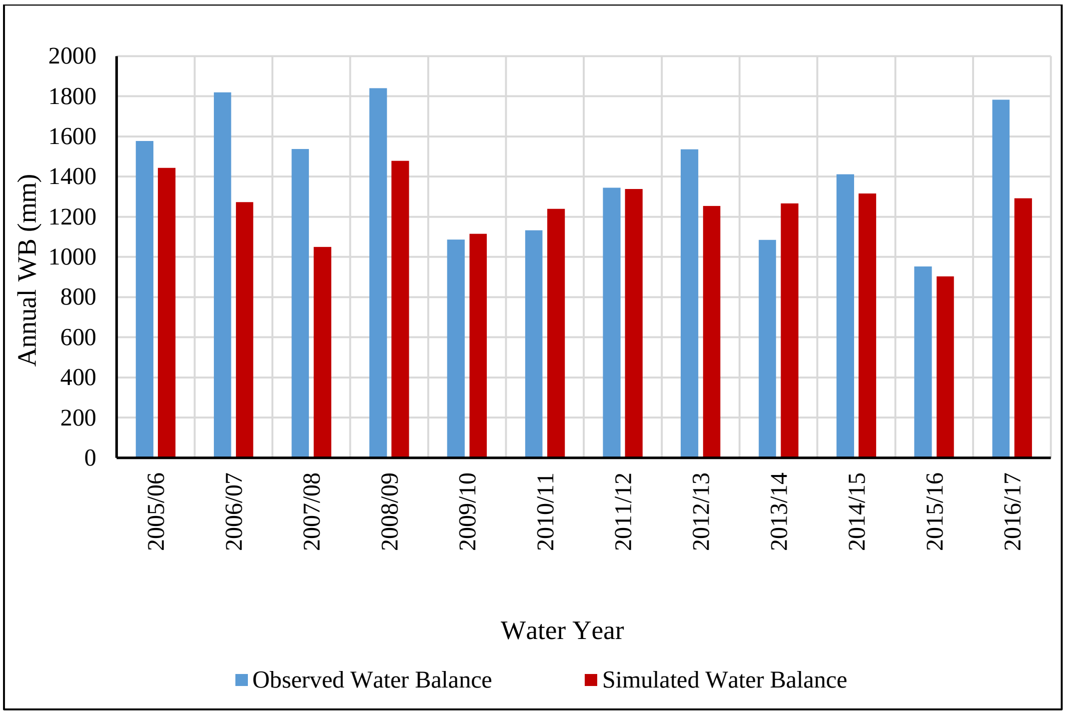


*Figure 5-27:*Annual Water Balance Comparison Verification (Physical Parameters)

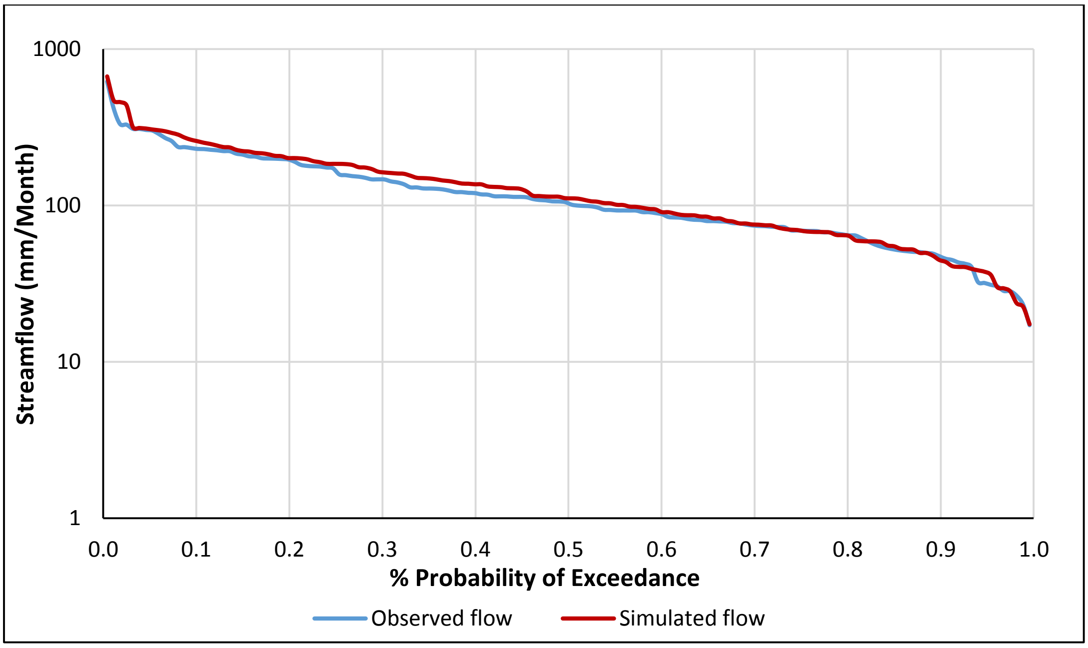


Figure 5-28:Flow duration curve – Calibration period (Physical Parameters)

