PRECIPITATION TRENDS OVER THE THREE CLIMATIC ZONES OF MAHAWELI BASIN AND EVALUATION OF CLIMATE CHANGE IMPACTS ON STREAMFLOW VARIABILITY

Dheerendra Kumar Yadav

(189251N)

Degree of Master of Science

Department of Civil Engineering

University of Moratuwa
Sri Lanka

September 2019

PRECIPITATION TRENDS OVER THE THREE CLIMATIC ZONES OF MAHAWELI BASIN AND EVALUATION OF CLIMATE CHANGE IMPACTS ON STREAMFLOW VARIABILITY

Dheerendra Kumar Yadav

(189251N)

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

Master of Science in
Water Resources Engineering and Management

Supervised by
Dr. R. L. H. L. Rajapakse

UNESCO Madanjeet Centre for
South Asia Water Management (UMCSAWM)

Department of Civil Engineering
University of Moratuwa
Sri Lanka

September 2019

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.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (Such as articles or books).

UOM Verified Signature

2019.09.24
……………………

Dheerendra Kumar Yadav

Date

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

UOM Verified Signature

2019.09.25
………………………

Dr. R.L.H.L. Rajapakse

Date

ACKNOWLEDGEMENT

First and foremost, I wish to express my sincere and heartfelt gratitude to the research supervisor and Course Coordinator Dr. R. L. H. L. Rajapakse for his patience, continuous guidance, support, encouragement and valuable advice throughout the research and let me experience the research of water resources, simulation models and practical issues beyond the textbooks, patiently corrected my writing.Rendering his unending support and guidance provided both in terms of academic and logistic welfare during my stay. He has been a source of inspiration and his guidance has made this a thoughtful and rewarding journey.

My sincere thanks go to Prof. N. T. S. Wijesekera, Centre Chairman and Overall Program Coordinator for giving us immense knowledge on research under the subject “Research methods” and for his guidance, support and constructive feedback at evaluations. I also wish to express my gratitude to support staff Mr.H.W Kumarasinghe, Ms. Vinu Kalanika, Ms. Janani, Mr. Ranaweera and Mr. Waruna and all other supporting staff of University of Moratuwa for their assistance given during the Master’s programme. I am truly fortunate to have had the opportunity to work with above all.

I would also like to thank my parents and family members. They were always supporting me and encouraging me with their best wishes. Finally, I would like to thank my SAF friends. They were always there cheering me up and stood by me through the good times and bad. A special thank you to all those support and friendship helped me to stay focused on this research and who have provided me with the encouragement to continue when the going got tough.

My sincere heartfelt gratitude goes to Late Shri Madanjeet Singh for his visionary and noble idea of providing a scholarship to pursue this course.

To all those whom I could not mention, please know that your help and support remains equally appreciate.

Precipitation Trends over the Three Climatic Zones of Mahaweli Basin and Evaluation of Climate Change Impacts on Streamflow Variability

ABSTRACT

Climate change is expected to inflict severe consequences on the hydrological cycle and water resources of a catchment. With this backdrop, it is crucial to have better insight into the functioning of current water resources systems along with future water resources planning and management due to the fact that amidst growing populations and ever-increasing resource use, competition among users, and more recently, widespread ecosystem degradation and climate change impacts have exacerbated the already grave situation. In order to assess this impact, a semi-distributed monthly water balance model was adopted and developed to simulate and predict the hydrological processes incorporating several predicted future climatic scenarios.

This study focuses on analyzing the long-term precipitation trends in the three distinct climatic zones and climate change impacts on streamflow variability in Mahaweli basin which extends over wet, dry and intermediate climatological zones. Monthly precipitation data for a span of 30 years from 1988-2018 have been used for trend analysis using Mann-Kendall and 15-year monthly rainfall and streamflow data set is used for calibration and validation of "*abcd*" hydrological model to evaluate the climate change impacts on streamflow for future water resources management at three selected sub-watersheds in each zone of the basin. The changes in precipitation and temperature during the study period were correlated differently with observed changes in streamflow. The rainfall trends in the intermediate and dry zone parts of the basin were identified to be positive while the trend in the wet zone part was found to be decreasing, however, not statistically significant in both cases. Streamflow precipitation elasticity was evaluated for sensitivity check.

The "abcd" hydrologic model can be recommended to use for streamflow simulations and water resources investigations in monthly temporal resolution for the watersheds which are having similar characteristics with parameter values in the ranges of *a* (0.961-0.998), *b* (0-250), *c* (0.001-0.999) and *d* (0.01-0.999). The *abcd* model has proven to be a valuable tool not only for assessing the hydrologic characteristics of diverse watersheds but also for evaluating the hydrologic consequences of climate change in selected basins which may also be helpful in both pre-disaster risk management and post-disaster rehabilitation.

Keywords: Lumped model, Mann-Kendall, Streamflow elasticity

TABLE OF CONTENTS

DECLARATION i

ACKNOWLEDGEMENT ii

ABSTRACT iii

TABLE OF CONTENTS iv

LIST OF TABLES xv

LIST OF ABBREVIATIONS xvii

1 INTRODUCTION 1

1.1 General Introduction 1

1.2 Problem statement 2

1.3 Research Objective 2

1.3.1 Main objective 2

1.3.2 Specific objectives 2

1.4 Scope and Limitations 3

1.5 Thesis Outline 4

2 LITERATURE REVIEW 5

2.1 Introduction 5

2.2 IPCC Climate Change Scenarios 6

2.3 Observed Climate Change over the South Asia 7

2.3.1 Impacts of rainfall variability in South Asia 10

2.4 Climate Change in Sri Lanka 11

2.4.1 Observed Trends of Climate in Sri Lanka 12

2.4.2 Impacts by Increased Temperature 12

2.4.3 Changes in the Pattern and Rate of Precipitation 13

2.5 Data Requirement for Trend Analysis 14

2.6 Mankendall Test for Trend Analysis and Sen’s Slope Estimation 14

2.7 Rainfall Elasticity of Streamflow 16

2.7.1 Importance of Rainfall Elasticity of streamflow 16

2.7.2 Elasticity Estimation using a Non -Parametric Estimator...................17

2.8 Hydrological Modeling and Hydrologic Model Classification 18

2.8.1 Monthly water balance models and model parameters.......................19

2.8.2 Lumped water balance models 20

2.8.3 Data period for monthly water balance models..................................20

2.8.4 Selection of Model for Study 21

2.9 The "abcd" Monthly Water Balance Model...23

2.9.1 The "abcd" model structure..23

2.9.2 Application of "abcd" model..25

2.9.3 Potential Evapotranspiration (PE) for the model 26

2.9.4 The “abcd" model parameters from literature....................................27

2.10 Parameter optimization...27

2.11 Objective functions 28

2.12 Applications of different objective functions by different modelers 29

2.12.1 Ratio of Absolute Error to Mean (RAEM) 30

2.12.2 Relative Error (RE)...30

2.12.3 Nash–Sutcliffe Efficiency (NSE) 31

2.12.4 Root Mean Square Error 32

2.12.5 Coefficient of Determination 32

2.13 Warm up period of the Model...34

2.14 Rainfall interpolation method 36

2.15 Literature review summary....................36

3 METHODS AND MATERIALS....................38

3.1 Methodology Brief....................38

3.1.1 Methodology flow chart....................39

3.2 Study Sites....................40

3.2.1 Nawalapitiya watershed (Wet Zone)....................42

3.2.2 Thaldena watershed (Intermediate Zone)....................44

3.2.3 Padiyatalawa watershed (Dry Zone)....................47

3.3 Data collection....................49

3.4 Data collection for Nawalapitiya....................50

3.4.1 Data collection for Thaldena....................51

3.4.2 Data collection for Padiyatalawa....................52

3.5 Isohyet averaged rainfall....................53

3.6 Data checking....................54

3.6.1 Visual data checking....................55

3.6.2 Co-relation between the stream flow and rainfall data....................56

3.6.3 Single mass curve analysis....................58

3.6.4 Double mass curve analysis....................61

3.6.5 Annual water balance....................62

3.7 Monthly, annual and seasonal runoff coefficients....................66

3.8 Statistical parameters of data for the selected range....................68

3.8.1 Precipitation....................68

3.8.2 Streamflow....................69

3.8.3 Evaporation....................71

4 ANALYSIS AND RESULTS....................73

4.1 Rainfall Trends of Wet Zone 73

4.2 Rainfall Trends of Dry Zone 75

4.3 Rainfall Trends of Intermediate Zones 77

4.4 Sen’s Slope Estimation of trend 80

4.5 Warm up period of the model for Padiyatalawa watershed 81

4.6 Calibration and validation of the ‘abcd’ model 84

4.7 Outflow hydrographs related to optimized parameters 88

4.8 Annual water balance check after calibration and validation 91

4.8.1 Annual water balance of Nawalapitya for calibration period 92

4.8.2 Annual water balance of Nawalpitiya for validation period 93

4.8.3 Annual water balance of Thaldena for calibration period 94

4.8.4 Annual water balance of Thaldena for validation period 94

4.8.5 Annual water balance of Padiyatalawa for calibration period 95

4.8.6 Annual water balance of Padiyatalawa for validation period 96

4.9 Demarcations of Flow Thresholds 96

4.10 Flow duration curves for Nawalapitiya 97

4.11 Flow duration curves for Thaldena 99

4.12 Flow duration curves for Padiyatalawa 100

4.13 Flow duration curve analysis for the simulated flow in the catchments 102

4.13.1 Flow duration curve match (Nawalapitiya-Calibration) 103

4.13.2 Flow duration curve match (Nawalapitiya-Validation) 104

4.13.3 Flow duration curve match (Thaldena -Calibration) 104

4.13.4 Flow duration curve match (Thaldena - Validation) 106

4.13.5 Flow duration curve match (Padiyatalawa -Calibration) 107

4.14 Model suitability analysis for different flow regimes 108

4.15 Application of the ‘abcd’ model for water resources investigation 109

4.16 Annual groundwater flow and surface runoff......................................110

4.17 Model Results For Climate Change Scenarios 113

4.17.1 Simulationof Climate Change Scenarios at Nawalapitiya Catchment 113

5 DISCUSSION...118

5.1 Model inputs...118

5.1.1 Isohyetal averaged rainfall 118

5.1.2 Stream flow 118

5.1.3 Evaporation 119

5.2 Rainfall Trend Over Three Climatic Zones of Mahaweli Basin 119

5.3 Model performance...120

5.4 Challenges faced in Modeling 127

5.5 Difficulties with data 128

5.6 Initial conditions for the model 129

5.7 Limitations of “abcd” model 129

6 CONCLUSION AND RECOMMENDATION 131

6.1 Conclusions 131

6.2 Recommendations...132

TABLE OF FIGURES

Figure 2-1: The "abcd" model structure....24

Figure 3-1: Methodology Flowchart....39

Figure 3-2: Location Map of Study Area (Mahaweli Basin, Sri Lanka)....41

Figure 3-3: Nawalapitiya watershed and stream network....42

Figure 3-4: Land use in Nawalapitiya in Mahaweli Ganga....43

Figure 3-5: Thaldena watershed and stream network....45

Figure 3-6: Landuse in Thaldena Catchment....46

Figure 3-7: Padiyatalawa watershed and stream network....47

Figure 3-8: Land use of Padiyatalawa in Maduru Oya Basin....48

Figure 3-9: Visual data checking for Nawalapitiya Catchment....55

Figure 3-10: Visual data checking for Thaldena Catchment....55

Figure 3-11: Visual data checking for Padiyatalawa Catchment....56

Figure 3-12: Correlation of observed stream flow and Rainfall Nawalapitiya....56

Figure 3-13: Correlation of observed stream flow and Rainfall Padiyatalawa....57

Figure 3-14: Correlation of observed stream flow and Rainfall Thaldena....57

Figure 3-15: Singe Mass Curve all station for trend analysis....58

Figure 3-16: Single Mass Curves for rain gauging stations -Nawalapitiya....59

Figure 3-17: Single Mass Curves for rain gauging stations -Thaldena....59

Figure 3-18: Single Mass Curves for rain gauging stations -Padiyatalawa....59

Figure 3-19: Single Mass Curve of evaporation for Padiyatalawa station....60

Figure 3-20: Single Mass Curve of evaporation for Kotmalle for Nawalapitiya....60

Figure 3-21: Single Mass Curve of evaporation for Girandurukotte for Thaldena....60

Figure 3-22: Double Mass Curve (Lower Spring Station) with other station data....61

Figure 3-23: Double Mass Curve (Badulla Station) with other station data....61

Figure 3-24: Annual Water Balance of Nawalapitiya Watershed 62

Figure 3-25: Annual rainfall and streamflow comparison for Nawalapitiya 63

Figure 3-26: Water Balance for Nawalapitiya Catchment..63

Figure 3-27: Annual runoff coefficient verses rainfall – Nawalapitiya.....................63

Figure 3-28: Annual Water Balance- Padiyatalawa Watershed................................64

Figure 3-29: Annual rainfall and streamflow comparison for Padiyatalawa 64

Figure 3-30: Annual runoff coefficient verses rainfall – Padiyatalawa.....................64

Figure 3-31: Annual Water Balance- Thaldena Watershed 65

Figure 3-32: Annual rainfall and streamflow comparison for Thaldena 65

Figure 3-33: Annual runoff coefficient verses rainfall – Thaldena Catchment 65

Figure 3-34: Annual water balance for Thaldena..66

Figure 3-35: Annual Runoff Coefficient Nawalapitiya 66

Figure 3-36: Annual Runoff Coefficient Thaldena 67

Figure 3-37: Annual Runoff Coefficient Padiyatalawa 67

Figure 3-38: Monthly comparison of Isohyetal average rainfall for Nawalapitiya....68

Figure 3-39: Monthly comparison of Isohyetal average rainfall for Thaldena 69

Figure 3-40: Monthly comparison of Isohyetal average rainfall for Padiyatalawa....69

Figure 3-41: Monthly Streamflow comparison for Nawalapitya 70

Figure 3-42: Monthly comparison of Stream flow Thaldena...................................70

Figure 3-43: Monthly comparison of Stream flow Padiyatalawa 71

Figure 3-44: Monthly Comparison of Pan Evaporation-Kotmalle (Nawalapitiya)....71

Figure 3-45: Monthly Comparison of Pan Evaporation-Girandurukotte (Thaldena).72

Figure 3-46: Monthly Comparison of Pan Evaporation-Padiyatalawa......................72

Figure 4-1: Rainfall Trends of wet zones Rain gauge station in Mahaweli Basin....74

Figure 4-2: Rainfall trends in rain gauge stations in Dry Zone of Mahaweli Basin...76

Figure 4-3: Rainfall trends in stations in Intermediate zone of Mahaweli Basin 79

Figure 4-4: Sen Slope Estimation 81

Figure 4-5: Warm up period and initial soil moisture storage in Padiyatalawa 82

Figure 4-6: Warm up period and initial ground moisture storage in Padiyatalawa....82

Figure 4-7: Warm up period and initial soil moisture storage in Thaldena 82

Figure 4-8: Warm up period and initial ground water storage in Thaldena...............83

Figure 4-9: Warm up period and initial soil moisture storage in Nawalapitiya 83

Figure 4-10: Warm up period and initial ground water storage in Nawalapitiya.......83

Figure 4-11: Simulated flow from first trial (2004~2013) in calibration- Nawalapitiya 84

Figure 4-12: Simulated flow from first trial (2014~2018) in validation- Nawalapitiya 85

Figure 4-13: Simulated flow from first trial (2004~2014) in calibration- Padiyatalawa 85

Figure 4-14: Simulated flow from first trial (2014~2018) in validation- Padiyatalawa 86

Figure 4-15: Simulated flow from first trial (2004~2014) in calibration- Thaldena ..86

Figure 4-16: Simulated flow from first trial (2014~2018) in validation-Thaldena 87

Figure 4-17: Outflow hydrograph of Nawalapitiya for calibration period 2004~2013 89

Figure 4-18: Outflow hydrograph of Nawalapitiya for validation period 2014~2018 89

Figure 4-19: Outflow hydrograph of Padiyatalawa for calibration period 2004~2013 90

Figure 4-20: Outflow hydrograph of Padiyatalawa for validation period 2014~2018 90

Figure 4-21: Outflow hydrograph of Thaldena for validation period 2014~2018 91

Figure 4-22: Outflow hydrograph of Thaldena for validation period 2014~2018 91

Figure 4-23: Annual water balance of Nawalapitiya – Calibration Period 92

Figure 4-24: Annual water balance of Nawalapitiya – Validation Period 93

Figure 4-25: Comparision of Observed and Simulated Water Balance of Nawalapitiya 93

Figure 4-26: Annual water balance of Thaldena – Calibration Period 94

Figure 4-27: Annual water balance of Thaldena – Validation Period 94

Figure 4-28: Annual water balance comparison for Thaldena 95

Figure 4-29: Annual water balance of Padiyatalawa – Calibration Period 95

Figure 4-30: Annual water balance of Padiyatalawa – Validation Period 96

Figure 4-31: Annual water balance comparision for Padiyatalawa 96

Figure 4-32: Flow Duration Curve for Nawalapitiya for the calibration period 97

Figure 4-33: Logarithmic plot of Flow Duration Curve of Nawalapitiya for calibration `...98

Figure 4-34: Flow Duration Curve for Nawalapitiya for the verification period 98

Figure 4-35: Logarithmic plot of flow Duration Curve of Nawalapitiya for verification 98

Figure 4-36: Flow Duration Curve for Thaldena for the calibration period 99

Figure 4-37: Log plot Flow Duration Curve for Thaldena for the calibration period 99

Figure 4-38: Flow Duration Curve for Thaldena for the verification period 99

Figure 4-39: Logarithmic plot of Flow Duration Curve of Thaldena for verification 100

Figure 4-40: Flow Duration Curve for Padiyatalawa for the Calibration period 100

Figure 4-41: Logarithmic plot of Flow Duration Curve of Padiyatalawa for Calibration 101

Figure 4-42: Flow Duration Curve for Padiyatalawa for the Verification period....101

Figure 4-43: Logarithm plot of Flow Duration Curve of Padiyatalawa for Verification 101

Figure 4-44: Flow duration curve observed and simulated Nawalapitiya-Calibration 103

Figure 4-45: Logarithmic plot observed and simulated flow Nawalapitiya -Calibration 103

Figure 4-46: Flow duration curve for the simulated flow in Nawalapitiya for validation 104

Figure 4-47: Logarithmic plot of observed to simulated flow Nawalapitiya Validation 104

Figure 4-48: Flow Duration Curve observed and simulated flow Thaldena Calibration 105

Figure 4-49: Logarithmic plot for observed and simulated flow Thaldena calibration 105

Figure 4-50: Flow Duration Curve observed and simulated flow Thaldena validation 106

Figure 4-51: Logarithmic plot for observed and simulated flow in Thaldena validation 106

Figure 4-52: Flow Duration Curve observed and simulated Padiyatalawa calibration 107

Figure 4-53: Logarithmic plot of observed and simulated flow Padiyatalawa validation 107

Figure 4-54: Flow Duration Curve observed and simulated flow Padiyatalawa......108

Figure 4-55: Logarithmic plot observed and simulated flow Padiyatalawa validation 108

Figure 4-56: Annual surface water and groundwater flow of Thaldena calibration 110

Figure 4-57: Annual surface water and groundwater flow of Thaldena validation..110

Figure 4-58: Annual surface water and groundwater flow of Nawalapitiya calibration 111

Figure 4-59: Annual surface water and groundwater flow of Nawalapitiya validation 111

Figure 4-60: Annual surface water and groundwater flow of Padiyatalawa Calibration 112

Figure 4-61: Annual surface water and groundwater flow of Padiyatalawa validation 112

Figure 4-62: Rainfall scenarios for Nawalapitiya..114

Figure 4-63: Soil moisture content with climate change (Nawalapitiya) 116

Figure 4-64: Groundwater storage with climate change...117

Figure 5-1: Observed Flow Vs Simulated Flow for Padiyatalawa Catchment 121

Figure 5-2: Observed Flow Vs Simulated Flow for Thaldena Catchment 121

Figure 5-3: Observed Flow Vs Simulated Flow for Nawalapitiya Catchment 122

Figure 5-4: Simulated flow Vs Observed flow in Nawalapitiya for calibration period 122

Figure 5-5: Simulated flow Vs Observed flow in Nawalapitiya for Validation Period 123

Figure 5-6: Simulated flow Vs Observed flow in Thaldena for calibration 123

Figure 5-7: Simulated flow Vs Observed flow in Thaldena for validation 124

Figure 5-8: Simulated flow Vs Observed flow in Padiyatalawa for calibration 124

Figure 5-9: Simulated flow Vs Observed flow in Padiyatalawa for validation 125

LIST OF TABLES

Table 2-1: Climate Change Scenarios 7

Table 2-2: Summary of Rainfall Trend, South Asia (Source: Sanjay et al., 2013) 8

Table 2-3: The a,b,c,d parameters from literatures 27

Table 3-1: Summary of Nawalapaitiya Watershed 43

Table 3-2: Summary of Land use Nawalapitiya Sub- catchment 44

Table 3-3: Summary of Thaldena Watershed 44

Table 3-4: Summary of land use type for Thaldena Catchment 46

Table 3-5: Summary of Thaldena Catchment 48

Table 3-6: Summary of land use type for Padiyatalawa 49

Table 3-7: Rainfall Gauging Station Details of Mahaweli Basin 50

Table 3-8: Data Sources and resolutions for Nawalapitiya 51

Table 3-9: Rainfall, Streamflow and Evaporation Station of Nawalapitiya 51

Table 3-10: Data Sources and resolutions for Thaldena 52

Table 3-11: Rainfall, Streamflow and Evaporation Station of Thaldena 52

Table 3-12: Data Sources and resolutions for Padiyatalawa 53

Table 3-13: Rainfall, Streamflow and Evaporation Station Padiyatalawa 53

Table 4-1: Summary of Trend of Mahaweli Basin 80

Table 4-2: Initial values for model parameters for all watersheds 87

Table 4-3: Objective function values from first calibration trial 87

Table 4-4: Optimized "abcd" parameters and objective functions 88

Table 4-5: Identified flow regimes for selected watersheds 102

Table 4-6: Climate change scenarios for Nawalapitiya 113

Table 4-7: Model Simulated Streamflow with Climate Change 114

Table 4-8: Soil moisture storage for scenarios (Nawalapitiya) 115

Table 4-9: Groundwater storage scenarios (Nawalapitiya).....................................116

Table 5-1: Parameters and objective function values 126

LIST OF ABBREVIATIONS

Abbreviation	**Description**
IPCC	Intergovernmental Panel on Climate Change
MSL	Mean Sea Level
Pt	Monthly precipitation
Et	Actual evapotranspiration,
Rt	Recharge to groundwater storage,
QU_t	Upper zone contribution to runoff
XU_t	Upper soil zone soil moisture storage at the current time step
XU_{t-1}	Upper soil zone soil moisture storage at the previous time step
MRAE	Mean Ratio of Absolute Error
MSE	Mean Square Error
NSE	Nash Sutcliffe efficiency
SC	Field capacity of the catchment
WMO	World Meteorological Organization
EOt	Evapotranspiration opportunity
Rt	Groundwater Recharge
XL_t	Soil moisture storage in ground water compartment after recharging
QL_t	Discharge from ground water compartment
Q_t	Total stream flow
PE	Potential Evapotranspiration
FAO	Food and Agriculture Organization
Kc	Crop coefficient
Cp	Pan Co-efficient
Rem	Relative Maximum Error
RMSE	Root Mean Square Error

1 INTRODUCTION

1.1 General Introduction

As the planet continues to warm up at an alarming rate, the influences of unstable weather might be dramatically changing the hydrologic cycle via adjustments to its individual components (Watts et al., 2015).There are perturbing projections of climate influences to global water sources (IPCC, 2007) and examples are found all over the world (Barnett et al., 2008; Cayan et al., 2008). The issue of climate change has emerged very strongly over the last two decades on a global scale in many areas around the world, and growing temperatures and their impact on the cryosphere and rainfall are evident. Sri Lanka, situated between 6 and 10 degrees to the North of the equator has predominantly a monsoonal and tropical climate. For proper water management practices, a detailed perception of change in precipitation in a catchment over time is essential. Monthly water balance models are widely used to identify water availability, watershed characteristics, water management, and hydrological impacts of climate change at the basin level and with long term perspectives.

The variability of rainfall has increased geographically, across seasons, and annually in Asia over the past few decades. Between the periods 2003-2012, an insignificant increase of 0.78°C was observed with respect to the period 1850-1900. It is stated in IPCC (2013) that the global mean surface temperature is projected to increase by 0.3 – 1.7°C, 1.1 – 2.6°C, 1.4 – 3.1°C and 2.5 – 4.8°C in RCP2.6, RCP4.5, RCP6.0 and RCP8.5 for the period1986-2005, respectively. This increasing global warming may disturb the globe's hydrological cycle and may even cause public health, industrial, and municipal water-related problems, resulting in an ecosystem imbalance in the hydropower sector (Mahmood, Babel & Shaofeng, 2015). However, according to Basnayake (2008); Basnayake et al., (2004); Basnayake and Vithanage (2004); De Silva (2006), it is difficult to conclude about climate change impacts on water resources due to contradicting rainfall projections.

The identification of rainfall trends over three climatic zones of Mahaweli Basin and then the performance of *abcd* lumped model in reproducing historical streamflow components is evaluated; and second, the differences in the simulated hydrological flows under climate change by the lumped model was evaluated on the watersheds lying in each climatic zone along with the elasticity of streamflow to rainfall.

1.2 Problem statement

Climate change or its increased variability is expected to alter the timing and magnitude of runoff. There is a need for an established tool for the watershed to manage water resources in a catchment under the climate change situation, Climate change regarding spatio-temporal variability of precipitation, temperature furthermore, humidity could have a solid effect on agriculture needs a significant and progressing research to act as needs be. In such a manner, climate change as precipitation variability attributable to the fluctuations of the stream has turned into a noteworthy test for water resources management in Sri Lanka where the agricultural framework is hugely rain-fed.

Hence, reliable stream flow estimation in monthly temporal scale is an important component for the management of water resources in Sri Lanka.

1.3 Research Objective

The research objective is to identify the variability of climate and its impact on the water resources management in Sri Lanka focusing on Mahaweli Basin which spans over all three main climatic zones in Sri Lanka.

1.3.1 Main objective

The objective of this study is to examine the nature of trends in precipitation over the three climatic zones of Mahaweli, as affected by the changes in climate impact and consequent effects on the streamflow on the watershed to manage water resources more productively.

1.3.2 Specific objectives

1. State of art literature review with a comprehensive study of climate change and its impact on streamflow.
2. Identify rainfall trend and investigating changes of the trendover the three climatic zones of Mahaweli basin.

3. Developing, calibration and verification of "*abcd*" lumped hydrologic model for catchments in each climatic zones.
4. Identify streamflow elasticity to the rainfall of the sub-catchment in each climatic zone respectively.
5. Derive conclusions and develop recommendations and guidelines targeting mitigatory measures.

1.4 Scope and Limitations

The findings of the study will introduce a quantification of possible variations in watershed discharge under the future climate change scenarios including how the river streamflow will behave according to rainfall variability.

Precipitation supplies water to river basins which in turn provide water for domestic use as well as industrial production which are economically important areas of the country where economic development and sustainability are concerned.

The "abcd" model is not capable of handling basins with any huge water storages and stream administrative structures in the watershed which will influence the natural reaction of the stream to the precipitation. For the chosen watersheds, it was ensured that there are no such huge water storages and this reality was confirmed in the visual information check by watching a fitting reaction of streamflow to precipitation. Notwithstanding that, as indicated by Martinez and Gupta (2010), the model does not perform well with its regular model structure for the catchments which has snow falling and the model structure should be adjusted likewise. The reason might be due to the drawback that the streamflow under such situation is made up of both runoff snowmelt. This was not an issue for the chosen watersheds since snowfall is not a mode of precipitation in Sri Lanka.

The model runs were carried out with available data for calibration and validation and where terrain data was not available for catchment delineation, satellite terrain data sources were used in combination with available stream and land use survey data sets. However, the accuracy and performance of the model and subsequent results are highly dependable on the input data sets used in the process.

1.5 Thesis Outline

Initially, a comprehensive state of the art literature study was undertaken for identifying the problem and better understanding the present status of research in the basin and climate change-related studies ongoing at the moment.

Therefore, Chapter One - Introduction covers a general scrutiny about climate change and related study, followed by problem identification and solving approach with the research main objective with specific objectives.

Chapter Two - Literature Study/Review part contains a review of climate change study and their impacts in South Asia and Sri Lanka, in respect to climate change and streamflow variability. Further, it is extended to cover topics hydrological modeling, model availability and data availability, etc., with a brief coverage onparameter evaluation and objective function, evaluation of model performance, followed by a deep literature survey onstreamflow elasticity and rainfall trend analysis.

Chapter Three - Methods and Materials part contains the whole methodology for solving the identified problem from details of the selected site, data collection, data checking and water balance checking for modeling, followed by overall research methodology followed in the study.Detailed introduction to hydrology of the basin and catchment characteristics are provided in this part for proper understanding of the gravity and linkage of theof the problem, objectives and solution approach.

Chapter Four - Analysis and Result contains the resultsobtained from the data checking, rainfall trend analysis and hydrological modeling exerciseswith the proper analysis, interpretation and evaluation of the results.

Chapter Five - Discussion

Chapter Six - Conclusion and Recommendations

2 LITERATURE REVIEW

2.1 Introduction

Climate change effects are a key theme of concern particularly when water is the fundamental topic.A study of climate change and rainfall trends over Sri Lanka with required data duration was conducted for literature review. Studies on climate change of South Asia and impacts on water resources were evaluated, regional climate change and scenario analysis for Sri Lanka taken for future analysis of water resources management using hydrological modeling with calibration and validation of model. A rainfall trend analysis of Sri Lanka studied for trend identification of three climatic zones.

There is evidence to confirm that the climate of South Asian locale has as of now change (IPCC, 2007; Wijeratne et al., 2009; Premalal, 2009; Eriyagama et al., 2010). Concurring to a inquire about report distributed by Worldwide Water Administration Organization, Sri Lanka,(Eriyagama et al., 2010)expressed “During 1961-1990, the country’s cruel discuss temperature expanded by 0.016°C per year, and cruel yearly precipitation diminished by 144 millimeters (mm) (7%) compared to that of 1931-1960. In any case, the greater address of national significance is what Sri Lanka’s climate will see like in 50 or 100 a long time and how arranged the nation is to tackle such changes.Scarcely any considers attempted to broaden future atmosphere situations for Sri Lanka and to recognize atmosphere modify impacts on agribusiness, water resources, the sea level, the farm section, the economy and wellbeing.

Quantitative estimates of the hydrological impacts of climate change at local and regional scales are crucial for understanding and resolving future water resource management issues connected with water supply for national and industrial water use, energy generation and agriculture (Steele-Dunne et al., 2008 ; Chen et al., 2012).In aspects to select a suitable hydrologic model for water resources quantification purpose of each watershed in the three climatic zone of Mahaweli, it is very crucial to study on the various forms of the hydrologic models present with their various usages and benefits,required most favorable number of model parameters, and selection of an most advantageous temporal resolution and data period. After model evaluation, components of the model, characteristics of the parameters, inputs, drawback and its applications in different regions of the world, have to be analyze. In application of the model for the corresponding watersheds, model calibration and validation principle must be identified to evaluate the model workability for the incorporated objectives. Drafting of initial values and intensification of warm up period for the model is also important in the modeling purpose which needs to be checked under literature review.

2.2 IPCC Climate Change Scenarios

Only SRES scenarios A1F1, A2, B1 and B2 were predicted for Sri Lanka. In a research conducted using HadCM3 GCMs, CSIRO and CGCM predict an rise in temperature of 2 – 3℃ in the A1F1 situation, 0.9 – 1.4℃ in the B1 situation and 1.7 – 2.5℃ in the A2 situation in the late 21st century (Basnayake, et al., 2004). Another research using the HadCM3 model anticipated a temperature rise of 1.6℃and 1.2℃by 2050, respectively under A2 and B2 scenarios (De Silva, 2006). Previous assessments showed consistency for temperature predictions across global climate models. Projections for precipitation have increased variability (Eriyagama, et al., 2010); (Mahanama & Zubair, 2011). Recent small drying trends have occurred in areas of Sri Lanka (Environment Ministry, 2000, 2010; Zubair et al., 2006). The assessment of climate change precipitation predictions in Sri Lanka is therefore particularly essential, given that annual rainfall has elevated spatial variability (500 mm to 5500 mm) ; (Lyon et al., 2009).Sri Lanka is located in a tropical climatic region. In tropical climates, large variant can be observed in parameters of RF, wind and strain while variant of temperature from season to season is usually now not considerable. On this segment, we summarize the general sample of climate observed in Sri Lanka. This assessment is especially based totally on Chandrapala (2007: a & b), Basnayake (2007 & 2004), Abhaysinghe (2007) and Jayatialke et al. (2004).

Critical climate change scenarios have been recognized by superimposing the worst-case scenario of both observed and expected changes in Sri Lanka for 2050 as shown in the table below.

Table 2-1: Climate Change Scenarios

Scenario	**Change**	**Precipitation**	**Temperature**
Scenario 1	NEM (Decrease) NEM (Increase)	34% 38%	2.5℃
Scenario 2	NEM (Decrease) NEM (Increase)	26% 16%	2.5℃
Scenario 3	NEM (Decrease) SWM (Decrease) (Monsoon shift by one month)	26% 16%	2.5℃
Scenario 4	Mean Annual Rainfall (Increase)	25%	2.5℃
Scenario 5	Mean Annual Rainfall Wet Zone (Increase)	7%	2.5℃
Scenario 5	Mean Annual Rainfall Intermediate Zone (Increase)	15%	2.5℃
Scenario 5	Mean Annual Rainfall Dry Zone (Increase)	22%	2.5℃

2.3 Observed Climate Change over the South Asia

Most South Asians are still involved in agriculture and related industries. This includes increased variability in both monsoon and winter rainfall pattern; increase in average temperature, with warmer winters; increased salinity in coastal areas, as a result of rising sea level and reduced discharge from major rivers; and increased frequency and/or severity of extreme weather events (floods, cyclones, droughts).

Table 2-2: Summary of Rainfall Trend, South Asia (Source: Sanjay et al., 2013)

S.No.	**Country**	**Precipitation Change**	**Temperature Change**
1.	Bangladesh	Increasing trend in May of around 1.0°C and in November of 1985 to 1998 of 0.5 ° C	Decadal rain anomalies since the 1960s above long-term averages
2.	India	An increase of 0.68°C per century with increasing annual mean temperature trends and warming during the post-monsoon and winter seasons	Increase in severe rainfall in the northwestern region during the summer monsoon in latest decades and decrease in rainy days along the eastern shore
3.	Nepal	An increase of 0.09°C per year in the Himalayas and 0.04°Cmore winter in the region.	No distinct long-term trends in 1948-1994 rainfall records
4.	Pakistan	A mean temperature increase of 0.6-1.0°C in coastal regions since the early 1900s	Decline in the coastal belt and hyper arid plains by 10-15% and increase in summer and winter precipitation in northern Pakistan over the last 40 years
5.	Sri Lanka	Between 1961 and 1990, 0.016°C increased annually over the whole country and 0.02°C increased annually in the central highlands.	An upward trend in February and a downward trend in June

Climate change is already affecting a large number of people across South Asia in different ways as Table 2-1 indicates. The region is particularly vulnerable to climate change owing to high population density and concentrated poverty, and existing climate variability. Climate change has the potential to compound the prevailing development problems and increase pressure on key resources needed to sustain growth.

The incidence of extreme occurrences and environmental degradation will impact many life and properties worth thousands of millions of dollars in the South Asian area due to global warming and climate change. These incidences are growing in intensity and severity year after year. South Asian nations have already been impacted by climate change and feasible measures are needed to minimize adverse impacts. According to Stern (2006),From the Himalayas, which feed a billion individuals on water, to Bangladesh's coastal regions, South Asian nations must prepare for the impacts of worldwide warming while working to tackle the human causes of climate change.

The gravity of the issue can be well understood by looking at statistical statistics and different trends and projections on climate change and its implications. If we fail to take meaningful action and suitable mitigation measures from now on, according to the experts projections, it may be too late or render our survival very hard. By the beginning of the 21st century, South Asia is expected to experience a 2-6℃warming.For the next two centuries, a warming of about 0.2℃ is expected According to specialists, South Asia is already experiencing climate change heats. South Asian nations are very susceptible to climate change for a variety of reasons: geo-climatic conditions, socio-economic demographic backgrounds, overwhelming reliance for livelihoods on agriculture and rural industries (Yohe and others (2008).

Climate change will influence horticulture division over South Asian countries very drastically. South Asia is under serious danger from sea-level rising and expanding rates of extraordinary occasions such as floods, dry seasons, violent winds, storms and inconsistency of storm. Mitigation and adaptive policies at worldwide, regional and local level are needed to address the reality of climate change. As an unit, South Asian nations can negotiate better with global groups and develop joint coping systems.

2.3.1 Impacts of rainfall variability in South Asia

Current climate vulnerabilities are heavily associated with climate variability, especially variability in precipitation. These climate change vulnerabilities are most important in semi-arid and arid low-income countries with big dryland tracts, where precipitation and streamflow focused over a few months, and where there are elevated year - to-year differences (Lenton, 2004). The significant issue in such areas is the absence of profound groundwater wells or reservoirs that result in a high rate of vulnerability to climate variability and climate change that is likely to further boost climate variability in the future. Water resources are inextricably related to climate, which means that the prospect of global climate change has serious consequences for water resources and regional growth (Riebsame et al., 1995). Intensive rainfall trends with the potential for huge occurrences of rainfall spread over a few days are probable to affect water recharge rates and conditions of soil moisture. A hotter climate, with its enhanced variability in climate, will boost both flood and droughts risk (Wetherald & Manabe, 2002). South Asia has large rivers, which are the regional economy's lifelines. Agricultural irrigation demand is estimated to increase by at least 10 percent in the arid and semi-arid regions of Asia for a temperature increase of 1.0°C (Fischer et al., 2002 ; Liu, 2002). Efforts to offset decreasing surface water accessibility owing to increased variability in precipitation will be hampered by a considerable decline in groundwater recharge in some water-stressed areas. The poor, who have the most restricted access to water resources, will continue to feel the most important effect. In many nations in South Asia, rapid depletion of water resources is already a source of concern. Approximately 2.5 billion individuals in South Asia will be impacted by water pressure and scarcity by 2050. These problems are generally exacerbated by long periods of droughts and floods and are often particularly serious during El Nino occurrences (Vogel, 2005;Stige et al.,2006). The effect of precipitation and evaporation modifications in some lakes and reservoirs could have deep impacts.

2.4 Climate Change in Sri Lanka

Weather and climate are ideas that are tightly linked. Weather defines the state of atmosphere over a brief period of moment (daily,hourly) in a specified geographical place. Climate is the average weather condition taken in months to years over a comparatively long period of time. Meteorological parameters determine both climate and weather. Temperature, rainfall, pressure, length and intensity of sunlight, moisture and direction and wind speed are among the main meteorological parameters.The world was split into a number of climatic areas based on the variability of climatic circumstances observed worldwide. Many of the key meteorological parameters are temperature, precipitation, strain, length and intensity of sunshine, humidity and path and speed of wind,based totally on the version of climatic situations found globally, the arena has been divided into a number of climatic zones. Similarly, future climate projections indicated that the temperature increases of 5.44℃ and 2.93℃ over South Asia in the summer of 2070-2099.In Sri Lanka, the observed climate change involves the rate of temperature rise from 1961 to 1990 being 0.016 ℃ per year, declining trend in annual average precipitation (MAR) by 144 mm (7%) in 1961-1990 compared to that in 1931-1960 and nation as a whole, the amount of successive dry days has risen while the amount of successive moist days has dropped.

Yearly precipitation fluctuation has expanded practically everywhere throughout the nation, yet inconstancy is high in the dry zone than middle of the road and wet zone. Few climate models for South Asia also project significant warming in the countries of South Asia, including in Sri Lanka, annual mean temperature increase in the range 2.5 - 4 ℃ for the IPCC scenario towards the end of the twenty-first century and IPCC predictions of greater warming during the north-eastern monsoon (NEM) and reduced warming during the SWM. The 2℃ temperature rise would influence an evaporation rise of 8 percent. While greater values for MAR are the bulk of the study project, a few surveys project lesser values. Projection shows a reduction of 26-34 percent in NEM rainfall and an increase of 16-38 percent in SWM rainfall relative to 1961-1990. Some scientists proposed that the SWM rise be greater than the NEM rise.

2.4.1 Observed Trends of Climate in Sri Lanka

The economy of Sri Lanka is highly reliant on water resource accessibility. Rain-fed and irrigated agriculture accounts for 22% of Sri Lankan exports, while sectors contributing to 75% of exports use energy from the domestic grid, 62% of which is produced by hydropower. Due to population growth and advances in irrigation and agricultural and industrial procedures, the quantity of water consumption has also risen over the previous centuries. A latest Madduma Bandara et.,2004, studyhas shown a substantial decrease in rainfall over the last century at Nuwara Eliya and a number of other stations on the western slopes of the highlands. The decrease of the Southwest Monsoon precipitation has been recognized as the cause of the decrease in total rainfall on the western slopes There has been no consistent rise or decline in trends for wet or dry zone in the last century. For stations on the eastern side like Badulla, no important trends have been noted. The regional mean temperature variation for Sri Lanka between 1960 and 2000 shows that the warming trend is between 1.5 and 2.6°C/100 years. The South-West warming is the least and the North-West and South-East warming is the highest.

Climate change in Sri Lanka In Sri Lanka, with a temperature rise from 1961 to 1990 of 0.016°C per year, decreasing trend in average annual precipitation (MAR) by 144 mm (7%) in 1961-1990 compared to 1931-1960 and the nation as a whole, the amount of concurrent dry days improved while the amount of successive moist days is reduced.

2.4.2 Impacts by Increased Temperature

There is no good-sized annual variant in temperature due to range in Sri Lanka. Consequently, the island does no longer experience an annual cycle of one-of-a-kind seasons with contrasting temperature differences as in temperate nations. However, mild version of monthly common temperature might be determined due to seasonal motion of solar and impact of rainfall. Hence, in many regions the good period is December-January. March-April and August are especially heat months. In a given day, most and minimum temperatures are normally recorded inside the afternoon and earlier than dawn of the sunlight, respectively. The rising temperatures can also indirectly decrease the impacts of CO2 by raising the demand for water. Rain-fed wheat grown at 450 ppm CO2 showed yield increases with temperature rises of up to 0.8°C but decreases with temperature rises above 1.5°C; extra irrigation was required to counterbalance these negative impacts (Xiao et al., 2005 ; Shivakumar & Stefanski, 2011). Temperature increases can have a negative effect on rice and wheat yields in tropical areas of South Asia where these plants have grown near their limit of temperature tolerance (Kelkar & Bhadwal, 2007). Kumar & Parikh (2001), shows that a 26°C increase in mean temperature and a 7% increase in mean rainfall, even after accounting for farm level adjustment, will lead to a 8.4% reduction in net profits in India. Half a degree temperature increase in Sri Lanka is expected to decrease rice production by 6 percent, and enhanced dryness will adversely impact the returns of critical products such as tea, rubber, and coconut reported in 2000 by the Ministry of Environment and Natural Resources. An increase of 2.5°C in average temperature would translate the wheat planting and growing phases into a much greater ambient temperature. Higher temperatures are more probable to result in yield decrease, primarily owing to shortening the crop life cycle, particularly the filling period of grain. An increase of 2.5°C in average temperature would translate the wheat planting and growing phases into a much greater ambient temperature. In these regions, dry land and mountain regions are more probable to be susceptible than others (Gitay et al., 2001), as well as ecosystem degradation are important (Hassan et al., 2005).Climate change is more probable to result in extra inequities as its effects are dispersed unevenly across space and time and impact the poor disproportionately (Tol, 2001 ; Stem, 2007).

2.4.3 Changes in the Pattern and Rate of Precipitation

Rainfall is the primary parameter that gives upward push to variability of climatic conditions at some stage in the once a year cycle. There are 3 fundamental assets of RF in Sri Lanka, Specificallymonsoonal, convectional and depressional thathas a median annual RF round 1861 mm with large version in regional distribution that range from 900 mm to 5000 mm in keeping with the distribution sample of RF from 3 resources, the Southwestern zone and positive regions of imperative highlands (western slope of relevant highlands) get hold of the very best RFareas on this place (e.g., Yatiyantota, Ginigathhena, Watawala) have recorded annual RF over 5000 mm.In evaluation, coastal areas in Southeastern (e.g., Yala, Palatupana) and Northwestern (e.g., Mannar) quarters receive the lowest annual RF of much less than 1000 mm. Many areas of South Asia have seen a slow but unique shift in precipitation frequency and this will boost many folds in the near future. Even regions that were previously very well-known as greater rainfall recipients are gradually becoming very dry regions and facing even a shortage of ordinary rainfall. Areas that have never seen periodic rainfall in the season have received a lot of rainfall in latest years and other traditional regions where rainfall used to be greater get almost nothing. Due to modifications in the rate of groundwater precipitation concentrations in many regions of South Asia, other sections will be over flooded. Agriculture will be impacted in both fields. Less precipitation will force individuals to pump more groundwater for farming and other uses. Over pumping and groundwater mass-use will also adversely affect the condition from another front.

2.5 Data Requirement for Trend Analysis

For the rainfall trend analysis of three climatic zones of Mahaweli 18 stations selected according to their distribution. Distribution of gauging stations were compared with WMO (1975) and found satisfactory. A 30 years of monthly rainfall data obtained Meteorology Department, Sri Lanka for identification climatological change as per IPCC suggestion. Therefore, the period of 30-year is assumed to be long enough for a valid mean statistic (Kahya & Kalayci, 2004).

2.6 Mankendall Test for Trend Analysis and Sen’s Slope Estimation

Statistically, trend is a major shift over time that can be detected through parametric and non-parametric processes, while trend analysis of a time series consists of trend magnitude and statistical significance. In this research, trend analysis of statistical significance was performed using Man- Kendall test while the estimator technique of nonparametric Sen’s slope method was used to determine the magnitude of the trend.

Trend analysis of rainfall were done utilizing the nonparametric Mann-Kendall (MK) test (Helsel and Hirsch, 1992). This test has been broadly utilized for hydrological information investigation (Lettenmaier et al., 1994; Molnar and Ramirez, 2001; Zhang et al., 2001; Birsan et al., 2005). It is a position based technique particularly reasonable for non-ordinarily conveyed information, edited information, and nonlinear patterns.This technique can be adopted in cases with non-normally distributed data, data containing outliers and non-linear trends (Helsel and Hirsch 1992; Birsan et al. 2005). The Mann-Kendall S Statistic is computed as follows:

If n>=8 and Ho holds, the statistic is:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(x_j - x_i\right) \text{ ....Equation 1}$$

According to this test, the null hypothesis Ho outlines that the de-seasonalised data (x1,.., xn) is a sample of n independent and identically distributed random variables. The alternative hypothesis H1 of a two-sided test is that the distributions of xk and xj are not identical for all k, j and n. The resulting test statistic S indicates an upward trend if its value is positive and a downward trend, otherwise.

$$\mathrm{Var}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{n_t} t_i (t_i - 1)(2t_i + 5) \right] \text{ ....Equation 2}$$

The standard test statistic Z is calculated as follows:

$$Z_{MK} = \frac{S+m}{\sqrt{V(S)}} \quad \begin{array}{l} m = 1 \quad if \quad S < 0 \\ m = 0 \quad if \quad S = 0 \\ m = -1 \quad if \quad S > 0 \end{array} \quad \left|Z_{MK}\right| > Z_{1-\alpha/2} \text{ ....Equation 3}$$

A positive estimation of Z shows an upward pattern, while a negative worth shows a descending pattern in the tried time arrangement. Factually critical patterns are commonly announced at the 10% criticalness level (α = 0.1, two-followed test), or certainty level β = 1 - α = 0.90. The pattern test measurement Z is utilized as a proportion of pattern greatness, or of its importance. It's anything but an immediate measurement of pattern greatness.