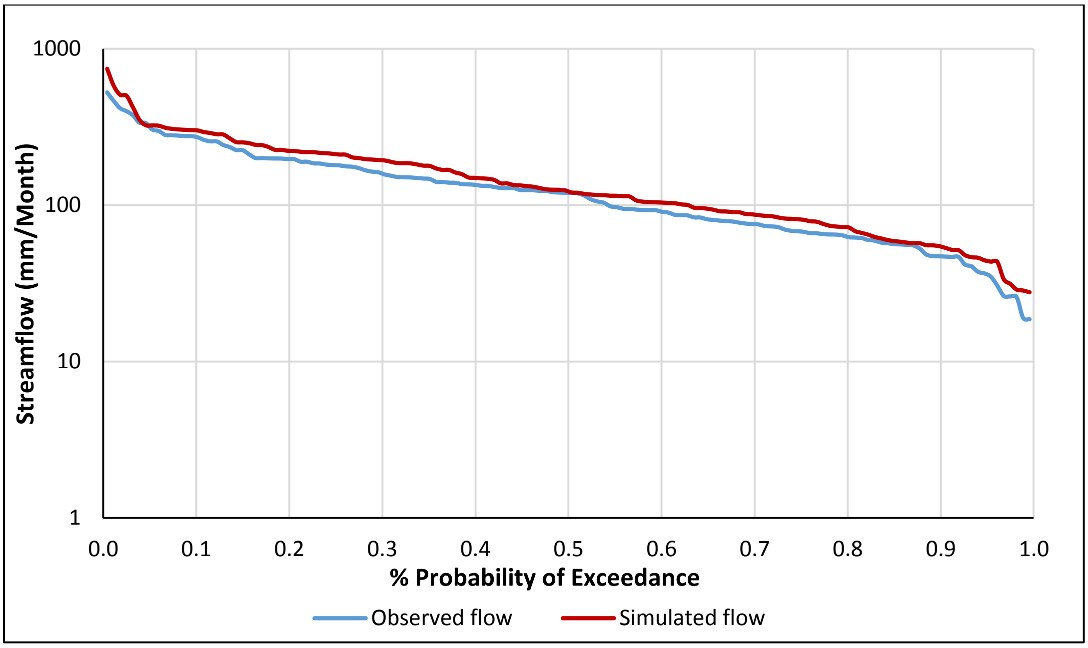
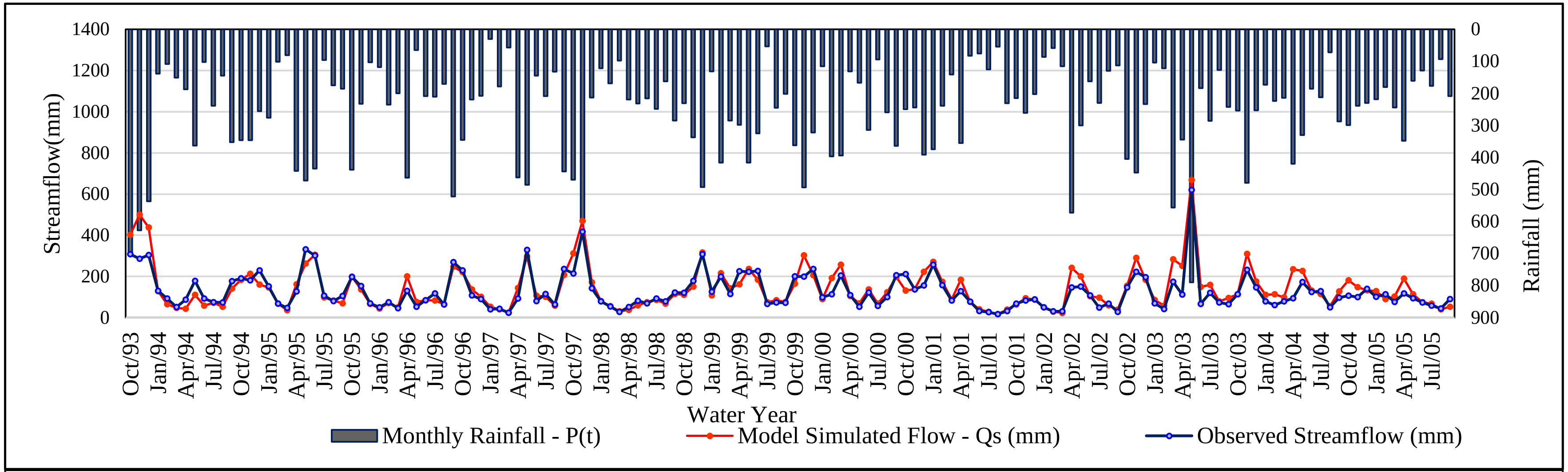


Figure 5-29:Flow duration curve – Verification period (Physical Parameters)



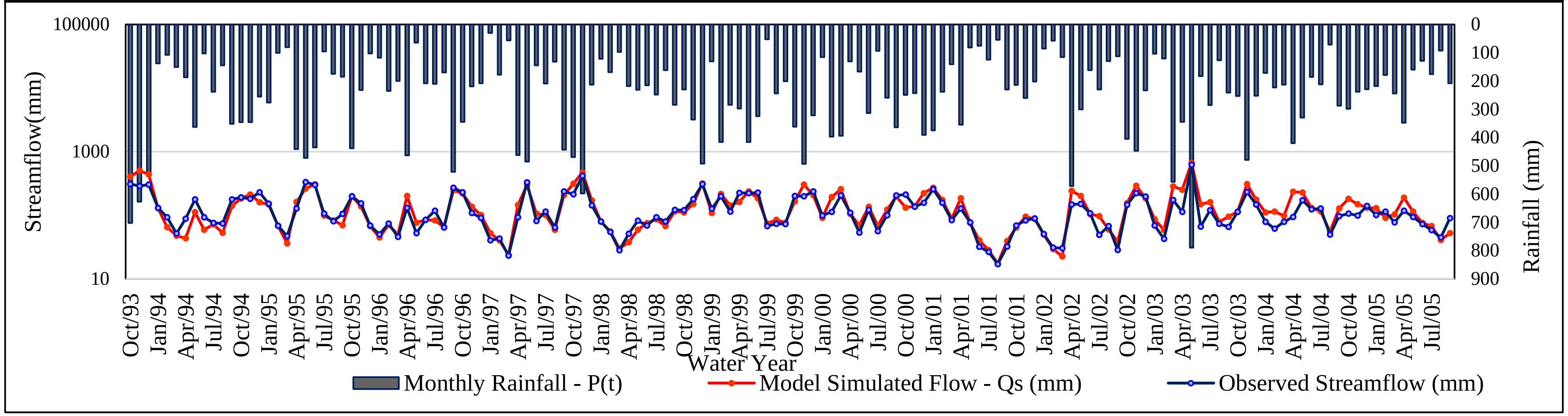


Figure 5-30:Hydrographs from model calibration using physical parameter on both normal and log scale

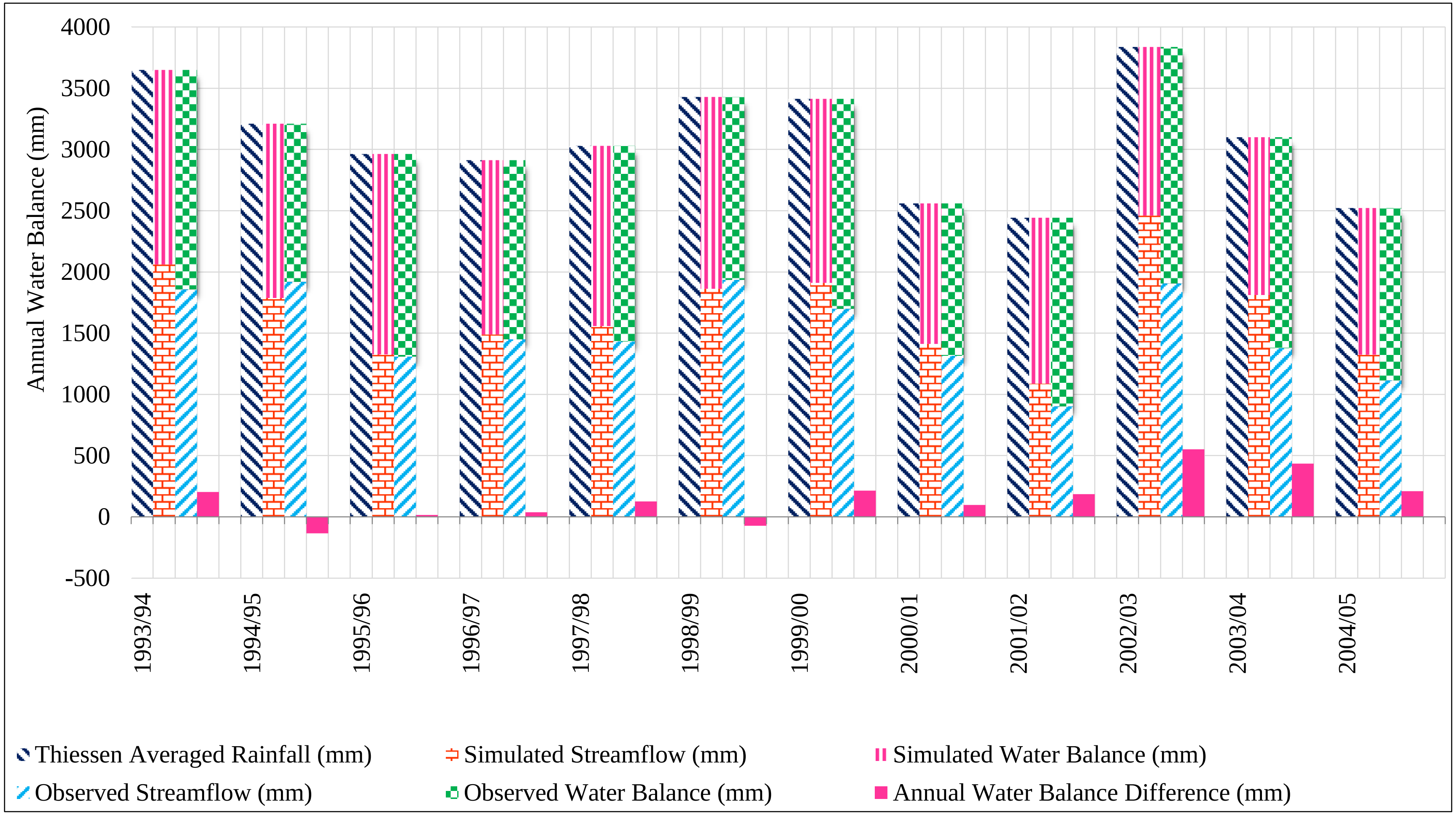


Figure 5-31:Annual Water Balance Comparison Calibration (Physical Parameters)

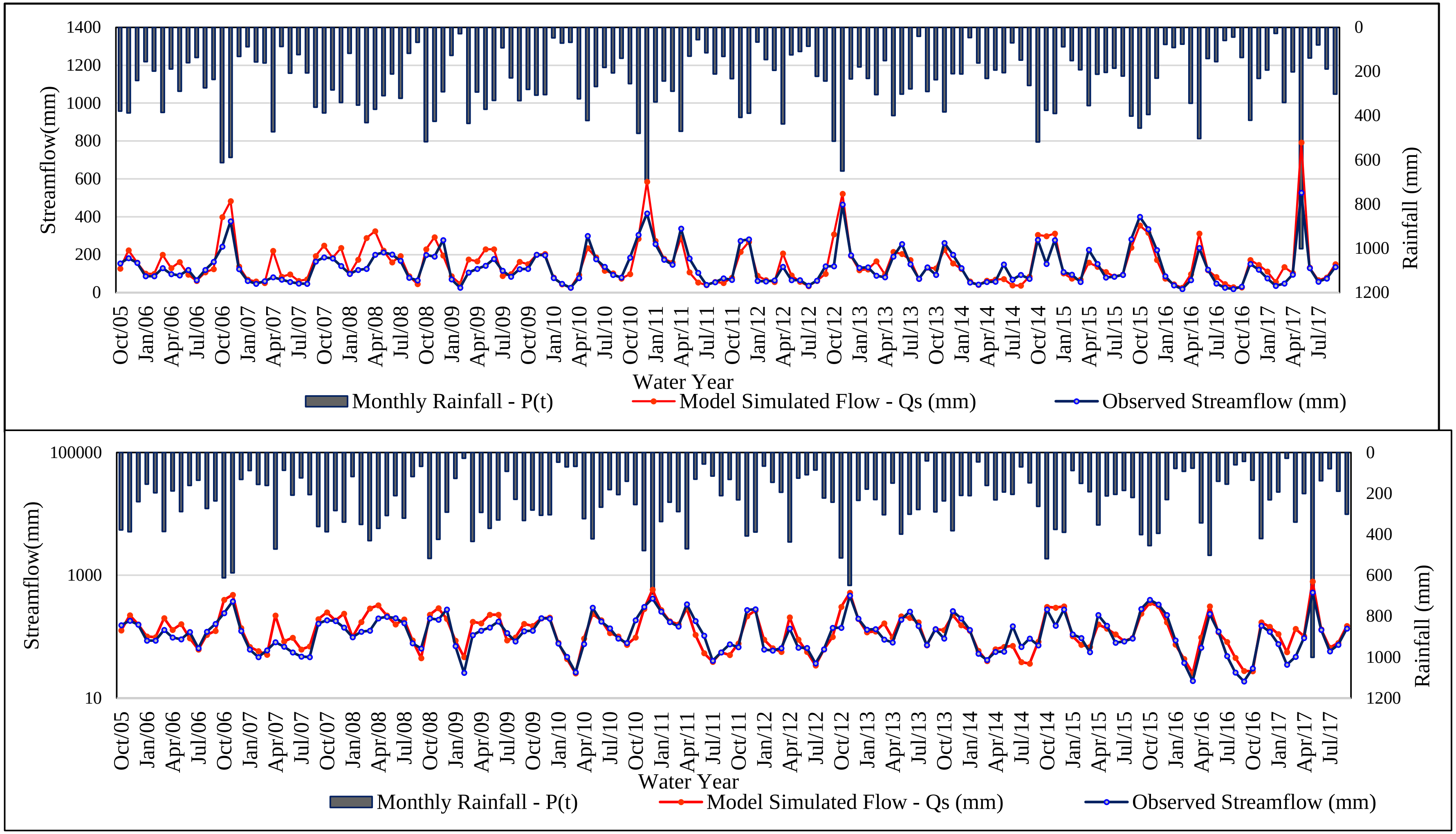


Figure 5-32:Hydrographs from Model Verification using Physical Parameter on both normal and log scale