The MK test ought to be connected to uncorrelated information (Helsel and Hirsch, 1992).This strategy is appropriate for almost direct pattern in the variable x and is less influenced by non-ordinary information and exceptions (Helsel and Hirsch, 1992). To check for the impact of the pre-brightening on the outcomes, we broke down both unique information just as prewhitened information. Since sequential relationship coefficients were by and large low for the yearly and occasional time arrangement, the contrasts between the two methodologies were not enormous. The technique was connected to yearly, occasional and monthly information. Four climatological seasonswere distinguished in the basin, and dissected independently

2.7 Rainfall Elasticity of Streamflow

There have been various examinations on the affectability of streamflow to atmosphere in specific, to changes in precipitation and potential evapotranspiration. A considerable lot of these studies are done to evaluate the potential effects of environmental change on streamflow also, water assets. Most include utilizing a hydrological model, where

a) The model is adjusted against chronicled streamflow information.
b) The information atmosphere information are altered to mirror an upgraded nursery condition.
c) The model is run utilizing the altered info information and the equivalent enhanced parameter esteems.
d) The reproduced streamflow is contrasted against the verifiable streamflow with given gauge of the environmental change sway on streamflow.

Various examinations have archived the affectability of streamflow to atmosphere changes for Basin over the world (Fu and Liu, 1991; Yates and Strzepek, 1998; Sankarasubramanian et al., 2001; McCarthy et al., 2001; Arnell, 2002; Chiew, 2006; Fu et al., 2007a). The greater part of these investigations include assessing the precipitation versatility of streamflow, which was presented by Schaake(1990) for assessing the affectability of streamflow to changes in atmosphere. Dooge (1992) and Dooge et al. (1999) named it an affectability factor furthermore, Kuhnel et al. (1991) named it an amplification factor.

2.7.1 Importance of Rainfall Elasticity of streamflow

The demonstrating approach commonly gives a dependable gauge of the sensitivity of streamflow to atmosphere where an appropriate model is utilized and adjusted appropriately. Be that as it may, the decision of the model, adjustment technique and alignment criteria are emotional. There may likewise be a need to utilize various models for locales with various climatic and physical attributes.

The vulnerability in results emerging from model decision can be overwhelmed by assessing the affectability of streamflow to atmosphere straightforwardly from the verifiable atmosphere what's more, streamflow information. The nonparametric estimator proposed by Sankarasubramaniam et al. (2001) offers a potential for assessing the affectability of streamflow to precipitation straightforwardly from the chronicled information that is effectively reproducible and "solid".

The fundamental constraints of this methodology are that it doesn't consider changes in the precipitation recurrence and appropriation, changes in vegetation qualities under various climatic conditions, and potential inputs between the environment what's more, the land surface. Be that as it may, the versatility gives a straightforward gauge of the affectability of longhaul streamflow to changes in long haul precipitation that can be utilized for evaluating environmental change sway in land and water assets ventures, preceding, or in the nonappearance of, an increasingly definite displaying study.

2.7.2 Elasticity Estimation using a Non -Parametric Estimator

Climate elasticity of streamflow might be characterized as the relative change in streamflow (Q), to the adjustment in a climatic variable, for example precipitation (P). Along these lines precipitation versatility of streamflow is characterized as (Schaake, 1990; Sankarasubramanian et al., 2001).

$$Ep(P,Q) = \frac{d(Q/Q)}{d(P/P)} = \frac{dQ}{dP} . \frac{P}{Q} \text{.......................................Equation 4}$$

One trouble with estimation of flexibility is that it is regularly evaluated from a hydrological model and, obviously, the type of the hydrological model is constantly obscure and approval of such a model remains a crucial test (Sankarasubramanian et al., 2001).The further verified and improved nonparametric estimator proposed by Sankarasubramaniam et al. (2001) is utilized here to gauge ε_p for the catchments of each climatic zone. The nonparametric estimator can be communicated as:

$$Ep = Median(\frac{Qt-\bar{Q}}{Q_t-\bar{P}}) \cdot {}^{\bar{P}}\!/_{\bar{Q}} \text{......................................Equation 5}$$

where $\bar{P}$ and $\bar{Q}$ are the mean annual rainfall and streamflow.

To estimate Ep a value of $\frac{Qt-\bar{Q}}{Q_t-\bar{P}}$ is calculated for each pair Q_t and P_t of and in the annual time series, and the median of these values is the nonparametric estimate of Ep. This nonparametric estimator of Ep is therefore defined at the mean value of the hydroclimatic variable.

2.8 Hydrological Modeling and Hydrologic Model Classification

Hydrological models provide a structure for the conceptualization and investigation of climate and water resources interactions (Xu, 1999; Jothityangkoon et al., 2001; Xu et al., 2005; Chen et al., 2012b; Jung et al., 2012; Jiang et al., 2012; Yang et al., 2012).For watershed management, hydrological modeling is essential as hydrology is the driving force behind many watershed procedures. Hydrology and hydrological interactions need to be studied and simulated to clarify the mechanisms governing procedures in a water body (streams, lakes or soil). There are many distinct large-scale watershed flow models that describe procedures linked to runoff, sediments, and nutrient motion through big river basin drainage networks. It is possible to apply equations of such models on distinct scales. (Singh et al.,1999) applied MIKE SHE, a physically derived distributed model, to detect the hydrological water balance of a small watershed in the western part of West Bengal's Midnapore district, India, with the aim of developing the paddy crop irrigation plan.

Hydrological models can be classified into two primary classifications, called physical models and abstract models, according to Chow, Maidment, and Mays (1988). Hydrological models can be classified into two primary classifications, called physical models and abstract models, according to Chow, Maidment, and Mays (1988). These variables can be spatial, temporal, and random function. Given this randomness, it is possible to categorize the abstract models into two kinds called deterministic and stochastic. The deterministic models, while the stochastic models consider randomness, do not consider randomness. Although nearly all hydrological phenomena consist of randomness, only if it is pronounced is regarded in modeling.

Based on spatial variability, the deterministic models are further classified as lumped and distributed. The lump models are spatially averaged models without taking into account the spatial variation, while the distributed models consider the variables as a function of the dimensions of space. Considering spatial variation as space independent and space correlated, the stochastic models are further described considering inter-influence on the random variables on discrete spatial points. According to Chow et al. (1988), practical modeling generally only takes into account one or two sources of variation, although there are five sources of variation (randomness, three dimensions of space, time). There are numerous other classifications than the classification mentioned above. According to Gayathri, Ganasri, and Dwarakish (2015), for instance, models can be categorized based on the input parameters and the magnitude of physical values applied in the model, as static and dynamic models considering time and empirical.

The use of hydrological models is very essential for a broad spectrum of applications, including water resource planning, watershed growth and management, flood forecast analysis, as well as system model evaluation of the design and couple. In water resources planning and forecasting, the use of mathematical models for hydrological computations has become increasingly common.

2.8.1 Monthly water balance models and model parameters

The main and traditional use of monthly water balance models was to explore the significance of various hydrological factors in various watersheds. For this purpose, many monthly water balance models were created. Water balance models have been developed in various time scales (e.g., hourly, daily, monthly and yearly) and different levels of complexity. Monthly water balance models were first developed in 1940s by Thornthwaite and later revised by Thornthwaite and Mather (Xu and Singh, 1998).These models have been introduced, altered and implemented to a broad range of hydrological issues since then (e.g. Gabos and Gasparri, 1983 ; Alley, 1984, 1985 ; Vandewiele et al., 1992 ; Xu and Vandewiele, 1995). They have recently been used to investigate the effect of climate change (e.g., Schaake and Liu, 1989 ; Arnell, 1992 ; Xu and Halldin, 1996). As monthly water balance models are constantly being used to cover a variety of hydrological concerns, extensive effort is made to develop such models and practices for their parameter estimation. Although many designs have acquired a good deal of experience, there is an ongoing need to upgrade the models and test them against practical needs. Furthermore, model consumers must have the chance to familiarize themselves with the concepts and build strong working understanding of their sensitivity, strengths and weaknesses. Models with many parameters have less chance of finding the best parameter than models with fewer parameters (Rinsema, 2014). Bashar (2005) concluded that simple models involving fewer parameters forecasted discharge in the Nile River Basin better than models using more parameters and complex mathematical computations. Although simple models with few parameters can have better performances and less calibration time, they may also undermine physical characteristics. Model selection is also tied to uncertainty in model results due to the assumptions and simplifications each model incorporates (Vaze, 2012).Melsen et al. (2016) determined that model performance is mainly limited by the model structure, not by parameters.

2.8.2 Lumped water balance models

The typical models used worldwide are the lumped models. These models define the watercourse as a single entity with a single input of precipitation (mean precipitation). The watershed outlet discharge is defined based on the system's global dynamics. This model form is not very physically based. They do not take into consideration that when traveling through a permeable river bed, part of the surface runoff may infiltrate and therefore underestimate the sub-surface element of river flow. The set of parameters is large, the description of the methods is still quite simplified, so much so that the contrast between these models and the lumped conceptual models is not considerable.

Developing models for studying strategies on water management is a complicated job that poses a basic science challenge (Welsh, 2007). In arid and semi-arid areas, where precipitation is restricted and/or rates of uneven and evapotranspiration (ET) are high, particularly complicated instances happen. Hydrological stability models are used to reconstruct and predict historical sequence.

2.8.3 Data period for monthly water balance models

Data duration for hydrological Modeling is a key factor as per study done in U.S.A for abcd model calibration and validation over 240 non-snow watersheds its is found that there is no significant change in the performance of the model. As a consequence of this research, it was discovered that only 52 percent and 50% of the catchments were categorized as excellent in calibration while being validated as excellent at 37 percent and 40% respectively. This shows that in case of an increase in calibration information period, there is only a tiny improvement in model efficiency (Martinez & Gupta, 2010). Much of the monthly modeling job was performed effectively, even with fewer information phases than the following 30 years. For, Application of the monthly water balance system "abcd" for three chosen U.S. basins, the information period of 17 years used by Al-Lafta, Al-Tawash and Al-Baldawi (2013), using 10 years for calibration and 7 years for verification. Vandewiele, Xu and Win (1992) used various information periods in the creation of 79 monthly water balance models for Belgium Burma and China. The utilization of two parameters of the monthly water balance model for 70 sub catchments in China, Xiong and Guo (1999) utilized data times of under 20 years for 17 catchments, data times of 20~25 years for 38 catchments, data times of 25~30 years for 13 catchments and data times of over 30 years for just 2 catchments.

On the literature, It can be concluded that no significant change in model performance will occur, even if the data period in the model calibration is increased by more than 10 years. And further, to create their monthly models, most modelers have not pursued a particular information duration.A data length of 10 years is necessary and sufficient for a reliable calibration of monthly water balance models of humid basins.

2.8.4 Selection of Model for Study

Water assets appraisal is vital to the investigation of catchment the executives (Wurbs, 2005). The improvement of models to study water-the executives strategies is a mind boggling task that shows a central logical test (Welsh, 2007). Particularly complex cases happen in bone-dry and semi-bone-dry locales, where precipitation is restricted and additionally unpredictable and evapotranspiration (ET) rates are high. Hydrological equalization models are utilized to reproduce chronicled arrangement and anticipate future ones (Puricelli, 2003). They depend on the guideline of mass preservation or the coherence condition (Essam, 2007; Rose, 2004), which considers that the distinction of information sources and yields will be reflected in water stockpiling in the catchment (Shimon, 2010; UNESCO, 1981).With the new improvement of computer aid designs helped instruments and progressively nitty gritty data, there is an expanding pattern to utilize appropriated or then again semi-conveyed models (Eder et al., 2005; Arnold et al., 1998). They give progressively point by point appropriated results on a catchment scale approximating heterogeneities of the framework. Be that as it may, vulnerability at high goals may decrease potential 25 gains in expectation exactness (Woodworker, 2006). All things considered, in spite of the straightforwardness of lumped models, they perform well in numerous examinations (Yang and Michel, 2000; Cameron et al., 1999; Uhlenbrook et al., 1999; Yang et al., 1995). Notwithstanding, they do not require as much information as the circulated models (which are inaccessible by and large), and the intricacy and prerequisites to process them are lower. Besides, adjustment of the lumped parameter models is significantly less tedious and created higher generally model execution in contrast with the more unpredictable conveyed models (Vansteenkiste et al., 2014). They 30 are especially helpful in little information-rich catchments and are utilized related to handling ponders (Chiew, 2010). Different studies have been led to think about circulated and lumped models (Koren et al., 2004; Zhang et al., 2004; Boyle et al., 2001; Refsgaard and Knudsen, 1996; Shah et al., 1996). The appropriateness of a model relies upon the basin and explicit territorial attributes.

In a lumped water balance model, catchment parameters and 10 variables are averaged in space, so hydrological processes are approached by conceptual solutions formulated by using semiempirical equations. The system is described using different reservoirs, the moisture content of which depends on the relationships (physical and empirical) between them (Xu and Singh, 1998). A lumped hydrological balance model may have only three or four parameters (Xu and Singh, 1998; Vandewiele et al., 1992; Alley, 1984) and can be implemented with several lines of computer code, whereas a complex model may have more than 20 parameters (Chiew, 2010). Some examples of 15 lumped models are the ABCD model (Zhao et al., 2016; Wang and Tang, 2014; Sankarasubramanian and Vogel, 2002; Alley,1985) GR2M (Lacombe et al., 2016; Mouelhi et al., 2006), Sacramento (Burnash et al., 1973), Guo-5p (Xiong and Guo, 1999;Guo, 1995), Témez (Singh and Kumar, 2016; Singh, 2000; Ferrer, 1993; Témez, 1991, 1987), Thornwaite-Mather (Lyon et al., 2004; Frankenberger et al., 1999; Calvo, 1986), IHACRES (Croke et al., 2006), SIMHYD (Chiew et al., 2002), GR4J (Perrin et al., 2003), AWBM (Boughton, 2009, 2007, 2006, 2004; Boughton and Chiew, 2007) and SMAR (O’Connel et al.,1970). More examples of rainfall-runoff models can be found in Singh (1995) and Singh and Frevert (2002). Hence, abcd linear conceptual hydrological model selected for study with two storage components one for ground water storage other for soil moisture storage with only 4 parameters.

2.9 The "abcd" Monthly Water Balance Model

This model was first created under the "Improved Methods for National Water Assessment" study by Harold A. Thomas Jr. in 1981. "Abcd" is a nonlinear, physical and lumped monthly water balance model that accepts monthly rainfall (P) and probable evapotranspiration (PET) as inputs, describes soil moisture storage (S) and groundwater recharge (G) as government factors, and lastly generates streamflow (Q) as output.

Model contains four parameters, out of which two of them representing runoff characteristics of the catchment while the other two parameters representing groundwater flow. The inputs of the model are monthly precipitation and potential evapotranspiration or pan evaporation and the outputs of the model are monthly runoff (direct and indirect), soil moisture, and ground water storage (Thomas, 1981).

The "abcd" model has the benefit of representing infiltration more realistically by enabling stream flow even under low soil humidity circumstances (Martinez & Gupta, 2010).

2.9.1 The "abcd" model structure

The model structure of the ' abcd ' model is as shown in Figure 2-1 according to Thomas (1981), Martinez and Gupta (2010) and Al-Lafta et al. (2013). Parameter ' a ' in the model represents the propensity of runoff to happen before full saturation of the land (Thomas et al., 1983). The 'b' parameter is the upper limit of the actual evapotranspiration and storage of soil moisture in a specified month.

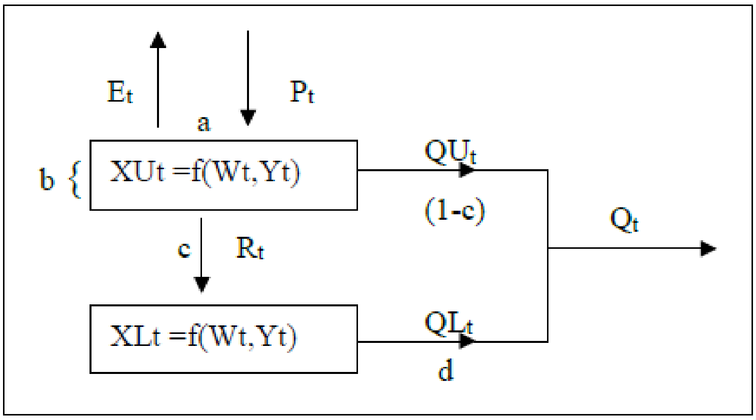


Figure 2-1: The "abcd" model structure

This parameter represents the catchment's capacity to hold water in the upper horizon of the soil. The 'c' parameter regulates the aquifers water input. The reciprocal parameter 'd ' corresponds to the average residence time of the groundwater (Al-Lafta et al., 2013).

By applying the continuity equation for the upper moisture zone;

$P_t - E_t - R_t - QU_t = \Delta XU = XU_t - XU_{t-1}$ ……………………………………………Equation 5

Where; P_t - Monthly precipitation

E_t - Actual evapotranspiration,

R_t - Recharge to groundwater storage,

QU_t - Upper zone contribution to runoff

XU_t and XU_{t-1} - Upper soil zone soil moisture storage at the current and previous time steps.

After rearranging equation-

$(P + XU_{t-1}) = (E_t + XU_t) + QU_t + R$

where $(P + XU_{t-1})$ is the available water (WA_t)

while $(Et + XU_t)$ is the evapotranspiration opportunity (EO_t)

$Yt=St+ETt=(Wt+b)/2a-\sqrt{((Wt+b)/2a)2-bWt/a)}$…………………….…. Equation 6

It is possible to write the nonlinear connection between Et, EOt and PEt

$E_t = EO_t \cdot \{1 - \exp(-PEt/b)\}$…………………………………………...Equation 7

Considering the water availability for runoff as $(WAt - EOt)$

Upper zone contribution to runoff,

$QU_t = (1 - c) \cdot (WAt - EOt)$……………………………………………Equation 8

Ground water recharge;

$R_t = C * (WA_t - EO_t)$ ……………………………………………………Equation 9

Soil moisture storage in ground water compartment after recharge;

$XL_t = (XL_t - 1 + R_t) \cdot (1 + d) - 1$ ……………………………………….....Equation 10

The discharge from ground water compartment as;

$QL_t = d \cdot (XL_t)$ ……………………………………………………………Equation 11

The total stream flow can be written as;

$Q_t = QU_t + QL_t$…………………………………………………………………………Equation 12

2.9.2 Application of "abcd" model

Rainfall-runoff models can be helpful instruments in future climate variability planning. These are used to translate predicted climate shifts (e.g., in precipitation or temperature) into predicted water availability modifications (e.g., Bergstrom et al., 2001 ; Bosshard et al., 2013 ; Chiew & McMahon, 2002 ; Chiew et al., 2009 ; Christensen et al., 2004 ; Faramarzi et al., 2013 ; Fowler et al., 2014 ; Hagemann et al., 2013 ; Vaze et al., 2011). Initially, the "abcd" model was used as a monthly water balance model. The model was later implemented as seasonal, monthly and annual under distinct time scales and the findings were examined for "reasonability" and consistency. It is not necessary to separate the internal and external runoff of both the reported flow in the implementation of the model, although the model has two water storage compartments in aquifers and sub-soil. The accessibility of soil moisture and ground water information will make it simple to determine the model's parameters, but the model can be equipped even without those information (Thomas, 1981).

In previous studies the “abcd” Model shows good results when implemented on yearly time scale (Thomas et al ,. 1983). But, according to Al-Lafta et al. (2013) and 764 basins according to Martinez and Gupta (2010), the "abcd" model was effectively implemented on a monthly time scale for 3 basins in the United States. The accessibility of soil moisture and ground water information will make it simple to determine the model's parameters, but the model can be equipped even without those information (Thomas, 1981).Lafta et al. (2013) discovered that the "abcd" model does not perform well in snow-dominated areas without adequate changes in the model composition and further, it was noted that the model indicates an intermediate amount of performance in mild (hot and wet) climates. Martinez and Gupta (2010) effectively discussed the snow impact by making suitable changes to the model framework "abcd."

2.9.3 Potential Evapotranspiration (PE) for the model

Under existing atmospheric conditions, the idealized amount of water evaporated per unit area, per unit time from an idealized, extensive free water surface is known as potential evapotranspiration. Estimating evapotranspiration as a fraction of rainfall is evidently not reliable on a monthly time scale, because it is not common for evapotranspiration to be greater than precipitation, especially during those months immediately following the end of the rainy season, and the fact that rainfall in most parts of the world is highly variable. This is one of the main input of the “abcd” model. Thomas (1981) used the technique of pan evaporation as the potential method of evapotranspiration for the first ' abcd ' model established. Few more techniques available to assess potential evapotranspiration other than the pan evaporation technique, temperature based techniques, radiation based techniques and combination techniques. Hargreaves Method and Thornthwaite Method are examples of techniques based on temperature, while Turc Method and Priestly-Taylor Method are examples of techniques based on radiation. FAO Penman-MonteithMethod can be developed as a normal technique for estimating reference evapotranspiration suggested by the United Nations International Commission for Irrigation and Drainage and Food and Agriculture. (Nikam, Kumar, Garg, Thakur, & Aggarwal, 2014). Eventually the concepts of real, potential and reference crop evapotranspiration can be confused as they are frequently used interchangeably in literature (Shuttleworth, 1993 ; Mimikou, et. al., 1991). A short set of definitions is provided below (taken from Shuttleworth, 1993).For Evaluation Potential evapotranspiration Hargraves equation is using observed temperature and latitude. The Hargreaves equation is a second technique based on temperature and although it expresses the reference plant evapotranspiration, it is used as a representative expression of prospective evapotranspiration (Hargreaves, 1981 ; Hargreaves et al., 1985). It has a connection with solar radiation

$Erc = 0.0022 * RA * (T_{max}-T_{min})^{.5} * (T + 17.8)$………………………Equation 13

RA = mean extra-terrestrial radiation [mm/day], which is a function of theLatitude.

SPT =Temperature Difference=Mean Monthly Maximum Temperature - MeanMonthly MinimumTemperature for the Month of Interest [^{0}C].

T = mean air temperature [°C].

2.9.4 The “abcd" model parameters from literature

In calibrating the model "abcd," having initial values for the parameters for a good start and checking the reliability of the estimated parameter values is very important and convenient. Vandewiele et al. (1992) ; Alley (1984) and Martinez, Gupta (2010) and Lafta et al. (2013) discovered that the four parameters (a, b, c, d) had distinct values for separate catchments without snowfall as in Table 2-3

Table 2-3: The a,b,c,d parameters from literatures

Parameter	Description	Range	References
a	Propensity of runoff to occur before the soil is fully saturated	0-1	Alley (1984),
b	Upper limit on the sum of evapotranspiration and soil moisture storage	0-4000	Martinez and Gupta (2010)
c	Degree of recharge to ground water	0-1	Sankarasubramaniam and Vogel (2002)
d	Release rate of groundwater to baseflow	0-1	Vandewiele and Xu (1992)

2.10 Parameter optimization

For the most part parameters are characterized into two system: physical and process parameters (Gupta, and Sorooshian, 1995). A physical parameter reflects parameters obtained from the watershed's physically measurable characteristics (e.g. catchment regions, impermeable area fraction and water bodies surface area, surface slope, etc.). Process parameters reflect non-directly measurable watershed characteristics depending on the model structure and spatial distribution (Xiong & Guo, 1999). In order to assess the parameter importance and sensitivity, three distinct methods can be implemented, evaluation of the parameter values during optimization, checking of the global minimum and detailed assessment of the variance matrix (Xu, 1997 ; Xu & Singh, 1998). Wijesekera (2000) proposes that while the mathematical indicators assist to define the best fit, it is essential to look at the water balance, time series of estimates regarding the observed rainfall and length curves in order to select the best parameter set for the specific catchment. Parameter values are closely related to the catchment conditions, such as climate change, afforestation and urbanization (Peel et al., 2011).

2.11 Objective functions

Applications for hydrological model have a range of goals, depending on the issue to be investigated. Woolhiser and Singh (2002). For model performance check, lots of modeler used objective function for evaluation. There are three main concerns of hydrologists to evaluate hydrological model performance, according to Kruse, Boyle, and Base (2005). Model performance assessment is essential to examine model precision as well as model reliability.

For 764 catchments in the United States, Martinez and Gupta (2010) used Nash – Sutcliffe effectiveness (NSE) as the model assessment criteria for applying the "abcd" monthly water equilibrium system. When evaluating the model, if the NSE value is between 1.00~0.75, it was regarded good while considering values between 0.75~0.67 as acceptable, 0.67~0.59 as bad and values below 0.59 as worst but in many other authors recommended NSE above 0.5 is acceptable and satisfactory.

The assessment criteria used by Lafta et al. (2013) were Mean Squared Error (MSE) to assess model output of the "abcd" model for the St. Johns River catchment, Kickapoo River catchment, and Leaf River catchment in the United States. For the St. Johns River catchment and Leaf River catchment, the respective MSE values are 5.31 and 6.68 , 7.14 and 8.25, respectively.

For the catchment of the Kickapoo river, the "abcd" model did not perform well, as the catchment is dominated by snow.

Mean Ratio of Absolute Error (MRAE) was used by Wijesekera and Rajapakse (2014) to calibrate and validate the water balance system for the Sri Lankan Aththanagalu Oya basin. The calibration and validation MRAE values obtained were 0.66 and 0.7 respectively, which are not usually deemed suitable for a healthy fit. In addition, NSE, coefficient of correlation and R^2 were used for the calibration.

Xiong and Guo (1999) obtained NSE, Relative Error (RE) and Relative Maximum Error (REM) to assess the two-parameter monthly water balance model.

Wijesekera (2000) used Mean Ratio of Absolute Error (MRAE) as the objective function to assess Gin Ganga model efficiency and received values for calibration and verification between 0.2-0.4 as MRAE values.

Mean Ratio of Absolute Error (MRAE) as the objective function for model performance assessment created for Kalu Ganga, Kelani Ganga and Attanagalu Oya sub-basins in Sri Lanka by Perera and Wijesekera (2011) and obtained values were 0.44, 0.30 and 0.90.

MSE and the NSE are the most commonly used objective functions for calibration and validation of hydrological models, according to Gupta, Kling, Yilmaz, and Martinez (2009). But in the context of Sri Lanka, MRAE can also be regarded as an objective function in elevated, medium and low flow modeling.

In contrast of Sri Lanka, MRAE can also be regarded as an objective function in elevated, medium and low flow modeling along with NSE.

2.12 Applications of different objective functions by different modelers

The performance evaluation of the model is carried out either subjectively or objectively. Visual inspection of the proximity of fit between real and simulated discharges is performed in the subjective evaluation and the model's systematic (under-estimation/overestimation) or dynamic (regular pattern) conduct is observed. Simplification and precipitation separation activities result in mistakes due to insufficient understanding of the interactions of all elements in a watershed (Nash &

Sutcliffe, 1970). A model's efficiency is based solely on how well the predicted values fit the observed values, assuming that the observed data are error-free while not necessarily the case (Moriasi et al, 2007). Each hydrological model has some constraints because it utilizes some simplification and empirical idealism, resulting in a mistake between the observed and simulated discharge.

Most of the efficiency criteria were formulated with the difference between the observed value and the simulated value at each stage and the variability of the relevant observations was normalized at each stage. To minimize mistakes due to reverse indications, absolute or square mistakes were taken into account when taking into account the summation of variations between observed and simulated discharge. This has resulted in a strong focus on bigger mistakes while neglecting minor mistakes.The bigger mistakes are usually correlated with elevated flows that will cause the hydrographs to fit maximum flows in calibration that are rather suitable for small flows that may represent base flow (Krause et al., 2005). It is therefore essential to select a suitable model with a minimum mistake to simulate as much as possible the rainfall-runoff relationship close to reality (Krause, Boyle, and Base, 2005). Project-specific criteria for model effectiveness are suggested to improve assessment effectiveness (Krause, Boyle, and Base, 2005).

2.12.1 Ratio of Absolute Error to Mean (RAEM)

This objective function shows the ratio of observed and calculated discharge to the measured flow average. RAEM will not be accurate if the flow information sequence is not represented correctly by the mean of the measured values. But the WMO guidelines suggested this objective function.

2.12.2 Relative Error (RE)

Relative error (RE) is described as the volumetric fit between the observed runoff sequence and the simulated series, which for a successful simulation is supposed to close to zero (Xiong & Guo, 1999).

$$RE=\Sigma(Q_{obs}-Q_{sim})/\Sigma Q_{obs} \text{ X } 100\% \text{..Equation 14}$$

2.12.3 Nash–Sutcliffe Efficiency (NSE)

The Nash – Sutcliffe effectiveness coefficient (NSE) model is used to evaluate hydrological models ' predictive capacity. Efficiency of Nash – Sutcliffe can be used to quantitatively define the precision of non-discharge model outputs. This indicator can be used to define other models ' predictive precision as long as information are observed to compare the outcomes of the model. NS is capable of taking values between –0 range and 1. A value of 1 shows an ideal agreement and a value of zero suggests that no portion of the original variance is explained by the model. The primary disadvantage in NSE, according to Legates and McCabe (1999), is the overestimation of higher values in the time series while neglecting the low flow values. While model development and using for hydrological outputs for a specific practical issue, it is then essential to evaluate its applicability and potential accuracy for the problem under consideration and to determine the values of the model parameters or constants for the catchment under consideration. This results in an overestimation of model efficiency at peak flows in runoff forecasts while miscalculating during low flow conditions. Therefore, during low flow periods Nash-Sutcliffe is not very soft (Krause et al., 2005). A adverse effectiveness in modeling implies that the model forecast is worse than using the measured flow average. This measure is extremely impacted by some extreme mistakes and can be biased when experiencing a broad variety of flow occurrences (Krause et al., 2005).

$NSE = 1 - \frac{\sum_{i=1}^{n}\left(Q_{O(i)} - Q_{s(i)}\right)^2}{\sum_{i=1}^{n}\left(Q_{O(i)} - Q_{a(o)}\right)^2}$ …..Equation 15

where,

Q_o= Observed discharge;

Q_s= Simulated discharge

Q_{ao}= Average of observed discharge

Mean Ratio Absolute Error (MRAE)

Mean Ratio Absolute Error have been defined as below;

MRAE=1/n[Σ|Yobs−Ycal|/Yobs]……………………..Equation 16

This effectiveness criteria shows the degree of correspondence between observed and calculated stream flow hydrographs and provides an average relative error of model performance with regard to the observed stream flow (Wijesekera, 2000). In addition, using MRAE as the objective function for Gin Ganga model assessment, Wijesekera (2000) showed that MRAE can be effectively used to assess model efficiency for elevated, medium and low flow flows. Since the monthly water balance models are chosen as the primary objective function for long-term resource assessment, the MRAE was chosen. It is thought that MRAE is a better objective function in instances where presences of all kinds of flow (elevated, intermediate and low) are probable to happen.

2.12.4 Root Mean Square Error

It is one of the generally utilized blunder list insights (Chu and Shirmohammadi, 2004; Singh et al., 2004; Vasquez-Amábile and Engel, 2005). In spite of the fact that it is ordinarily acknowledged that the lower the RMSE the better the model execution, just Singh et al. (2004) have distributed a rule to qualify what is viewed as a low RMSE dependent on the perceptions standard deviation. In view of the proposal by Singh et al. (2004), a model assessment measurement, named the RMSE-perceptions standard deviation proportion (RSR), was created. RSR institutionalizes RMSE utilizing the perceptions standard deviation, and it consolidates both a blunder file and the extra data suggested by Legates and McCabe (1999).

2.12.5 Coefficient of Determination

The determination coefficient R^2 is described as the square value of the Bravais Pearson correlation coefficient. Determination coefficient (R^2) is an indicator of how far the model explains the overall variance in the information observed. A significant restriction of R^2 is that it portrays the linear connection between the two information sets, and a big R^2 value can be obtained with a bad model continuously overestimating or underestimating the findings. Therefore, if R^2 is used for model checking, it is recommendable to assume extra data that can manage this problem.

$R^2 = 1 - [\ \Sigma\, (yi - xi)^2 / \Sigma\, (yi - y)^2\ ]$……………………………………Equation 17

yi = Actual discharge

xi = Model discharge

Pearson's relationship coefficient (r) also, coefficient of assurance (R^2) depict the level of collinearity among mimicked and estimated information. The connection coefficient, which reaches from −1 to 1, is a record of the level of direct connection among watched and reenacted information. On the off chance that r = 0, no direct relationship exists. On the off chance that r = 1 or −1, an ideal positive or negative direct relationship exists. Also, R^2 depicts the extent of the change in estimated information clarified by the model. R^2 ranges from 0 to 1, with higher qualities demonstrating less blunder difference, and regularly values more noteworthy than 0.5 are viewed as satisfactory (Santhi et al., 2001, Van Liew et al., 2003). In spite of the fact that r and R^2 have been broadly utilized for model assessment, these measurements are oversensitive to high outrageous qualities (exceptions) and inhumane toward added substance and corresponding contrasts between model forecasts and estimated information (Legates and McCabe, 1999)

NSE was suggested for two noteworthy reasons:

(1) It is suggested for use by ASCE (1993) and Legates and McCabe (1999).

(2) It is all around regularly utilized, which gives broad data on announced qualities. Sevat and Dezetter (1991) likewise observed NSE to be the best target work for mirroring the general attack of a hydrograph. Legates and McCabe (1999) recommended an adjusted NSE that is less touchy to high extraordinary qualities because of the squared contrasts, yet that altered adaptation was not chosen on account of its restricted utilize and coming about relative absence of announced qualities.

Objective functions, such as Root Mean Squared Error (RMSE) and Nash-Sutcliffe Efficiency (Nash and Sutcliffe, 1970) are routinely used to minimize the difference between the observed and simulated flows. Common hydrology model assessment metrics include Nash-Sutcliffe effectiveness NSE (Nash and Sutcliffe, 1970 ; Krause et al., 2005 ; Bai et al., 2009), root-mean-squared error, determination coefficient, AIC (Akaike, 1973), Bayesian data criterion BIC (Schwarz, 1978), and Kashyap data criterion KIC (Kashyap, 1982).

2.13 Warm up period of the Model

For the hydrological models, the typical proposed warm-up period ranged from one to several years, which may result in information being underused. The warm-up model is a adjustment method for the model to achieve an ' ideal ' state, where inner shops (e.g. soil humidity) pass from the estimated initial condition to an ' ideal ' state. A warm-up period for accessing a model to operate sufficiently before the simulation period to initialize significant model variables or enable significant procedures to achieve a vibrant balance (Daggupati.P.et.al.,2015). There were 42 warm-up techniques as per the literature done by (Hoad.K.et.al, 2008). Every technique was ordered into one of 5 fundamental kinds of system as depicted by Robinson (2004) which are graphical, Heuristic, Measurable, Initialisation inclination tests and hybrid.

Initial values should be there for initial soil water moisture and ground water storage for model stabilization. Initialization bias happens when a model is begin in an unrealistic state that requires changes to the original value and usually happens in non-terminating simulations, but it can also occur in terminating simulations (Hoad, Robinson, & Davies, 2008). There are five primary techniques to deal with initialization bias as follows, according to Robinson (2004);

1. Run the model till realistic condition (stable condition for non-terminating simulations) is reached. Delete information from the warm-up period gathered.
2. Set initial conditions in the model so that in a realistic situation the simulation begins.
3. Set the original partial requirements, warm up the model and delete the warm-up information.
4. Run template that makes the bias impact negligible for a very lengthy moment.
5. Estimate the parameters of a stable state from a brief simulation run (Sheth-Voss, Willemain, & Haddock, 2005).

Warmup period calculation is essential for hydrological Modeling. Robinson (2004) classified the techniques available for calculating the warm-up period as below into five primary classifications;

1. Heuristic approaches – Truncation techniques with few fundamental assumptions that provide (easy) guidelines to determine when to truncate the information sequence.
2. Graphical methods –Methods of truncation involving visual inspection of the output time series and human judgment.
3. Statistical techniques – Techniques of truncation based on the principles of statistics.
4. Hybrid techniques – To determine the warm-up period, a mixture of initialization bias trials with truncation techniques.
5. Bias tests for initialization – trials to determine whether there is any bias in the information for initialization.

Therefore, they are not strictly methods of obtaining the truncation point, but they can be adapted to do so in an iterative manner, or they can be used in combination with the above methods of truncation to determine if they work sufficiently.

At the first development of "abcd" model, Thomas (1981) assumed test values as initial values for soil moisture and groundwater with a tentative setting of a, b, c and d parameters and routed the system over 8 cycles until the initial soil moisture and groundwater storage were semi-stable.

The original soil humidity value (S_0) has some impact on model results, according to Xiong and Guo (1999), and it will be more crucial in instances where the information duration is lower.

From above all literatures it is clear that lots of modeler had use several techniques for warmup period calculation and initial moisture content for hydrological modeling. For the current study we have used method of Robinson (2004), The model will be routed by amount of cycles until soil humidity and groundwater storage are quasi-stable using arbitrary values as original values.

2.14 Rainfall interpolation method

Exact precipitation information are of prime significance for some ecological investigations, particularly whenever identified with water assets. At little scales, the utilization of estimations from individual raingauge checks may be proper. Anyway at bigger scales, it is required to attract uncommon thoughtfulness regarding the suitable portrayal of the spatial precipitation designs, which are generally interjected from point estimations" (Wagner Paul D. et al., 2012). Be that as it may, spatial changeability of precipitation adds to the intricacy of evaluating precipitation and is a key factor that must be fused into estimations. There are various methodologies that hydrologists use to represent spatial variety in precipitation gauges (Knight Y., 2005). Hence spatial interjection is increasingly valuable in precipitation information if there are adequate precipitation areas around the examination territory.

There are a number of techniques available for rainfall interpolation. Kriging Ordinary technique is extremely appropriate for rainfall interpolation compared to Inverse Distance Weighting (IDW), Natural Neighbor, Spline, and Trend techniques, according to Mahalingam, Deldar , and Vinay (2015). But in this research, the polygon technique of Thiessen was used for comparison, which among hydrologists is very popular. Thus, given the simplicity and validity of this technique for water balance modeling, the Thiessen polygon technique was used in this study as the technique of rainfall interpolation for trend analysis of basin and isohyetal method for hydrological Modeling due to the catchment location at tributaries and high elevations.

2.15 Literature review summary

Over the past few centuries, distributed hydrological models based on lumped and physics have been created and commonly used to simulate hydrological procedures for understanding watershed behaviors. A number of papers previously reviewed hydrologic modeling: Todini (2007) reviewed the past, present and future state of art of hydrologic modeling; Davision and Kamp (2008) reviewed the capability of deterministic hydrologic models to simulate low flows; Praskievicz and Chang (2009) reviewed the hydrological models for basin-scale climate change and urban development impacts; Moradkhani and Sorooshian (2009) reviewed the rainfall-runoff modeling and their uncertainty analysis and recently Daniel et al. (2011) reviewed a state of the art of watershed modeling and its applications. After literature review of several hydrological model and nonlinear lumped model “abcd” with least parameter was selected for study as it contains ground water storage. The model structure and parameter function were recognized in detail by reviewing various ' abcd ' model applications. The validity of hydrological models under miscellaneous temporal resolutions was explored and the survey chosen monthly resolution. Potential evapotranspiration, one of the outputs, taking account the accessibility of pan evaporation information appropriate to the catchments chosen. Due to its simplicity in implementation and broad use among hydrologists in Sri Lanka even for distributed hydrological models .catchments, the Isohetal technique was chosen for rainfall interpolation .For linear values for original soil moisture and ground water storage, it is necessary to handle the warm-up period without influencing the efficiency of the model .The model can be run for number of cycles until it reaches the semi-stable state as Thomas (1981) had done in applying the "abcd" model by incorporating some of Robinson's later (2004) proposed methods. Pearson corelation was picked as the objective function for parameter optimization, it is particularly suitable for performance evaluation in moderate and low flow regimes and a broad variety of applications among Sri Lankan hydrologists.

3 METHODS AND MATERIALS

3.1 Methodology Brief

A deep background survey done for finding the research problem in the current Modeling era for Sri Lanka. The study area selection was done depending on the three climatic zones of Sri Lanka. Problems were identified, objective and specific goals formed, and literature review was conducted to define current status and current understanding of hydrological models, model applications and features of the basin under changing climatic conditions. Summary of literature and review of literature done on climate change and trend analysis of Sri Lanka. A suitable lump monthly model with a suitable number of parameters was chosen based on literature review, taking into account research question, time limitations, accessibility of information, price and simplicity of model. A further literature study was done for the chosen model to find a suitable information collection period. Data on rainfall and Temperature collected from Department of Meteorology and Streamflow data was collected from the Irrigation Department. Visual inspection, annual water balance, single mass curve and double mass curve were considered as the main methods of data inspection. A literature review was done for selecting objective functions for model performance evaluation and calculation of evapotranspiration. The model warm-up literature was researched to set the model's original soil moisture and groundwater storage. The whole dataset was divided in two parts 10 years data used for calibration and recent 5 years data used for validation of model. After validation of model and objective functions evaluation for Sri Lanka is identified and then the model can be used for calculating streamflow under climate change scenarios. The uncertainty in results arising from model choice can be overcome by estimating the sensitivity of streamflow to climate directly from historical data. The nonparametric estimator proposed by Sankarasubramaniam et al. (2001) offers a good potential for estimating the sensitivity of streamflow to rainfall directly from the data that is easily reproducible and “defensible”. After demonstration of model under climate change in each climatic zone catchment discussion and conclusion made for the climatic zones.

3.1.1 Methodology flow chart

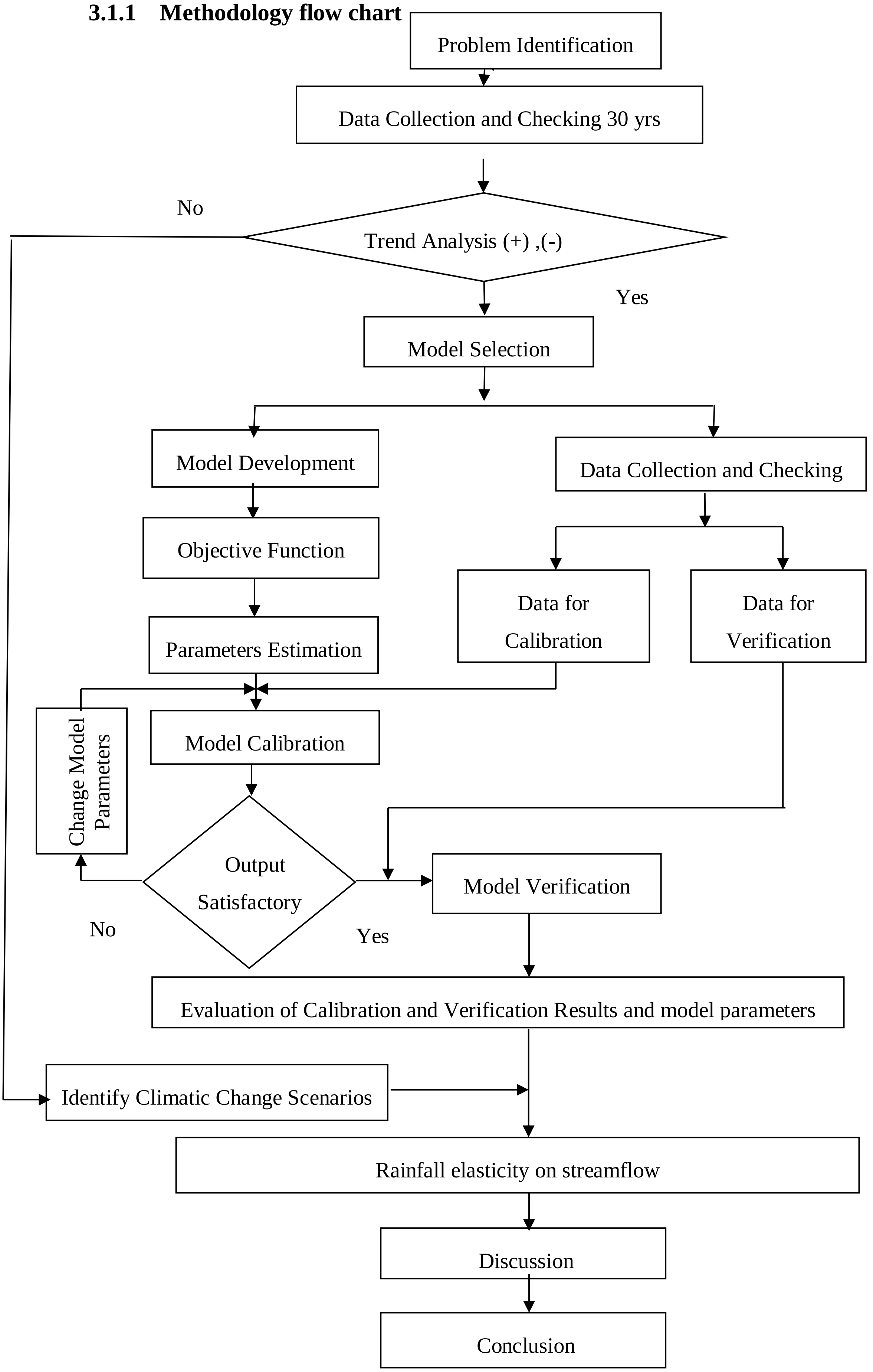


Figure 3-1: Methodology Flowchart

3.2 Study Sites

The Mahaweli River, the longest river in Sri Lanka, flows 335 km originating from central hill lands to north/northeast, covering about 16% of Sri Lanka’s land area. The basin area is estimated to be 10,322 km^2. Mahaweli basin spans over all three climatic zones of Sri Lanka. The annual precipitation in the basin is 28,000 MCM and 9,000 MCM is discharged to the sea. The basin is unique and crucial due to ~1,000 km2 of irrigated lands and hydroelectricity from six dams supplying ~ 40% of Sri Lanka's electricity needs.The Mahaweli Basin of Sri Lanka is selected for study as it lies in all the three climatic zones of Sri Lanka. The rainfall trend analysis has been done from 18 selected rainfall station uniformly distributed along with whole basin according to the three climatic zones. Mahaweli Ganga rises at an elevation of 8,000 ft in the central hills above M.S.L. and flows down to Koddiar Bay on the east coast of the island south of Trincomalee. The Mahaweli river is the longest in Sri Lanka and its complete length exceeds 335 length and the drainage area is 10,327 km^2 It originates from the country's central highlands, passes through the middle country and lastly reaches the ocean on the South East coast. The river's mean annual runoff is 7.2 million acrefeet. This is more than 20 Percent of the complete runoff of all the Island's waterways. The mean yearly precipitation in the zone is high being 75 to 217 creeps in the upper 820 sq. miles of the catchment which lie in the wet zone and 65 to 75 crawls in the lower compasses of 3,214 sq. miles which lie in the dry zone. Disregarding the ideal precipitation and soil conditions in the basin, the huge hydropower potential because of the steep radiant of the stream bed in the upper compasses and the high overflow in the waterway accessible for water system advancement, the Mahaweli stays a standout amongst the least mis used streams in the Island. About 72.5% of the land in the basin reasonable for rural improvement is still in wilderness. Furthermore, the use of the waterway spillover for water system is under 10%. The first hydropower improvement has quite recently been finished on the venture out of a complete potential assessed at 50% of the complete accessible hydropower capabilities of the considerable number of streams in the nation. The whole basin 30% area lies in dry zone and rest 70% in intermediate and wet zone.