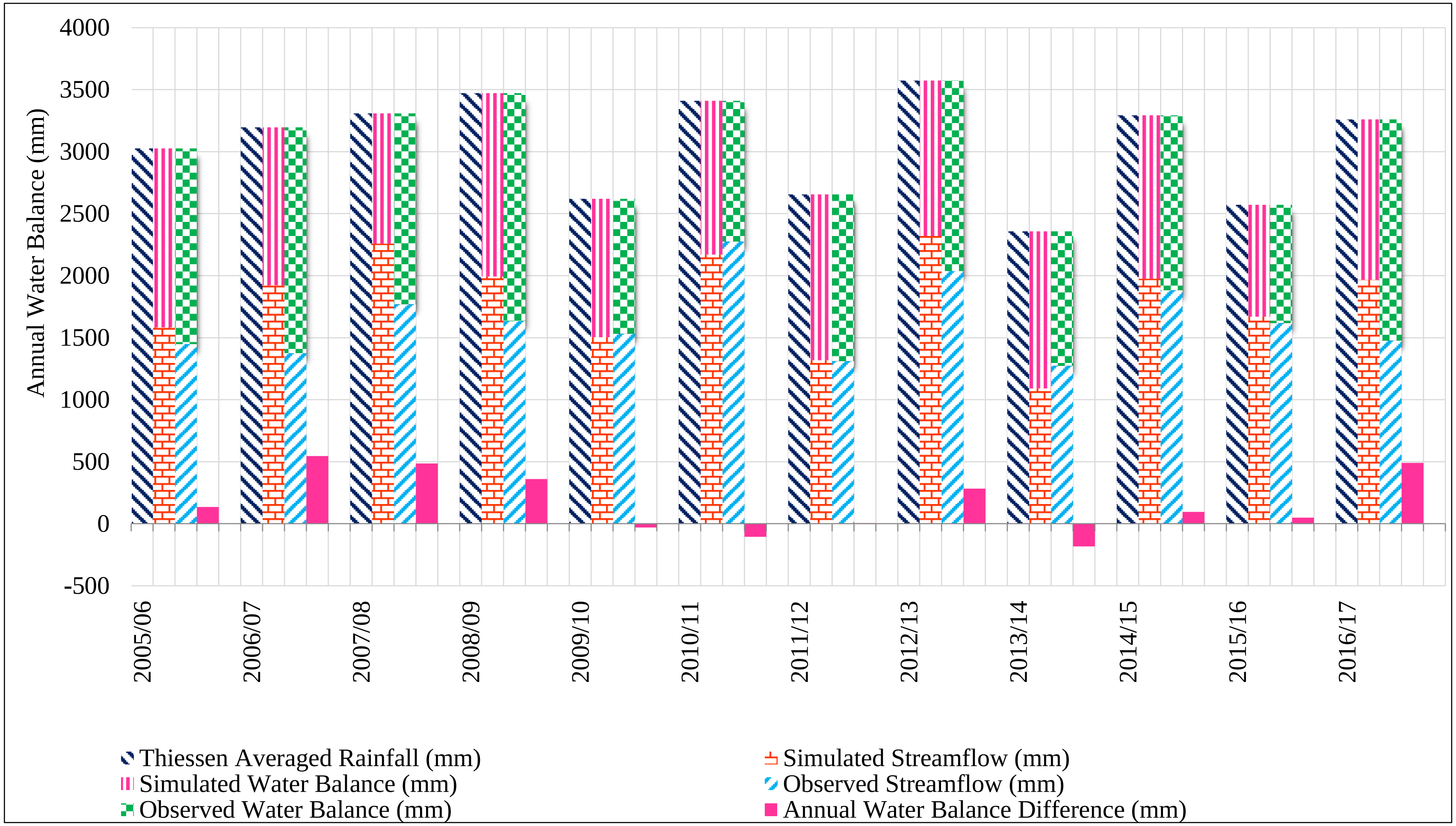


Figure 5-33:Annual Water Balance Comparison Verification (Physical Parameters)

Table 5-19:Mean Rainfall computation for parameter C

| **Year/month** | **Oct(0.7)** | **Nov(0.6)** | **Dec(0.6)** | **Jan(0.6)** | **Feb(0.6)** | **Mar(0.7)** | **Apr(0.7)** | **May(0.8)** | **Jun(0.8)** | **Jul(0.8)** | **Aug(0.8)** | **Sep(0.7)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1993/94 | 702.4 | 627.3 | 537.0 | 137.9 | 108.1 | 151.0 | 186.7 | 362.5 | 102.2 | 238.2 | 144.7 | 352.0 |
| 1994/95 | 346.2 | 346.2 | 255.1 | 276.1 | 100.9 | 80.9 | 441.7 | 472.3 | 434.9 | 95.9 | 174.9 | 185.3 |
| 1995/96 | 438.2 | 231.8 | 102.8 | 117.8 | 235.3 | 199.7 | 463.0 | 64.9 | 208.4 | 210.5 | 169.9 | 522.0 |
| 1996/97 | 345.0 | 218.7 | 207.7 | 30.0 | 178.2 | 56.6 | 461.9 | 485.6 | 144.8 | 208.7 | 131.9 | 443.6 |
| 1997/98 | 469.2 | 598.3 | 212.9 | 121.3 | 168.8 | 97.4 | 218.6 | 231.7 | 215.6 | 248.2 | 162.1 | 284.7 |
| 1998/99 | 230.5 | 336.7 | 492.8 | 131.0 | 416.4 | 284.4 | 297.9 | 415.8 | 324.3 | 52.7 | 244.3 | 201.5 |
| 1999/00 | 362.1 | 493.7 | 322.1 | 115.4 | 396.5 | 394.1 | 130.8 | 166.8 | 313.9 | 93.9 | 259.2 | 363.9 |
| 2000/01 | 249.1 | 243.5 | 391.3 | 374.5 | 238.5 | 140.5 | 354.7 | 81.9 | 75.5 | 124.6 | 54.0 | 230.7 |
| 2001/02 | 214.6 | 260.4 | 201.8 | 85.8 | 57.9 | 115.3 | 572.1 | 300.1 | 161.9 | 229.9 | 129.6 | 112.9 |
| 2002/03 | 404.7 | 447.4 | 232.9 | 103.4 | 121.0 | 556.6 | 344.4 | 789.6 | 183.1 | 285.7 | 126.9 | 241.6 |
| 2003/04 | 253.6 | 479.2 | 252.7 | 172.3 | 223.5 | 213.5 | 419.6 | 330.0 | 185.6 | 211.8 | 71.6 | 287.7 |
| 2004/05 | 298.6 | 238.7 | 229.5 | 218.4 | 179.5 | 244.0 | 347.6 | 159.9 | 128.4 | 176.4 | 92.9 | 208.4 |
| 2005/06 | 378.6 | 386.9 | 240.7 | 154.9 | 197.6 | 385.5 | 188.0 | 288.7 | 160.5 | 135.9 | 273.4 | 236.4 |
| 2006/07 | 612.2 | 588.4 | 131.1 | 88.2 | 156.5 | 161.1 | 472.0 | 86.5 | 207.9 | 123.5 | 205.8 | 361.8 |
| 2007/08 | 387.8 | 283.4 | 339.7 | 117.4 | 351.6 | 431.1 | 371.2 | 308.7 | 210.5 | 320.9 | 117.9 | 67.8 |
| 2008/09 | 518.1 | 424.9 | 291.4 | 126.9 | 28.4 | 435.1 | 292.7 | 371.0 | 330.2 | 92.7 | 229.0 | 332.0 |
| 2009/10 | 281.0 | 306.6 | 304.8 | 47.9 | 70.9 | 67.6 | 323.5 | 421.9 | 267.2 | 181.9 | 205.9 | 140.2 |
| 2010/11 | 254.2 | 479.7 | 691.8 | 338.0 | 242.6 | 289.5 | 470.8 | 130.3 | 55.9 | 115.2 | 210.8 | 131.5 |
| 2011/12 | 232.1 | 407.7 | 388.4 | 66.4 | 146.4 | 194.5 | 437.0 | 124.9 | 109.4 | 85.2 | 222.1 | 242.5 |
| 2012/13 | 515.0 | 649.7 | 233.9 | 179.1 | 230.5 | 304.0 | 150.3 | 398.6 | 301.9 | 278.9 | 40.6 | 290.6 |
| 2013/14 | 236.5 | 382.8 | 209.7 | 210.9 | 46.4 | 161.2 | 231.2 | 193.4 | 204.9 | 70.4 | 147.8 | 262.9 |
| 2014/15 | 519.1 | 375.3 | 390.2 | 88.4 | 150.7 | 192.3 | 354.3 | 212.0 | 204.1 | 184.8 | 220.5 | 401.5 |
| 2015/16 | 455.5 | 394.5 | 229.7 | 77.7 | 91.6 | 76.2 | 344.0 | 502.8 | 141.3 | 155.3 | 59.7 | 43.5 |
| 2016/17 | 135.9 | 420.9 | 231.2 | 192.7 | 28.0 | 339.8 | 201.1 | 1001.2 | 138.7 | 79.9 | 188.8 | 301.8 |
| Mean Rainfall | 368.3 | 400.9 | 296.7 | 148.8 | 173.6 | 232.2 | 336.5 | 329.2 | 200.5 | 166.7 | 161.8 | 260.3 |

Table 5-20:Mean Evaporation computation for parameter

| **Year/month** | **Oct** | **Nov** | **Dec** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1993/94 | 85 | 81.22 | 78.82 | 85.97 | 103.78 | 114.97 | 119.47 | 108.4 | 106.07 | 94.08 | 97.34 | 78.9 |
| 1994/95 | 82.37 | 76.43 | 87.8 | 91.07 | 100.71 | 136.51 | 94.79 | 107.85 | 81.12 | 95.95 | 74.45 | 94.37 |
| 1995/96 | 92.5 | 94.65 | 97.19 | 91.59 | 86.53 | 148.22 | 82.37 | 126.46 | 76.46 | 93.46 | 95.64 | 97.68 |
| 1996/97 | 87.72 | 89.72 | 99.29 | 136.12 | 130.43 | 127.09 | 104.22 | 75.85 | 105.2 | 74.31 | 105.21 | 70.44 |
| 1997/98 | 78.14 | 68.38 | 75.51 | 96.27 | 116.87 | 146.72 | 121.07 | 88.61 | 82.07 | 95.49 | 81.2 | 76.2 |
| 1998/99 | 75.59 | 101.78 | 65.88 | 99.38 | 93.57 | 128.65 | 70.09 | 95.49 | 113.08 | 97.35 | 98.79 | 95.8 |
| 1999/00 | 73.06 | 86.76 | 99.5 | 79.8 | 79.12 | 79.12 | 87.23 | 108.42 | 66.19 | 71.89 | 55.2 | 72.8 |
| 2000/01 | 113.05 | 72.07 | 85.04 | 67.42 | 104.78 | 121.11 | 82.9 | 72.85 | 88.13 | 84.38 | 92.73 | 78.34 |
| 2001/02 | 63.19 | 96.07 | 87.52 | 76.89 | 82.95 | 105.84 | 81.98 | 76.54 | 86.84 | 76.93 | 88.96 | 107.55 |
| 2002/03 | 60.09 | 83.91 | 62.05 | 95.13 | 92.68 | 104.01 | 95.3 | 75.55 | 80.063 | 78.27 | 84.03 | 88.57 |
| 2003/04 | 63.14 | 58.34 | 104.1 | 100.34 | 100.37 | 102.92 | 80.97 | 79.47 | 95.89 | 69.76 | 87.25 | 81.18 |
| 2004/05 | 80.25 | 71.83 | 78.45 | 70.46 | 100.37 | 93.98 | 96.89 | 103.29 | 88.01 | 88.28 | 87.45 | 94.9 |
| 2005/06 | 70.66 | 68.05 | 82.07 | 67.08 | 69.28 | 76.58 | 60.04 | 61.4 | 63.49 | 73.46 | 67.66 | 63.65 |
| 2006/07 | 50.47 | 47.59 | 61.49 | 83.56 | 86.74 | 105.78 | 89.97 | 95.94 | 81.48 | 62.25 | 50.87 | 47.85 |
| 2007/08 | 40.48 | 61 | 57.36 | 59.54 | 57.02 | 40.11 | 82.00 | 83.00 | 104.00 | 66.00 | 45.42 | 83.87 |
| 2008/09 | 70.84 | 61.28 | 72.18 | 97.05 | 108.61 | 80.43 | 68.48 | 67 | 52.085 | 73.62 | 52.11 | 67.65 |
| 2009/10 | 90.47 | 42.12 | 39.05 | 87.87 | 90.98 | 101.9 | 86.16 | 61.83 | 68.01 | 84.13 | 74.48 | 63.34 |
| 2010/11 | 65.13 | 49.94 | 48.51 | 65.11 | 74.68 | 85.97 | 79.14 | 80.12 | 88.86 | 70.17 | 79.3 | 82.25 |
| 2011/12 | 83.86 | 65.2 | 72.19 | 103.8 | 80.52 | 113.7 | 73.85 | 95.9 | 77.2 | 87.7 | 73.58 | 66.51 |
| 2012/13 | 72.64 | 72.97 | 56.65 | 76.67 | 82.22 | 89.81 | 98.43 | 54.36 | 52.98 | 64.76 | 82.1 | 66.68 |
| 2013/14 | 70.84 | 75.72 | 69.81 | 82.79 | 98.22 | 107.35 | 69.17 | 64.77 | 62.12 | 79.22 | 54.51 | 64.34 |
| 2014/15 | 48.39 | 52.73 | 53.84 | 90.54 | 82.96 | 96.47 | 93.53 | 75.33 | 73.87 | 74.4 | 95.39 | 60.18 |
| 2015/16 | 61.19 | 64.27 | 51.04 | 66.62 | 69.83 | 91.69 | 80.52 | 53.59 | 72.75 | 81.71 | 79.45 | 75.09 |
| 2016/17 | 74.41 | 58.693 | 72.93 | 81.383 | 85.63 | 85.2 | 92 | 65.19 | 65.26 | 73.67 | 65.52 | 56.36 |
| Mean Evp | 73.06 | 70.86 | 73.26 | 85.52 | 90.79 | 103.51 | 87.11 | 82.38 | 80.47 | 79.64 | 77.86 | 76.44 |

# 6 DISCUSSION

## 6.1 Model selection

Though various water balance models are available in hydrology, but watershed mangers need to select a suitable model for a particular hydrological practice. therefore, several guidelines, journal publications, monographs and manuals from 1998 to 2016 were extensively reviewed to find the most suitable model based on the options for water balance modelling. capability for water balance modelling, suitability for monthly temporal resolution, physical based parameters, special preferences such as climatic regions, and the ability to use for the purpose of water management.

Recommendations in the literature were also assessed by considering the advantages and disadvantages associated with relevance, user friendliness, application accuracies, reputation, technical support, availability of resources for data collection and model development etc.

Firstly, essential set of criteria were chosen such as number of parameters, types of input data, model components, Temporal scale, spatial extent, Applicability in water balance modelling, Ease of modelling, Number of Sri Lankan application. To short list the available models and then a comprehensive evaluation was done for recommendations.

Finally, two parameters monthly water balance model was selected based on the advantages such as less number of parameters, availability of data for selected watershed, easy to handle, less operation time. In order to apply for water balance modelling considering rainfall station weights and physical parameters in Nilwala at Pitabeddara watershed.

## 6.2 Data collection and checking

Twenty-four years' monthly rainfall, pan evaporation and streamflow data were collected for Pitabeddara watershed at Nilwala Ganga basin. five rain gauge stations were selected such as Kirama, Dampahala, Goluwawatta, Deniyaya, Annigkanda, the streamflow data of Pitabeddara gauge station were collected from irrigation department while pan evaporation data of Denyiaya station and rainfall data were collected from meteorology Department.