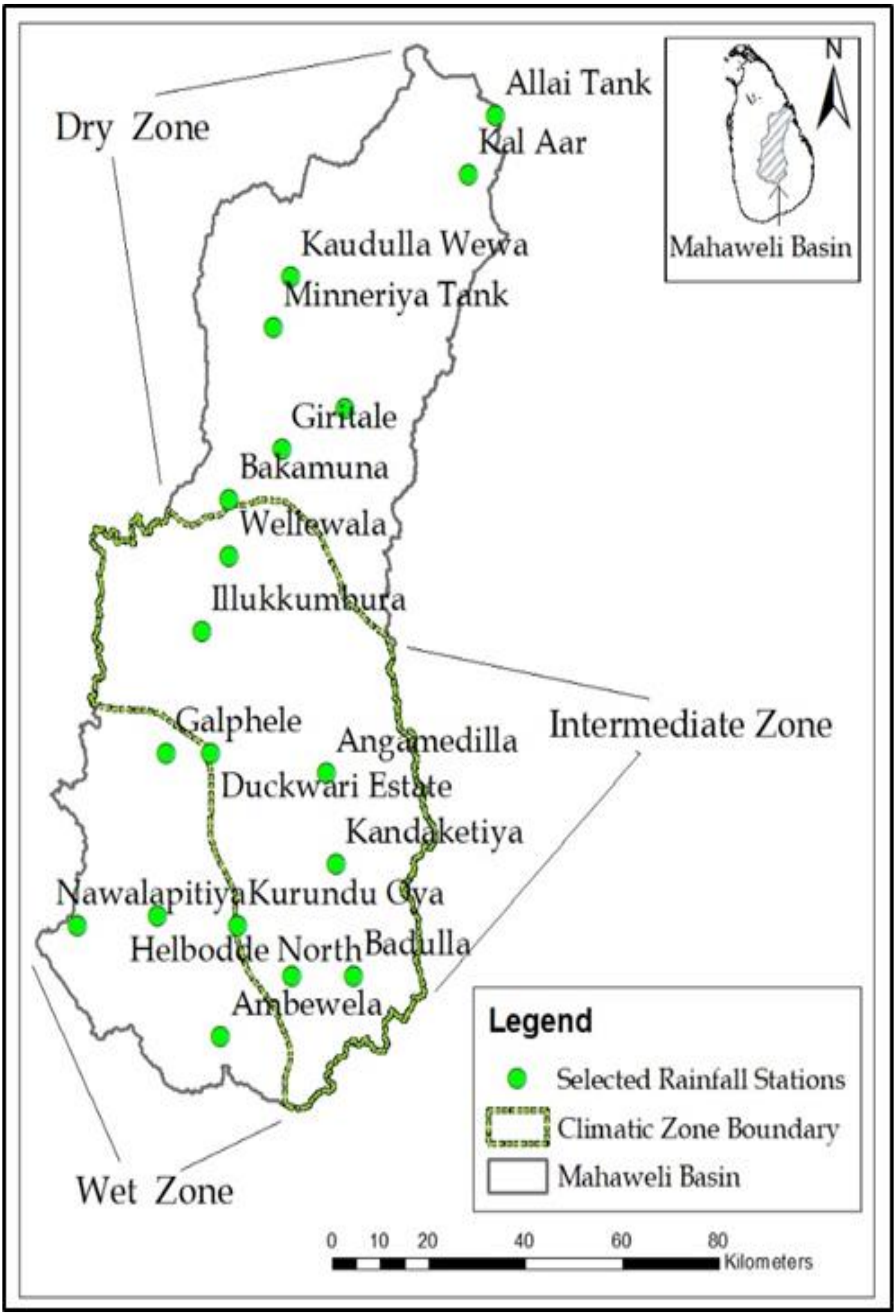


Figure 3-2: Location Map of Study Area (Mahaweli Basin, Sri Lanka)

3.2.1 Nawalapitiya watershed (Wet Zone)

Nawalapitiya watershed is a sub watershed of Mahaweli Ganga basin (Figure 6-3) which is about 10,327 km^2 in size situated in Kandy and Nuwara Eliya districts at elevation of 580m, bordering Kelani Ganga basin from West and Maha Oya basin from North West.

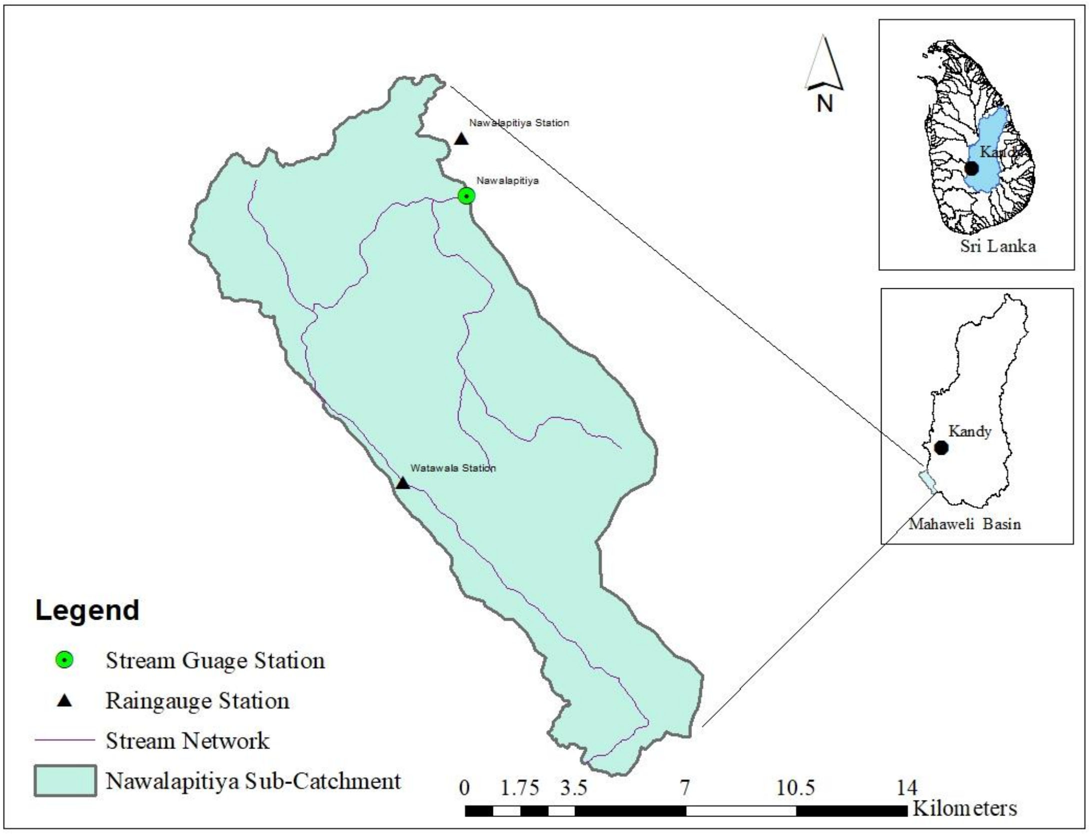


Figure 3-3: Nawalapitiya watershed and stream network

The selected watershed is in wet climatic zone of Sri Lanka. The major soil type of the watershed is Red-Yellow Podzolic while having a hilly, rolling terrain type. The Average temperature of the watershed is about 16℃ The average annual rainfall in the UMCA varies remarkably from 5500 mm in the Southwest to 1700 mm in the Southeast (White et aI., 1993). The catchments Agro-ecological zone is Wet Zone Mid Country Intermediate WM1.The other details regarding the administrative boundaries and the stream networks have been shown in Table 3-1.

Table 3-1: Summary of Nawalapaitiya Watershed

Mahaweli Ganga RiverBasin (km²)	10,327.00
Watersheda at Nawalapitiya (km²)	176.00
Divisional Secretary Divisions (DSD)	Pasbage Korela
District	Nuwara Eliya ,Kandy
Province	Central Provinces
Maximum Stream Length (km)	23.00

According to the latest land use maps which has been updated by Survey Department of Sri Lanka in 2003.

Original in Color

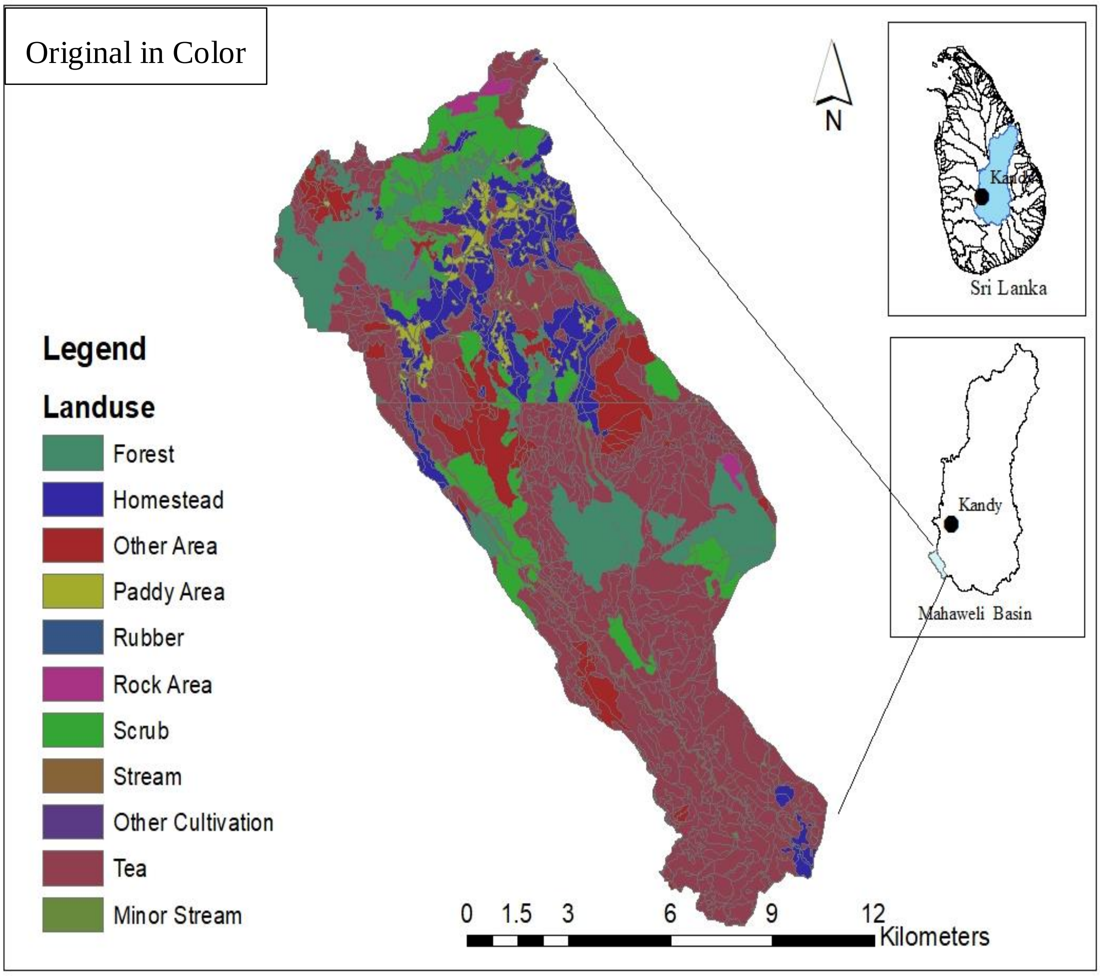


Figure 3-4: Land use in Nawalapitiya in Mahaweli Ganga

Summary of Land use Nawalapitiya Sub- catchment is described in Table 3-2.

Table 3-2: Summary of Land use Nawalapitiya Sub- catchment

#	GF Code	Land use type	Area (km^2)	Area (%)
1	FRSUA	Forest-Unclassified	27.13	15%
2	HOMSA	Homesteads	20.77	12%
3	OTHRA	Other Areas	18.16	10%
4	PDDYA	Paddy area	3.20	2%
5	RBBRA	Rubber	1.42	1%
6	ROCKA	Rock	1.26	1%
7	SCRBA	Scrub	16.50	9%
8	STRMA	Stream	1.87	1%
9	OTHRA	Other Area	0.04	0%
10	TEAA	Tea	85.12	48%
11	WTRHA	Minor Stream	0.76	0%
Total			176.02	100%

3.2.2 Thaldena watershed (Intermediate Zone)

Thaldena watershed is a sub watershed of Mahaweli Ganga basin (Figure 6-5) which is about 10,327 km^2 in area situated in Badulla districts at elevation of 310 m, bordering Menik Ganga basin and Kirindi Oya basin from South. The selected watershed is in intermediate climatic zone of Sri Lanka. The major soil type of the watershed is Red-Yellow Podzolic while having a hilly, rolling terrain type. The Average temperature of the watershed is about 23°C. The annual rainfall in 1885mm yearly.

Table 3-3: Summary of Thaldena Watershed

Mahaweli Ganga River Basin(km^2)	10,327.00
Watershed at Nawalapitiya(km^2)	276.00
Divisional Secretary Divisions (DSD)	Meegahakivula
District	Badulla
Province	Uva Provinces
Maximum Stream Length (km)	25.60

The catchments Agro-ecological zone is Intermediate Mid Country Intermediate IM1.The other details regarding the administrative boundaries and the stream networks have been shown in Table 3-2

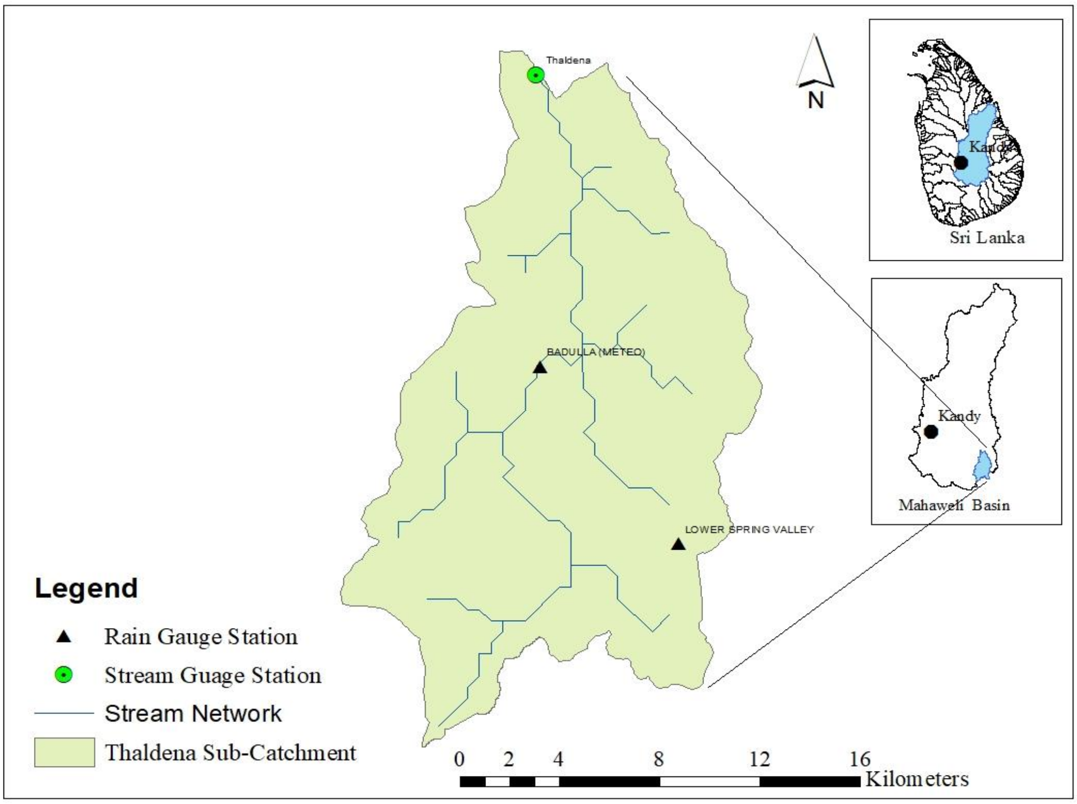


Figure 3-5: Thaldena watershed and stream network

According to the latest land use maps which has been updated by Survey Department of Sri Lanka in 2003.

The Landuse map for Thaldena catchment prepared according to Survey Department as per Figure 6-6 and the whole land use type is summarized in table format for area calculation as in the Table 5-3.

In the catchment 49% area is for tea plantations and 25% is for homestead as per the table formulated from land use map.

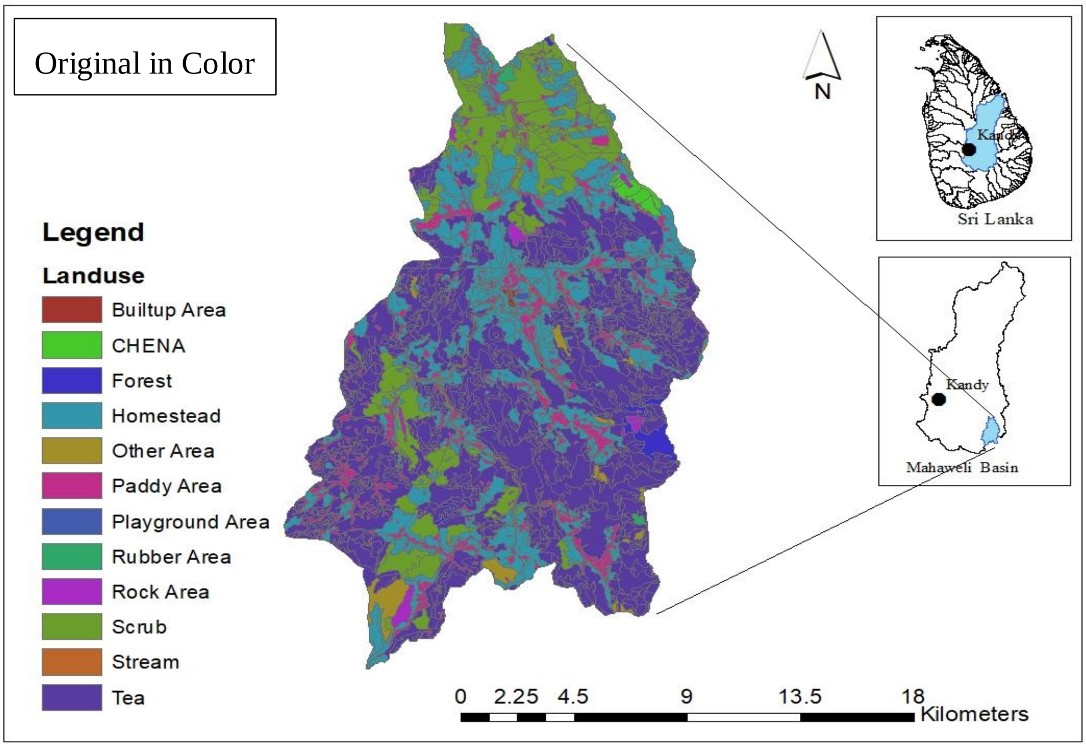


Figure 3-6: Landuse in Thaldena Catchment

Table 3-4: Summary of land use type for Thaldena Catchment

#	**GF Code**	**Land use type**	**Area (km^2)**	**Area (%)**
1	BLTPA	Built up area	0.25	0%
2	CHENA	Chena	1.86	1%
3	FRSUA	Forest-Unclassified	2.46	1%
4	HOMSA	Homesteads/Garden	68.37	25%
5	OTHRA	Other Cultivation	4.28	2%
6	PDDYA	Paddy	21.18	8%
7	PLGDA	Playground	0.14	0%
8	RBBRA	Rubber	0.66	0%
9	ROCKA	Rock	2.26	1%
10	SCRBA	Scrub land	37.27	14%
11	STRMA	Stream	2.71	1%
12	TEAA	Tea	276.02	49%
Total			276.02	100%

3.2.3 Padiyatalawa watershed (Dry Zone)

The Padiyatalawa watershed (Figure-6-7) is a sub watershed of Maduru Oya basin in dry zone of Sri Lanka. The Maduru Oya is a major stream in the North Central Province of Sri Lanka. It is approximately 135 km in length.The drainage area of the basin is 1,439 km^2 It lies between the Mahaweli Ganga basin (West), Mundeni Aru basin (East).Drainage area of the Padiyatalawa watershed is 159 km^2.

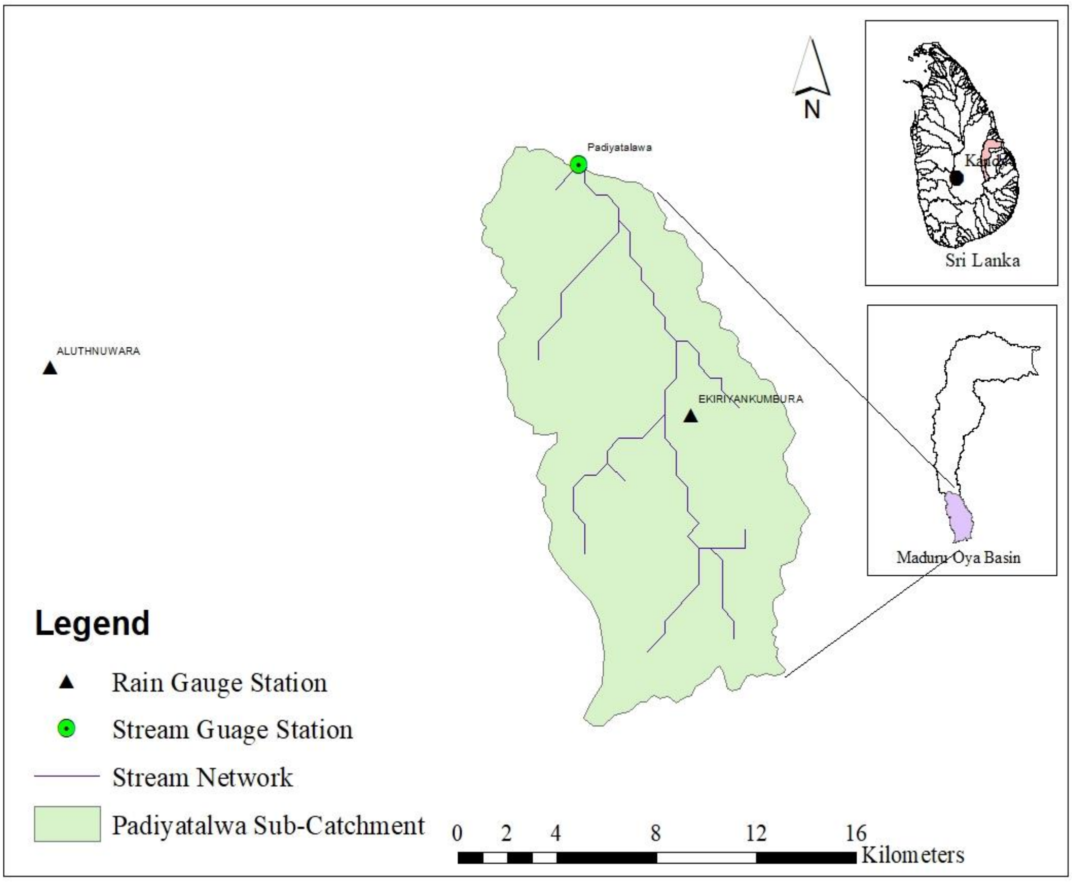


Figure 3-7: Padiyatalawa watershed and stream network

In the selected study area, there is one stream gauging station at Padiyatalawa catchment area. The selected watershed is in Dry climatic zone of Sri Lanka. The major soil type of the watershed is reddish brown earth and immature brown. The Average temperature of the watershed is about 26.5℃. The annual rainfall in aproximately 1885 mm yearly. The catchments Agro-ecological zone is Intermediate Low Land Country IL2.The other details regarding the administrative boundaries and the stream networks have been shown in Table 3-3.

Table 3-5: Summary of Thaldena Catchment

Maduru Oya River Basin(km²)	1,439.00
Watershed at Deraniyagala (km²)	159.00
Divisional Secretary Divisions (DSD)	Padiyatalawa
District	Ampara
Province	Eastern Provinces
Maximum Stream Length(km)	21.00

According to the latest land use maps which has been updated by Survey Department of Sri Lanka in 2003.

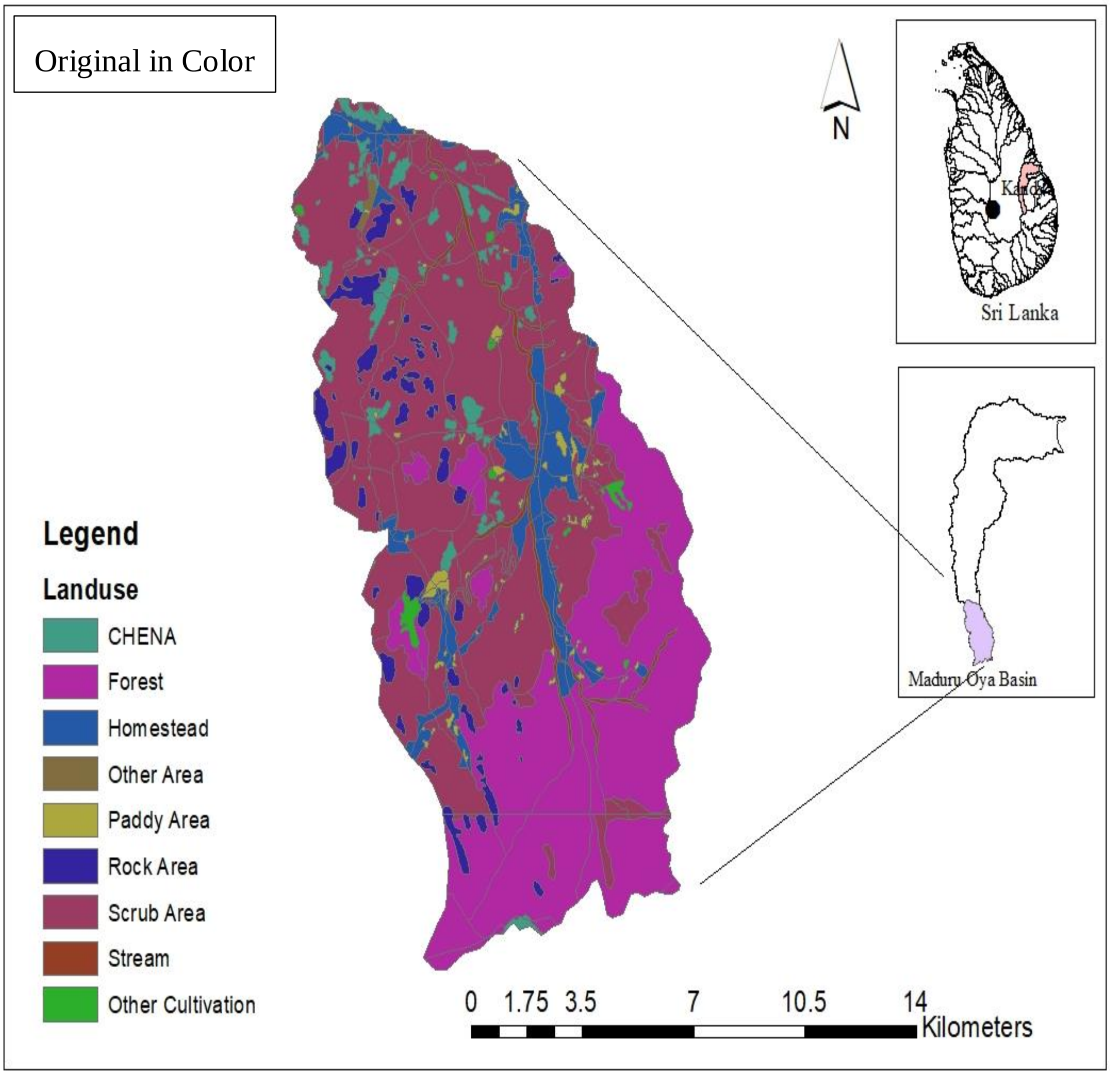

Original in Color

Figure 3-8: Land use of Padiyatalawa in Maduru Oya Basin

Table 3-6: Summary of land use type for Padiyatalawa

#	GF Code	Land use type	Area (km^2)	Area (%)
1	CHENA	Coconut	7.15	4%
2	FRSUA	Forest-Unclassified	47.13	30%
3	HOMSA	Grass Land	15.12	10%
4	OTHRA	Other Area	0.29	0%
5	PDDYA	Paddy	4.30	3%
6	ROCKA	Rock	8.26	5%
7	SCRBA	Scrub	73.42	46%
8	STRMA	Stream	2.26	1%
9	OTHRA	Other Cultivation	1.07	1%
Total			159.02	100%

3.3 Data collection

The collection of precipitation, temperature and stream flow information was conducted in accordance with the rules of the World Meteorological Organization (WMO) of the Sri Lankan Department of Meteorology and Irrigation, which are the accountable state organizations for maintaining the databases of the above-mentioned information. For the catchment delineation of watershed at Nawalapitiya, Thaldena in Mahaweli Ganga basin and Padiyatalawa at Maduru oya basin.The study was carried out on climatic regions of the basin to find out the potential long- term variations of temperature and rainfall patterns. Climatic data for the 30 years period were collected from Metrology department from 1988~2018 from 18 metrological stations selected from each climatic zone covering whole Mahaweli basin for rainfall trend analysis.

For rainfall trend analysis of Mahaweli Basin 19 rain gauge stations selected as in Table 3-7.

Table 3-7: Rainfall Gauging Station Details of Mahaweli Basin

S.No	Climatic Zone	Station	Latitude	Longitude	Altitude (m)
1	Intermediate Zone	Anagamadilla	7.85	80.91	16
2		Illukkumbura	7.55	80.76	1219
3		Kirklees	6.98	80.93	1433
4		KurunduOya	7.06	80.83	16
5		Wellawaya	7.67	80.81	160
6		Badulla	6.98	81.05	669
7		Duckwary	7.35	80.78	1006
8		Kandeketiya	7.16	81.01	16
9	Wet Zone	Ambewela	6.88	80.88	1828
10		Galphele	7.35	80.7	701
11		Nawalapitiya	7.06	80.53	16
12		Hebodde North	7.08	80.68	1494
13	Dry Zone	Bakamuna	7.76	80.81	16
14		Polonnaruwa	7.91	81.03	16
15		Minneria tank	8.05	80.9	16
16		Kaudullaweva	8.13	80.93	16
17		Kal Aar	8.3	81.26	12
18		Allai tank	8.4	80.31	6
19		Giritale	7.9	80.9	16

3.4 Data collection for Nawalapitiya

For the study, Nawalapitiya and Watawala rain gauge stations were selected, which are located inside the watershed as shown in Figure 6-3. The selected evaporation station is which is also located inside the watershed and Nawalapitiya is the stream gauge location which is the point of interest for the demarcation of watershed. The main criteria of selection of the stations were the availability of data for the selected period and the location with respect to the watershed. The selected period for data checking was 2004 October to 2018 September (15 years).

Table 3-8: Data Sources and resolutions for Nawalapitiya

Data Types	Temporal Resolution	Spatial Resolution (km^2/station)	Data Period	Source
Rainfall	Monthly	88	2004-2018	Dept. of Meteorology
Evaporation	Monthly	176	2004-2018	Dept. of Meteorology
Stream flow	Monthly	176	2004-2018	Dept. of irrigation
Land Use	N/A	1:50000	Updated 2003	Dept. of Survey
Temperature	Monthly	176	2004-2018	Dept. of Meteorology

Table 3-9: Rainfall, Streamflow and Evaporation Station of Nawalapitiya

Station	Location Coordinates		District
	Longitude	Latitude	
Rainfall Stations			
Nawalapitiya	80° 32' 3.76" E	7°3'17.97" N	Nuwara Eliya
Watawala	80°32'20.34" E	6°56'41.81" N	Nuwara Eliya
Temperature Station			
Kotmalle	80°35'27.81"E	7°1'20.31"N	Nuwara Eliya
Stream flow Station			
Nawalapitiya	80°32'04" E	7°02'51"N	Nuwara Eliya
Evaporation Station			
Kotmalle	80°35'27.81"E	7°1'20.31"N	Nuwara Eliya

3.4.1 Data collection for Thaldena

For the study, two rain gauge stations were selected Badulla and Lower Spring which are located Inside the watershed as shown in Figure 6-5. The selected evaporation station is Girandurukotte which is also located outside of the watershed and Thaldena is the stream gauge location which is the point of interest for the demarcation of watershed. The main criteria of selection of the stations were the availability of data for the selected period and the location with respect to the watershed. The selected period for data checking was 2004 to 2018 (15 years).

Table 3-10: Data Sources and resolutions for Thaldena

Data Types	Temporal Resolution	Spatial Resolution (km^2/station)	Data Period	Source
Rainfall	Monthly	69	2004-2018	Dept. of Meteorology
Evaporation	Monthly	69	2004-2018	Dept. of Meteorology
Stream flow	Monthly	276	2004-2018	Dept. of Irrigation
Land Use	N/A	1:50000	Updated 2003	Dept. of Survey
Temperature	Monthly	276	2004-2018	Dept. of Meteorology

Table 3-11: Rainfall, Streamflow and Evaporation Station of Thaldena

Station	Location Coordinates		District
	Longitude	Latitude	
Rainfall Stations			
Badulla	81° 02' 60" E	6°48' 58" N	Badulla
Lower Spring	81° 05' 60" E	6° 55' 12" N	Badulla
Temperature Station			
Girandurukotte	81°02'60"E	7° 02 '60 " N	Badulla
Stream flow Station			
Thaldena	81°02’53’’ E	7°05'27" N	Badulla
Evaporation Station			
Girandurukotte	81°02'60"E	7° 02 '60 " N	Badulla

3.4.2 Data collection for Padiyatalawa

For the study, two rain gauge stations were selected, Kanderketiya and Ekeriyankumbura which is located inside the watershed except Kandeketiya as shown in Figure 6-7. The selected evaporation station is Padiyatalawa which is also located outside of the watershed and Padiyatalawa is the stream gauge location which is the point of interest for the demarcation of watershed. The main criteria of selection of the stations were the availability of data for the selected period and the location with respect to the watershed. The selected period for data checking was 2004 to 2018 (15 years).

Table 3-12: Data Sources and resolutions for Padiyatalawa

Data Types	**Temporal Resolution**	**Spatial Resolution (km^2/station)**	**Data Period**	**Source**
Rainfall	Monthly	159	2004-2018	Dept. of Meteorology
Evaporation	Monthly	159	2004-2018	Dept. of Meteorology
Stream flow	Monthly	159	2004-2018	Dept. of irrigation
Land Use	N/A	1:50000	Updated 2003	Dept. of Survey
Temperature	Monthly	159	2004-2018	Dept. of Meteorology

Table 3-13: Rainfall, Streamflow and Evaporation Station Padiyatalawa

Station	**Location Coordinates**		**District**
	Longitude	**Latitude**	
Rainfall Stations			
Ekiriyankumbura	81° 13' .12" E	7°17'60" N	Ampara
Aluthnuwara	80°28'3.52"	7°13'47.99"	Ratnapura
Temperature Station			
Padiyatalawa	81°15'00" E	7°24'00" N	Ampara
Stream flow Station			
Padiyatalawa	81°11'31" E	7°23'01"N	Ampara
Evaporation Station			
Padiyatalawa	81°15'00" E	7°24'00" N	Ampara

3.5 Isohyet averaged rainfall

Isohyet method was selected as the rainfall interpolation method based on the findings of the literature review. 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 more suited for hilly areas .Traditional approaches for estimating areal and point rainfall have included station-average, Thiessen polygon, inverse distance weighting (IDW), and isohyetal methods (Thiessen 1911; Shepard1968; McCuen 1989). Several studies have found that geostatistics produces better estimates of precipitation than traditional methods (Bacchi and Kottegoda 1995; Christel and Reed 1999; Goovaerts 2000;

Campling et al., 2001; Drogue et al. 2002; Buytaert et al., 2006). The Isohyetal method allows the use of judgment and experience in drawing the contour map. The accuracy is largely dependent on the skill of the person performing the analysis and the number of gauges. If simple linear interpolation between stations is used for drawing the contours, the results will be essentially the same as those obtained by the Thiessen method. The advantages of both the Thiessen and Isohyetal methods can be combined where the area closes to the gauge is defined by the polygons but the rainfall over that area is defined by the contours from the Isohyetal method. This combination also eliminates the disadvantage of having to draw different polygon patterns when analyzing several different storm events with a variety of reporting gauges. Regardless of the technique selected for analysis of basin average rainfall, a regional map of areal distribution for the total storm event is also produced.

3.6 Data checking

Hydrological information used to handle water must be coherent, stationary and homogeneous (Dahmen, Hall, & others, 1990). Data screening, information tracking and visual checking, correlation checking and relative consistency and homogeneity double mass analysis are commonly used fundamental techniques of information checking (Dahmen et al., 1990). The Normal Ratio Method (De Silva, Dayawansa, & Ratnasiri, 2007), Inverse Distance Method (Suhaila, Sayang, & Jemain, 2008), Homogeneity Analysis and Regression Method (Wijesekera & Perera, 2016) may be used for managing missing information.

Data obtained were screened for outliers, and missing values were estimated using a linear interpolation method (Schatzman, 2002) after carrying out Single Mass Curve (S-Curve) analysis. The consistency of the precipitation data has been checked by the Double Mass curve technique (Subramanya, 1994). Outlier testing was carried out for the entire data set. Double mass plots indicated the homogeneity of annual rainfall and streamflow data. Initially time series plots were used to identify the data duration that showed a significant compatibility between the rainfall and streamflow.

3.6.1 Visual data checking

The main purpose of visual data check is to check the response of the flow to the rainfall which is considered as the most important aspect in water balance Modeling.

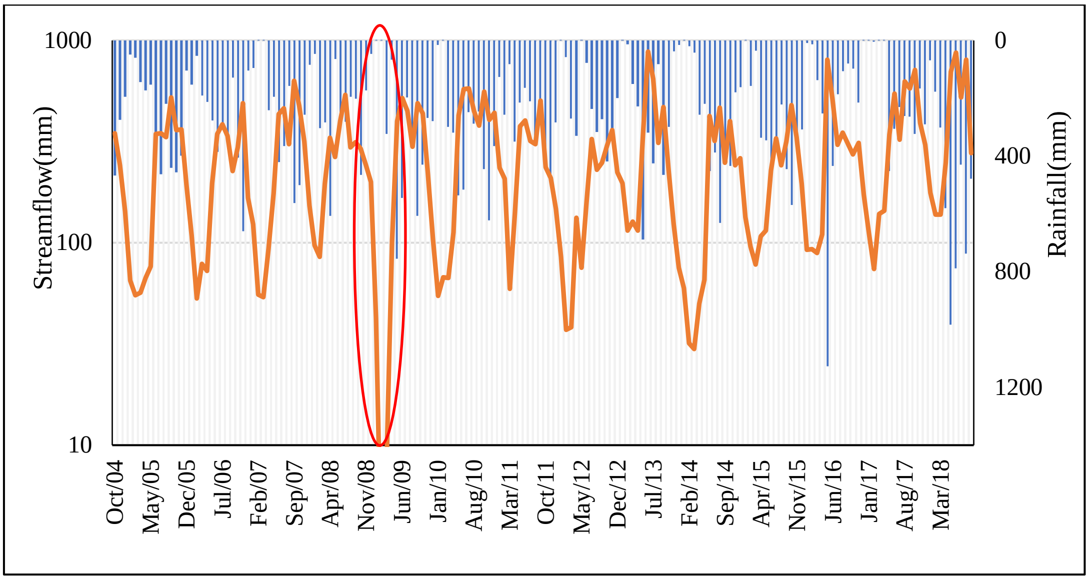


Figure 3-9: Visual data checking for Nawalapitiya Catchment

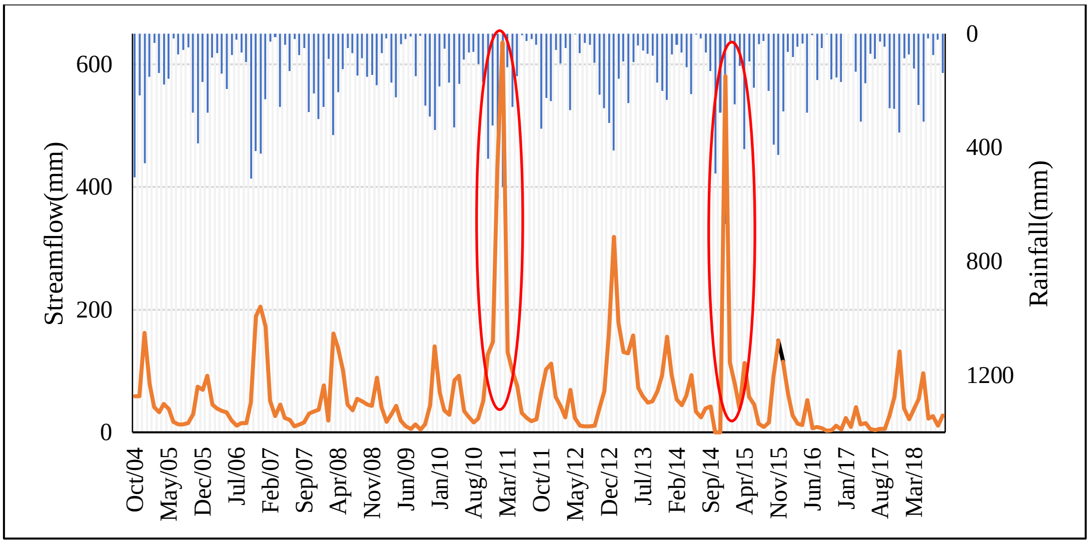


Figure 3-10: Visual data checking for Thaldena Catchment

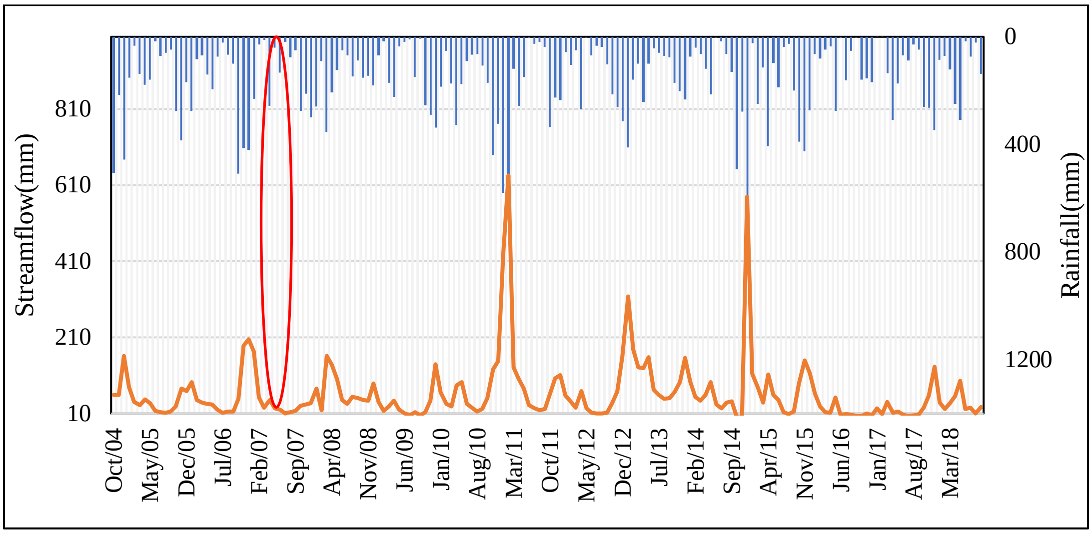


Figure 3-11: Visual data checking for Padiyatalawa Catchment

3.6.2 Co-relation between the stream flow and rainfall data

Corelation between rainfall and streamflow were obtained using Scatter Plot.

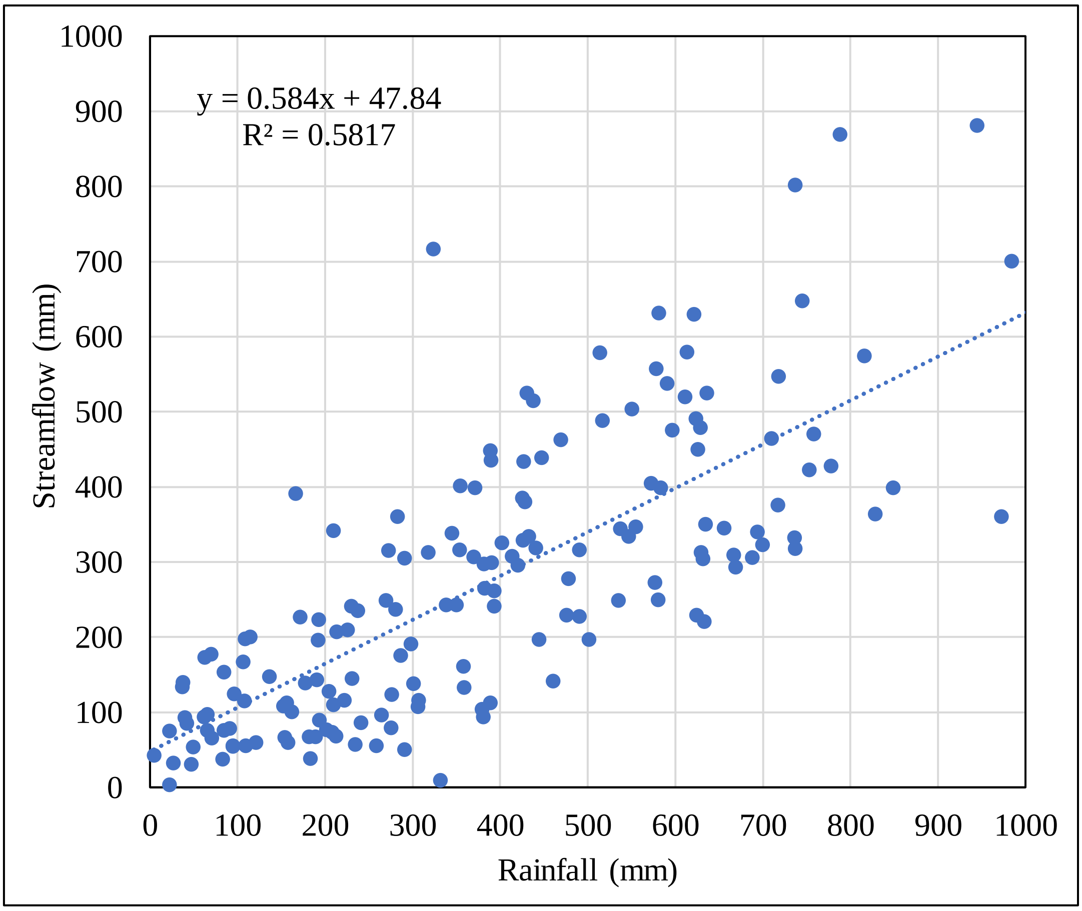


Figure 3-12: Correlation of observed stream flow and Rainfall Nawalapitiya

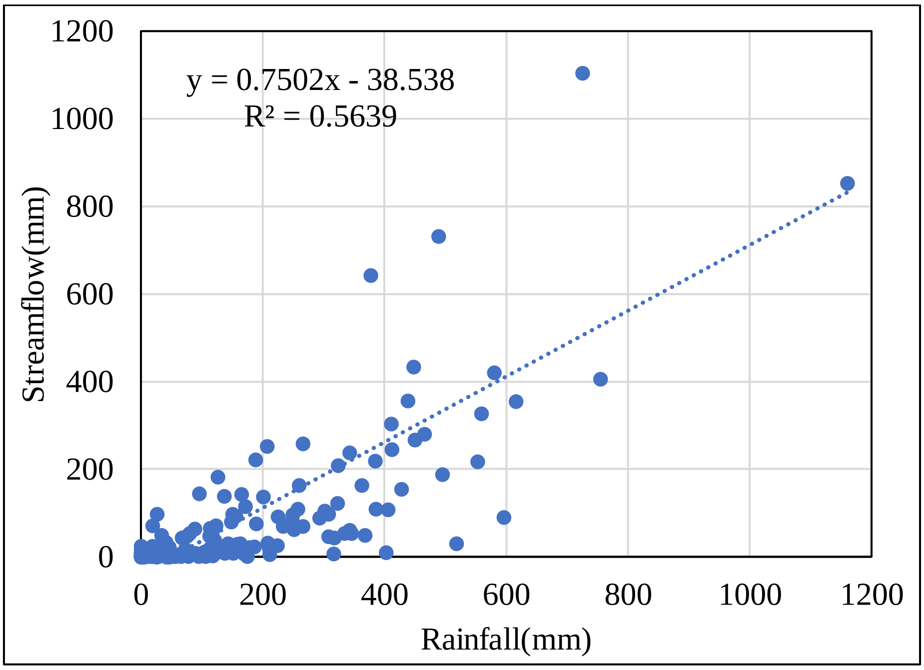


Figure 3-13: Correlation of observed stream flow and Rainfall Padiyatalawa

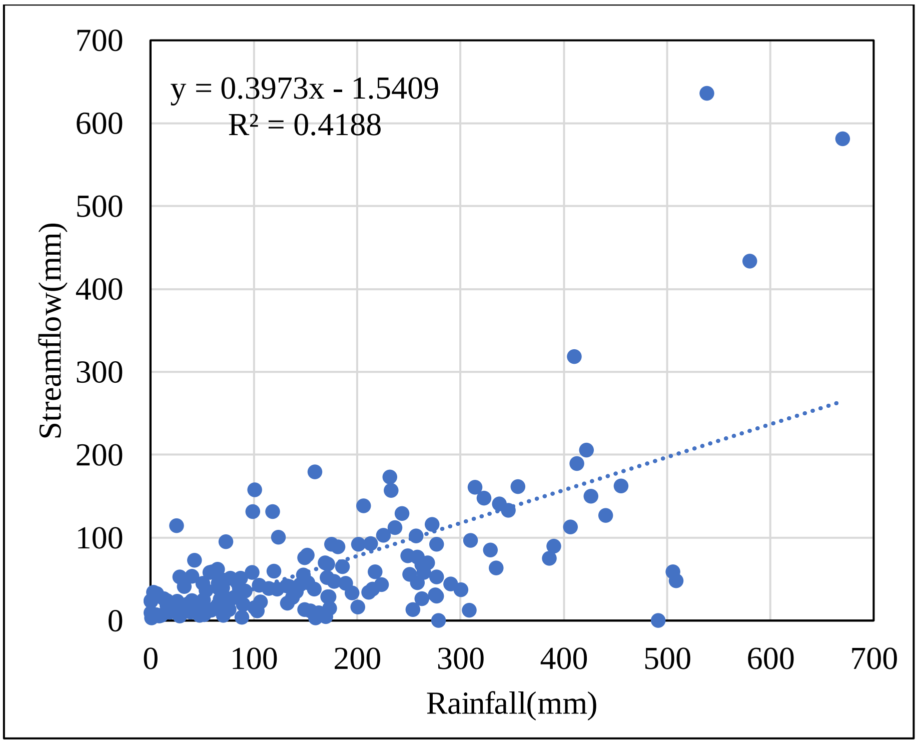


Figure 3-14: Correlation of observed stream flow and Rainfall Thaldena

3.6.3 Single mass curve analysis

Single mass curve investigation was completed for the precipitation, stream and vanishing information thinking about the consistency in yearly cycles, which is a similar idea of linear regression, which is utilized effectively to gauge the missing precipitation (Sharifi, 2015; Caldera, Piyathisse, and Nandalal, 2016).