Earlier to use the data in to the model, quality of the data was checked by conducting several methods such as outlier testing was performed for finding the unrealistic data, graphical checking was done by plotting the rainfall and streamflow data annual water balance analysis was done to find the runoff coefficient and watershed behavior over the selected watershed, spatial distribution of rainfall and streamflow gauge station were checked  according to WMO guidelines, double mass curve analysis was done for checking  inconsistency of data. Thiessen polygon method was performed using ArcGIS tools. After finding the missing the data, it was filled by nearby station method.

### 6.3 Rainfall spatial variability

Prior to use the rainfall in to the model it is necessary to find the average rainfall of the selected area for this purpose many methods have been used in hydrology such as isohyet reciprocal distance method Thiessen Polygon Method, Reciprocal Distance Squared Method, Kriging Method, Multiqua-dric Equations method.

Since the development of hydrologic models Several methods have been used for spatial distribution of rainfall but selecting the suitable method which can give the accurate rainfall value is still a large obstacle in front of watershed modelers in order to apply water balance models successfully. while Thiessen average rainfall is the most common method used in rainfall- runoff modelling. Therefore, in this study for the purpose of comparison the model performance  two methods were used for the average rainfall computation first Thiessen polygon method was used by incorporating the Thiessen weights then the average rainfall was computed by optimizing the station weights suggested by Musiake and Wijesekera (1990) respectively. both Thiessen average rainfall and optimized rainfall are in the table below.

Table 6-1: Rainfall Average by Thiessen and Optimized station weights

| Water Year | Thiessen Average Rainfall (mm) | Optimized Rainfall(mm) |
|---|---|---|
| 1993/94 | 3650.2 | 3188.06 |
| 1994/95 | 3210.4 | 2970.21 |
| 1995/96 | 2964.1 | 2586.87 |
| 1996/97 | 2912.7 | 2750.18 |
| 1997/98 | 3028.7 | 2826.23 |
| 1998/99 | 3428.3 | 3074.77 |
| 1999/00 | 3412.6 | 3011.76 |
| 2000/01 | 2558.9 | 2273.34 |
| 2001/02 | 2442.3 | 2111.69 |
| 2002/03 | 3837.4 | 3178.06 |
| 2003/04 | 3101.2 | 2601.23 |
| 2004/05 | 2522.3 | 2376.82 |
| 2005/06 | 3027.12 | 2783.51 |
| 2006/07 | 3195.11 | 2916.86 |
| 2007/08 | 3308.08 | 2724.28 |
| 2008/09 | 3472.42 | 2942.72 |
| 2009/10 | 2619.37 | 2455.90 |
| 2010/11 | 3410.40 | 3553.42 |
| 2011/12 | 2656.40 | 2618.04 |
| 2012/13 | 3573.07 | 2947.30 |
| 2013/14 | 2358.16 | 2113.79 |
| 2014/15 | 3293.25 | 2862.44 |
| 2015/16 | 2571.76 | 2129.35 |
| 2016/17 | 3260.05 | 2814.20 |

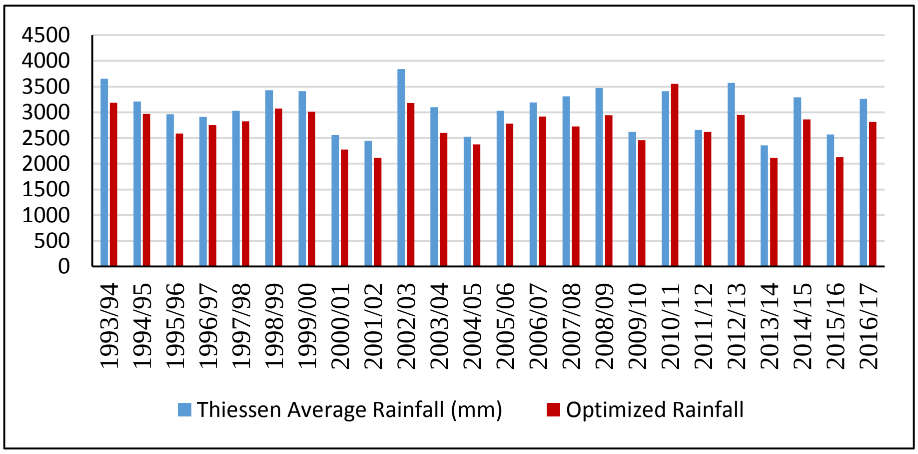


Figure 6-1:Thiessen and Optimized Rainfall Comparison

## 6.4 Model Development

### 6.4.1 Flow duration curve for High Medium and Low flows

Flow duration curve was plotted for the whole data set from water year (October 1993 to September 2017) in order to find the high, medium and low flow threshold values, these values was found (< 14%) for High, between (14%-79%) as intermediate and (>79%) as low flow threshold values respectively.

### 6.4.2 Initial soil water content

Initial soil water content (S) which has its own influence on monthly streamflow, Q(t), specifically for limited observed data accurate value of soil water content S(o) has special impact on model performance. Particularly, when the used date set is enough long. similarly, here for this study the initial soil water content was selected after five times model runs over the calibration period data set from the year 1393 to 2005. After the five times model run the initial soli water storage value was found 165.06(mm).

### 6.4.3 Objective functions selection

Though many objective functions are available for model optimization but modelers search to select a suitable objective function according to their related study. Therefore, several objective function usages, merits and demerits were reviewed such as (RMSE, SSR, SAR, WRMS, MAER, MRAE, RAEM, CRM, Nash-Sutcliffe) among all these objective functions the mean ratio of absolute error (MRAE) proposed by World Meteorological Organization (WMO,1975) which is widely used for water resource management and it can match each and every point such as high, medium and low flows of the two hydrographs. In this study the(MRAE) was calculated for overall, high, intermediate and low flows respectively.

### 6.4.4 Calibration and verification

For the purpose of calibration and verification first the entire 24 years’ data set from the year 1993 to 2017 was divided in two parts 12 years (1993 – 2005) for calibration and 12 years (2005 – 20170) for verification during the Calibration period using Thiessen rainfall in the model the MRAE Value was found 0.22 and using optimized rainfall the MRAE Value was found same 0.22 while during the verification period with Thiessen rainfall the MRAE value was found 0.31 and with optimized rainfall the MRAE value was obtained 0.27 respectively.