Single mass curves were plotted for all the rainfall stations in one graph to check the consistency of rainfall data and to observe the relative variation as shown in Figure 6-15to Figure 6-18 for Thaldena, Nawalapitiya and Padiyatalawa watersheds. Further, the consistency was checked in the Isohyetal averaged rainfall, since it will directly affect the monthly water balance.

For Rainfall trend analysis of Mahaweli Basin all the rainfall station selected according to WMO guideline and single mass curve plotted for all stations.

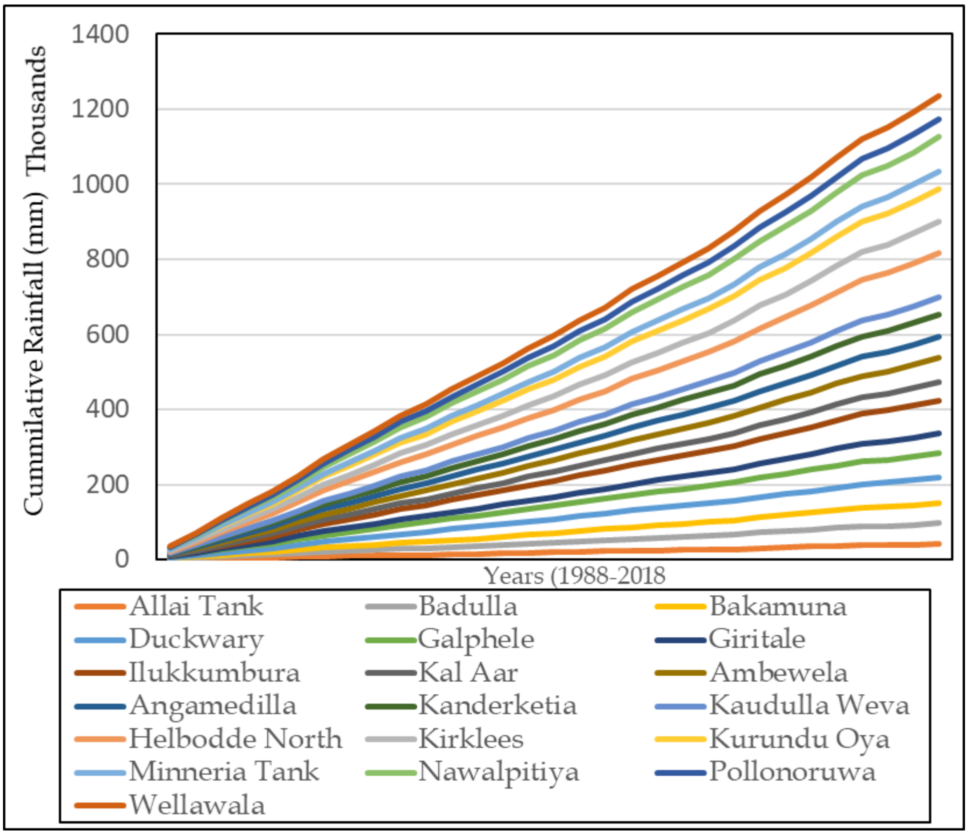


Figure 3-15: Singe Mass Curve all station for trend analysis

A good consistency was observed in rainfall data of selected stations in all the three watersheds. The consistency was checked by the uniformity of the gradient of the single mass curve.Single mass curves plotted for each catchment selected stations according to guidelines.

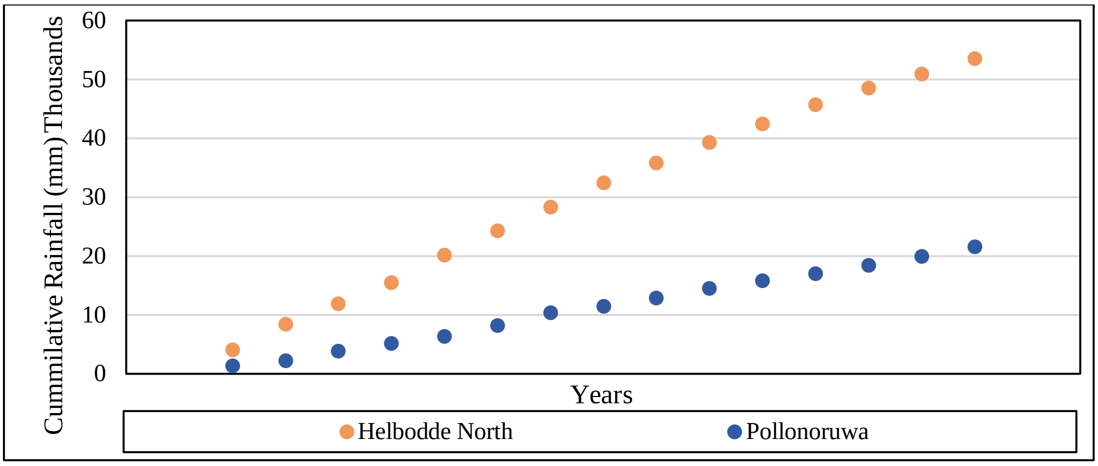


Figure 3-16: Single Mass Curves for rain gauging stations -Nawalapitiya

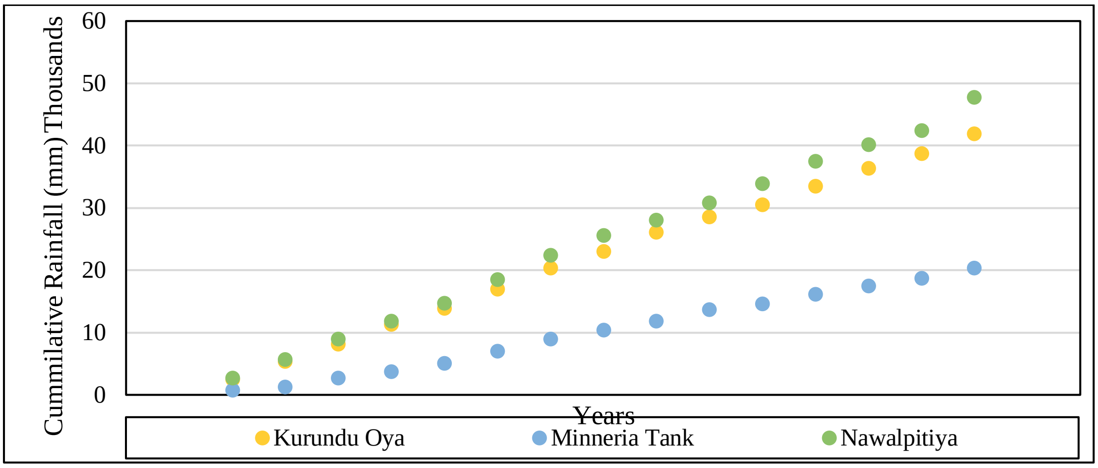


Figure 3-17: Single Mass Curves for rain gauging stations -Thaldena

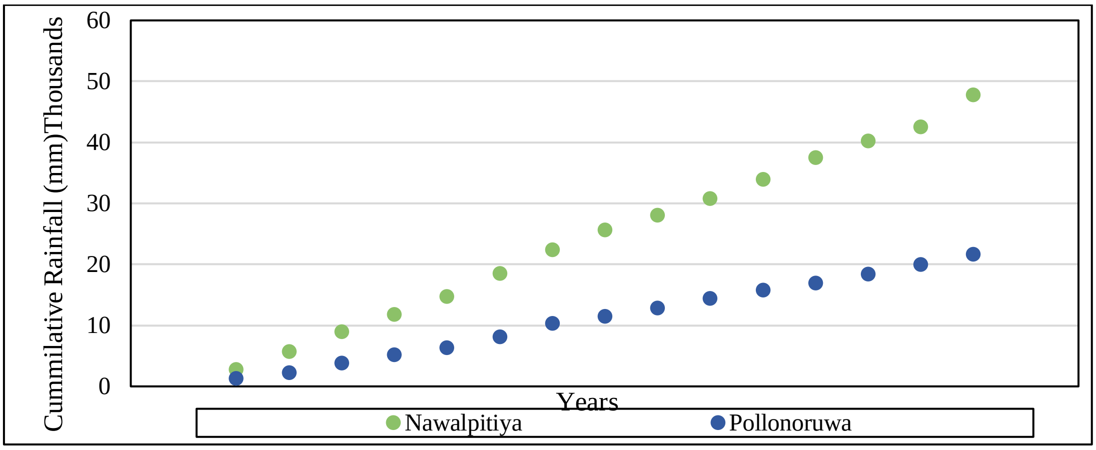


Figure 3-18: Single Mass Curves for rain gauging stations -Padiyatalawa

Single mass curve was plotted as shown in Figure 3-19 for pan evaporation data at Padiyatalawa evaporation station to check the consistency of the evaporation data.

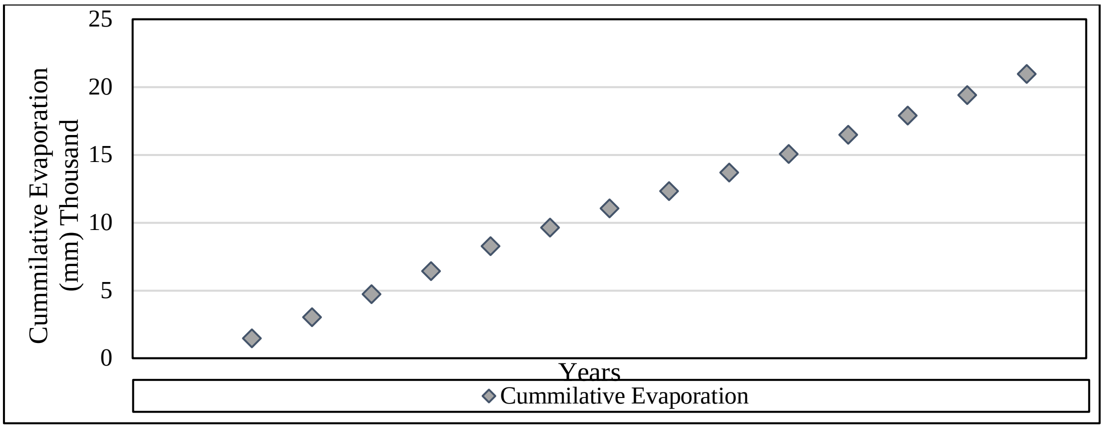


Figure 3-19: Single Mass Curve of evaporation for Padiyatalawa station

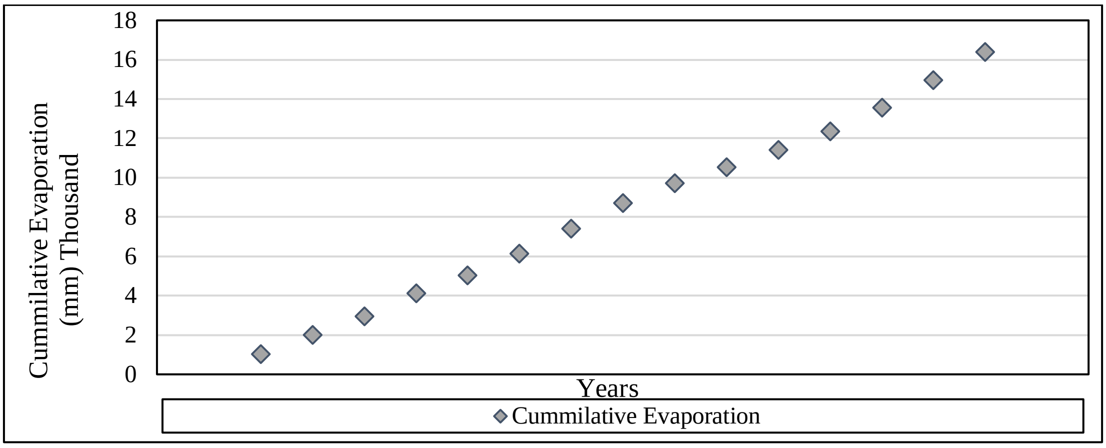


Figure 3-20: Single Mass Curve of evaporation for Kotmalle for Nawalapitiya

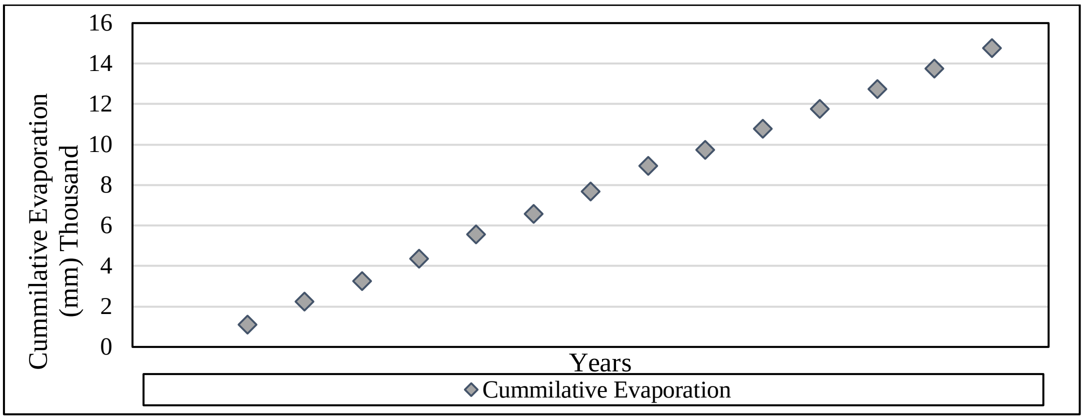


Figure 3-21: Single Mass Curve of evaporation for Girandurukotte for Thaldena

3.6.4 Double mass curve analysis

The double mass curve analysis was done for all the stations of Three watersheds as Shown.on the off chance that the conditions important to the chronicle of a downpour check station have experienced a significant change during the account time frame, irregularity would emerge in the precipitation information of that station. The fundamental explanations behind an irregularity might be expected to a moving of a downpour check to another area, changes in the area of the station, changes in the biological system because of cataclysms and event of an observational mistake from a specific date and so forth. The check which is done to distinguish this irregularity is the Twofold mass bend procedure which depends on the rule that when each recorded information originates from a similar parent populace, they are steady (Subramanya, 2008).

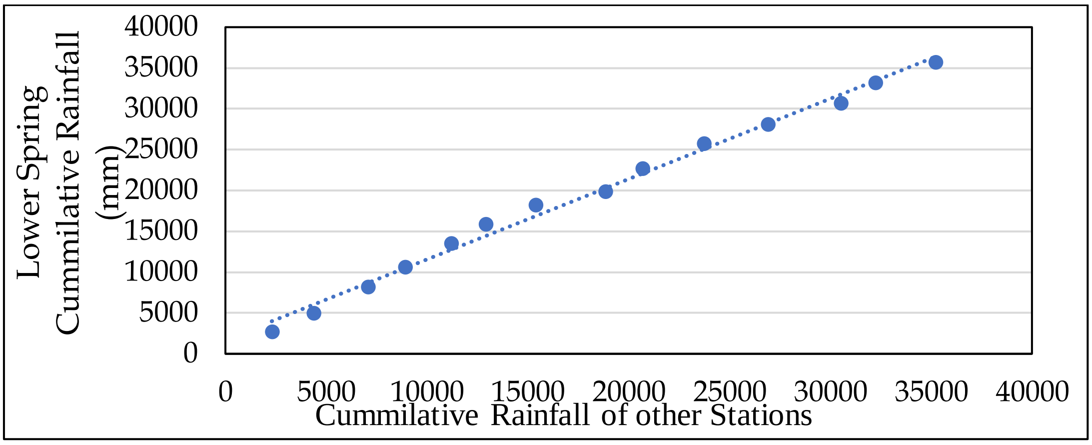


Figure 3-22: Double Mass Curve (Lower Spring Station) with other station data

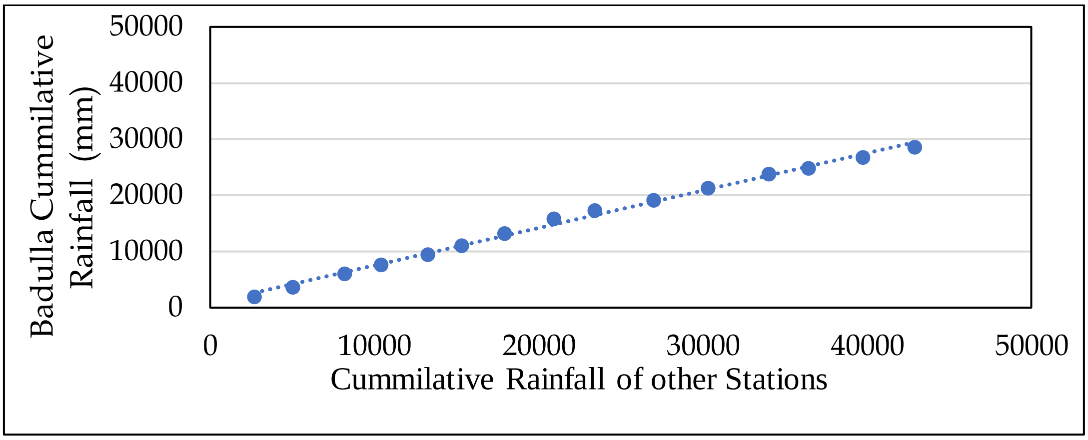


Figure 3-23: Double Mass Curve (Badulla Station) with other station data

3.6.5 Annual water balance

For a watershed, in an interval of time Δt, continuity equation can be written as,

Mass Inflow – Mass Outflow = Change in Mass Storage

$P - R - G - E - T = \Delta S$……………………………………..Equation 18

P- Precipitation, R- Surface Runoff, G- Net Ground Water Flow, E- Evaporation, T- Transpiration and ΔS- Change of Storage (Subramanya, 2008)

The above equation can be rearranged neglecting the change of storage (ΔS) in annual cycles as,

$P - (R+G) - E - T = 0$………………………………………Equation 19

Rainfall - Stream flow = Evapotranspiration

Therefore, The Isohyetal averaged rainfall minus streamflow which is water balance was calculated and plotted against the annual pan evaporation to check the annual water balance for Nawalapitiya, Thaldena and Padiyatalawa watersheds which have been shown in Figure (3-24),(3-32) and Figure (3-28).

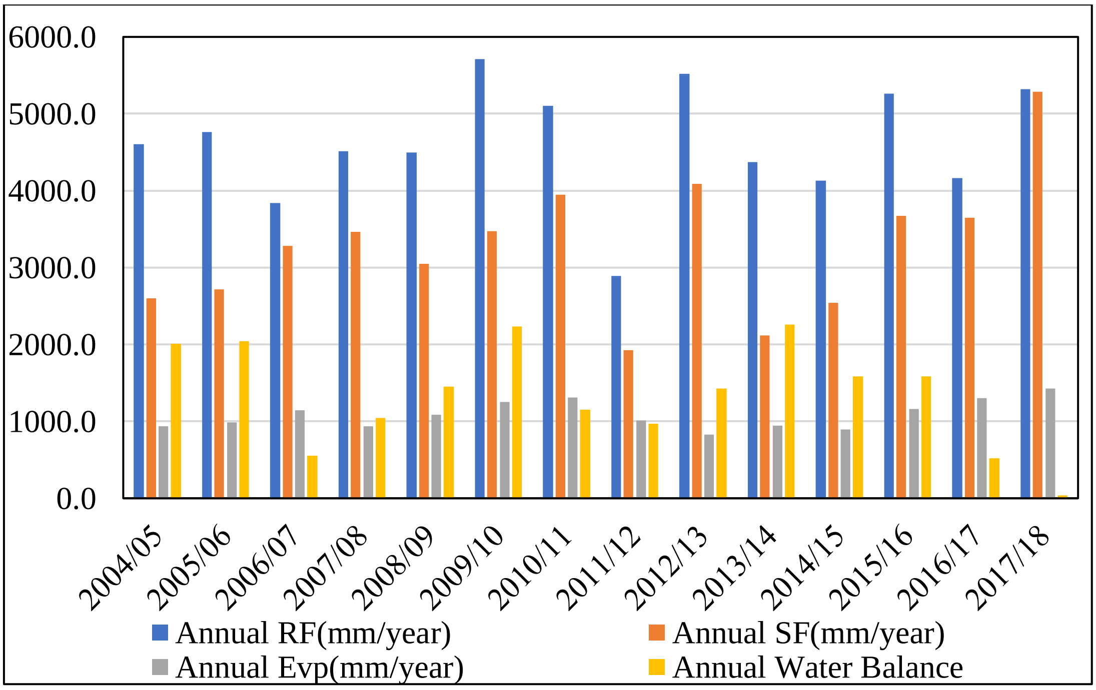


Figure 3-24: Annual Water Balance of Nawalapitiya Watershed

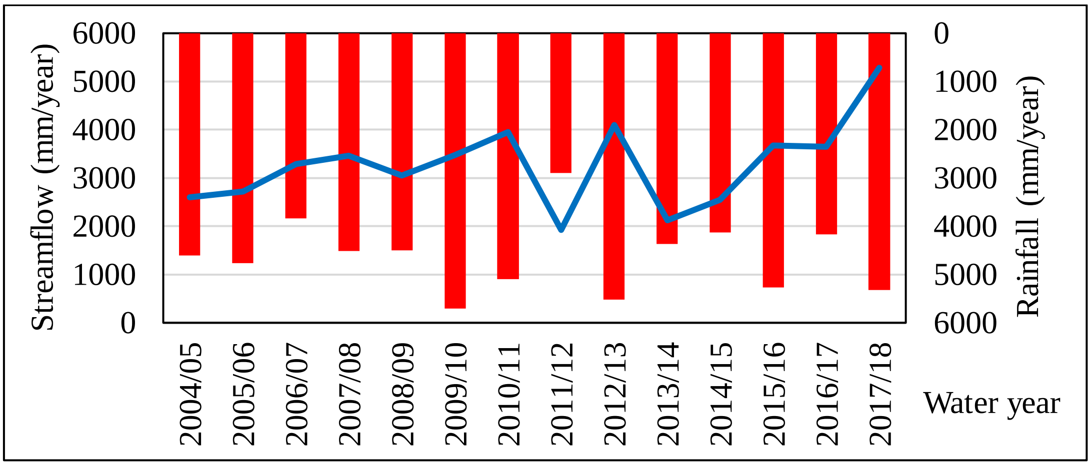


Figure 3-25: Annual rainfall and streamflow comparison for Nawalapitiya

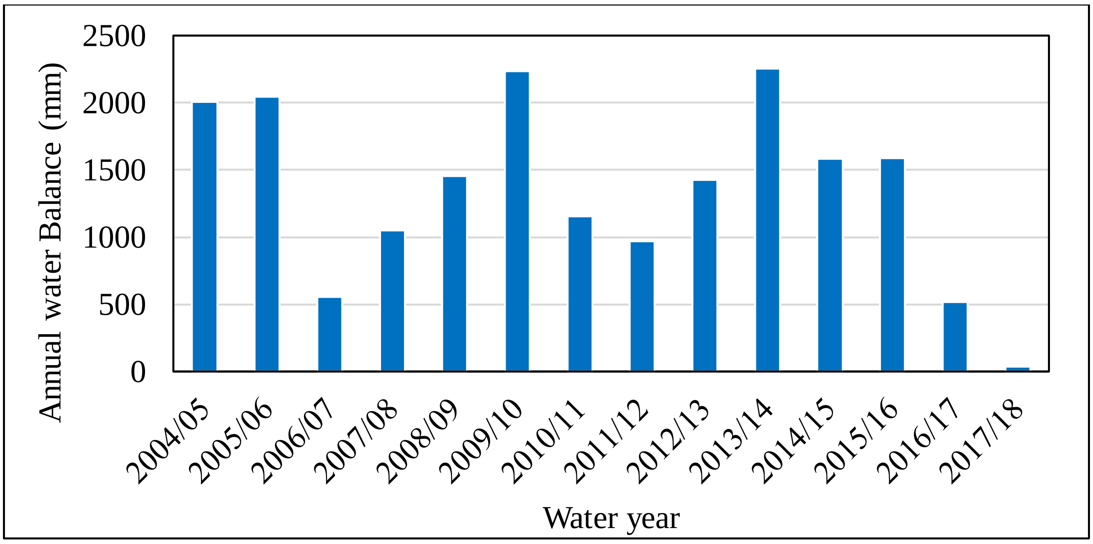


Figure 3-26: Water Balance for Nawalapitiya Catchment

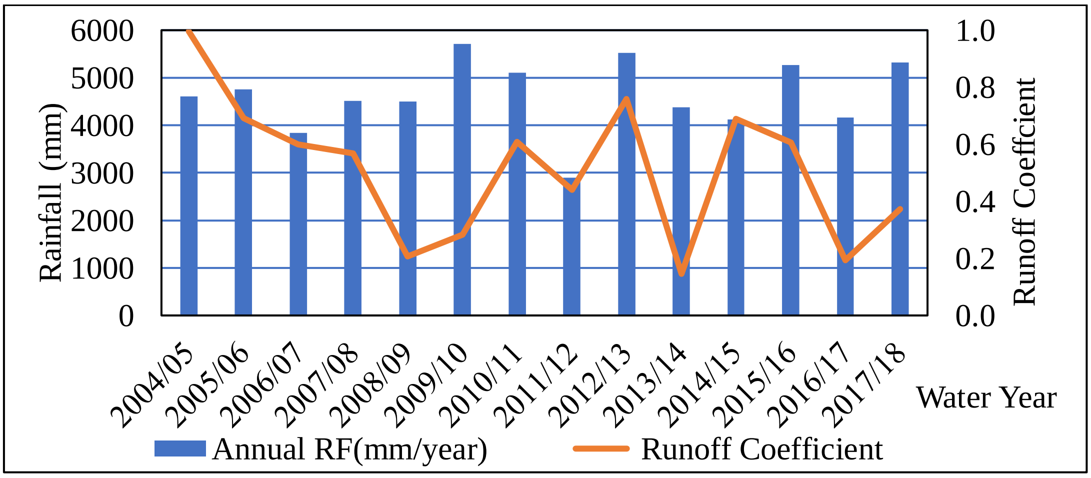


Figure 3-27: Annual runoff coefficient verses rainfall – Nawalapitiya

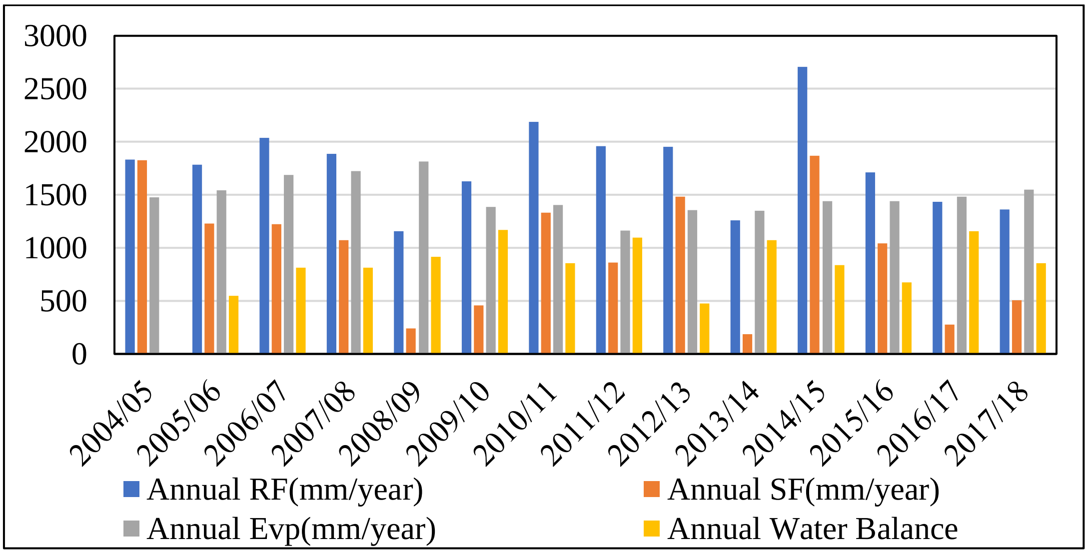


Figure 3-28: Annual Water Balance- Padiyatalawa Watershed

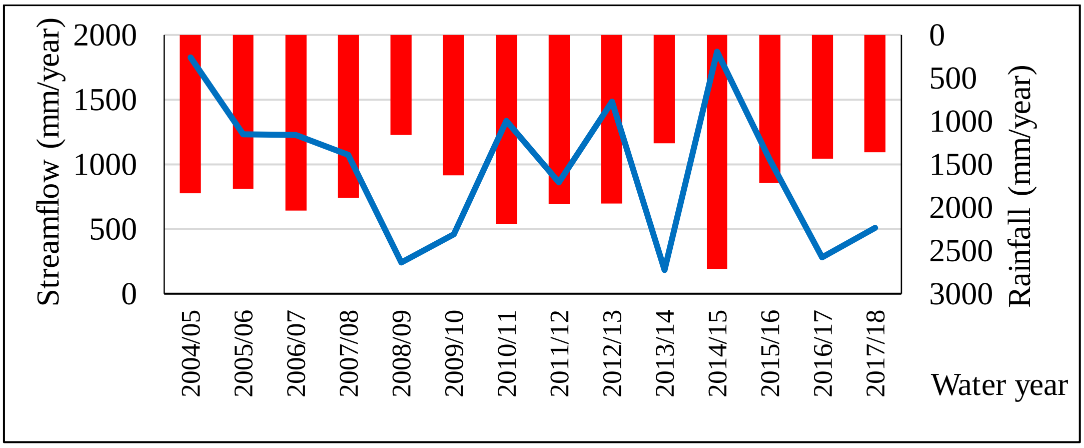


Figure 3-29: Annual rainfall and streamflow comparison for Padiyatalawa

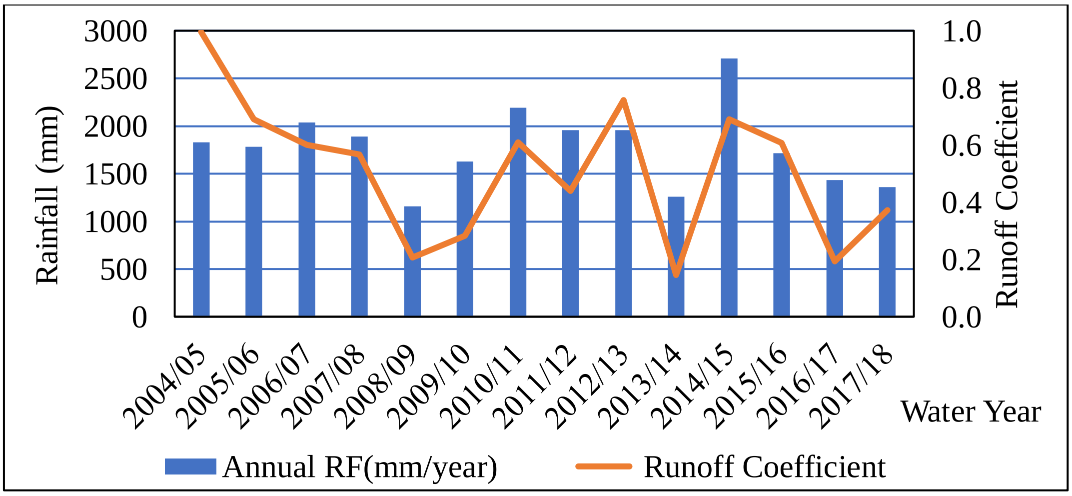


Figure 3-30: Annual runoff coefficient verses rainfall – Padiyatalawa

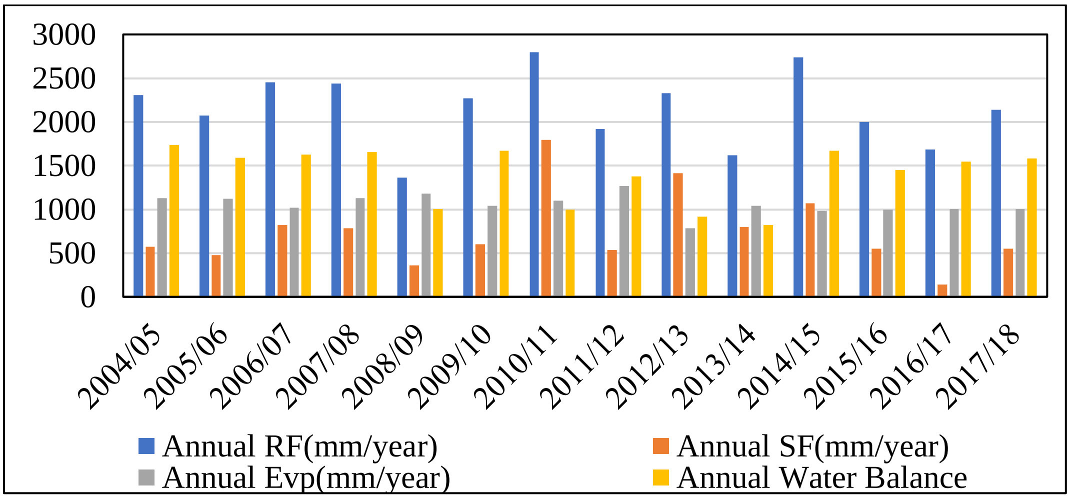


Figure 3-31: Annual Water Balance- Thaldena Watershed

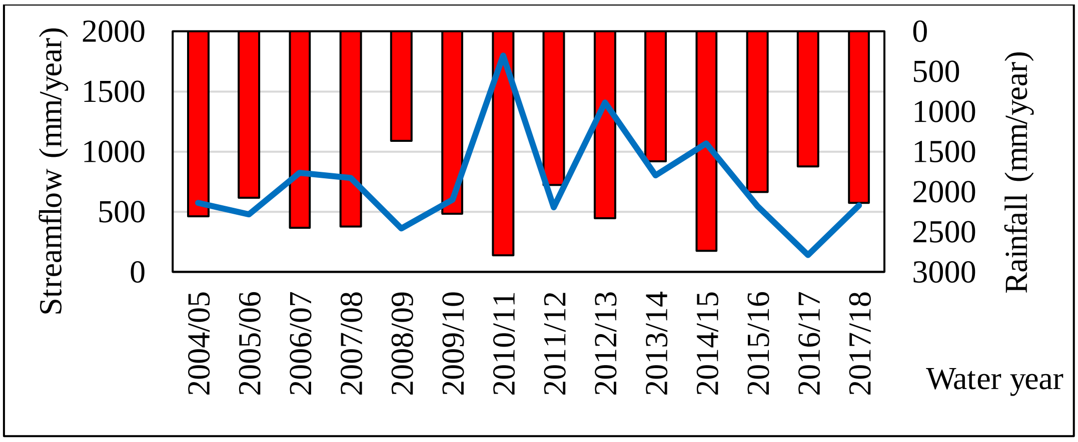


Figure 3-32: Annual rainfall and streamflow comparison for Thaldena

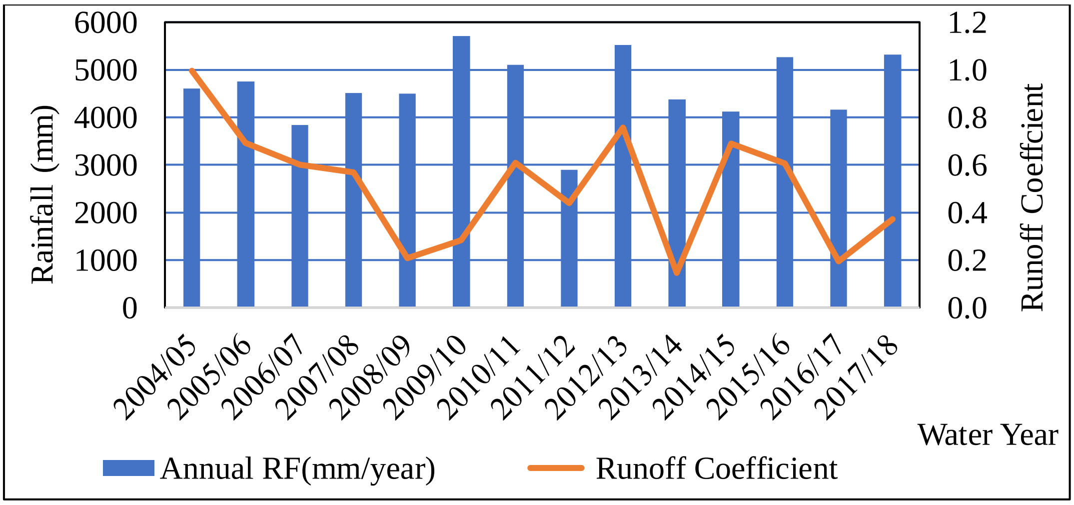


Figure 3-33: Annual runoff coefficient verses rainfall – Thaldena Catchment

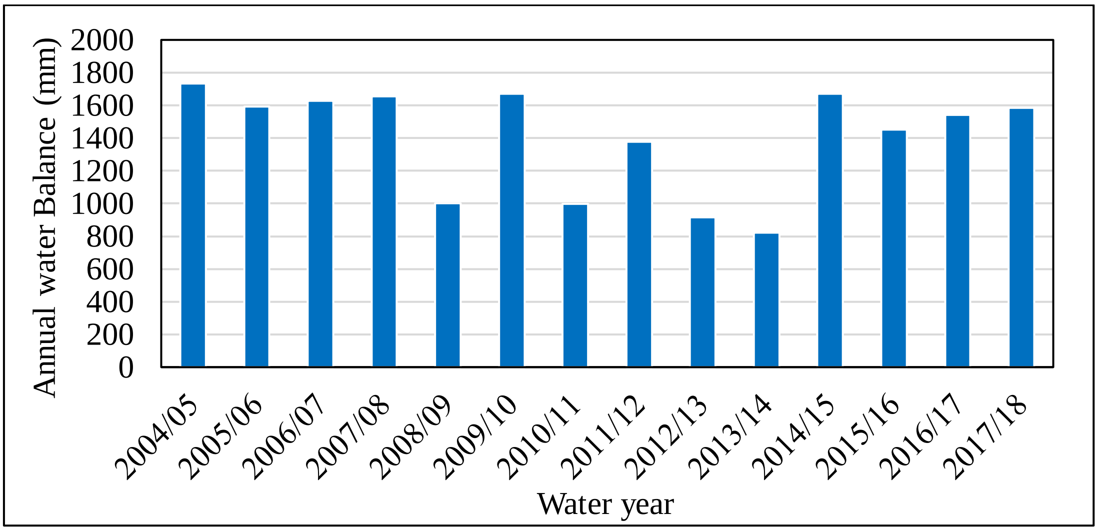


Figure 3-34: Annual water balance for Thaldena

3.7 Monthly, annual and seasonal runoff coefficients

Monthly and annual runoff coefficients were calculated by dividing streamflow by Thiessen averaged rainfall and plotted against the corresponding Isohyetal averaged rainfall. The identified periods with data errors were further verified with the annual plot of the runoff coefficients as shown in Figure 3-35 and Figure 3-36 and Figure 3-37 in all watersheds.

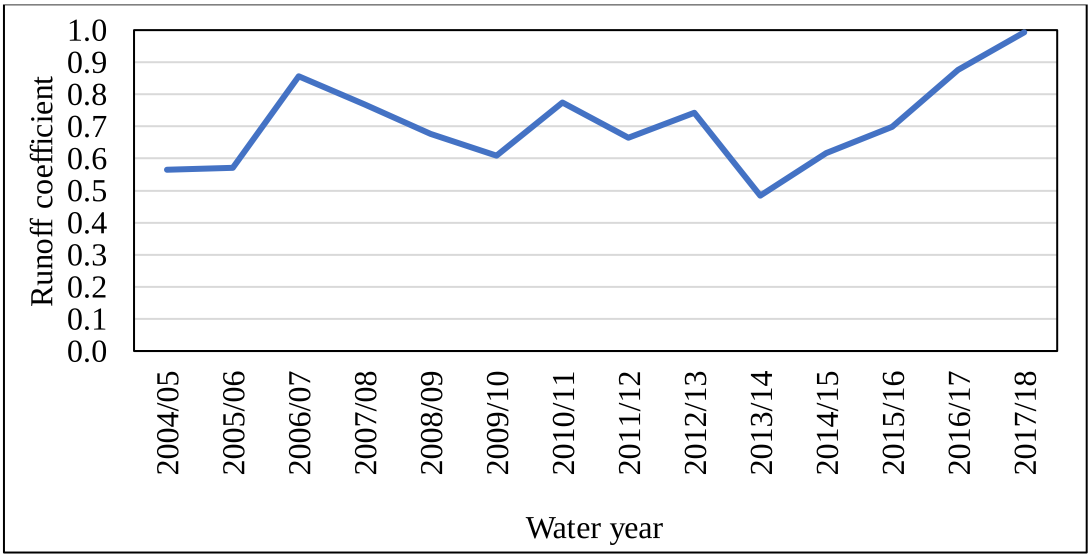


Figure 3-35: Annual Runoff Coefficient Nawalapitiya

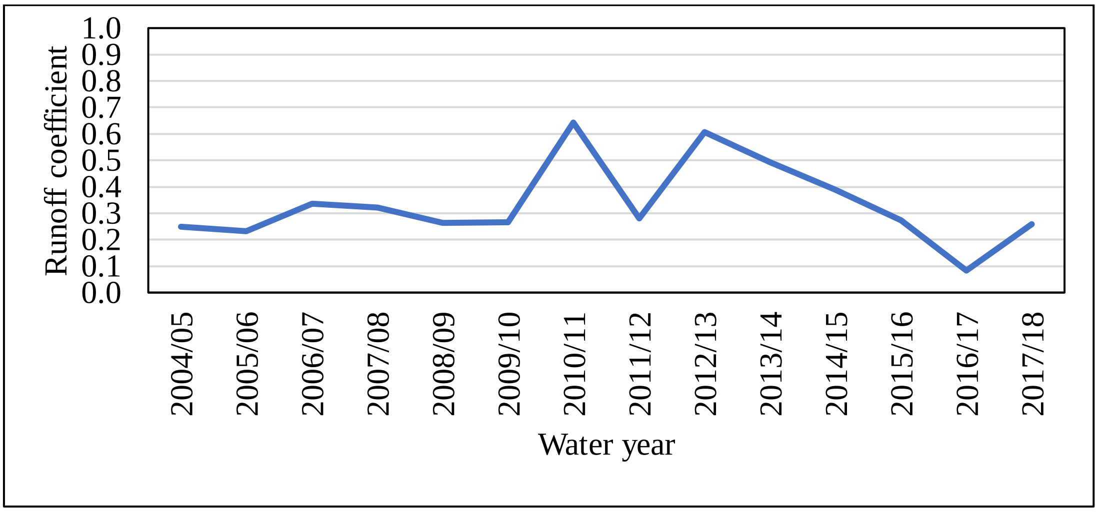


Figure 3-36: Annual Runoff Coefficient Thaldena

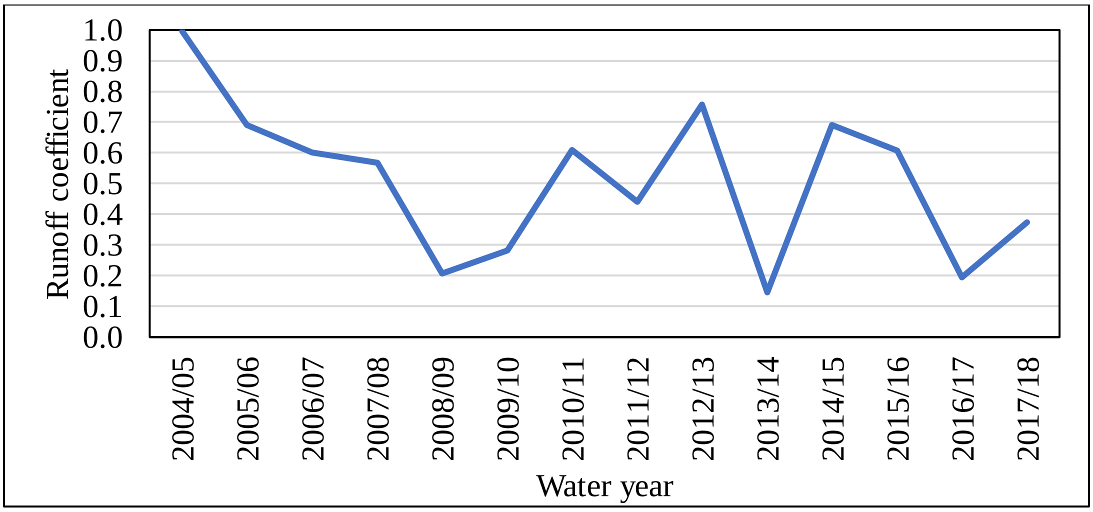


Figure 3-37: Annual Runoff Coefficient Padiyatalawa

In Nawalapitiya watershed the average runoff coefficient is 0.70 while in Thaldena the annual runoff coefficient is 0.33 in the catchment Padiyatalawa in Maduru Oya basin has the runoff of 0.55.

On comparing all watersheds, relatively high values of runoff coefficients were observed in Nawalapitiya watersheds may be due to the mountainous terrain existing. In Padiyatalawa watershed run off was very high near to 0.9. In this month, isoyetal averaged rainfall is 1832 mm and the stream flow is 1825 mm. But in the visual check of rainfall verses streamflow, no unrealistic response was observed in this month.

3.8 Statistical parameters of data for the selected range

The data set were evaluated graphically for all catchments under the statistical parameters like monthly maximum, minimum, mean and standard deviation of rainfall, evaporation and stream flow data.

3.8.1 Precipitation

For all the three catchments 15 years of data were collected and statically evaluated.

In Nawalapitiya watershed, for the selected data period (2004-2018), the monthly mean of Isohytal averaged rainfall varies from 145 ~ 488 mm, while varying the minimum and maximum from 6 ~ 252 mm and 282 ~ 910 mm, respectively. The Isohyetal averaged rainfall variation in 12 months for the considered data period for Nawalapitiya watershed has been shown in Figure 3-38

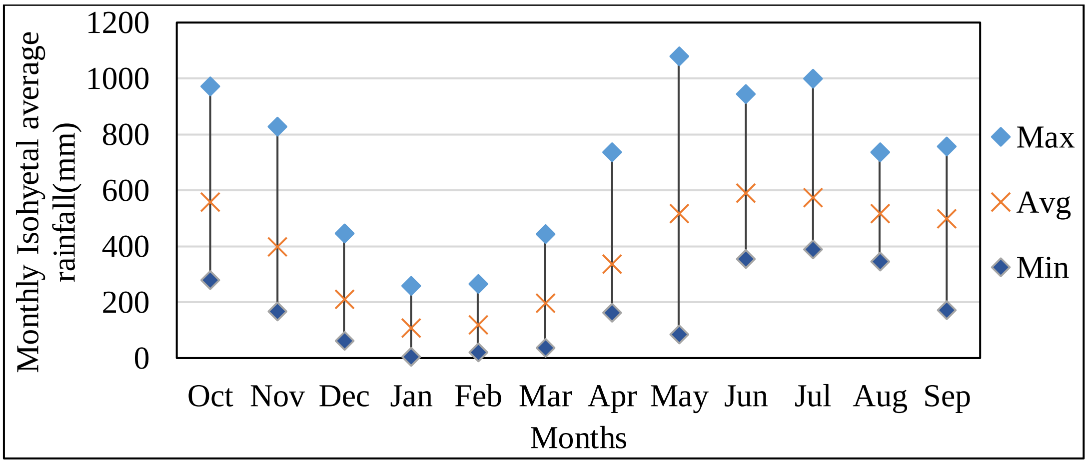


Figure 3-38: Monthly comparison of Isohyetal average rainfall for Nawalapitiya

In Thaldena watershed, for the selected data period (2004-2018), the monthly mean of Isohytal averaged rainfall varies from 23 ~ 935 mm, while varying the minimum and maximum from 23 ~ 274 mm and 216 ~ 935 mm, respectively .The Isohyetal averaged rainfall variation in 12 months for the considered data period for Thaldena watershed has been shown in Figure 3-39.

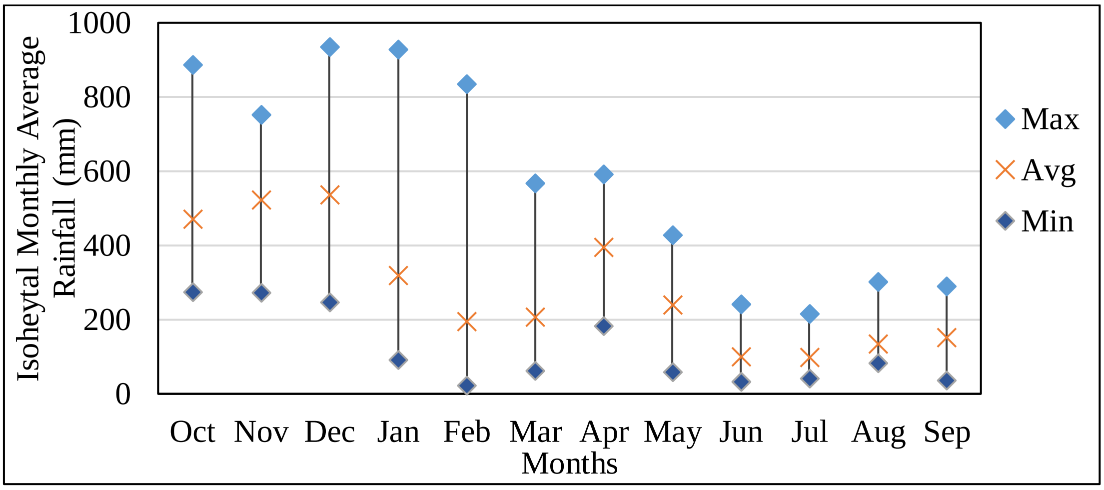


Figure 3-39: Monthly comparison of Isohyetal average rainfall for Thaldena

In Padiyatalawa watershed, for the selected data period (2004-2018), the monthly mean of Isohytal averaged rainfall varies from 72 ~ 223 mm, while varying the minimum and maximum from 2 ~ 220 mm and 86 ~ 720 mm, respectively .The Isohyetal averaged rainfall variation in 12 months for the considered data period for Padiyatalawa watershed has been shown in Figure 3-40.

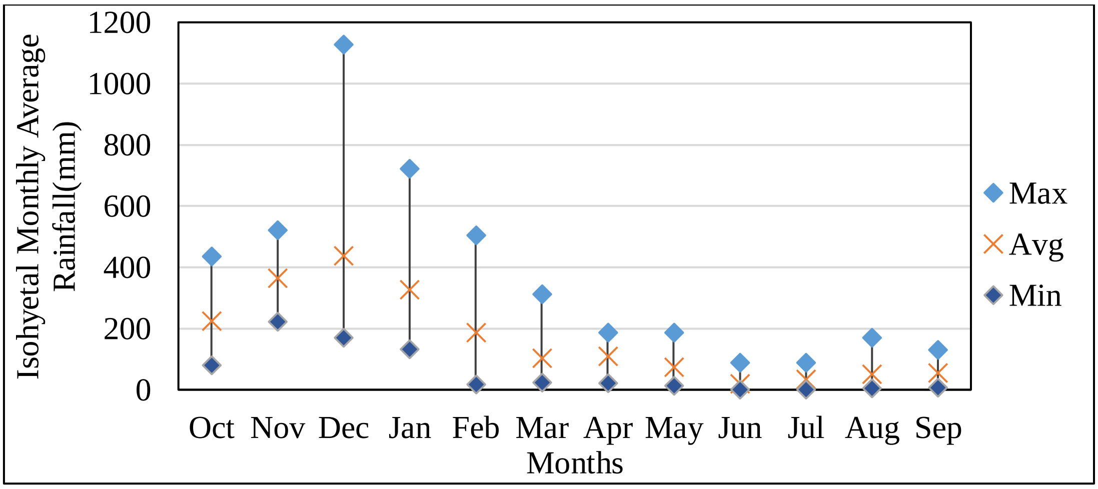


Figure 3-40: Monthly comparison of Isohyetal average rainfall for Padiyatalawa

3.8.2 Streamflow

In Nawalapitiya watershed, for the selected data period (2004-2018), the monthly mean of stream flow varies from 108~371 mm, while varying the minimum and maximum from 44~177 mm and 216~934 mm respectively. The stream flow variation in 12 months for the considered data period for Nawalapitiya sub-catchment has been shown in Figure 3-41.

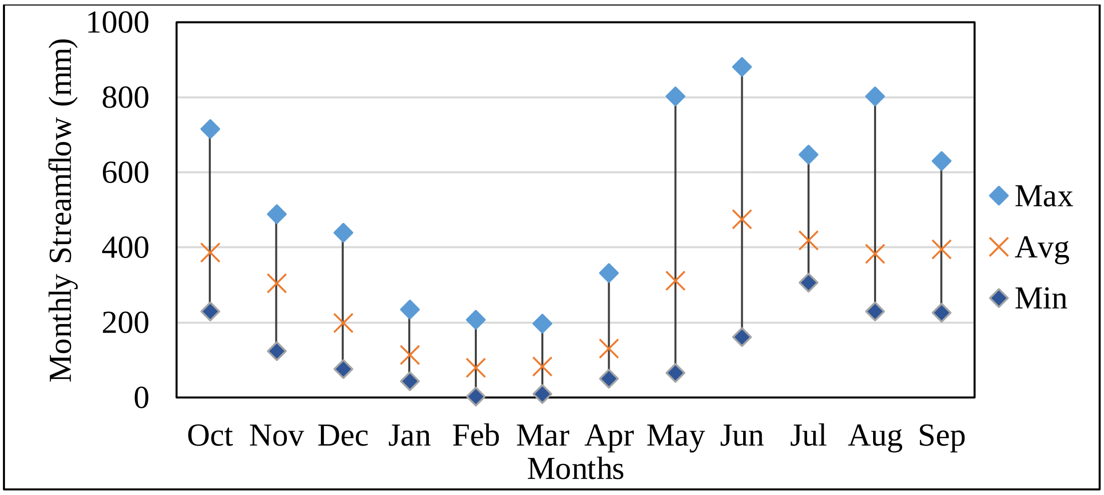


Figure 3-41: Monthly Streamflow comparison for Nawalapitya

In Thaldena sub-catchment, for the selected data period (2004-2018), the monthly mean of stream flow varies from 8~635 mm, while varying the minimum and maximum from 1~23 mm and 50~635 mm respectively. The stream flow variation in 12 months for the considered data period for Thaldena sub-catchment has been shown in Figure 3-42.

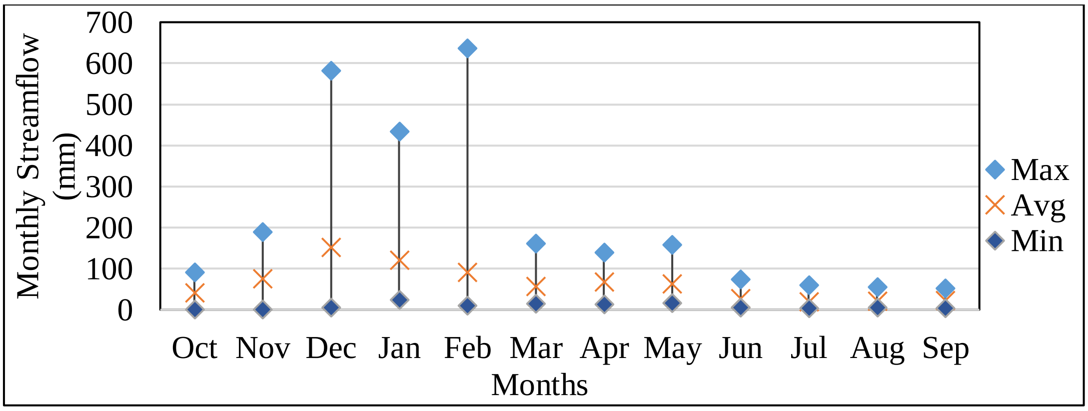


Figure 3-42: Monthly comparison of Stream flow Thaldena

In Padiyatalawa sub-catchment watershed, for the selected data period (2004-2018), the monthly mean of stream flow varies from 03~321 mm, while varying the minimum and maximum from 1.3~ 22 mm and 10~1546 mm respectively. The streamflow variation in 12 months for the considered data period for Padiyatalawa sub-catchment has been shown in Figure 3-43.

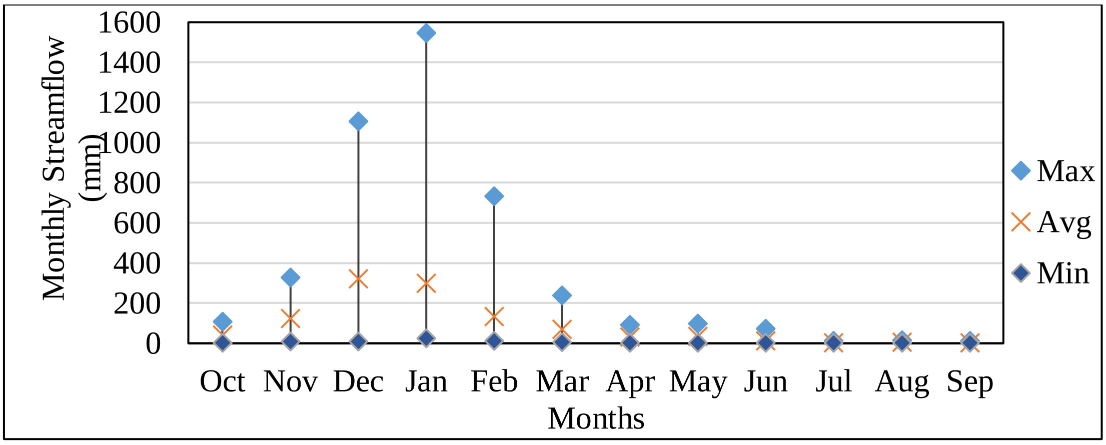


Figure 3-43: Monthly comparison of Stream flow Padiyatalawa

3.8.3 Evaporation

For Nawalapitiya watershed, from 2004-2018 monthly mean of pan evaporation at Kotmalle station varies from 96 ~ 136 mm, while varying the minimum and maximum from 63 ~ 97 mm and 118 ~ 186 mm, respectively. The variation of pan evaporation in 12 months for the considered data period for Kotmalle station of wet zone has been shown in Figure 3-44.

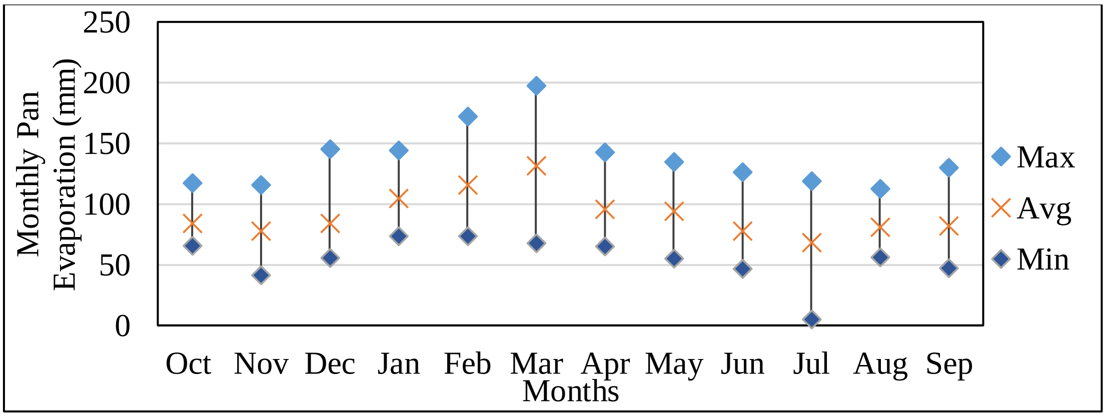


Figure 3-44: Monthly Comparison of Pan Evaporation-Kotmalle (Nawalapitiya)

For Thaldena watershed, from 2004-2018 monthly mean of pan evaporation at Girandurukotte station varies from 84 ~ 125 mm, while varying the minimum and maximum from 43 ~ 73 mm and 84 ~ 129 mm, respectively. The variation of pan evaporation in 12 months for the considered data period for Thaldena watershed of intermediate zone has been shown in Figure 3-45.

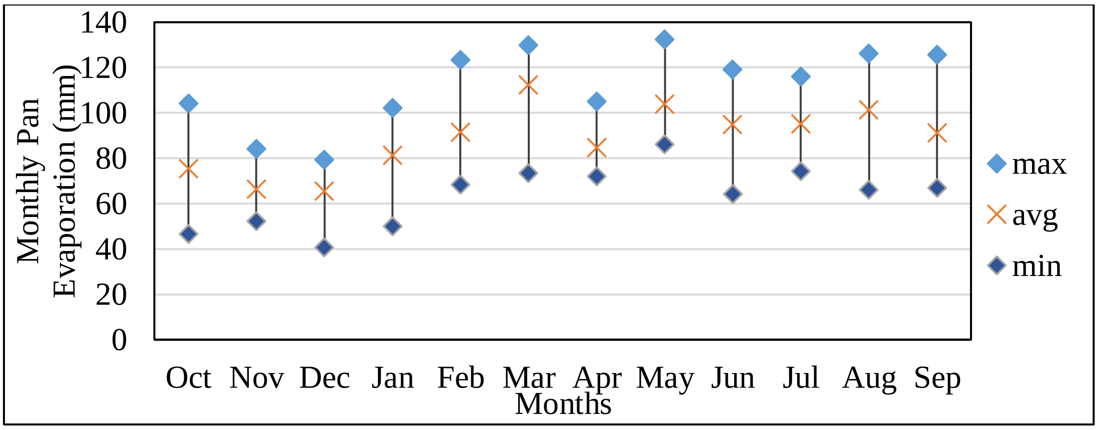


Figure 3-45: Monthly Comparison of Pan Evaporation-Girandurukotte (Thaldena)

For Padiyatalawa watershed, from 2004-2018 monthly mean of pan evaporation at Rathnapura station varies from 54 ~ 168 mm, while varying the minimum and maximum from ~ 137 mm and 135 ~ 186 mm, respectively. The variation of pan evaporation in 12 months for the considered data period for Padiyatalawa watershed of dry zone has been shown in Figure 3-46.

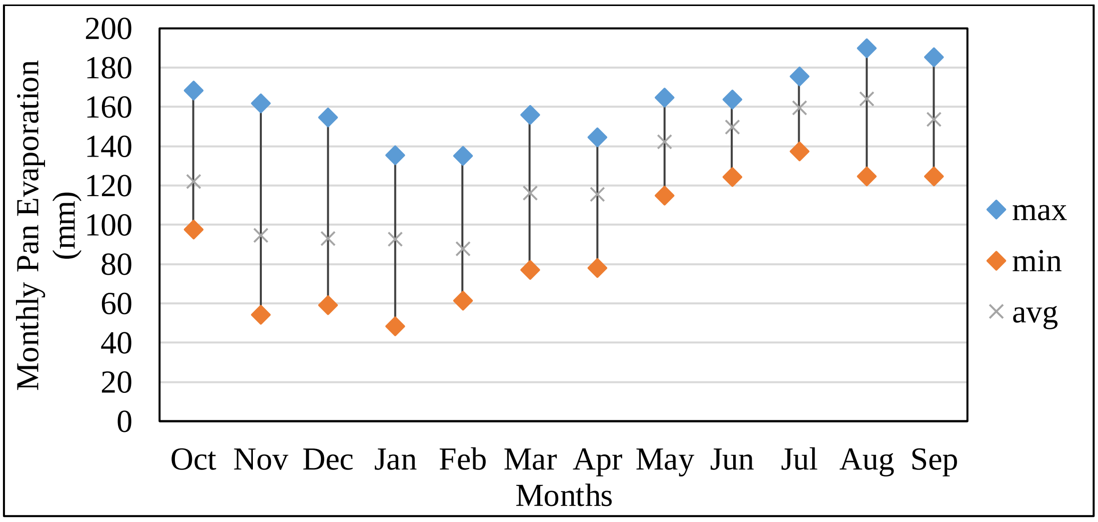


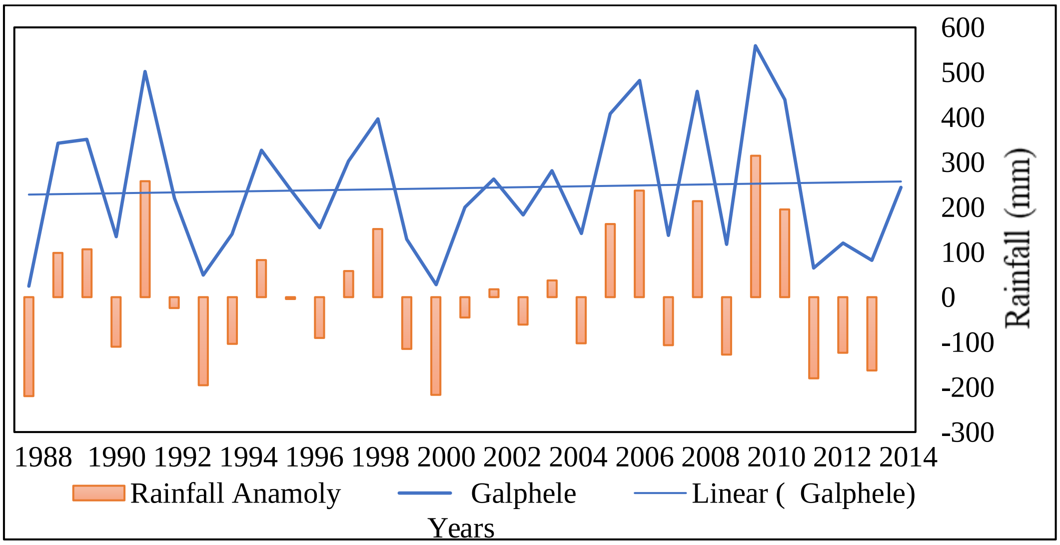
Figure 3-46: Monthly Comparison of Pan Evaporation-Padiyatalawa

4 ANALYSIS AND RESULTS

On running the Mann-Kendall test on 30 years of rainfall data in each zone, the following results were obtained for the 18 stations distributed over entire basin. Results of trend analysis on yearly data for complete records shows an increasing trend at all stations in dry zone of Mahaweli Basin, The Z statistic for the analysis of trend conducted on the longer period of observations at all station is much smaller than the Z obtained when analysing the common period of record (1988-2018). This is in agreement with findings of recent research on hydroclimatic trends, whichsuggest that longer periods of data exhibit fewer and less significant trends than shorter data periods (Birsan et al., 2005). Results of trend analyses on seasonal seasonal rainfall data for the all gauging stations are shown in annexures for the same period of record. There is no common behaviour at stations in term of trends in the monthly and seasonal rainfall. Analysis of graphs and statistical tests showed prolonged variability in the average annual rainfall over each climatic zone across the three climatic period partitions, and this variation and change was statistically determined.

4.1 Rainfall Trends of Wet Zone

In wet zone,four (4) rain gauge stations were selected for trend analysis. Only Ambewela station shows positive trends rest all three stations shows negative trend in that only Nawalapitiya station negative trend were found significant as Figure 4-1.



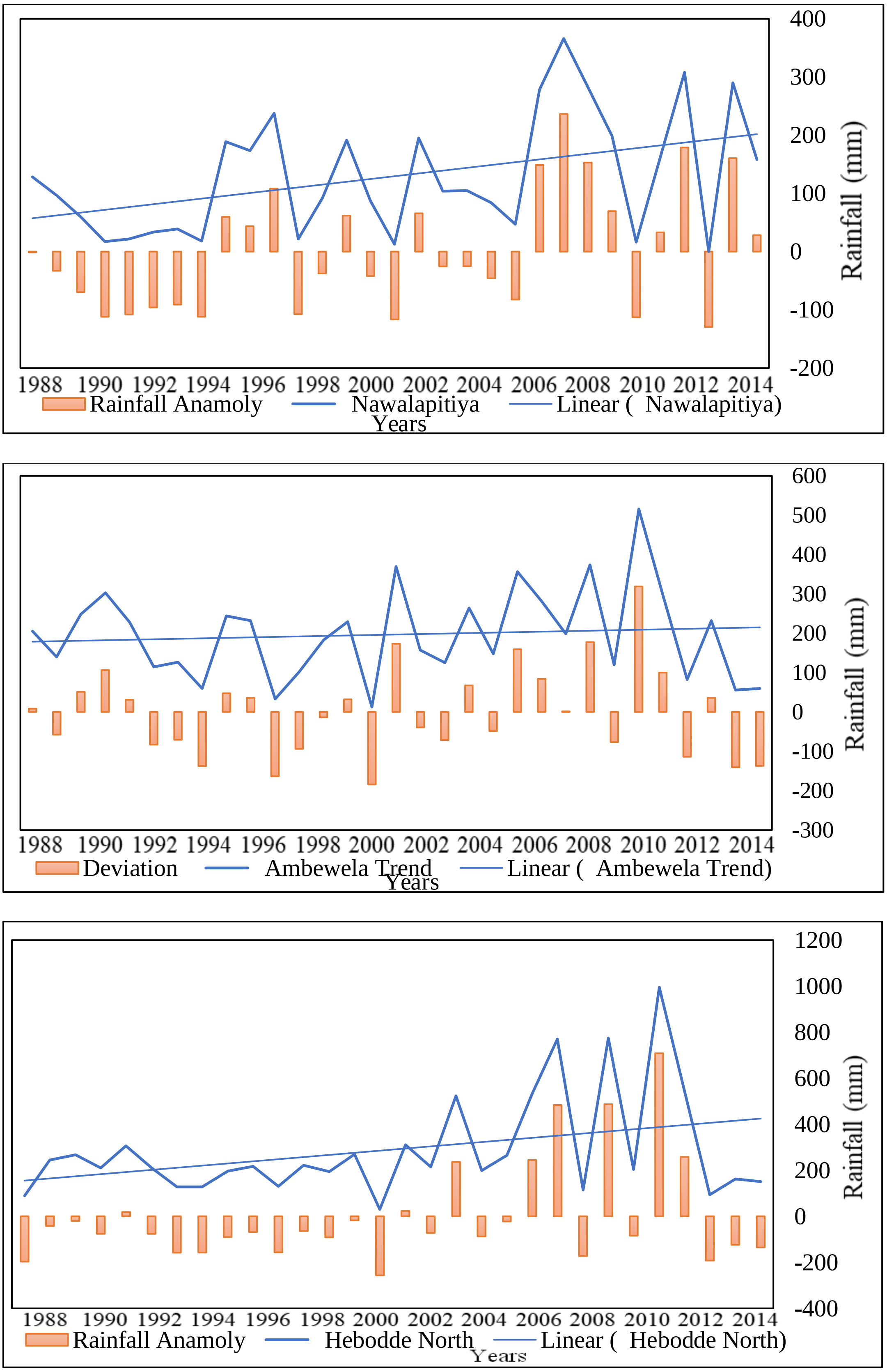
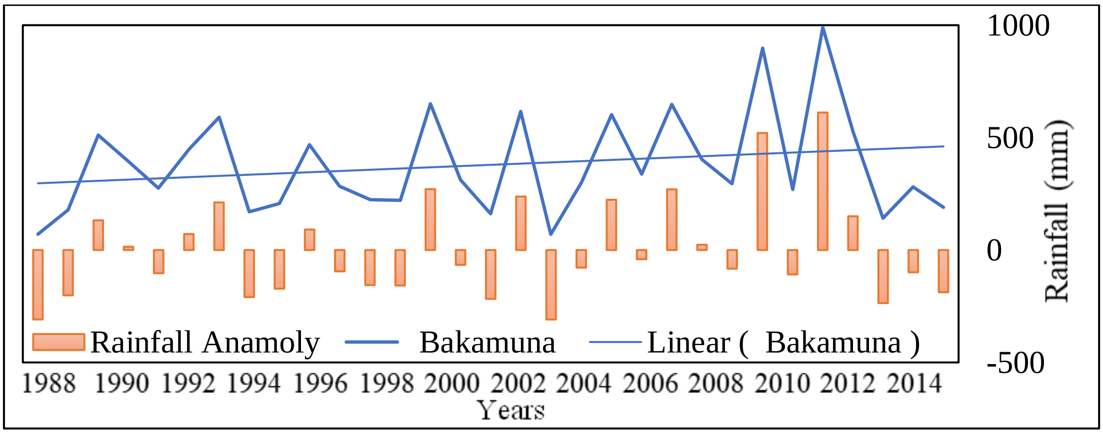
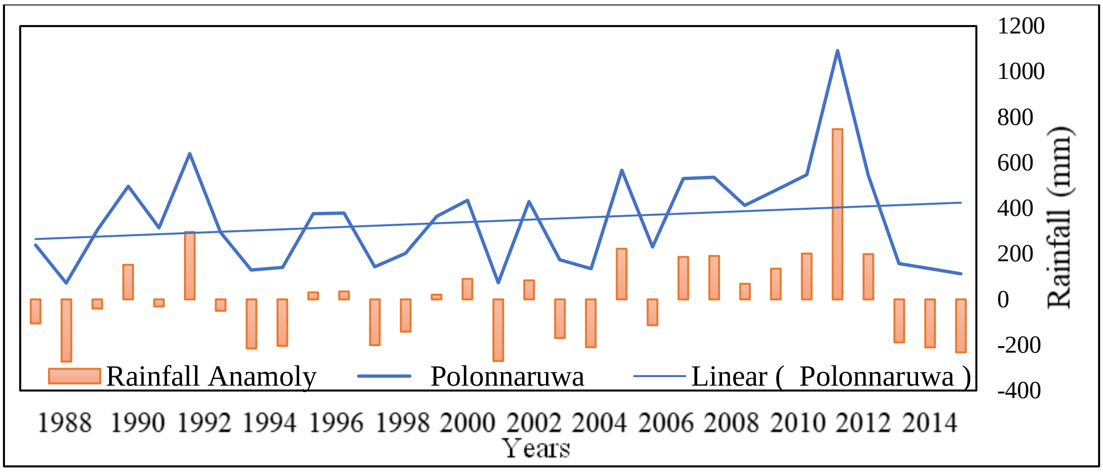


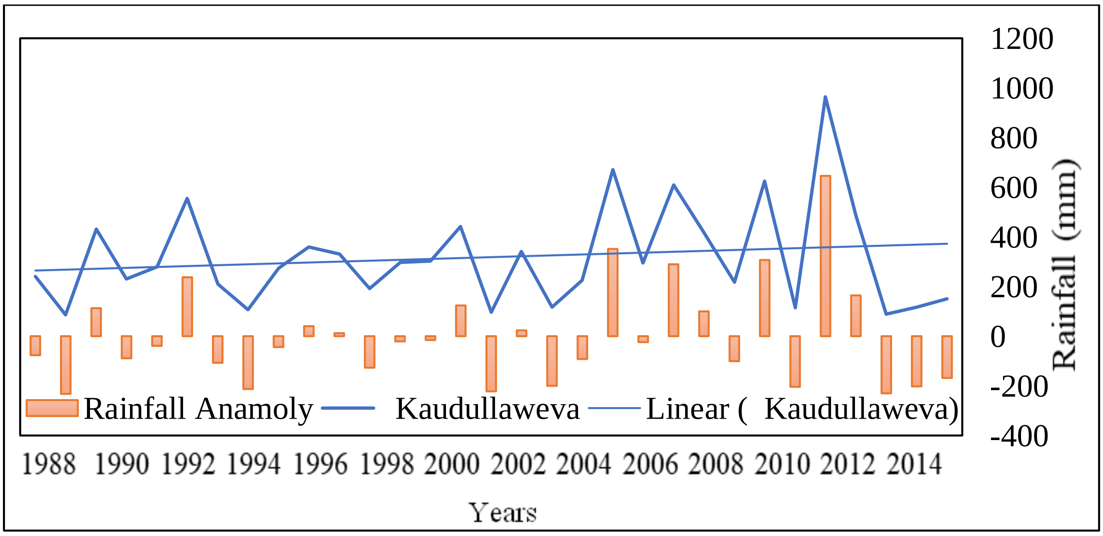
Figure 4-1: Rainfall Trends of wet zones Rain gauge station in Mahaweli Basin

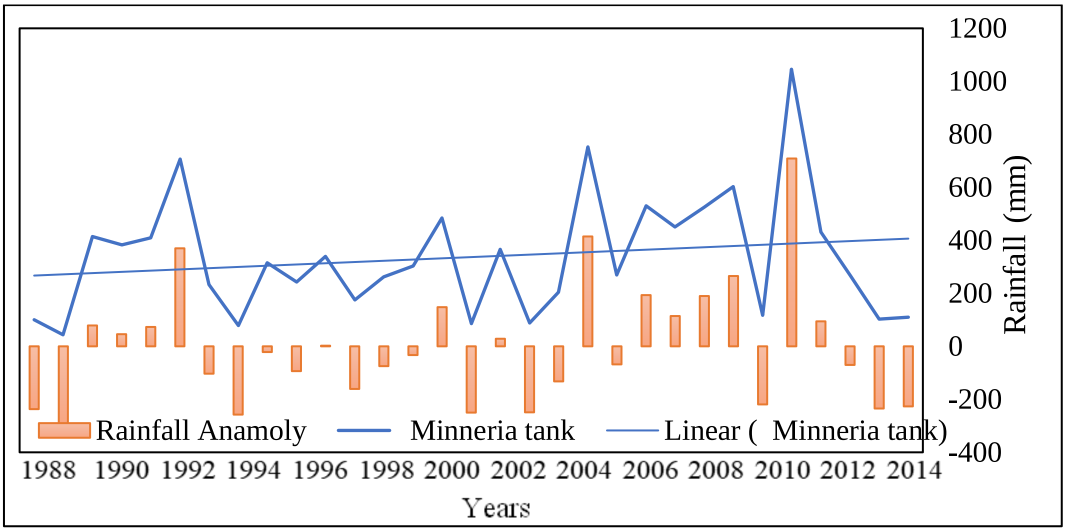
4.2 Rainfall Trends of Dry Zone

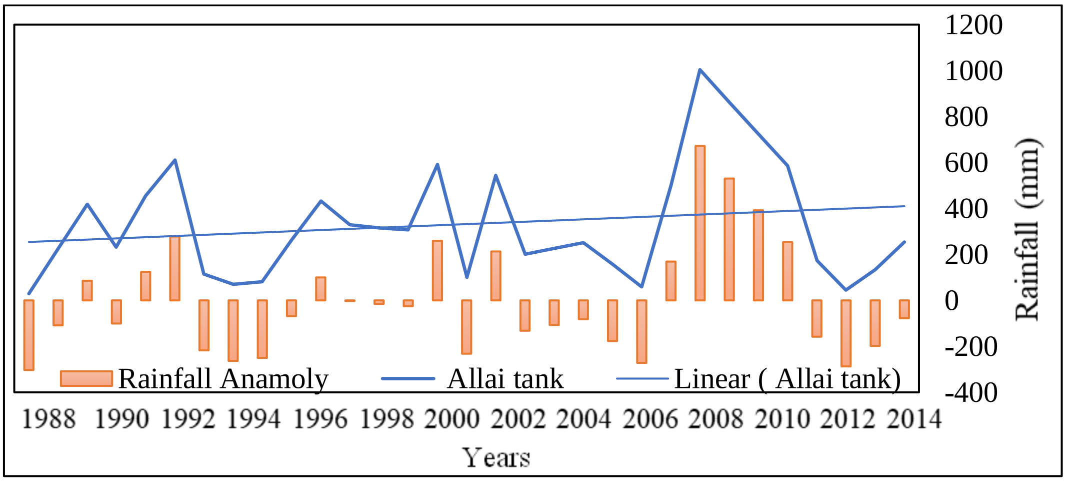
In dry zone of basin 7 stations were selected uniformally distributed over basin all the stations shows positive rainfall trend only Pollonoruwa ,Giritale and Mineria tank trends were found stastically significant as Figure 4-2.











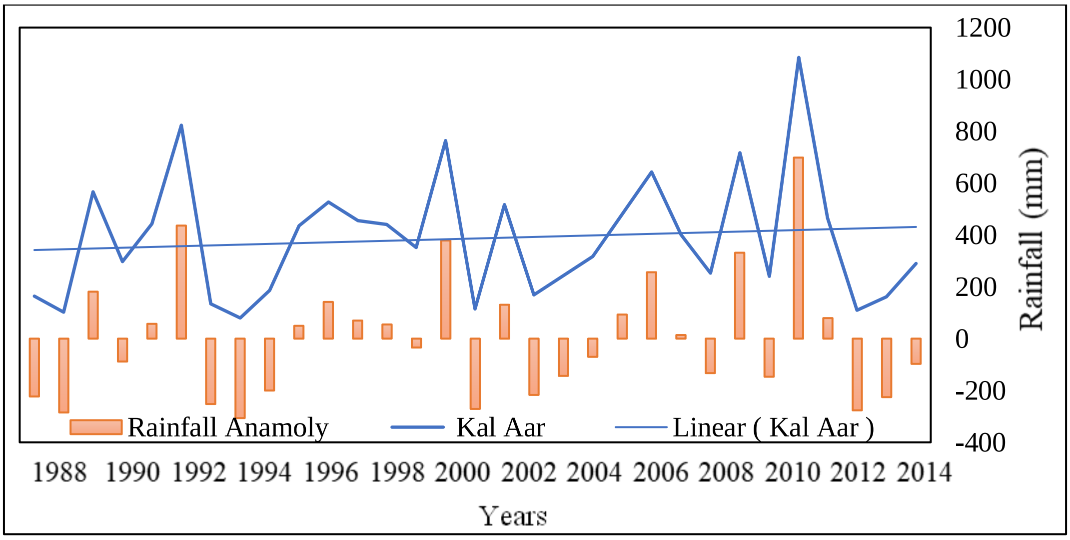
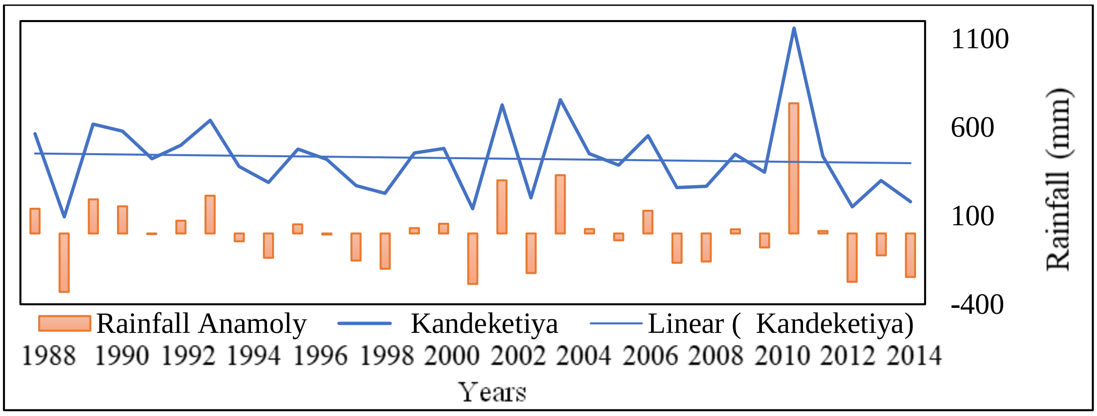
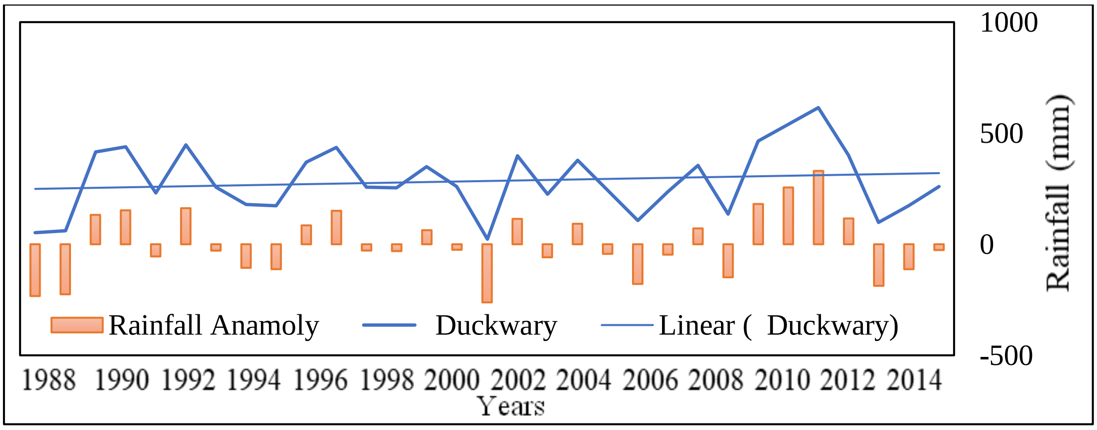


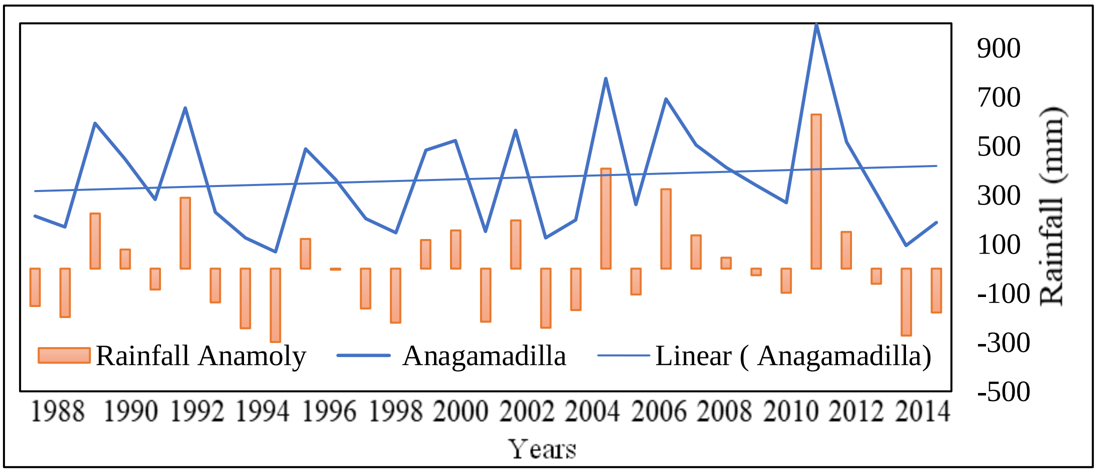
Figure 4-2: Rainfall trends in rain gauge stations in Dry Zone of Mahaweli Basin

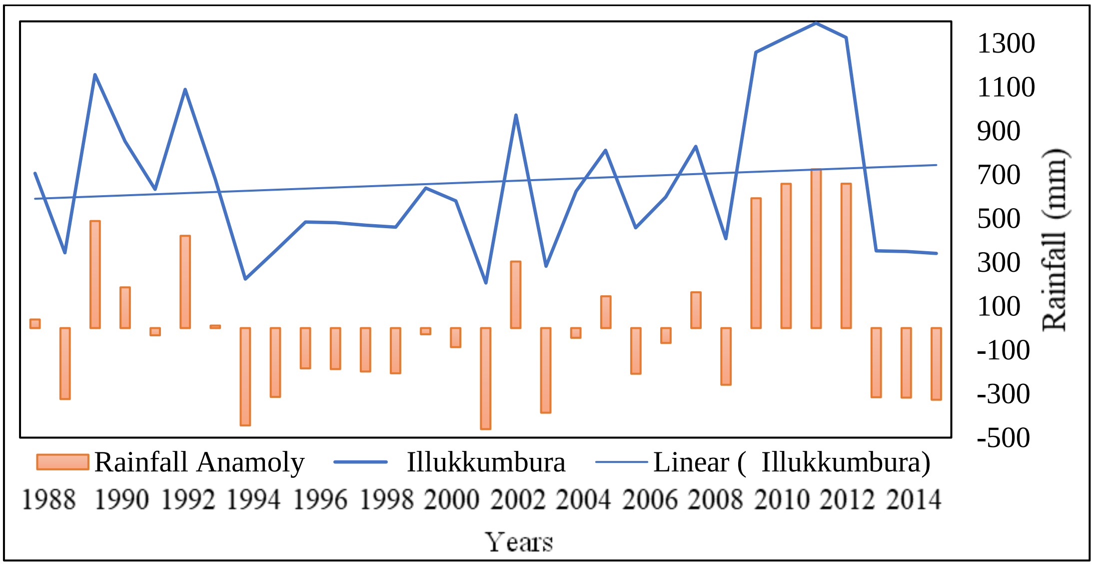
4.3 Rainfall Trends of Intermediate Zones

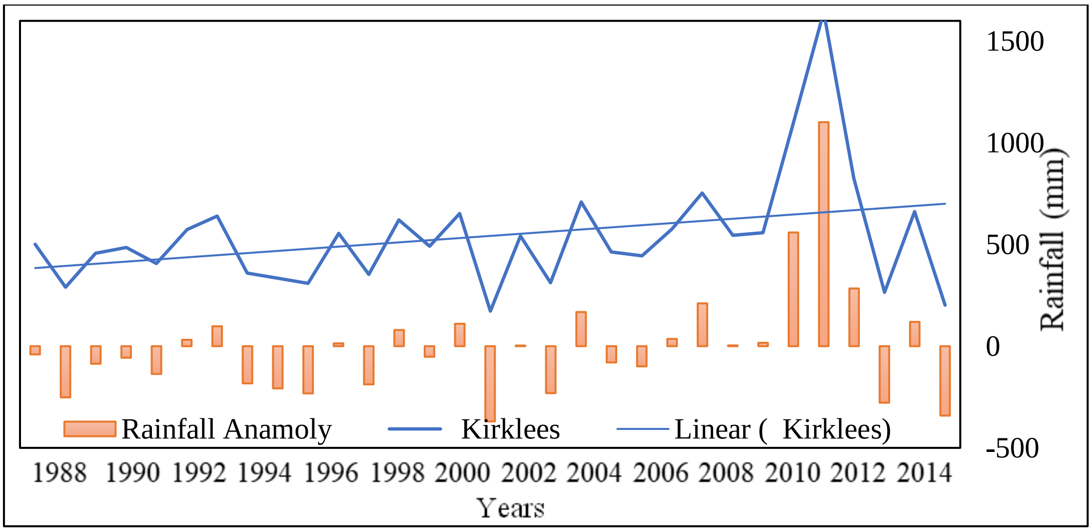
In the intermediate zone of Mahaweli Basin, 8 stations were selected for spatially uniform coverage of intermediate zone of the basin in that only two station Kurundu Oya and Duckwary estate show negative trend and Duckwary trend was stastically significant rest 6 stations shows a positive trend Kirklees,Wellawala and Kanderketiya were having stastically significant trend (Figure 4-3).

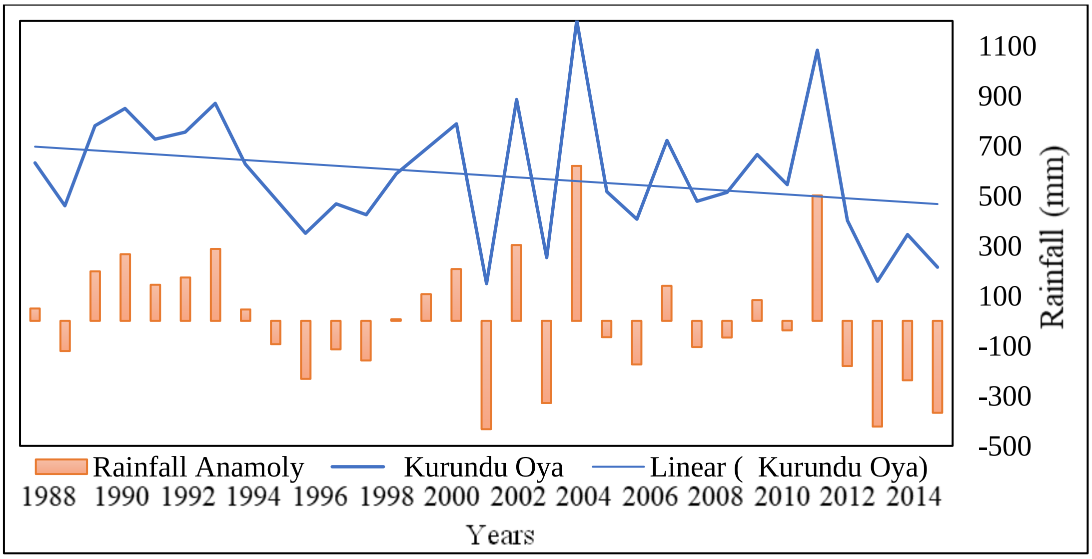


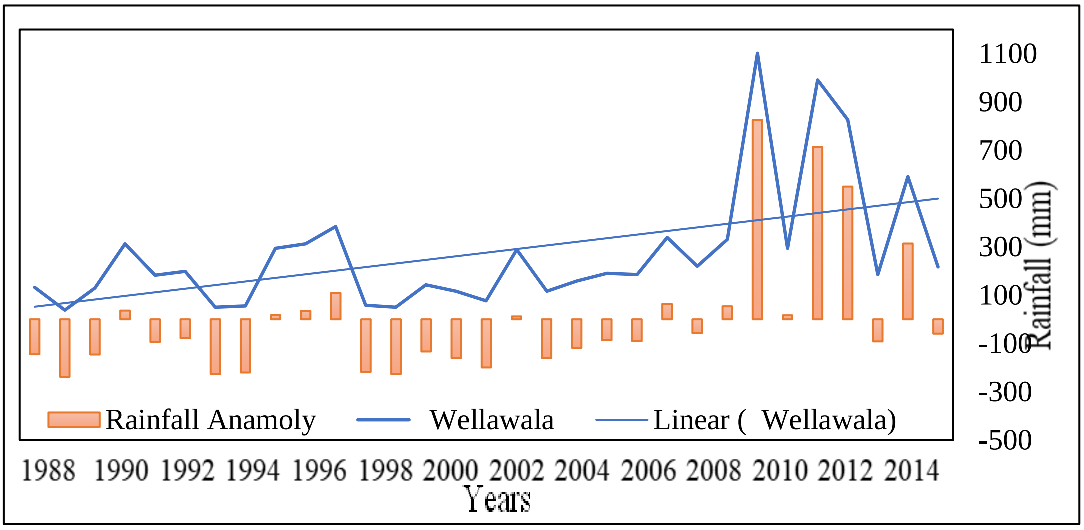





1300
1100
900
700
500
300
100
-100
-300
-500
Rainfall (mm)
Rainfall Anamoly
Illukkumbura
Linear (Illukkumbura)
1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014
Years


1500
1000
500
0
-500
Rainfall (mm)
Rainfall Anamoly
Kirklees
Linear (Kirklees)
1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014
Years


1100
900
700
500
300
100
-100
-300
-500
Rainfall (mm)
Rainfall Anamoly
Kurundu Oya
Linear (Kurundu Oya)
1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014
Years



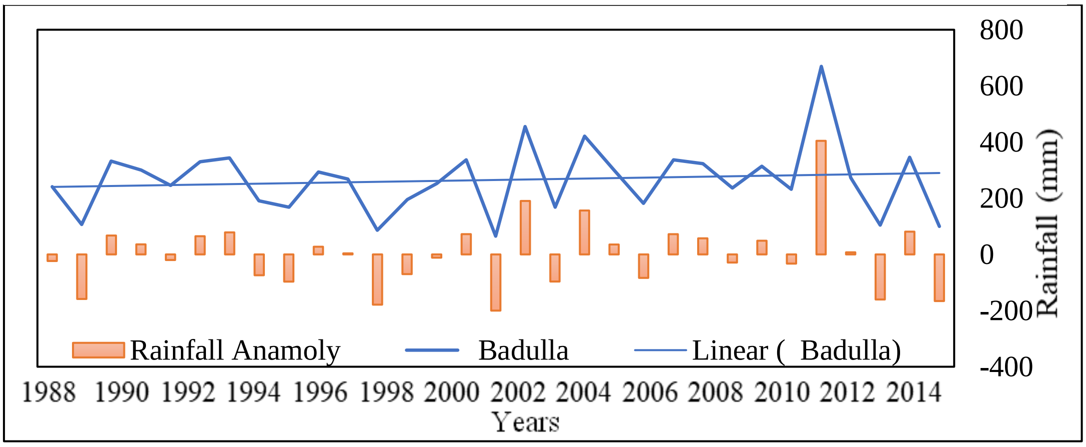


Figure 4-3: Rainfall trends in stations in Intermediate zone of Mahaweli Basin

Out of 19 stations of Mahaweli basin, 14 showed positive trends and 5 stations showed negative trends in the basin over the three climatic zones among them few were statically significant other were non -significant as referred in Table 4-1

Trend analysis revealed a significant increasing trend of at least 0.001 confidence at 9 stations. The slope of the increase *Q* ranges from 0.53mm/year Allai Tank to 3.23 mm/year at Kirkees. The spatial distribution of the *Z* values, shown from Table 4-1 highlight that the highest trend increasewas witnessed in Wellawala (*Z*=3.8) and the lowest in Allai Tank (*Z*=0.69).