Similarly, the MRAE value was obtained 0.67 in calibration period and 0.71 in verification period with physical parameters in the model which didn't show good fitting of match between observed and simulated hydrograph

## 6.5 Overall comparison of models performance

Table 6-2:Overall Summary sheet of all models results

| Comparison of model performance | 2p Theissen rainfall | | 2p Optimized rainfall | | 2p and station weights | | 2p physical parameter | |
|---|---|---|---|---|---|---|---|---|
| | Calib | Verif | Calib | Verif | Calib | Verif | Calib | Verif |
| C | 1.50 | 1.50 | 1.30 | 1.30 | 1.41 | 1.41 | 1.40 | 1.40 |
| SC | 1700 | 1700 | 1600 | 1600 | 1550 | 1550 | 1500 | 1500.00 |
| MRAE - Overall | 0.22 | 0.31 | 0.22 | 0.27 | 0.20 | 0.26 | 0.23 | 0.28 |
| MRAE - High | 0.09 | 0.14 | 0.08 | 0.05 | 0.06 | 0.06 | 0.66 | 0.52 |
| MRAE - Intermediate | 0.05 | 0.15 | 0.06 | 0.08 | 0.08 | 0.08 | 0.52 | 0.52 |
| MRAE - Low | 0.07 | 0.16 | 0.09 | 0.15 | 0.10 | 0.12 | 0.48 | 0.28 |
| Soil Water Storage - Beginning | 230.2 | 361.2 | 213.0 | 326.7 | 211.4 | 317.0 | 229.52 | 178.10 |
| Soil Water Storage - End | 230.2 | 361.2 | 213.0 | 326.7 | 211.47 | 317.0 | 229.52 | 178.10 |
| Maximum Storage | 473.3 | 473.1 | 441.1 | 445.2 | 427.4 | 431.6 | 417.17 | 417.59 |
| Minimum Storage | 163.33 | 189.85 | 157.91 | 182.62 | 161.89 | 179.4 | 144.32 | 170.12 |
| Maximum Flow | 603.9 | 745.6 | 456.9 | 620.9 | 444.96 | 689.7 | 1993-2005 | 1993-2005 |
| Minimum Flow | 19.61 | 27.69 | 19.62 | 27.41 | 21.62 | 27.4 | 667.99 | 792.05 |
| Data Period | 1993-2005 | 2005-2017 | 1993-2005 | 2005-2017 | 1993-2005 | 2005-2017 | 1993-2005 | 2005-2017 |

# 7 CONCLUSIONS & RECOMMENDATIONS

## 7.1 Conclusions

1. Two parameter monthly water balance model during calibration and verification period showed very good results. for Nilwala ganga basin at Pittabeddra watershed. Using Thiessen rainfall in the model The C parameter value was found 1.5 and the Sc parameter value was found 1700 respectively. the average MRAE value indicated very good fitting with value of 0.22 in calibration period and 0.31 in verification period.
2. while using optimized rainfall in the model the C parameter value was found 1.3 and the Sc parameter value was found 1600. Similarly, average MRAE value indicated very good fitting with value of 0.22 in calibration period and 0.27 in verification period respectively.
3. The value of C parameter found 1.4 and the value of Sc parameter was found 1500 form physical characteristics of the catchment and the MRAE Value was obtained with good fitting 0.23 and 0.28 both and calibration and verification period.
4. From station weights and two parameters optimization the value of C and Sc was obtained 1.41 and 1550 with the average MRAE value 0.19 in calibration and 0.25 in verification period respectively.
5. Two parameter monthly water balance model suggested by Xiong and Guo (1999) was found very simple model for monthly runoff simulation. the optimized rainfall showed good results then Thiessen rainfall in the model, in addition the parameters estimation method from physical of the catchment did show good results then automatic optimization method using observed data for Pittabedrra watershed.
6. As a result, the station weights and two parameters optimization together give better results than all the other methods used in this study in two parameters monthly water balance model

## 7.2 Recommendations

1. It is recommended to apply Two parameter monthly water balance model in other watersheds for checking the variation of C and Sc parameters values.
2. It is recommended to check the performance of two parameters monthly water balance model with different average rainfall methods.
3. It is recommended to check the method of parameters estimation from physical characteristics of the catchment in several other watersheds.
4. It is recommending that the model parameters and station weighs optimization can give good results while using two parameter model

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# ANNEX A – DATA checking

Table A-1:Thiessen Average Rainfall Data

| **year** | **Monthly rainfall(mm/month)** | | | **Annual rainfall (mm/year)** |
|---|---|---|---|---|
| | **Maximum** | **Mean** | **Minimum** | |
| 1993/94 | 702.4 | 304.2 | 102.2 | 3650.2 |
| 1994/95 | 472.3 | 267.5 | 80.9 | 3210.4 |
| 1995/96 | 522.0 | 247.0 | 64.9 | 2964.1 |
| 1996/97 | 485.6 | 242.7 | 30.0 | 2912.7 |
| 1997/98 | 598.3 | 252.4 | 97.4 | 3028.7 |
| 1998/99 | 492.8 | 285.7 | 52.7 | 3428.3 |
| 1999/00 | 493.7 | 284.4 | 93.9 | 3412.6 |
| 2000/01 | 391.3 | 213.2 | 54.0 | 2558.9 |
| 2001/02 | 572.1 | 203.5 | 57.9 | 2442.3 |
| 2002/03 | 789.6 | 319.8 | 103.4 | 3837.4 |
| 2003/04 | 479.2 | 258.4 | 71.6 | 3101.2 |
| 2004/05 | 347.6 | 210.2 | 92.9 | 2522.3 |
| 2005/06 | 386.9 | 252.3 | 135.9 | 3027.1 |
| 2006/07 | 612.2 | 266.3 | 86.5 | 3195.1 |
| 2007/08 | 431.1 | 275.7 | 67.8 | 3308.1 |
| 2008/09 | 518.1 | 289.4 | 28.4 | 3472.4 |
| 2009/10 | 421.9 | 218.3 | 47.9 | 2619.4 |
| 2010/11 | 691.8 | 284.2 | 55.9 | 3410.4 |
| 2011/12 | 437.0 | 221.4 | 66.4 | 2656.4 |
| 2012/13 | 649.7 | 297.8 | 40.6 | 3573.1 |
| 2013/14 | 382.8 | 196.5 | 46.4 | 2358.2 |
| 2014/15 | 519.1 | 274.4 | 88.4 | 3293.2 |
| 2015/16 | 502.8 | 214.3 | 43.5 | 2571.8 |
| 2016/17 | 1001.2 | 271.7 | 28.0 | 3260.0 |

Table A-2:Evaporation Data

| **year** | **Monthly Evaporation (mm/month)** | | | **Annual rainfall (mm/year)** |
|---|---|---|---|---|
| | **Maximum** | **Mean** | **Minimum** | |
| 1993/94 | 119.47 | 96.16833 | 78.82 | 1154.02 |
| 1994/95 | 136.51 | 93.61833 | 74.45 | 1123.42 |
| 1995/96 | 148.22 | 98.5625 | 76.46 | 1182.75 |
| 1996/97 | 136.12 | 100.4667 | 70.44 | 1205.6 |
| 1997/98 | 146.72 | 93.8775 | 68.38 | 1126.53 |
| 1998/99 | 128.65 | 94.62083 | 65.88 | 1135.45 |
| 1999/00 | 108.42 | 79.92417 | 55.2 | 959.09 |
| 2000/01 | 121.11 | 88.56667 | 67.42 | 1062.8 |
| 2001/02 | 107.55 | 85.93833 | 63.19 | 1031.26 |
| 2002/03 | 104.01 | 83.30442 | 60.09 | 999.653 |
| 2003/04 | 104.09 | 85.31 | 58.34 | 1023.72 |
| 2004/05 | 103.29 | 87.84667 | 70.46 | 1054.16 |
| 2005/06 | 82.07 | 68.61833 | 60.04 | 823.42 |
| 2006/07 | 105.78 | 71.99917 | 47.59 | 863.99 |
| 2007/08 | 104 | 64.98333 | 40.11 | 779.8 |
| 2008/09 | 108.61 | 72.61125 | 52.085 | 871.335 |
| 2009/10 | 101.9 | 74.195 | 39.05 | 890.34 |
| 2010/11 | 88.86 | 72.43167 | 48.51 | 869.18 |
| 2011/12 | 113.7 | 82.83417 | 65.2 | 994.01 |
| 2012/13 | 98.43 | 72.5225 | 52.98 | 870.27 |
| 2013/14 | 107.35 | 74.905 | 54.51 | 898.86 |
| 2014/15 | 96.47 | 74.8025 | 48.39 | 897.63 |
| 2015/16 | 91.69 | 70.64583 | 51.04 | 847.75 |
| 2016/17 | 92 | 73.0205 | 56.36 | 876.246 |