In General, dry zone of Mahaweli Basin has increasing trends and wet zone has negative trend and intermediate zone zone also has positive trend.

Table 4-1: Summary of Trend of Mahaweli Basin

Climatic Zone	Station Name	Z Test	Sen's Slope (Q)	Trend	Significance
Intermediate Zone	Anagamadilla	0.85	0.747	Positive	No
	Illukkumbura	1.02	0.874	Positive	No
	Kirklees	3.16	3.230	Positive	Yes
	Kurundu Oya	-0.44	-0.464	Negative	No
	Wellawala	3.81	2.424	Positive	Yes
	Badulla	1.33	0.886	Positive	No
	Duckwary	-1.77	-1.820	Negative	Yes
	Kandeketiya	1.80	1.361	Positive	Yes
Wet Zone	Ambewela	0.61	0.603	Positive	No
	Galphele	-2.07	-1.490	Negative	No
	Nawalapitiya	-0.27	-0.239	Negative	Yes
	Hebodde North	-0.27	-0.497	Negative	No
Dry Zone	Bakamuna	2.58	2.000	Positive	Yes
	Polonnaruwa	2.38	1.495	Positive	Yes
	Minneria tank	1.94	1.283	Positive	Yes
	Kaudullaweva	1.53	1.220	Positive	No
	Kal Aar	1.39	0.833	Positive	No
	Allai tank	0.65	0.532	Positive	No
	Giritale	2.07	1.393	Positive	Yes

4.4 Sen’s Slope Estimation of trend

As expressed, beforehand, the Mann–Kendall test just demonstrates the course however not the size of huge patterns. In this way, the size is typically controlled by Sen's test (Sen 1968) which is likewise a nonparametric method. The strategy utilizes a straight model to ascertain the difference in incline and the fluctuation of the residuals ought to be consistent in time.

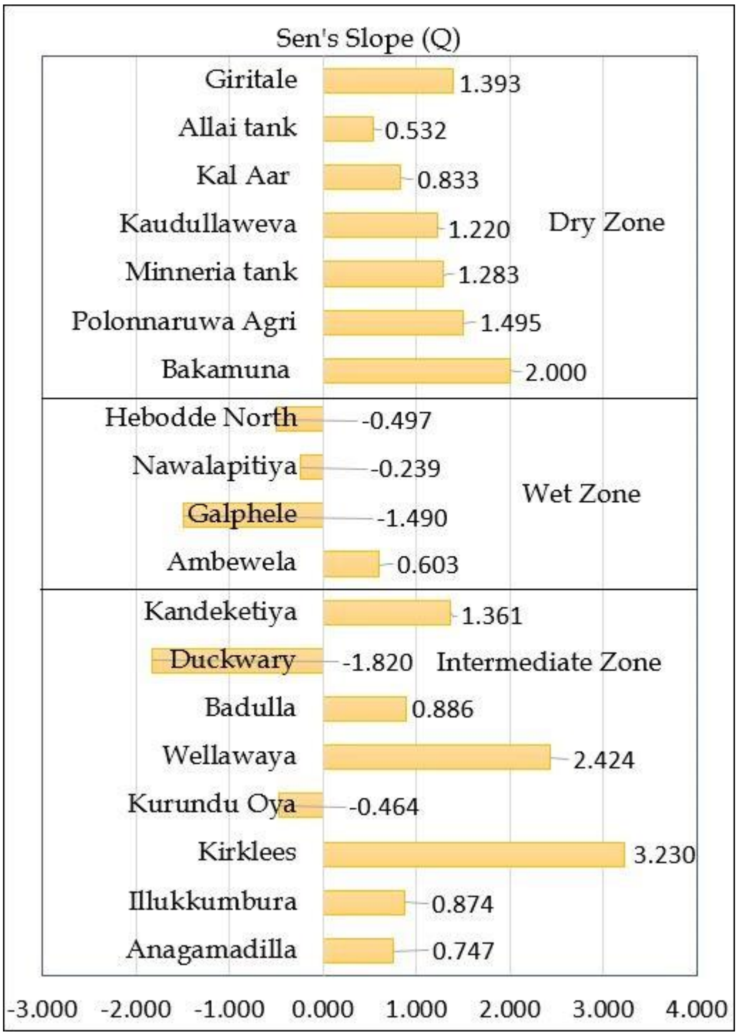


Figure 4-4: Sen Slope Estimation

4.5 Warm up period of the model for Padiyatalawa watershed

In the improvement of the two-parameter model by Xiong a Guo (1999) and the 'abcd' model by Thomas (1981), discretionary qualities had been utilized as starting qualities expressing that the test esteems are not required. In this investigation, utilizing complete informational collection (adjustment and approval) of Mahaweli Ganga and Maduru oya basin, models were kept running for 5 cycles and saw that the soil moisture storage (St-1) and the groundwater storage (Gt-1) are coming to the semi unfaltering state after one cycle for every watershed as appeared in Figure 4-5, Figure 4-6, Figure 4-7,Figure 4-8, Figure 4-9 and Figure 4-10

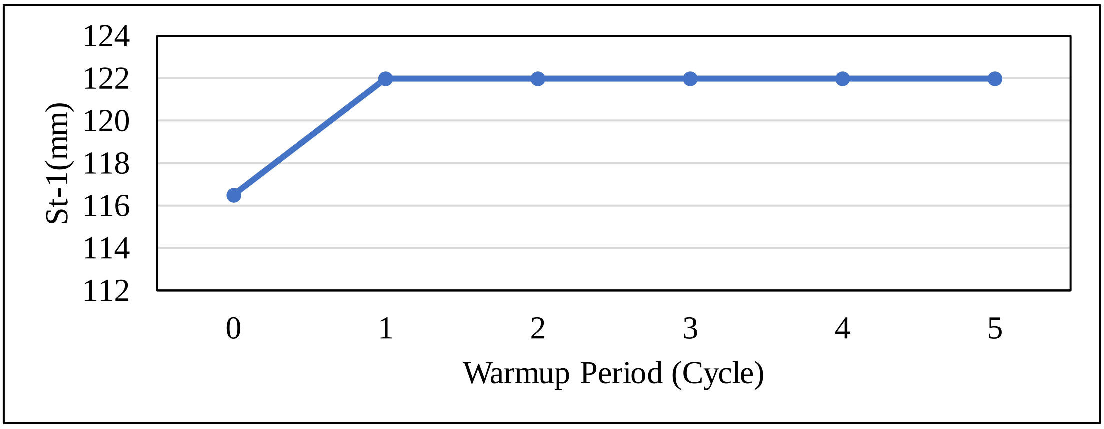


Figure 4-5: Warm up period and initial soil moisture storage in Padiyatalawa

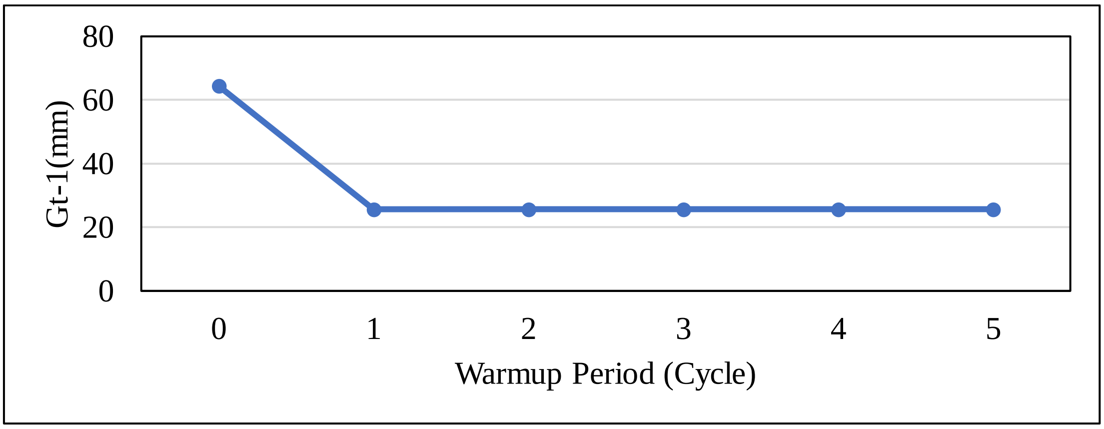


Figure 4-6: Warm up period and initial ground moisture storage in Padiyatalawa

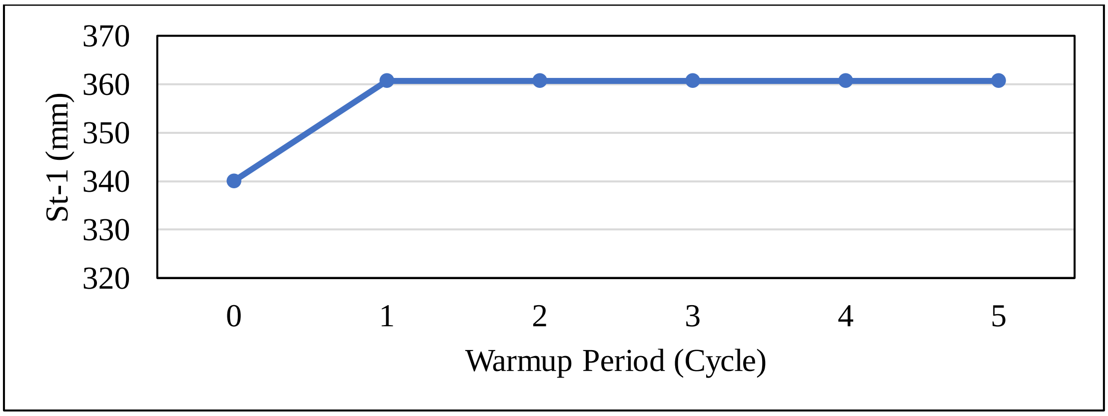


Figure 4-7: Warm up period and initial soil moisture storage in Thaldena

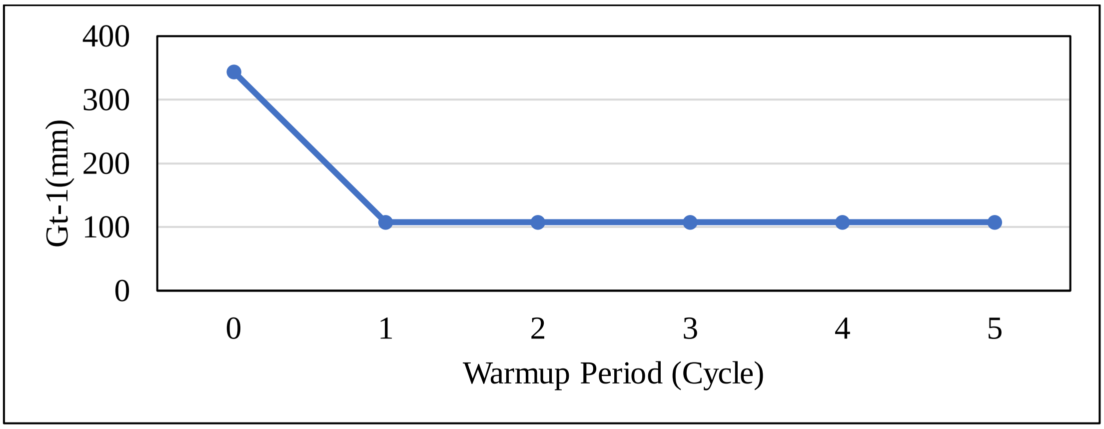


Figure 4-8: Warm up period and initial ground water storage in Thaldena

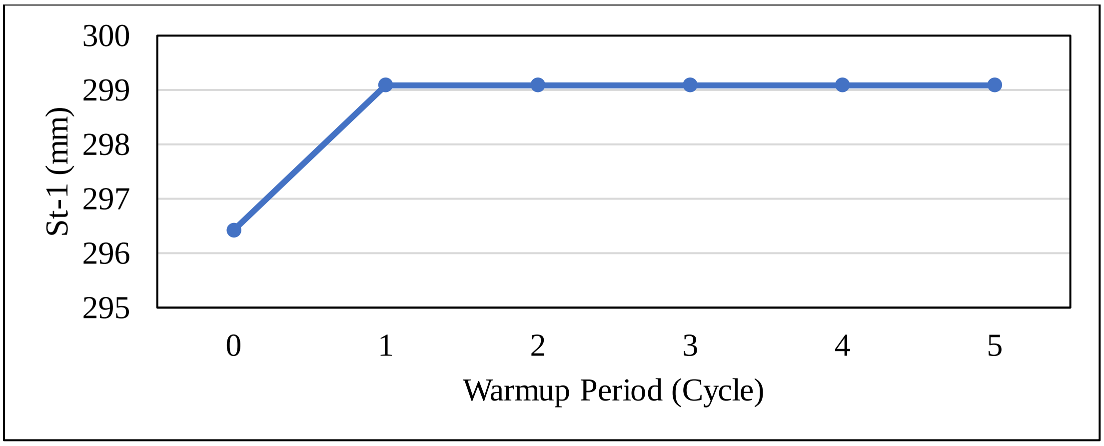


Figure 4-9: Warm up period and initial soil moisture storage in Nawalapitiya

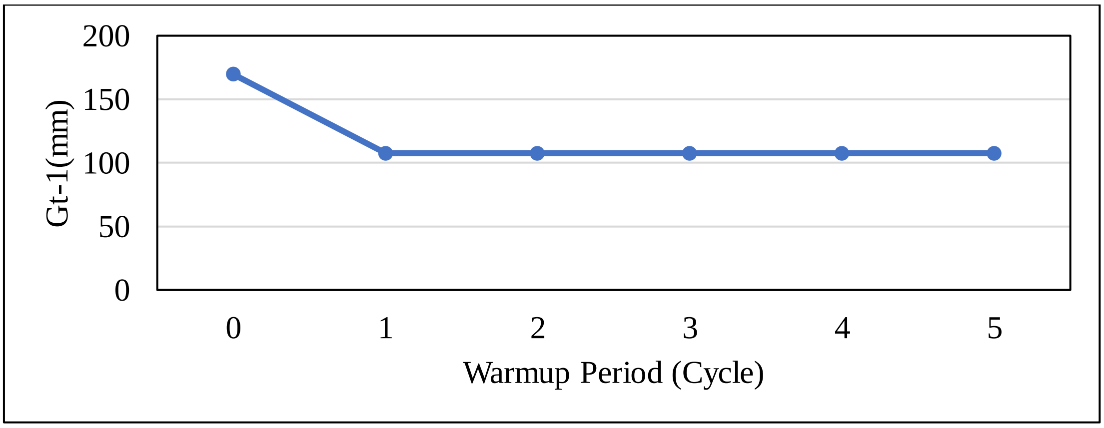


Figure 4-10: Warm up period and initial ground water storage in Nawalapitiya

4.6 Calibration and validation of the ‘abcd’ model

Several literatures referred for calibration of a,b,c and d parameters value and have been used as initial values for model and calibration and validation of the model dataset 5 cycles were run .First trial of model run shows satisfactory results for all sub-catchments .NSE and MRAE values were used for comparison. Then the model was calibrated for the global minimum of MRAE using manual optimization in excel sheet along with excel solver dynamic interface of excel which can be used for parameter optimization method. While setting the range of parameters the values beyond the literature also considered as global minimum can lies beyond the literature values, At the optimization it was seen that NSE and MRAE had reached to a very high and low values Simultaneously. After optimization, the parameter values were used for the validation period and observed the objective function. Even in the validation period, it was observed good values for both MRAE and NSE.

The visual similarity of the modeled hydrograph with the observed hydrograph was checked in both adjustment and validation process. A poor visual similarity was seen in the main preliminary at alignment as appeared in Figure 4-11 to Figure 4-13 and Figure 4-17 a decent visual similarity was seen when the parameters were advanced in adjustment and validated as appeared in Figure 4-12 ,Figure 4-14 and Figure 4-16.

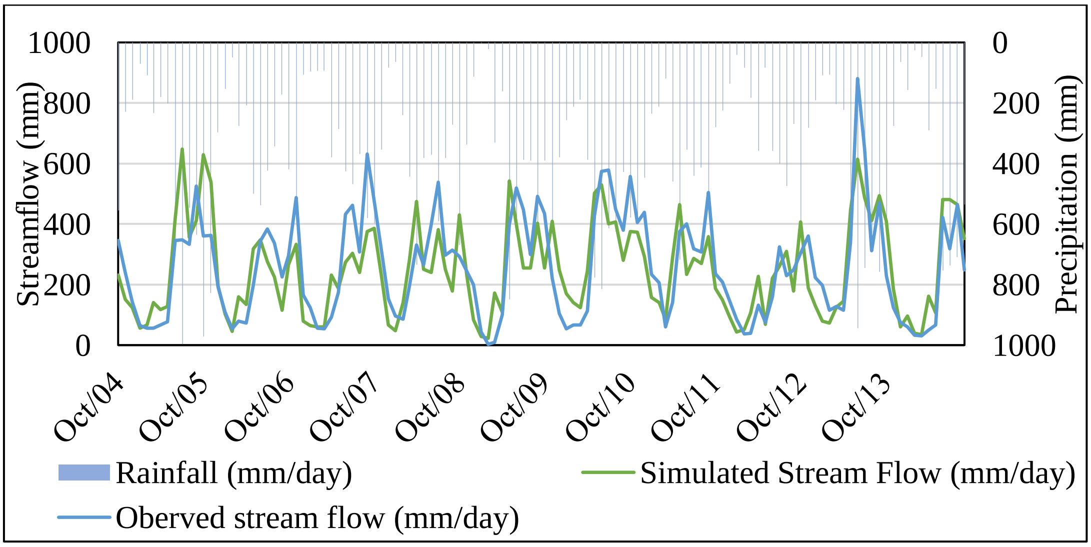


Figure 4-11: Simulated flow from first trial (2004~2013) in calibration- Nawalapitiya

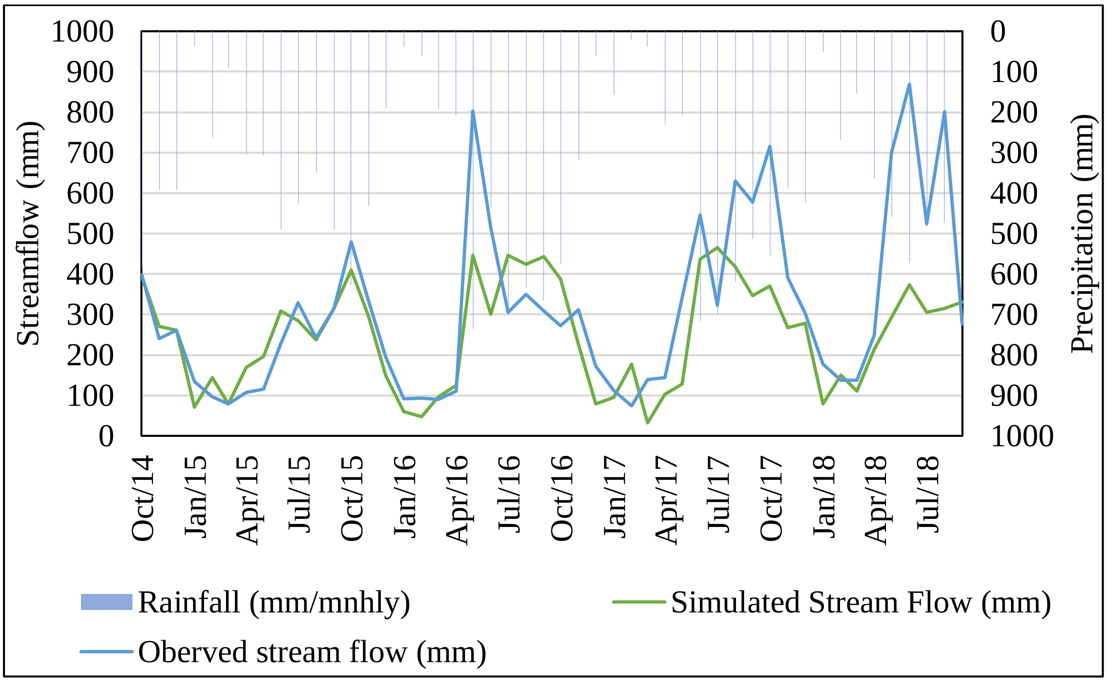


Figure 4-12: Simulated flow from first trial (2014~2018) in validation- Nawalapitiya

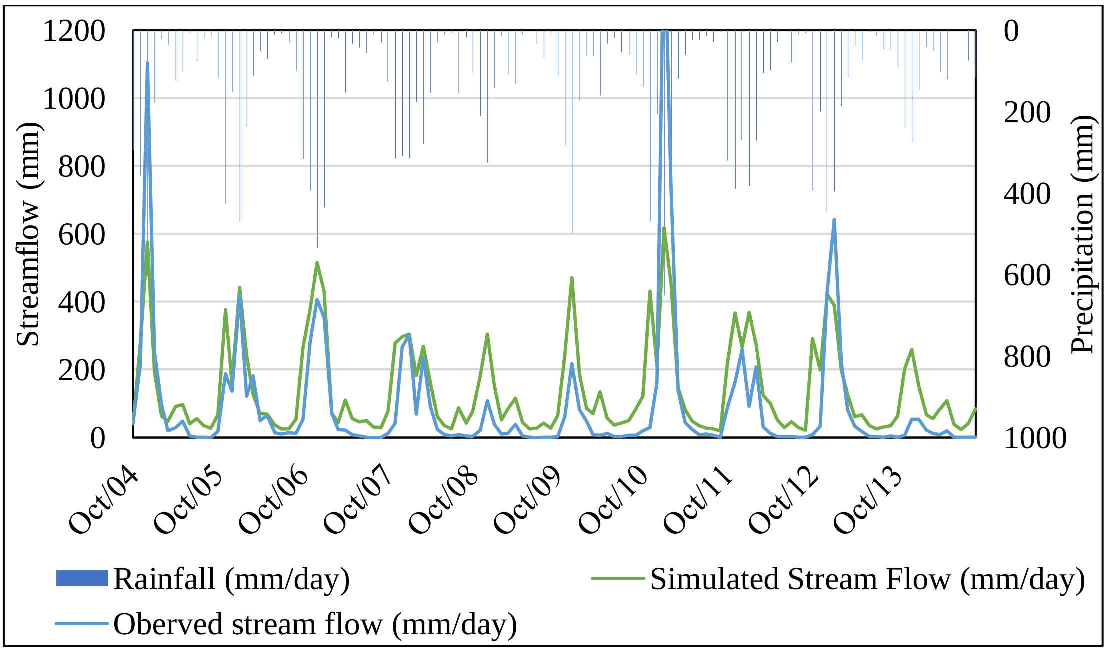


Figure 4-13: Simulated flow from first trial (2004~2014) in calibration- Padiyatalawa

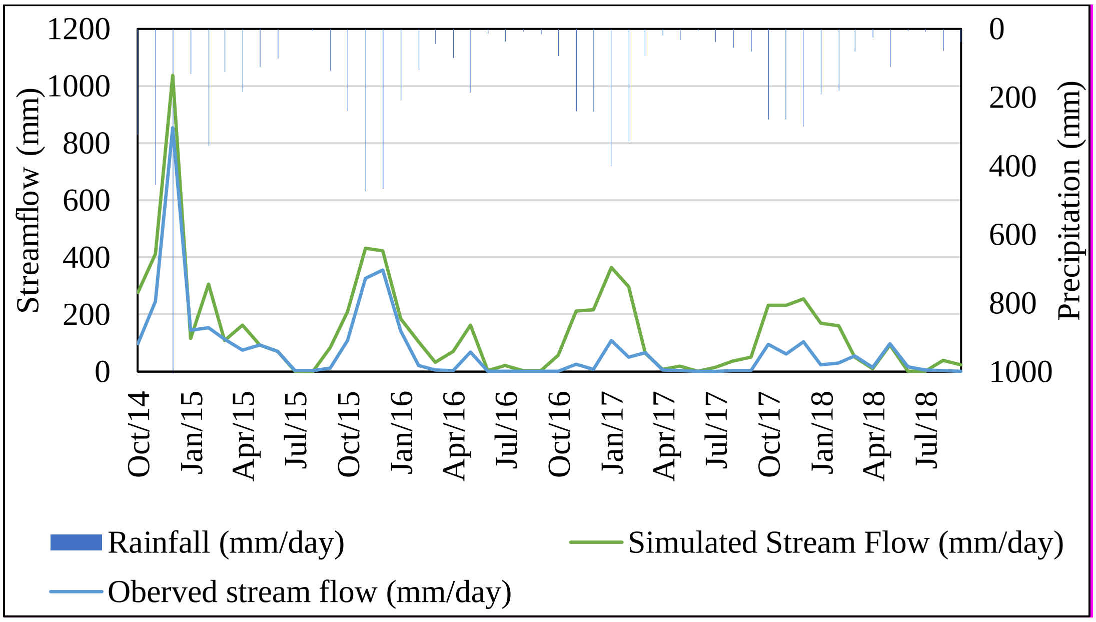


Figure 4-14: Simulated flow from first trial (2014~2018) in validation- Padiyatalawa

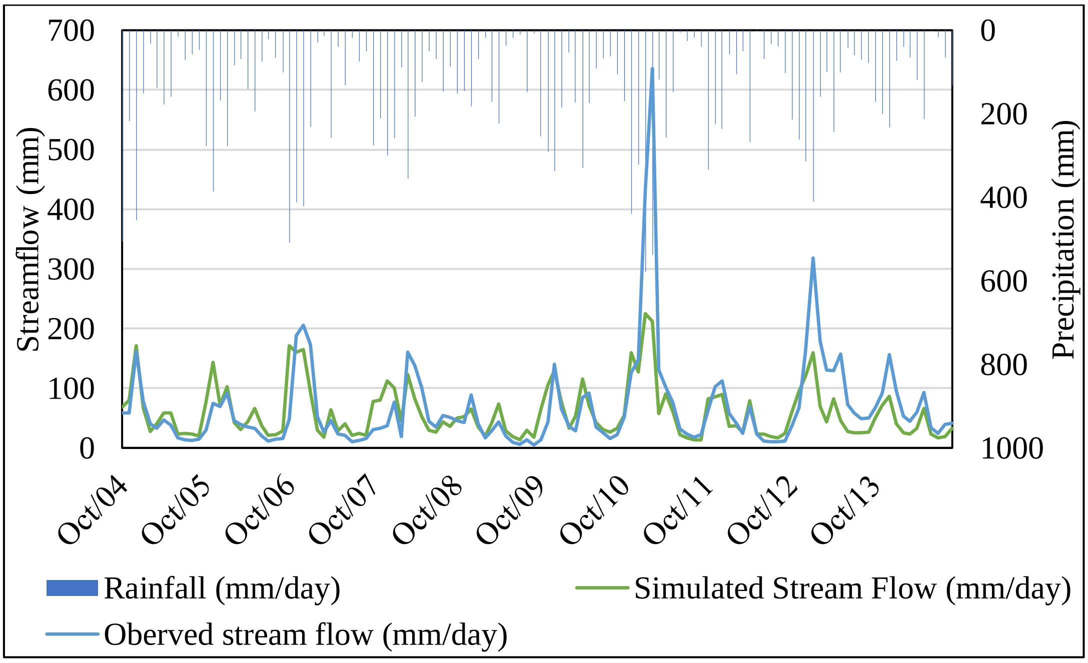


Figure 4-15: Simulated flow from first trial (2004~2014) in calibration- Thaldena

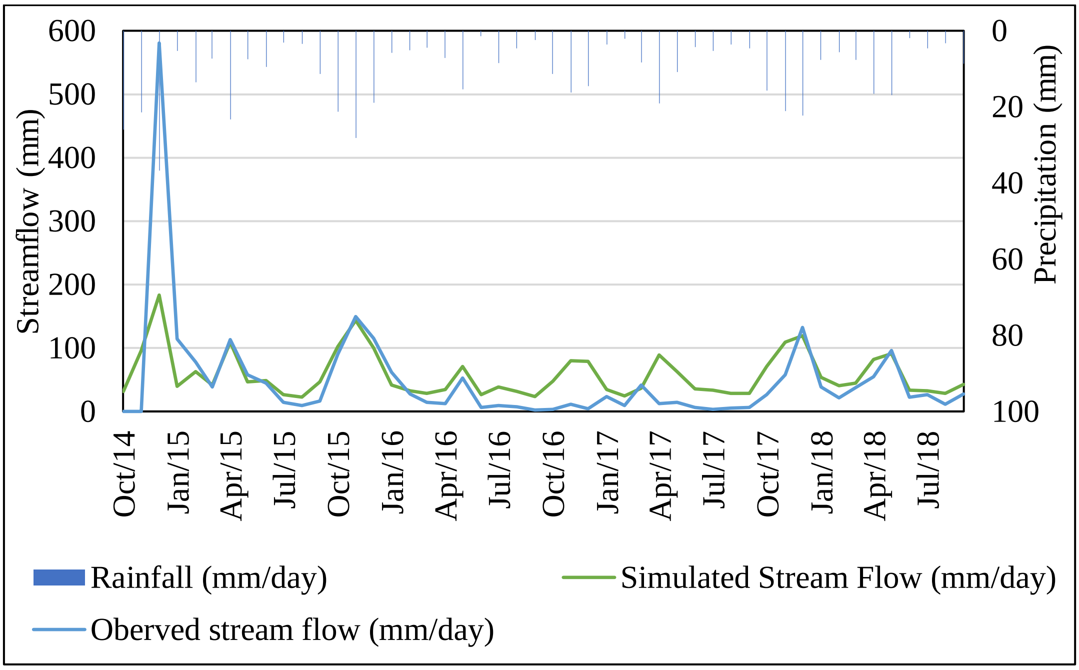


Figure 4-16: Simulated flow from first trial (2014~2018) in validation-Thaldena

Table 4-2: Initial values for model parameters for all watersheds

Model Parameter	**Range from literature**	**Average as the initial value for the model**
a	0.873-0.999	0.98
b	14-1900	25
c	0-1	0.5
d	0-1	0.001

Table 4-3: Objective function values from first calibration trial

Watershed	**MRAE**	**Nash Sutcliff Efficiency**
Nawalapitiya	0.13	0.52
Thaldena	0.13	0.57
Padiyatalawa	0.22	0.56

Table 4-4: Optimized "abcd" parameters and objective functions

Watershed	**Parameter**	**Parameter value**	**Objective function**			
			Calibration		**Validation**	
			MRAE	**Nash**	**MRAE**	**Nash**
Nawalapitiya	a	0.98	0.196	0.66	0.12	0.53
	b	20				
	c	0.35				
	d	0.003				
Thaldena	a	0.98	0.143	0.60	0.07	0.44
	b	54				
	c	0.53				
	d	0.003				
Padiyatalawa	a	0.99	0.331	0.53	0.22	0.62
	b	32				
	c	0.10				
	d	0.001				

4.7 Outflow hydrographs related to optimized parameters

Modelled stream was plotted on the highest point of the observed stream, to see the visual similarity of the outpouring hydrograph in the wake of upgrading parameters by utilizing MRAE and NSE.

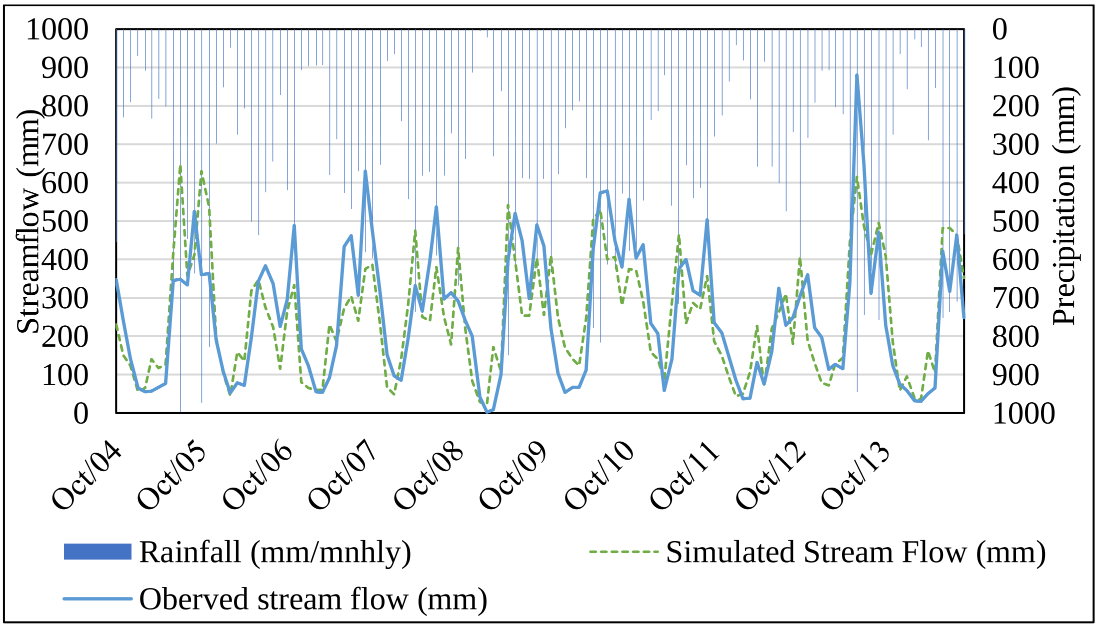


Figure 4-17: Outflow hydrograph of Nawalapitiya for calibration period 2004~2013

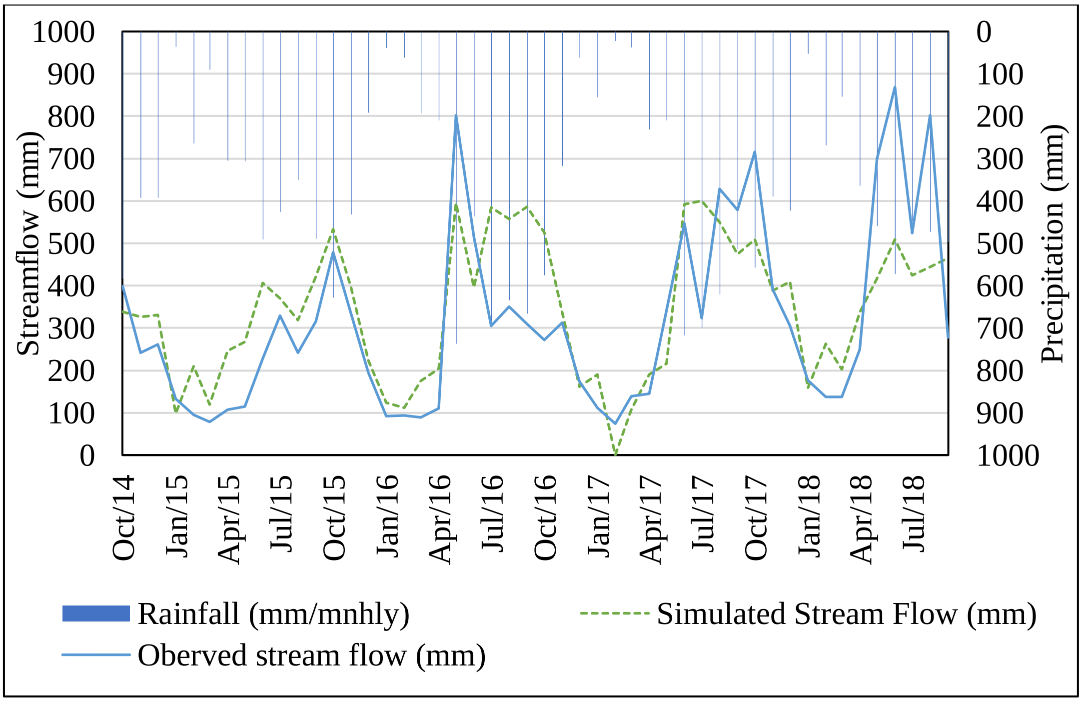


Figure 4-18: Outflow hydrograph of Nawalapitiya for validation period 2014~2018

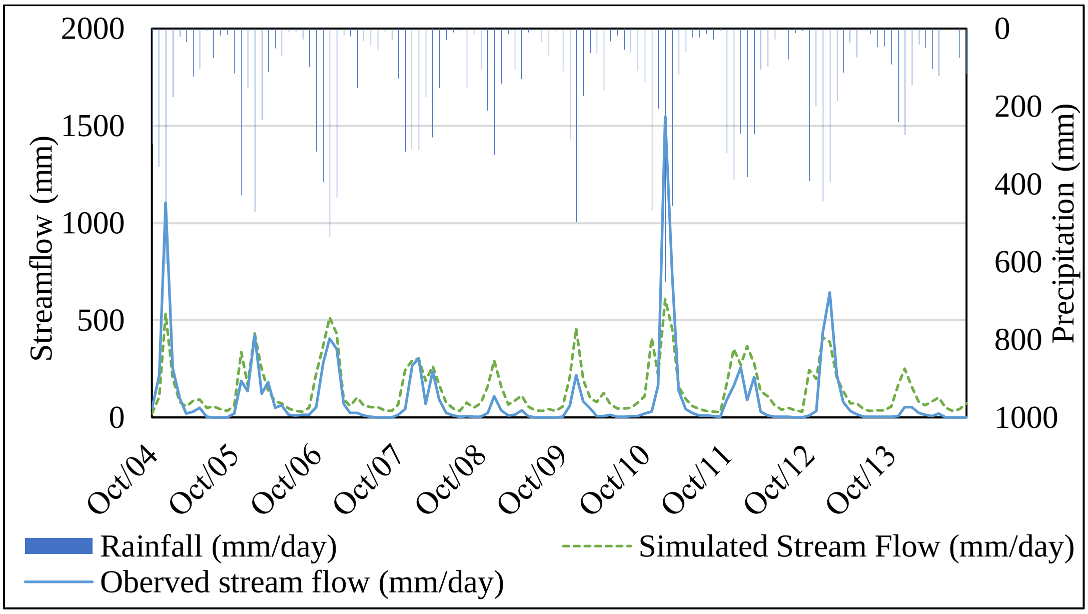


Figure 4-19: Outflow hydrograph of Padiyatalawa for calibration period 2004~2013

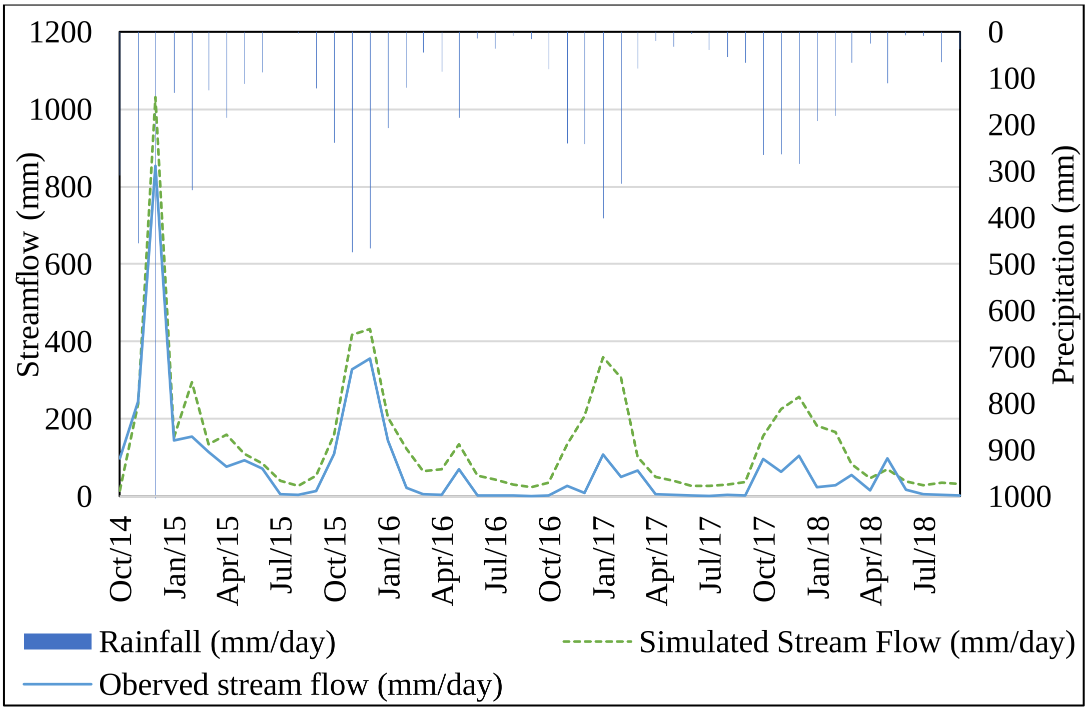


Figure 4-20: Outflow hydrograph of Padiyatalawa for validation period 2014~2018

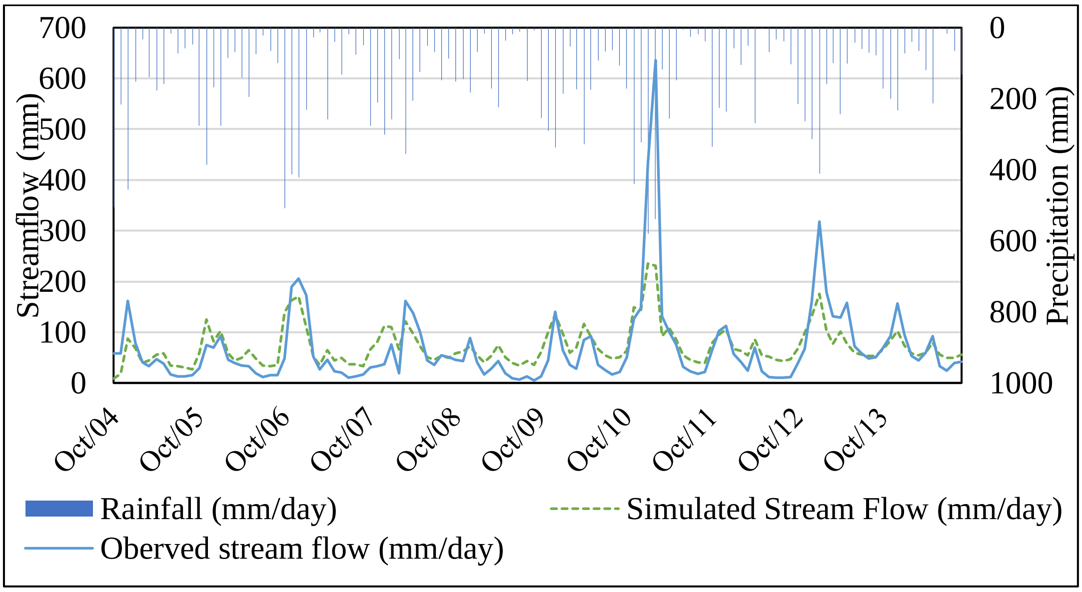


Figure 4-21: Outflow hydrograph of Thaldena for validation period 2014~2018

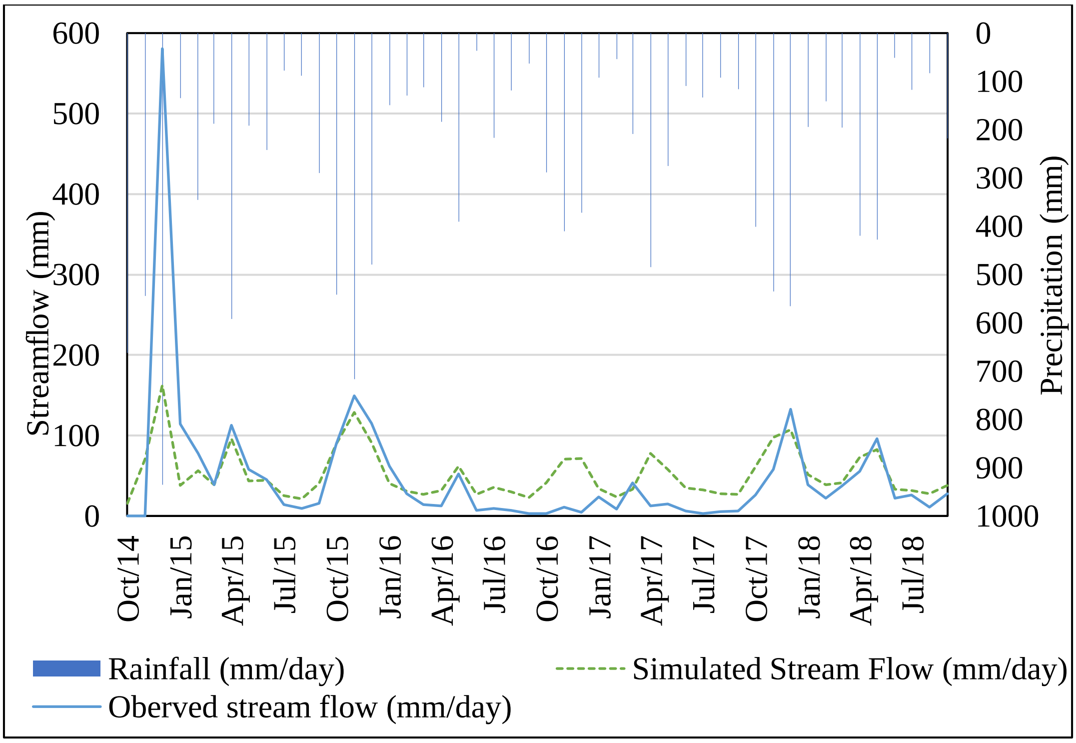


Figure 4-22: Outflow hydrograph of Thaldena for validation period 2014~2018

4.8 Annual water balance check after calibration and validation

A yearly water balance was performed by utilizing isohyet averaging of precipitation, pan evaporation , observed stream and simulated stream as appeared in Figure 4-23 to Figure 4-25. The contrast between the observed water balance and the water balance from the modelled stream (Yearly water balance difference) was differentiated in a different segment to check the water balance in stream simulation. In the alignment, it is required to keep up the past water balance which was existed between the observed stream and precipitation in simulated condition.

4.8.1 Annual water balance of Nawalapitya for calibration period

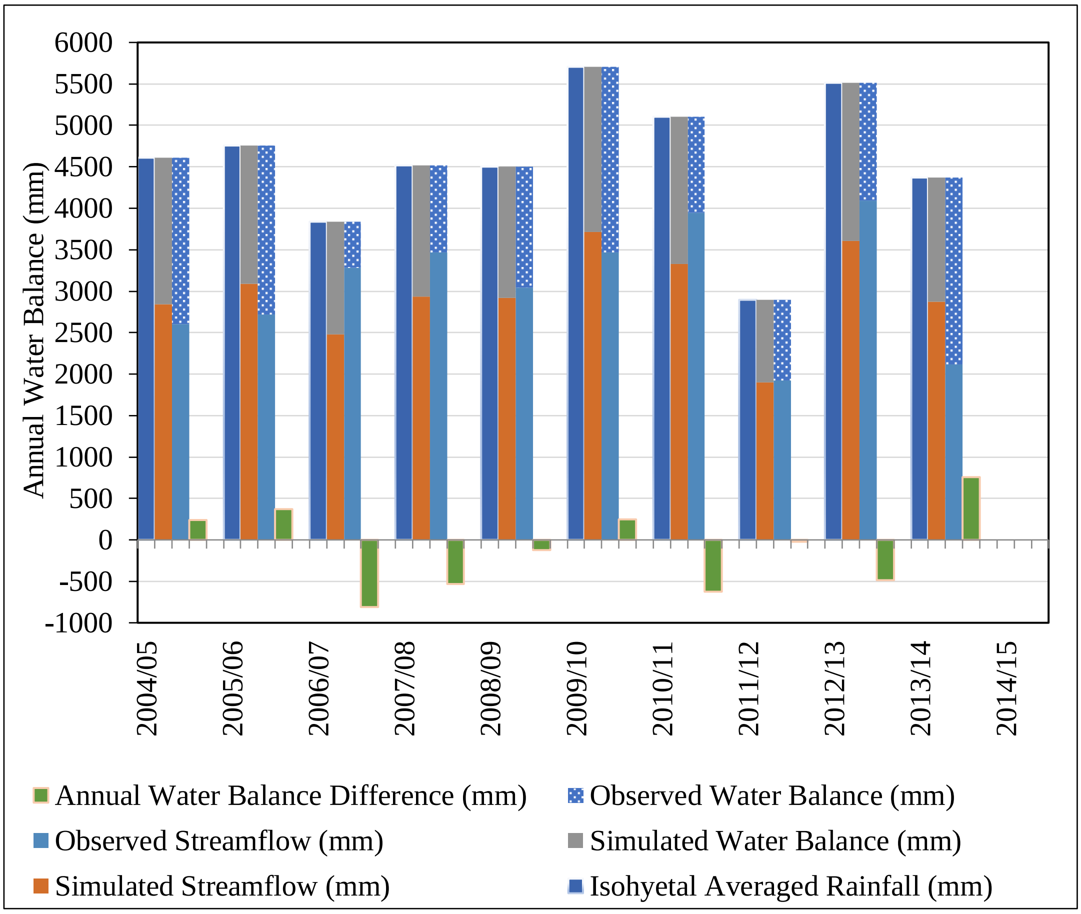


Figure 4-23: Annual water balance of Nawalapitiya – Calibration Period

4.8.2 Annual water balance of Nawalpitiya for validation period

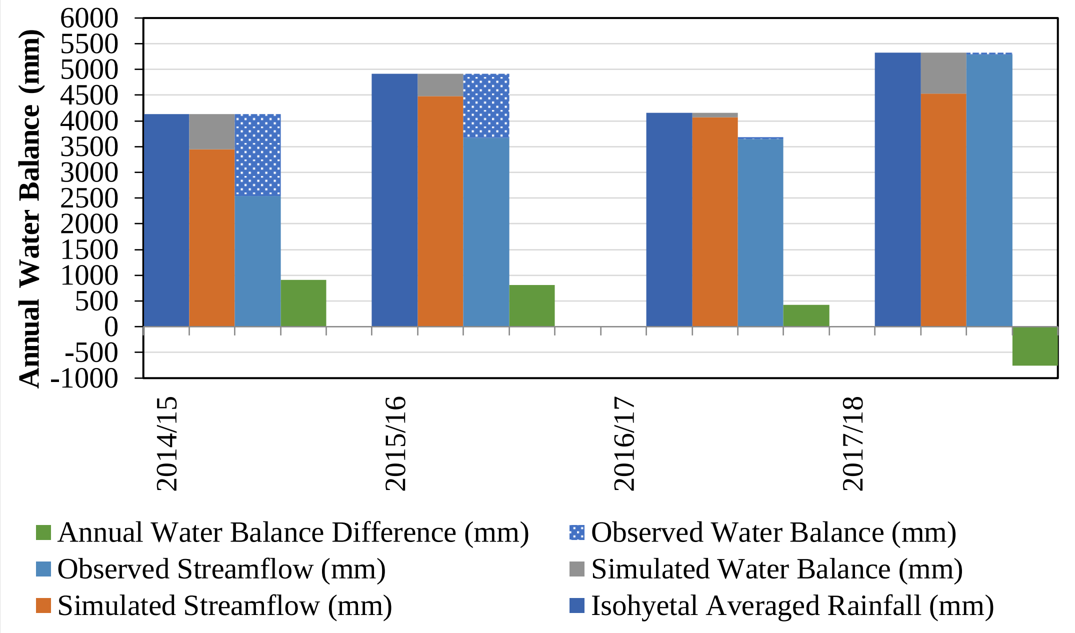


Figure 4-24: Annual water balance of Nawalapitiya – Validation Period

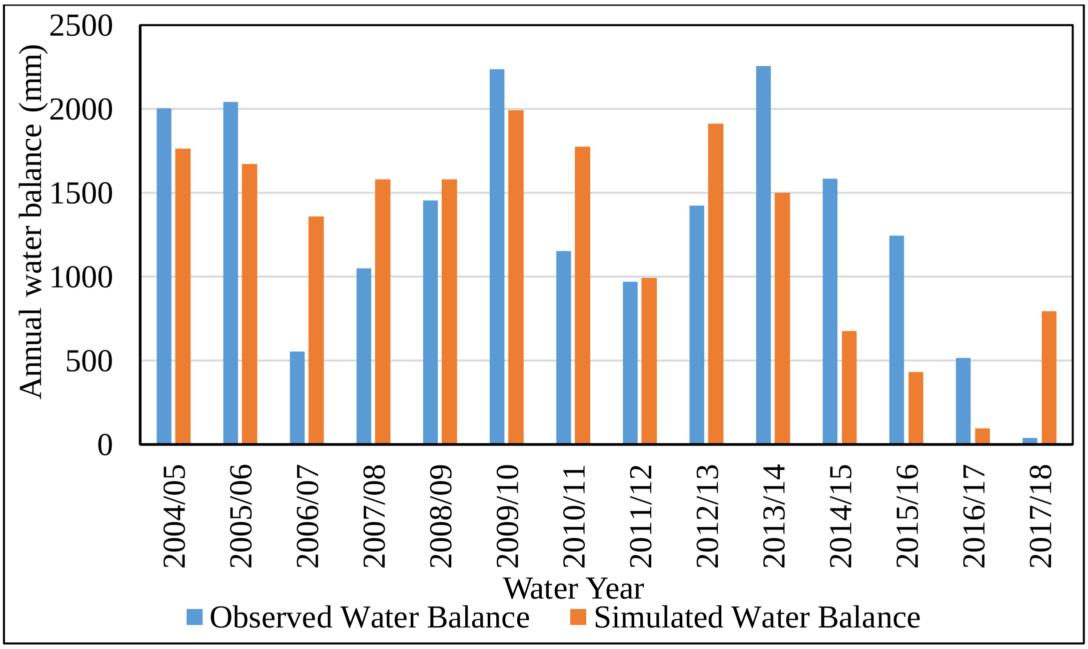


Figure 4-25: Comparision of Observed and Simulated Water Balance of Nawalapitiya

4.8.3 Annual water balance of Thaldena for calibration period

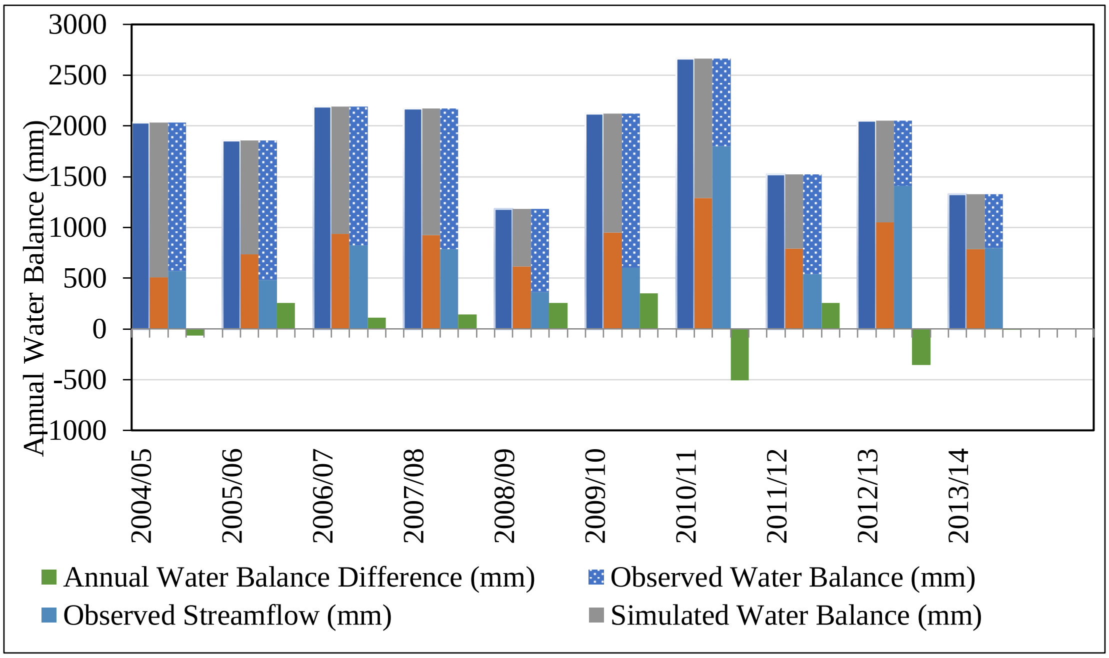


Figure 4-26: Annual water balance of Thaldena – Calibration Period

4.8.4 Annual water balance of Thaldena for validation period

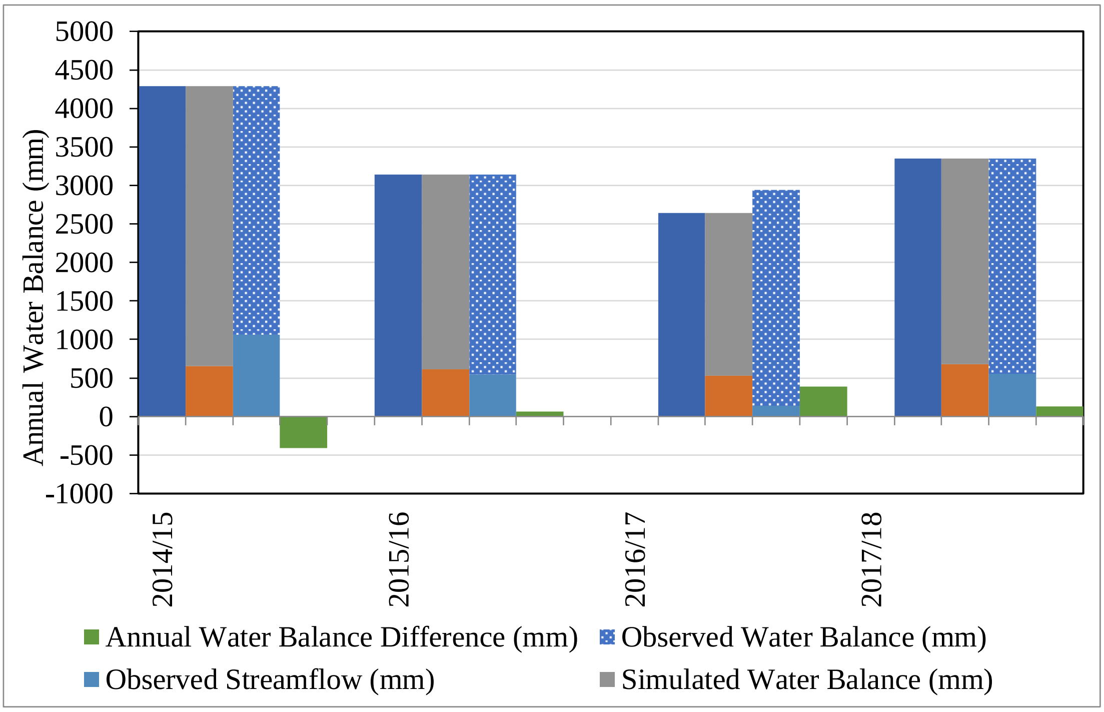


Figure 4-27: Annual water balance of Thaldena – Validation Period

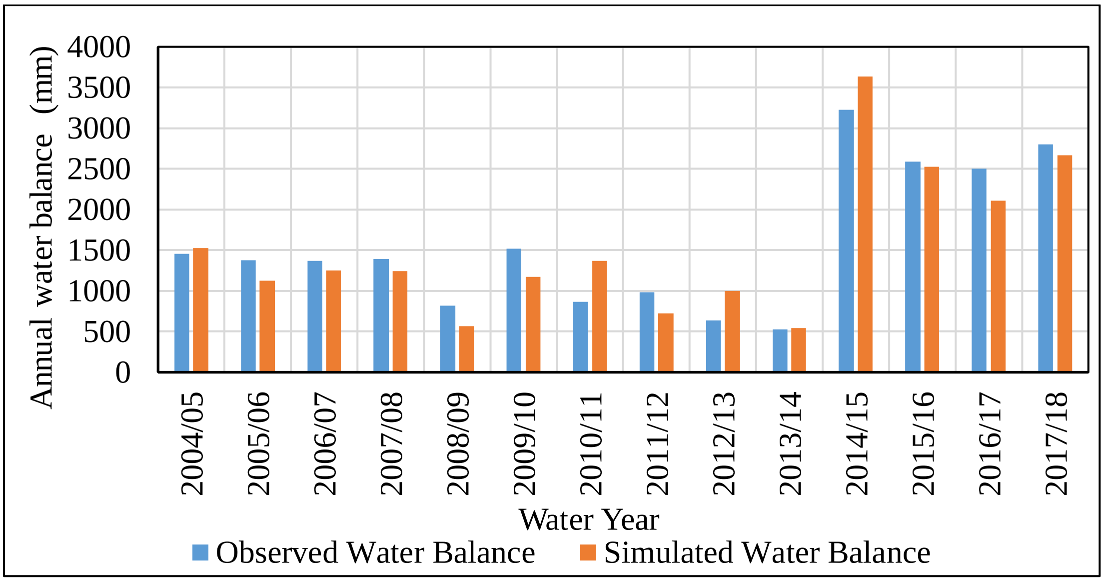


Figure 4-28: Annual water balance comparison for Thaldena

4.8.5 Annual water balance of Padiyatalawa for calibration period

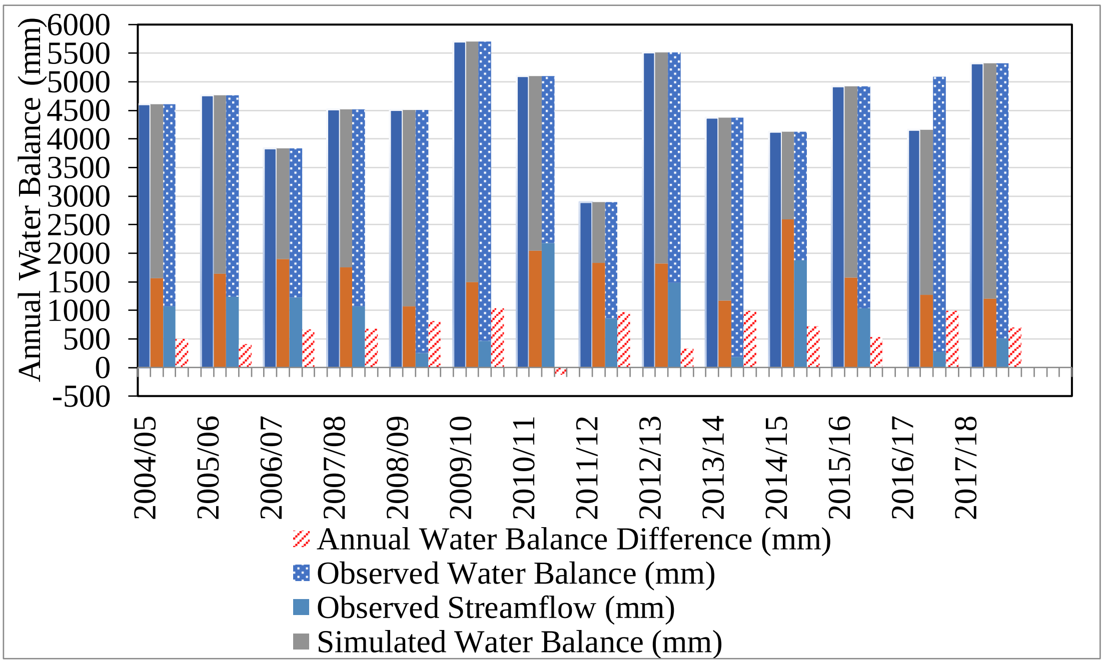


Figure 4-29: Annual water balance of Padiyatalawa – Calibration Period

4.8.6 Annual water balance of Padiyatalawa for validation period

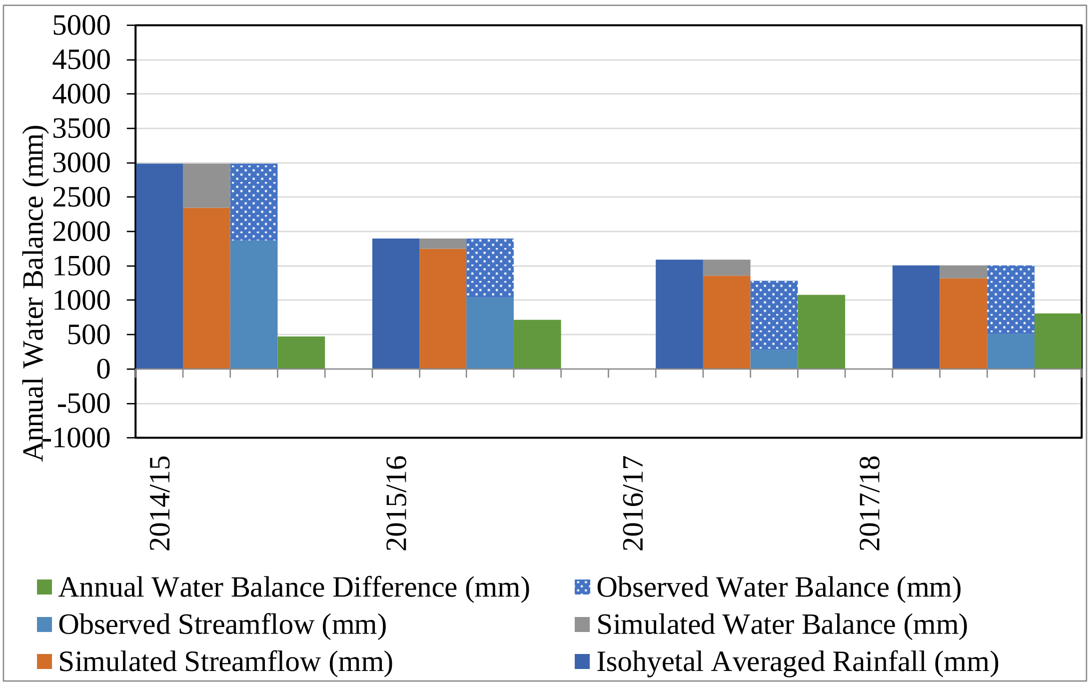


Figure 4-30: Annual water balance of Padiyatalawa – Validation Period

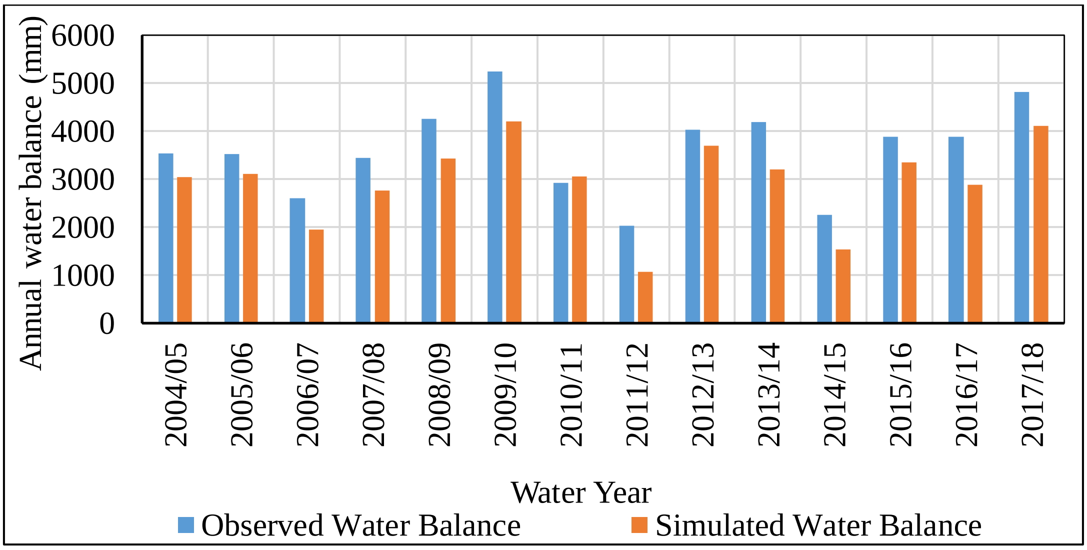


Figure 4-31: Annual water balance comparision for Padiyatalawa

4.9 Demarcations of Flow Thresholds

A flow duration curve describes the capacity of the watershed to give streams of different sizes. The state of a stream term bend in its upper and lower areas is especially noteworthy in assessing the watershed and stream attributes. The state of the bend in the high stream area demonstrates the sort of flood system the watershed is probably going to have, and the state of the low stream district portrays the capacity of the bowl to support low streams during dry periods. A lofty bend, which shows high streams for brief periods would be normal for downpour caused floods on little watersheds.

In building up flow duration curve , the month to month released discharged were modified by the plummeting request and positioned beginning from first. The exceedance likelihood was determined as pursues.

P = 100 * [M / (n + 1)] Where, P = the probability that a given flow will be equaled or exceeded (% of time)

M = the ranked position on the listing (dimensionless) n = the number of events for period of record (dimensionless)

The probability of exceedance indicates how much percentage a discharge value has been exceeded. Graphs were plotted as shown in Figure 4-30, Figure 4-32, Figure 4-34 and Figure 4-36, exceedance probability verses observed stream flow for Padiyatalawa, Nawalapitiya and Thaldena watersheds for calibration and validation period separately to identify the three flow regimes of high, medium and low. It was difficult to identify the deflection point of slope by simple observation which led to plot the logarithmic observed stream flow against the exceedance probability as shown in Figure 4-32, Figure 4-34, Figure 4-36.

4.10 Flow duration curves for Nawalapitiya

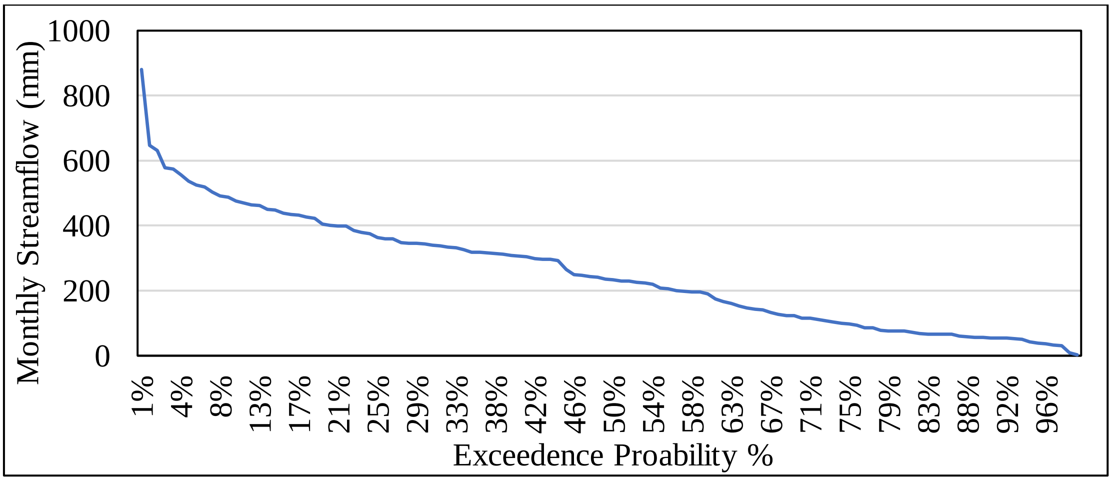


Figure 4-32: Flow Duration Curve for Nawalapitiya for the calibration period

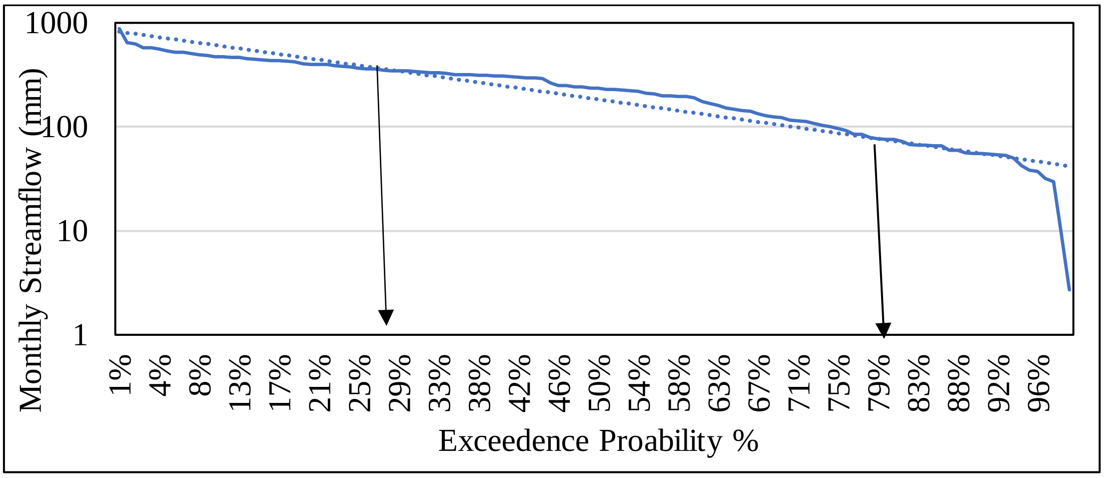


Figure 4-33: Logarithmic plot of Flow Duration Curve of Nawalapitiya for calibration

`

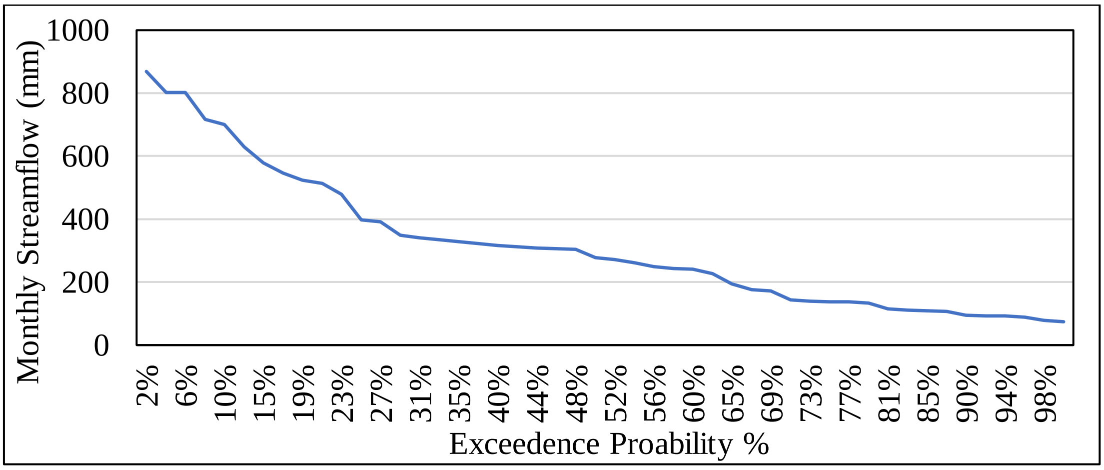


Figure 4-34: Flow Duration Curve for Nawalapitiya for the verification period

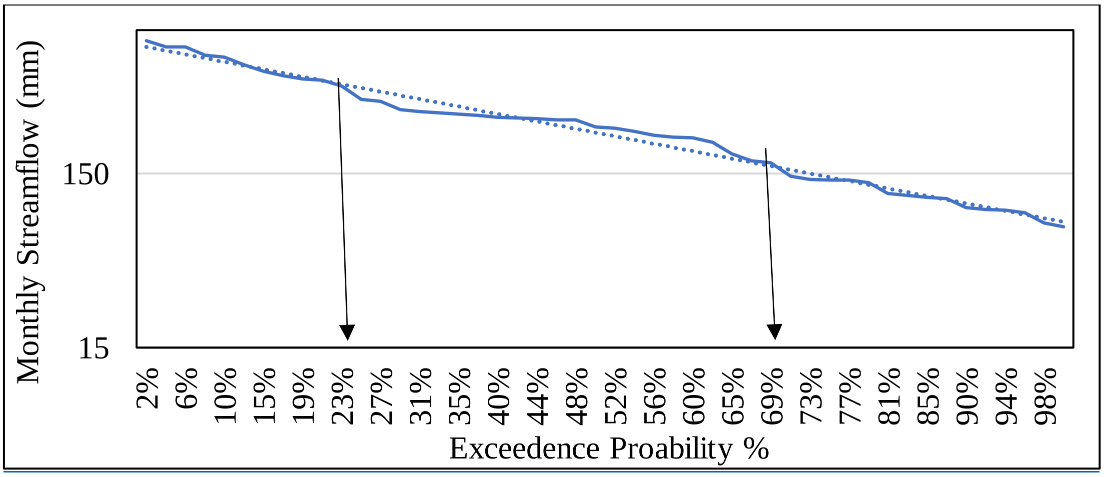


Figure 4-35: Logarithmic plot of flow Duration Curve of Nawalapitiya for verification

4.11 Flow duration curves for Thaldena

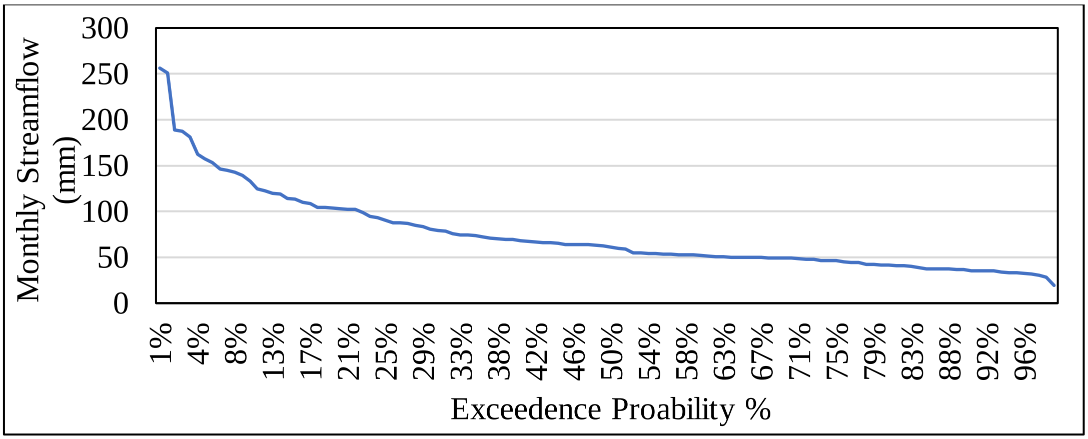


Figure 4-36: Flow Duration Curve for Thaldena for the calibration period

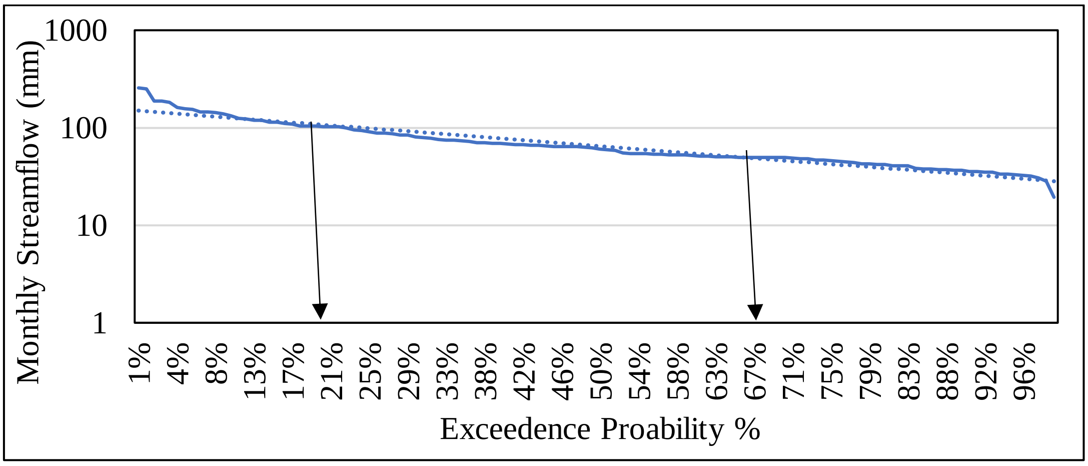


Figure 4-37: Log plot Flow Duration Curve for Thaldena for the calibration period

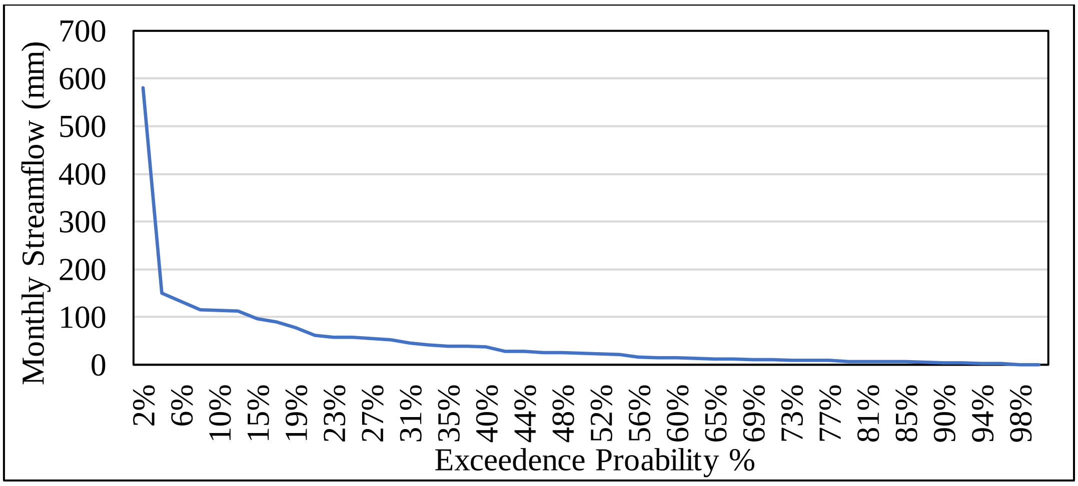


Figure 4-38: Flow Duration Curve for Thaldena for the verification period

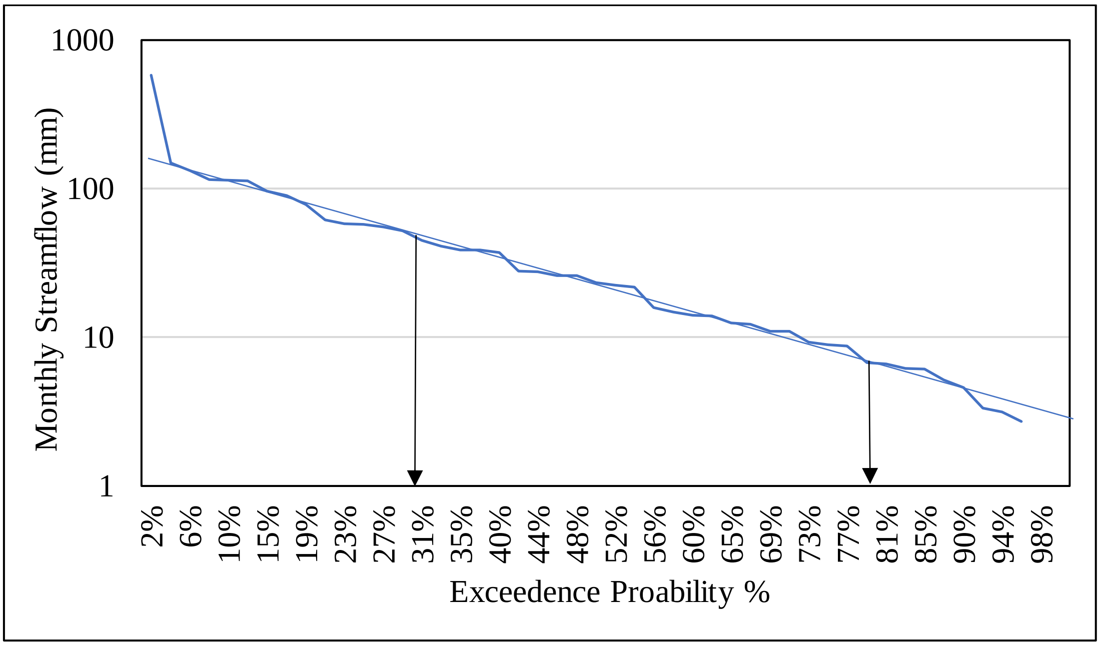


Figure 4-39: Logarithmic plot of Flow Duration Curve of Thaldena for verification

4.12 Flow duration curves for Padiyatalawa

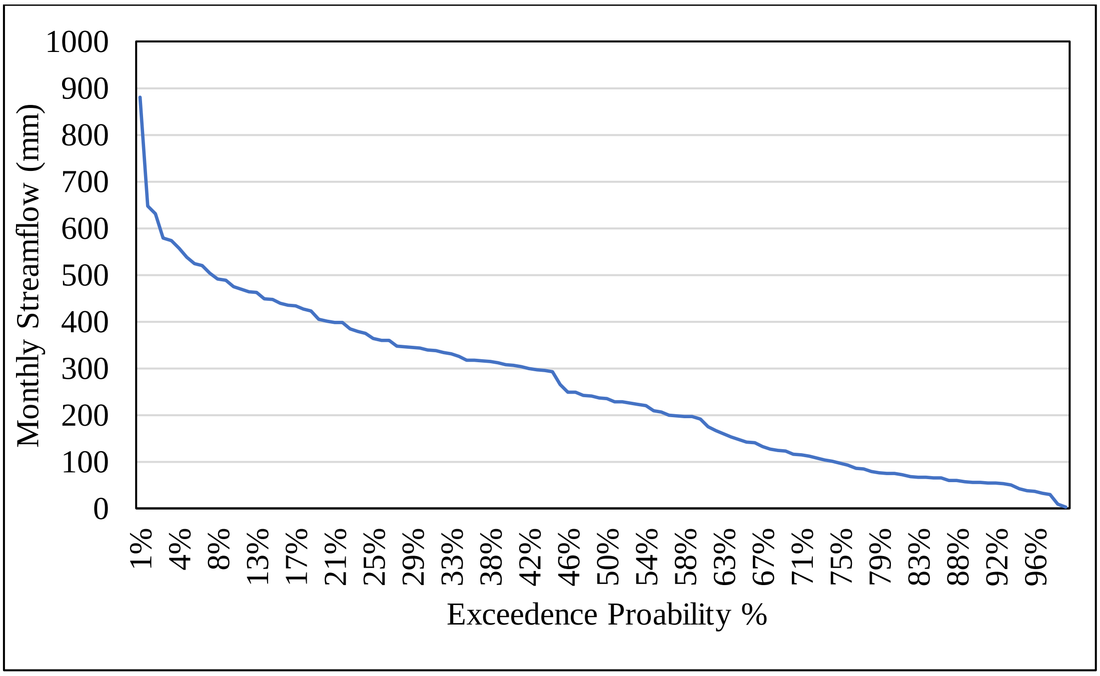


Figure 4-40: Flow Duration Curve for Padiyatalawa for the Calibration period

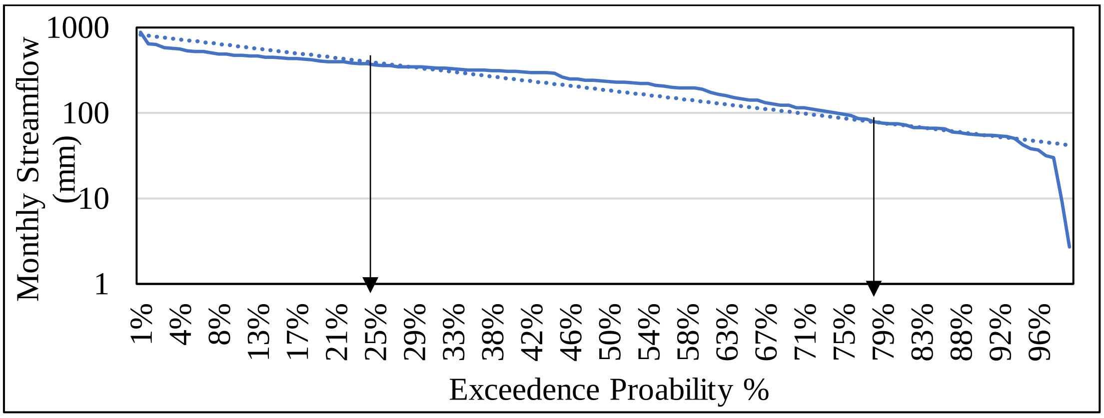


Figure 4-41: Logarithmic plot of Flow Duration Curve of Padiyatalawa for Calibration

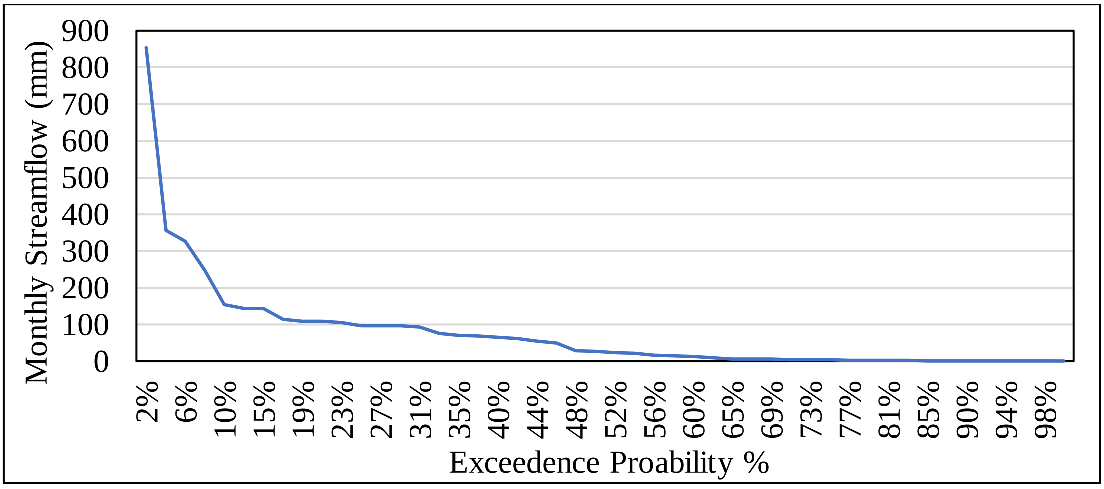


Figure 4-42: Flow Duration Curve for Padiyatalawa for the Verification period

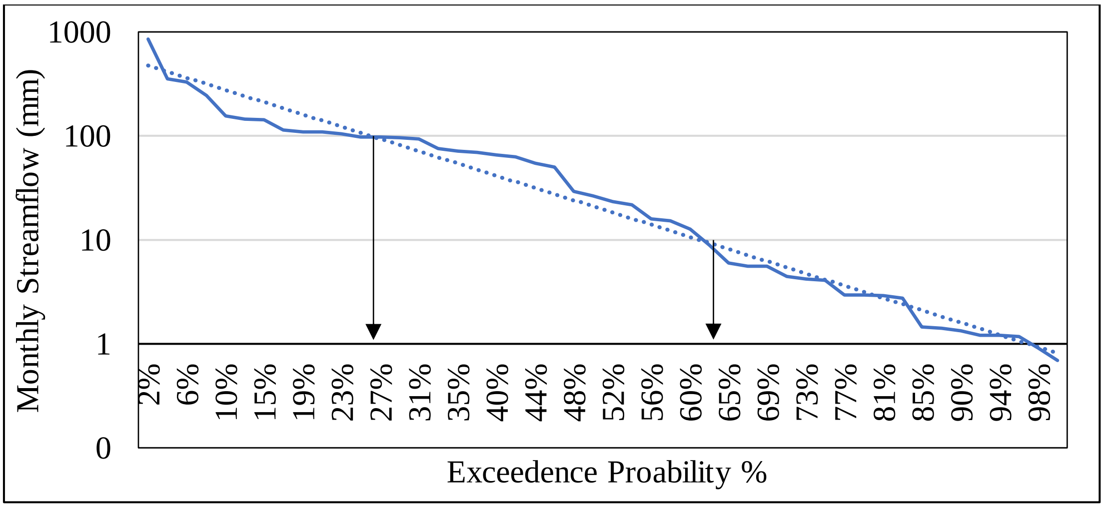


Figure 4-43: Logarithm plot of Flow Duration Curve of Padiyatalawa for Verification

By logarithmic plots of flow duration curves, flow regimes were identified easily by using the deflection points and summarized in Figure 4-43.

Table 4-5: Identified flow regimes for selected watersheds

Watershed		**Flow Regime**	**Exceedance Probability**	**Relevant Discharge (mm)**
Nawalapitiya	Calibration	High	<30	>454
		Medium	30-80	454-245
		Low	>80	<245
	Validation	High	<23	>600
		Medium	23-70	600-275
		Low	>70	<275
Thaldena	Calibration	High	<20	>163
		Medium	20-68	73-68
		Low	>68	<68
	Validation	High	<30	>160
		Medium	30-80	160-93
		Low	>80	<93
Padiyatalawa	Calibration	High	<25	>396
		Medium	25-80	396-68
		Low	>80	<68
	Validation	High	<26	>346
		Medium	26-64	346-53
		Low	>64	<53

4.13 Flow duration curve analysis for the simulated flow in the catchments

The flow duration curves for the simulated flow in both calibration and validation were plotted on top of the observed flow duration curve to check the matching of simulation visually for the three flow regimes.

4.13.1 Flow duration curve match (Nawalapitiya-Calibration)

For Nawalapitiya, simulated flow was plotted for the corresponding observed flow in the flow duration curves in normal and logarithmic plots considering calibration period as shown in Figure 4-45.