Table A-3:Streamflow Data

| **year** | **Monthly Streamflow (mm/month)** | | | **Annual Streamflow (mm/year)** |
|---|---|---|---|---|
| | **Maximum** | **Mean** | **Minimum** | |
| 1993/94 | 308.49 | 154.78 | 51.42 | 1857.40 |
| 1994/95 | 331.13 | 160.07 | 47.27 | 1920.85 |
| 1995/96 | 269.72 | 109.11 | 45.53 | 1309.30 |
| 1996/97 | 328.32 | 120.90 | 23.12 | 1450.79 |
| 1997/98 | 417.94 | 119.32 | 28.23 | 1431.83 |
| 1998/99 | 308.44 | 161.23 | 67.15 | 1934.71 |
| 1999/00 | 236.28 | 141.50 | 53.17 | 1698.03 |
| 2000/01 | 257.70 | 109.61 | 17.10 | 1315.29 |
| 2001/02 | 150.05 | 75.14 | 28.33 | 901.64 |
| 2002/03 | 619.61 | 158.93 | 42.29 | 1907.18 |
| 2003/04 | 232.57 | 114.71 | 49.58 | 1376.47 |
| 2004/05 | 140.22 | 92.86 | 44.70 | 1114.36 |
| 2005/06 | 181.80 | 120.76 | 65.00 | 1449.11 |
| 2006/07 | 376.09 | 114.59 | 46.69 | 1375.10 |
| 2007/08 | 211.78 | 147.59 | 64.15 | 1771.02 |
| 2008/09 | 276.85 | 136.07 | 25.80 | 1632.87 |
| 2009/10 | 298.40 | 127.72 | 26.29 | 1532.65 |
| 2010/11 | 417.87 | 189.74 | 40.67 | 2276.83 |
| 2011/12 | 280.43 | 109.35 | 36.65 | 1312.16 |
| 2012/13 | 465.22 | 169.76 | 73.18 | 2037.11 |
| 2013/14 | 261.62 | 106.10 | 41.72 | 1273.22 |
| 2014/15 | 281.75 | 156.84 | 56.17 | 1882.08 |
| 2015/16 | 399.19 | 134.94 | 18.63 | 1619.32 |
| 2016/17 | 526.64 | 123.05 | 30.56 | 1476.59 |

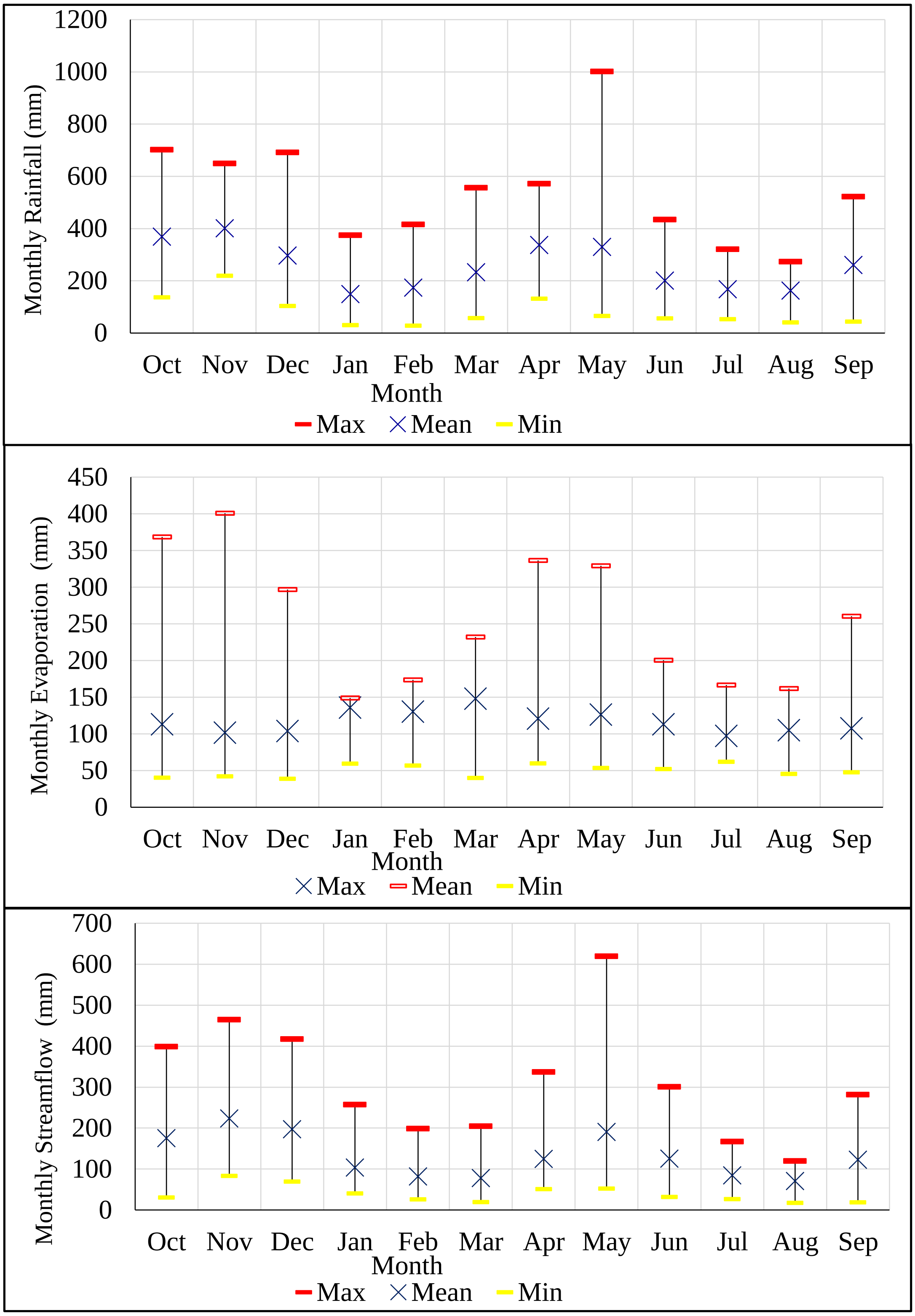

Figure 9-1:Variation of Maximum, Mean and average monthly rainfall, streamflow & evaporation