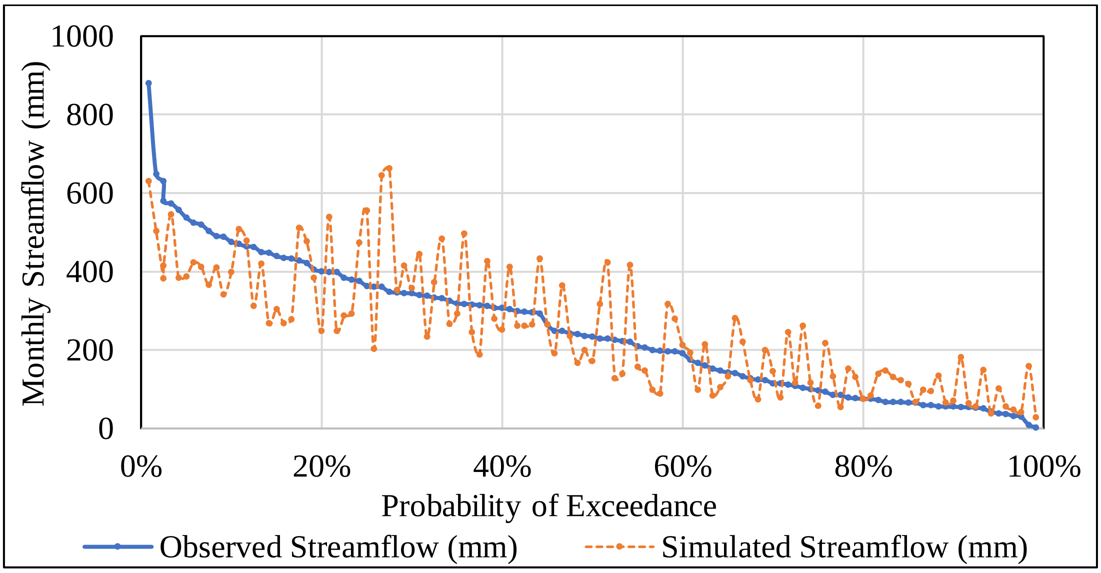


Figure 4-44: Flow duration curve observed and simulated Nawalapitiya-Calibration

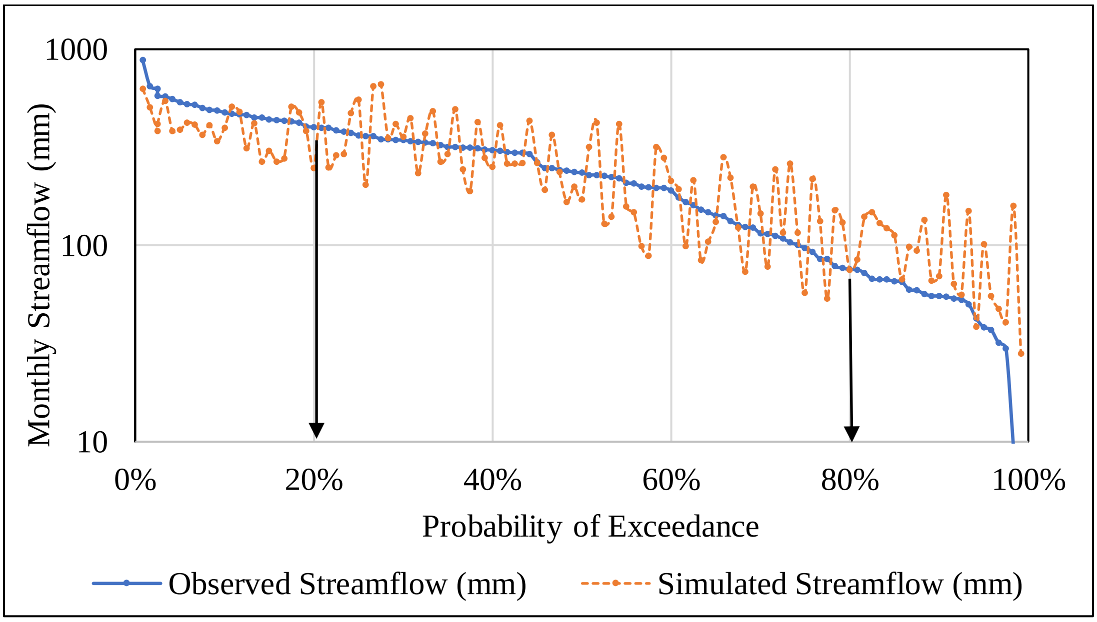


Figure 4-45: Logarithmic plot observed and simulated flow Nawalapitiya -Calibration

4.13.2 Flow duration curve match (Nawalapitiya-Validation)

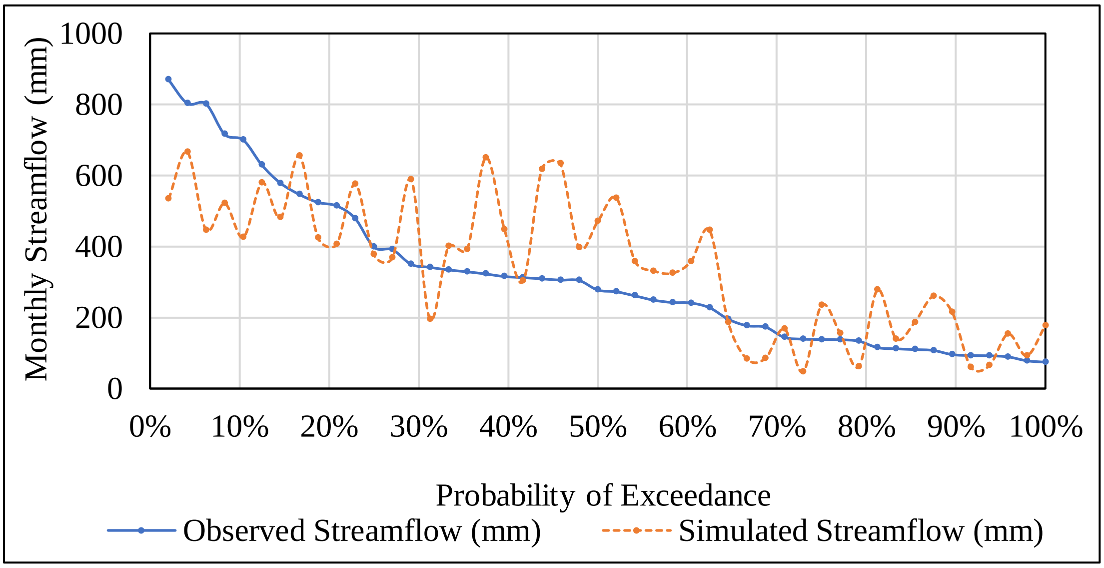


Figure 4-46: Flow duration curve for the simulated flow in Nawalapitiya for validation

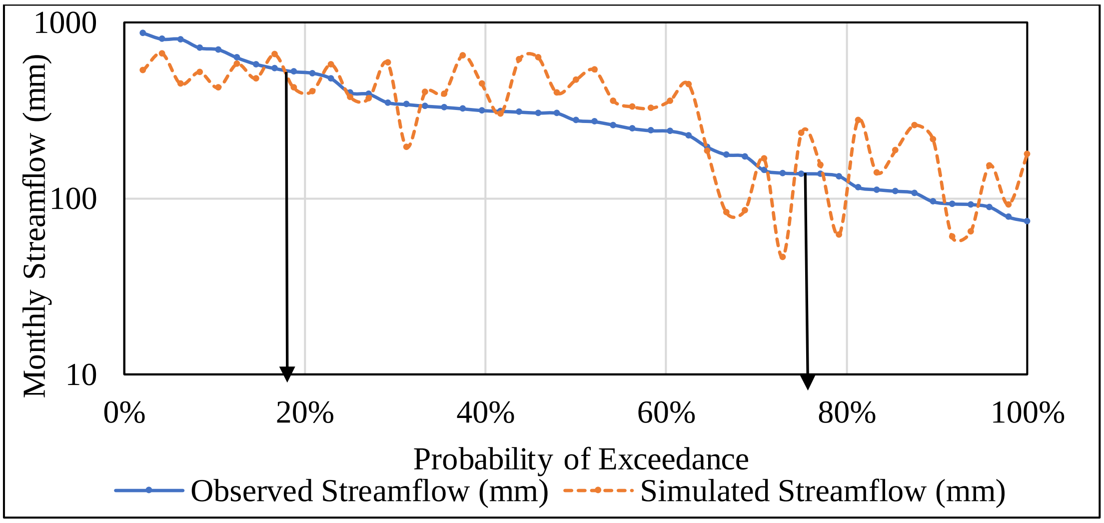


Figure 4-47: Logarithmic plot of observed to simulated flow Nawalapitiya Validation

4.13.3 Flow duration curve match (Thaldena -Calibration)

For Thaldena, simulated flow was plotted for the corresponding observed flow in the flow duration curves in normal and logarithmic plots considering validation period as shown in Figure 4-50.

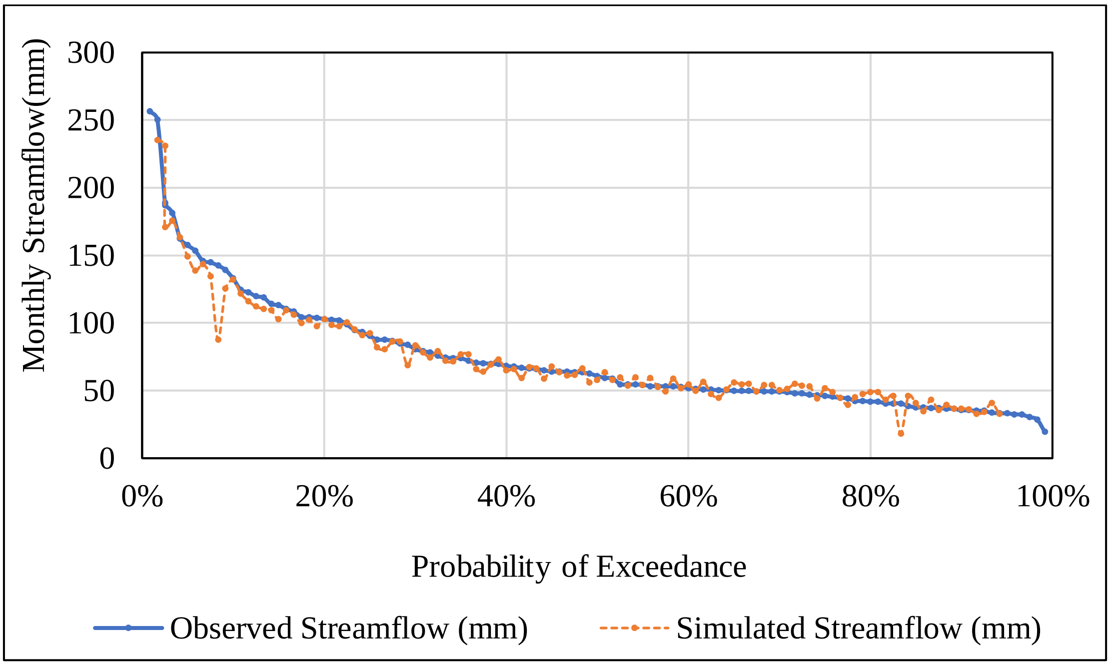


Figure 4-48: Flow Duration Curve observed and simulated flow Thaldena Calibration

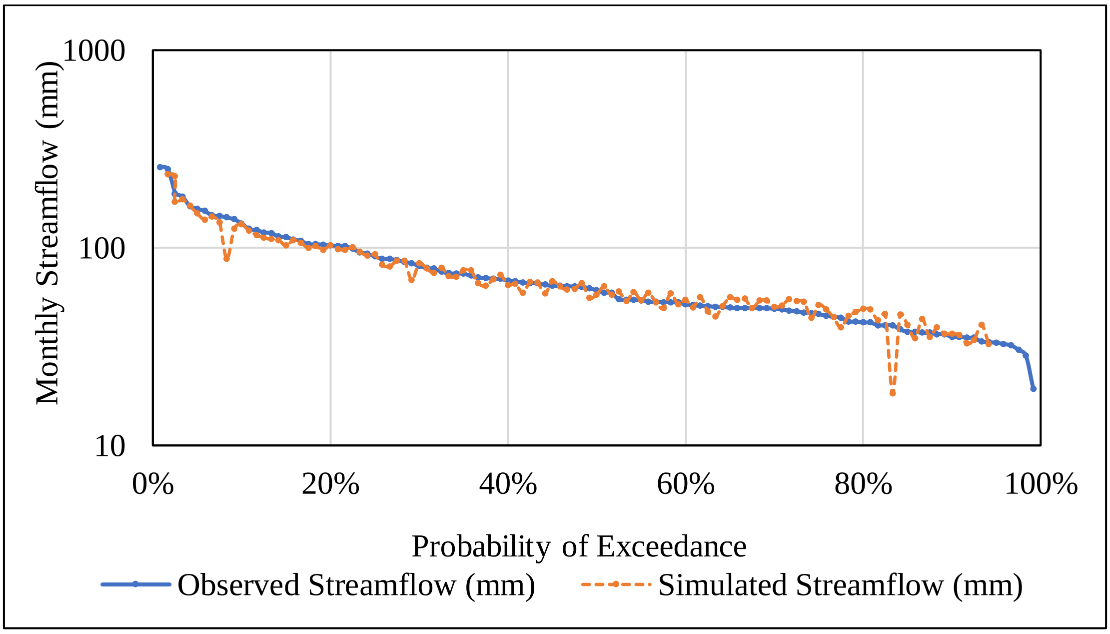


Figure 4-49: Logarithmic plot for observed and simulated flow Thaldena calibration

4.13.4 Flow duration curve match (Thaldena - Validation)

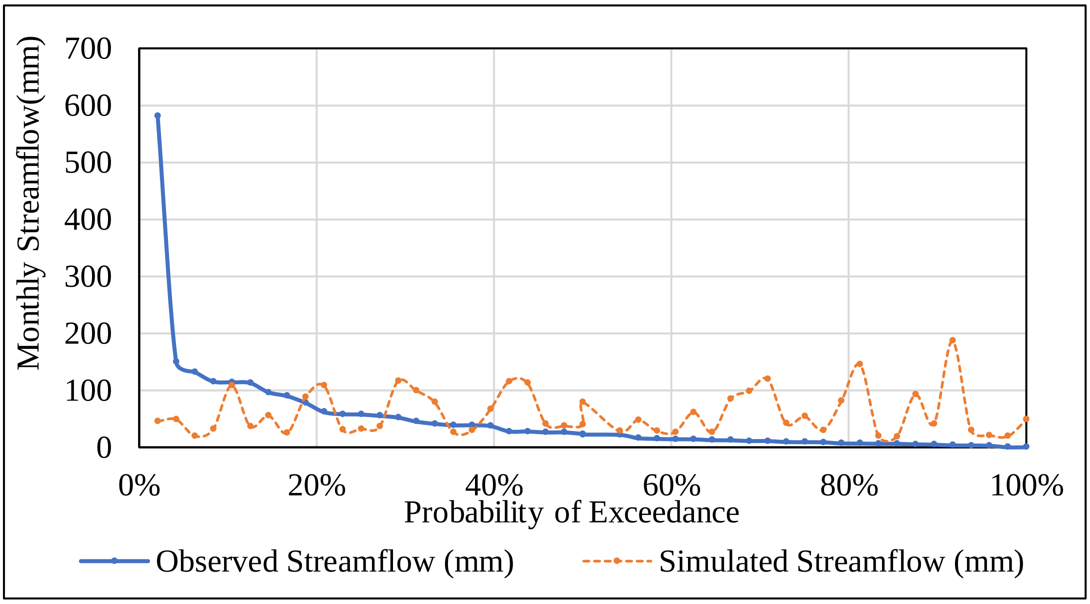


Figure 4-50: Flow Duration Curve observed and simulated flow Thaldena validation

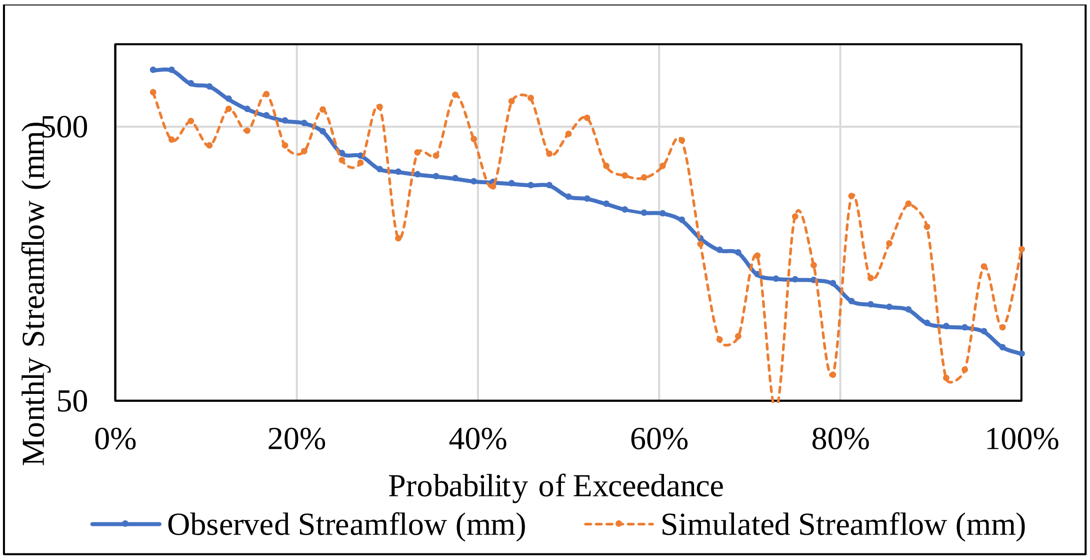


Figure 4-51: Logarithmic plot for observed and simulated flow in Thaldena validation

4.13.5 Flow duration curve match (Padiyatalawa -Calibration)

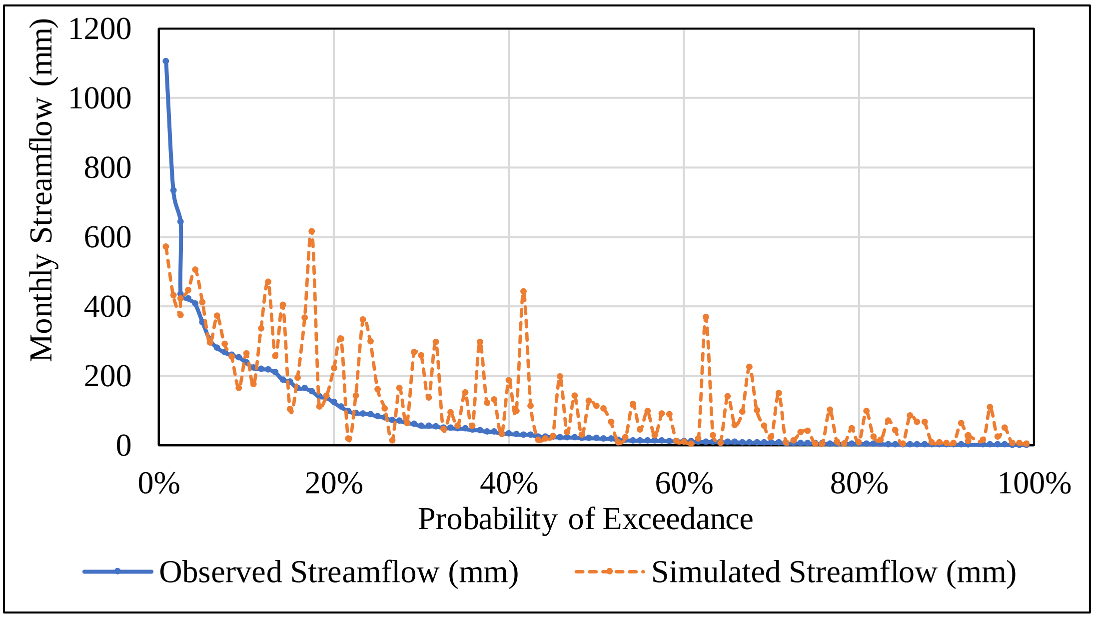


Figure 4-52: Flow Duration Curve observed and simulated Padiyatalawa calibration

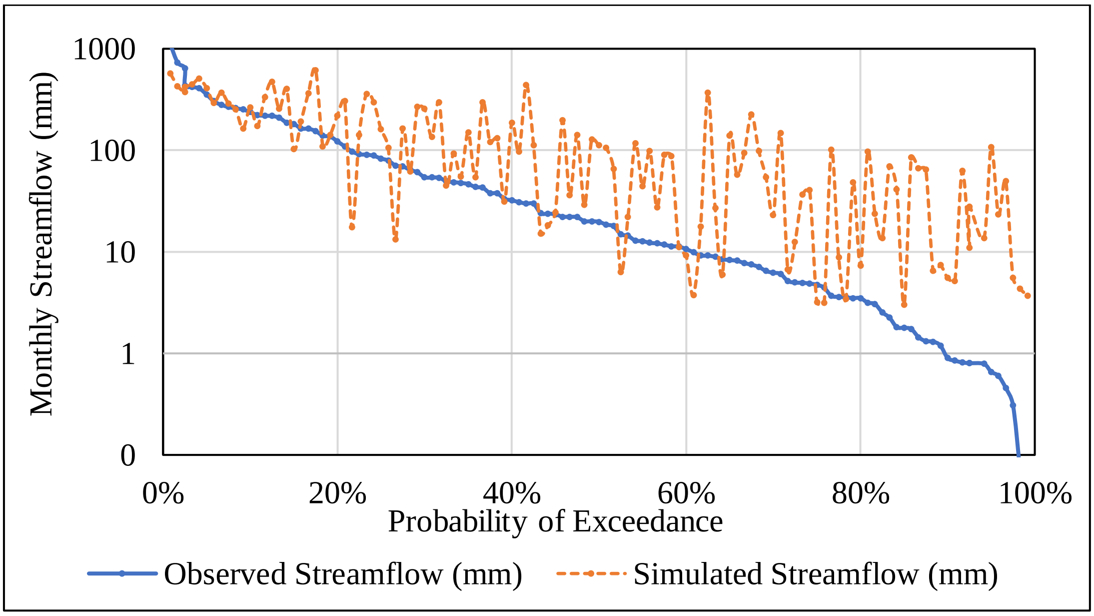


Figure 4-53: Logarithmic plot of observed and simulated flow Padiyatalawa validation

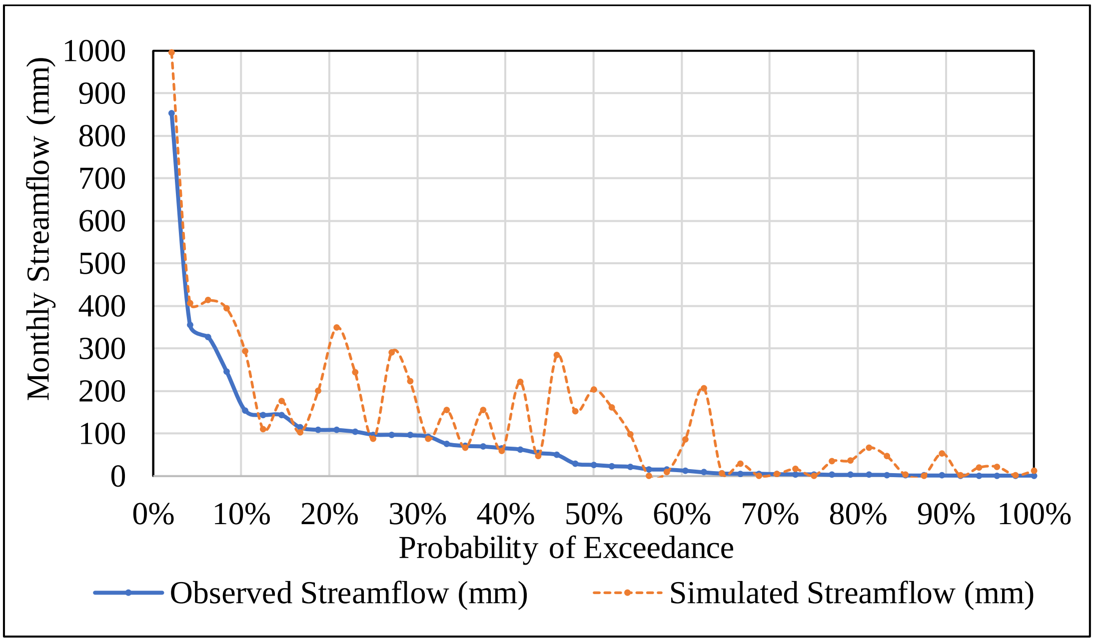


Figure 4-54: Flow Duration Curve observed and simulated flow Padiyatalawa

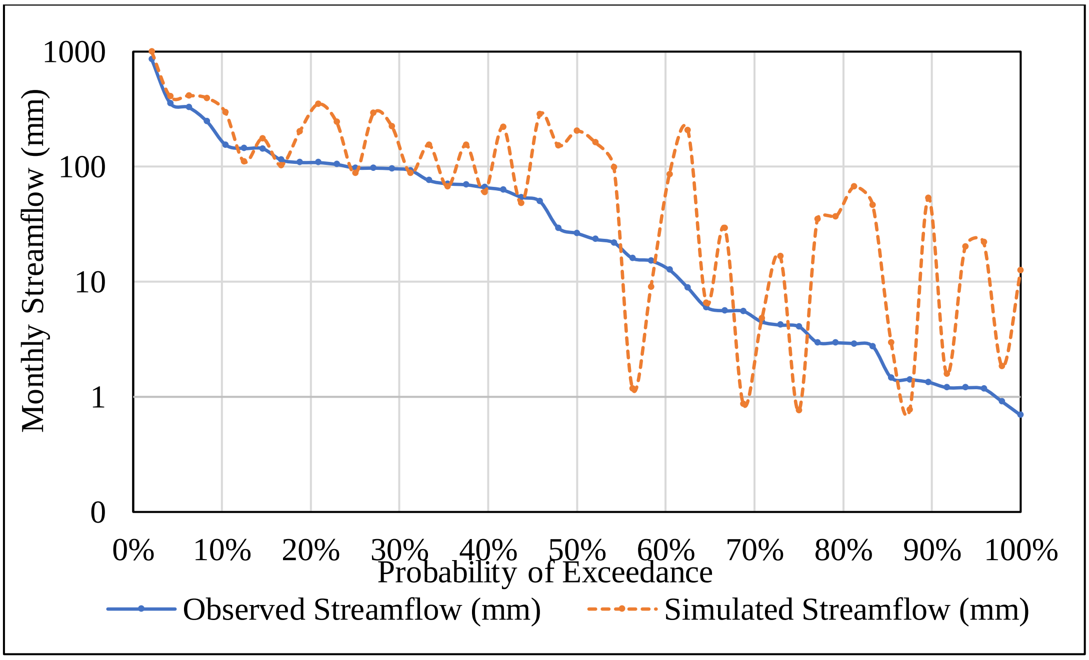


Figure 4-55: Logarithmic plot observed and simulated flow Padiyatalawa validation

4.14 Model suitability analysis for different flow regimes

After the general calibration and validation of 'abcd' model, it is essential to check the exhibition of the model for various stream systems which had been recognized and condensed under Table 4-8. By utilizing this high, medium and low regimes, the observed stream was separated, and the objective functions were checked. Since the amount of information exceptionally for high and low stream systems is low, Nash Sutcliffe proficiency criteria was very digressed and did not consider for checking. In any case, MRAE criteria gave fitting outcomes with the exception of in low stream system for the two watersheds. The after effects of stream flow investigation are exhibited in Table 4-8.

Table 4-8: MRAE for high medium and low flows

Watershed	**Flow Regime**	**Pearson Value**	
		Calibration	**Validation**
Nawalapitiya	High	0.59	0.69
	Medium	0.69	0.59
	Low	0.69	0.98
Thaldena	High	0.95	0.34
	Medium	0.97	0.91
	Low	0.83	0.26
Padiyatalawa	High	0.64	0.97
	Medium	0.56	0.57
	Low	0.24	0.68

4.15 Application of the ‘abcd’ model for water resources investigation

Under the water assets examination, the soil moisture content, groundwater capacity, surface spillover and groundwater stream is considered as the fundamental parts and can be promptly get those as a yield from the "abcd" model. Yearly groundwater stream and surface water stream have been distinguished for the watersheds, for adjustment and approval periods independently as appeared in Figure 7-57

4.16 Annual groundwater flow and surface runoff

For all catchments annual ground water flow and surface runoff graphs were plotted.

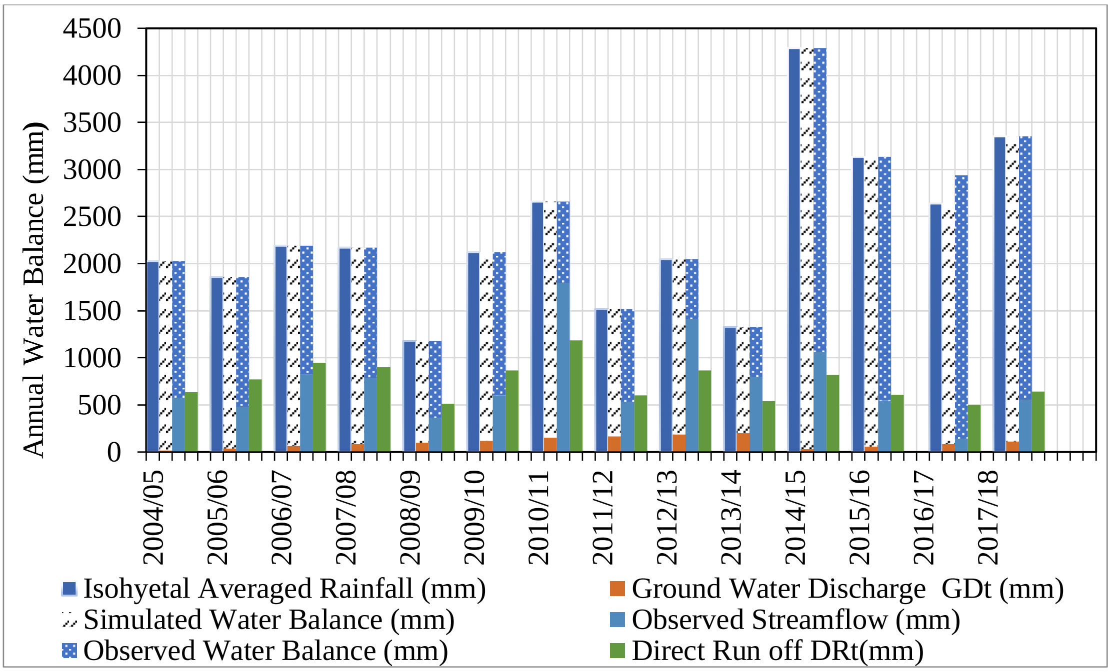


Figure 4-56: Annual surface water and groundwater flow of Thaldena calibration

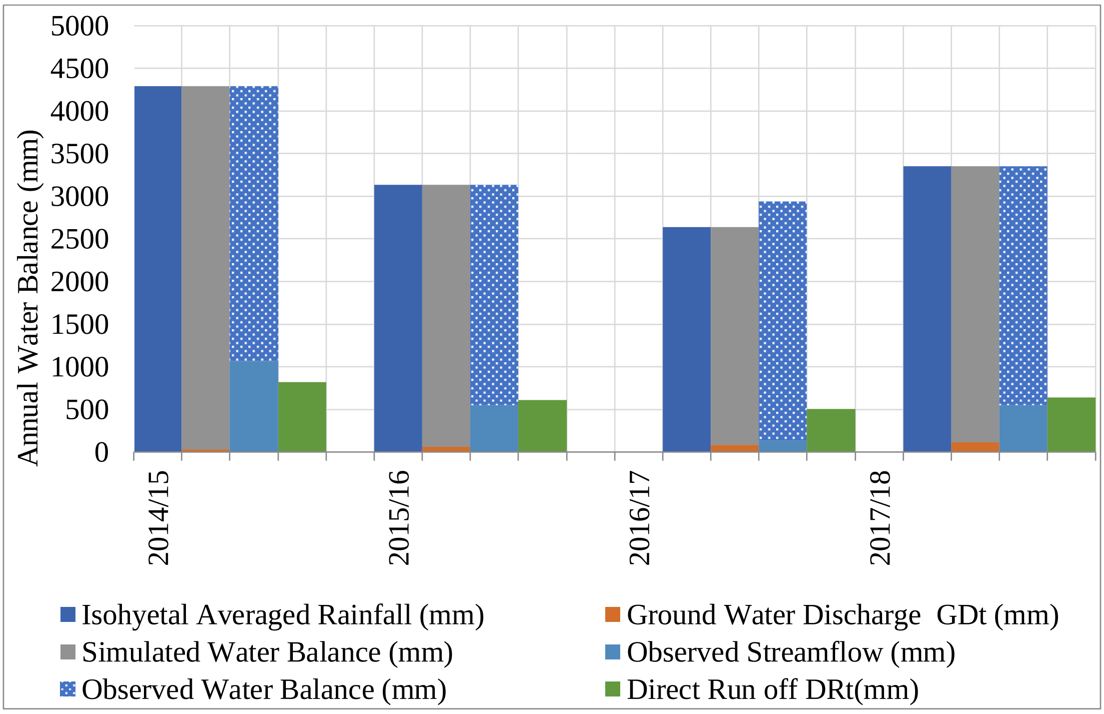


Figure 4-57: Annual surface water and groundwater flow of Thaldena validation

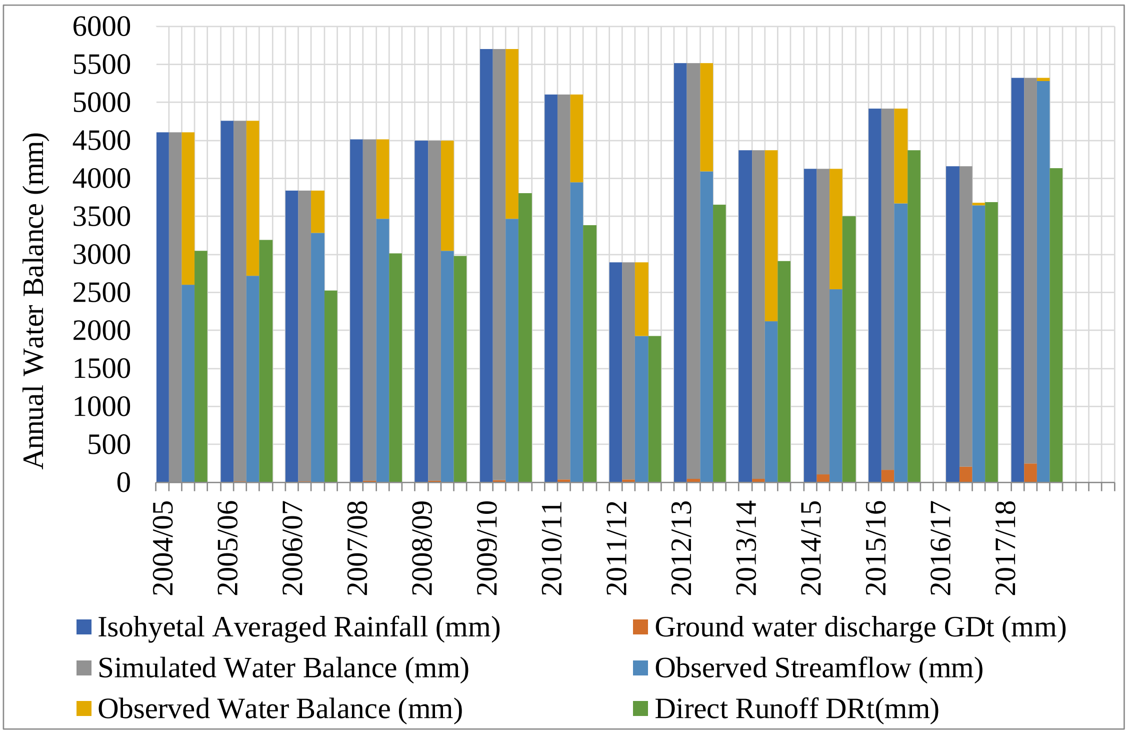


Figure 4-58: Annual surface water and groundwater flow of Nawalapitiya calibration

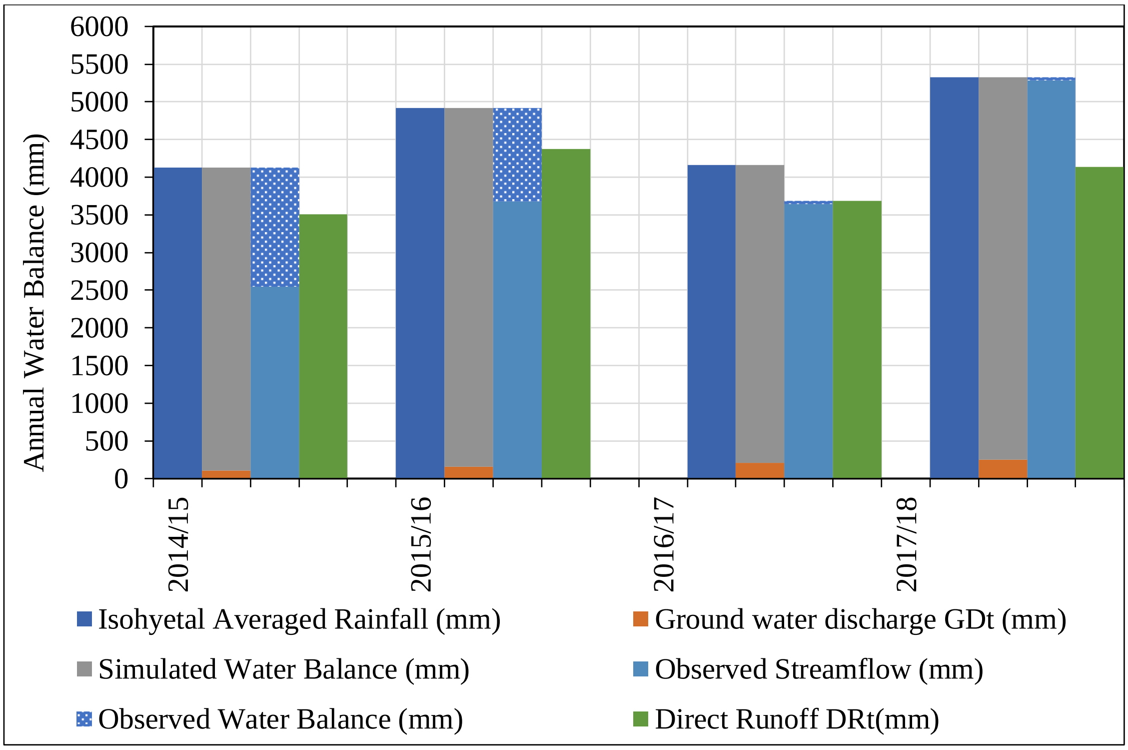


Figure 4-59: Annual surface water and groundwater flow of Nawalapitiya validation

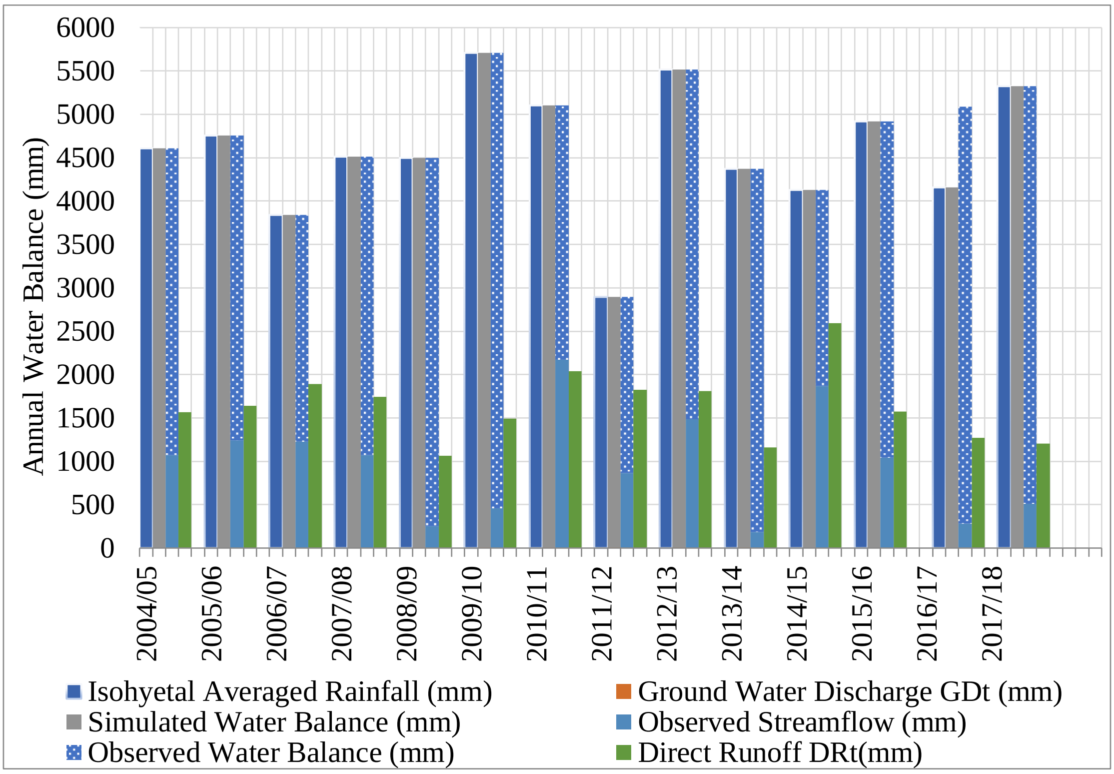


Figure 4-60: Annual surface water and groundwater flow of Padiyatalawa Calibration

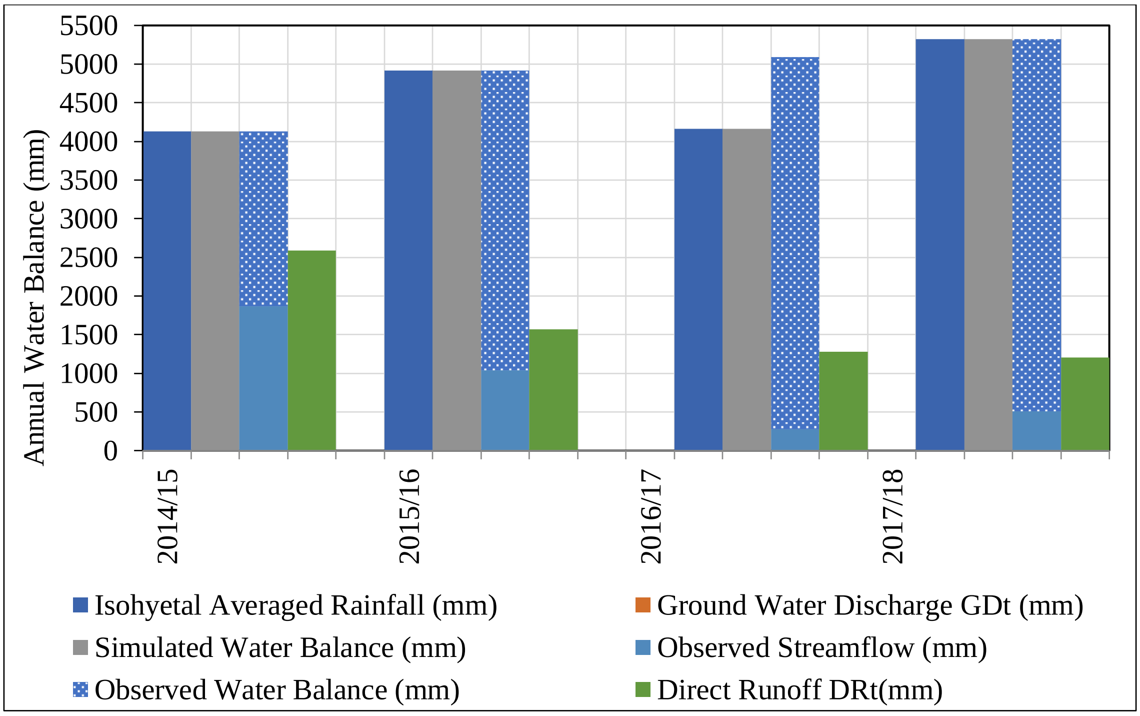


Figure 4-61: Annual surface water and groundwater flow of Padiyatalawa validation

4.17 Model Results For Climate Change Scenarios

The “abcd” model was used to model the streamflow for future climate change scenarios.

4.17.1 Simulationof Climate Change Scenarios at Nawalapitiya Catchment

For Nawalapitiya catchment scenarios rainfall data used for simulating streamflow for future.

Table 4-6: Climate change scenarios for Nawalapitiya

Month	Base line Rainfall (mm)	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
		Projected RF (mm)	Projected RF (mm)	Projected RF (mm)	ProjectedRF (mm)	Projected RF (mm)
Oct	401.61	265.06	297.19	50.66	502.011	429.721
Nov	68.46	45.18	50.66	94.28	85.5768	73.2537
Dec	127.40	84.09	94.28	50.66	159.255	136.323
Jan	68.46	45.18	50.66	54.04	85.5768	73.2537
Feb	73.03	48.20	54.04	95.59	91.2821	78.1375
Mar	129.18	85.26	95.59	309.03	161.47	138.218
Apr	266.40	367.64	309.03	398.12	333.005	285.053
May	343.20	473.62	398.12	473.83	429.004	367.227
Jun	408.47	563.69	473.83	351.65	510.587	437.063
Jul	303.14	418.34	351.65	347.64	378.929	324.363
Aug	299.69	413.57	347.64	380.25	374.613	320.668
Sep	327.80	452.37	380.25	297.19	409.754	350.749
Minimum	68.46	45.18	50.66	50.66	85.58	73.25
Average	234.74	271.85	241.91	241.91	293.42	251.17
Maximum	408.47	563.69	473.83	473.83	510.59	437.06

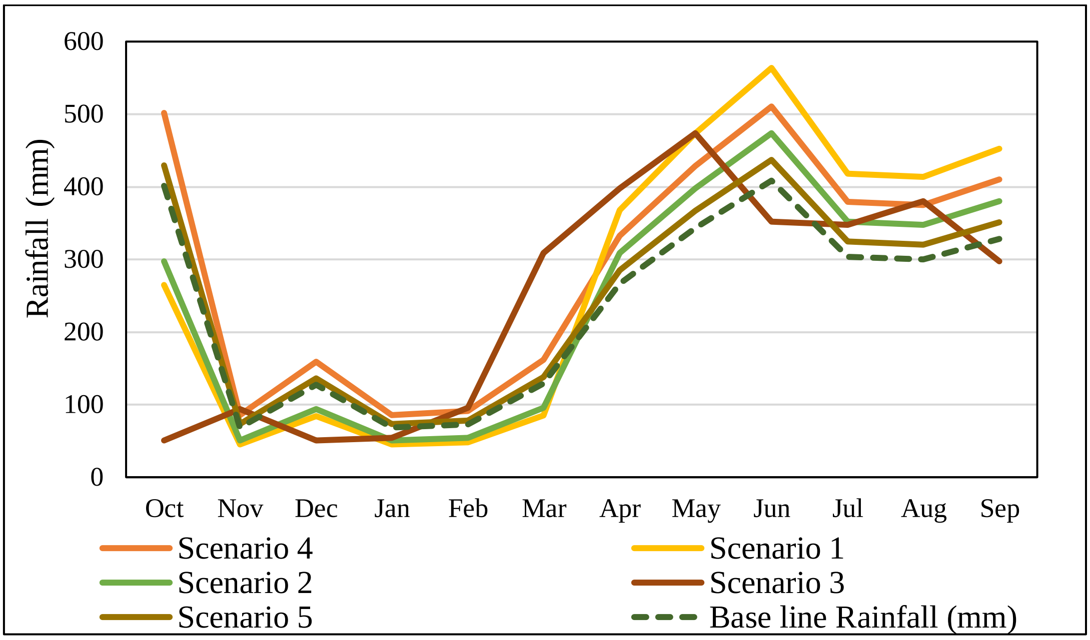


Figure 4-62: Rainfall scenarios for Nawalapitiya

Table 4-7: Model Simulated Streamflow with Climate Change

Estimated Streamflow (mm/Month						
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Month	Base Scenarios (mm)	Projected SF (mm)	Projected SF (mm)	Projected SF (mm)	ProjectedSF (mm)	Projected SF (mm)
Oct	243.93	147.51	165.77	110.50	328.35	267.14
Nov	139.79	106.45	115.59	76.97	158.65	144.99
Dec	149.05	101.59	113.71	56.59	180.62	157.57
Jan	99.65	73.64	80.18	47.36	117.04	104.26
Feb	83.58	59.08	64.81	60.97	101.01	88.03
Mar	113.02	69.04	79.06	247.74	144.48	121.24
Apr	231.10	302.49	256.44	356.96	294.35	248.30
May	313.19	429.26	360.61	437.07	393.76	335.33
Jun	379.72	522.82	439.03	341.71	476.38	406.42
Jul	297.18	408.54	343.36	339.06	371.98	317.79
Aug	293.94	405.64	340.48	368.90	368.39	314.52
Sep	316.41	438.24	367.27	297.02	397.11	338.67
Min	83.58	59.08	64.81	47.36	101.01	88.03
Avg	221.71	255.36	227.19	228.40	277.68	237.02
Max	379.72	522.82	439.03	437.07	476.38	406.42

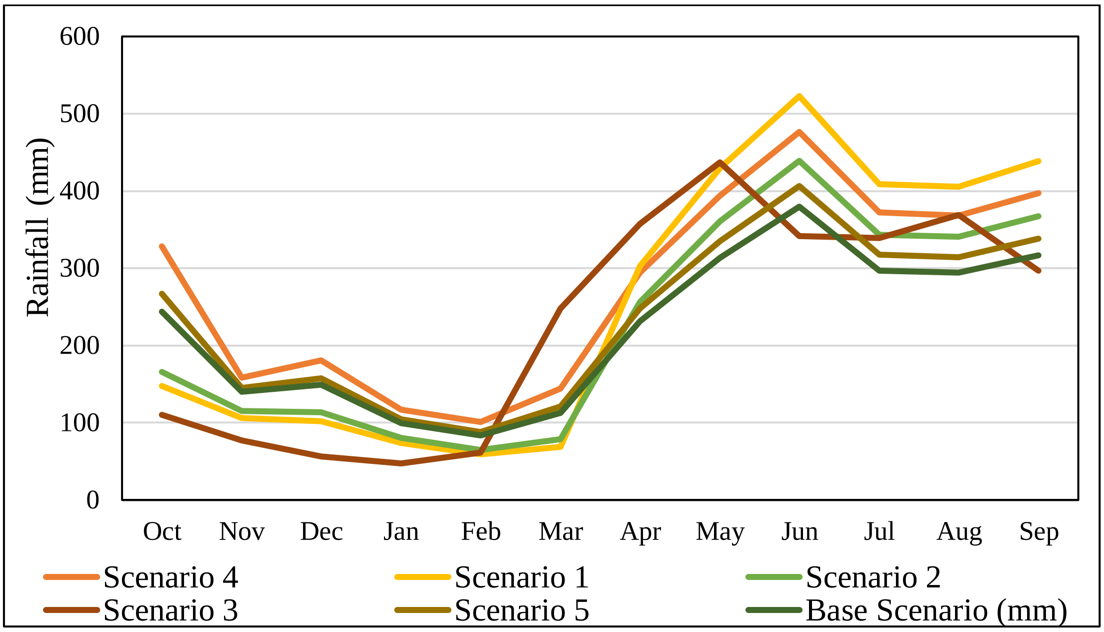


Table 4-8: Soil moisture storage for scenarios (Nawalapitiya)

Estimated Soil Moisture Storage (mm/month						
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Month	Base Scenario (mm)	Projected SM (mm)	Projected SM (mm)	Projected SM (mm)	Projected SM (mm)	Projected SM (mm)
Oct	536.63	536.63	520.31	520.31	541.02	537.96
Nov	523.76	523.76	512.54	512.54	527.86	524.73
Dec	532.90	532.90	524.44	524.44	536.32	533.69
Jan	519.55	519.55	510.73	510.73	523.50	520.28
Feb	515.65	515.65	505.09	505.09	520.44	516.52
Mar	525.57	525.57	516.20	516.20	529.00	526.09
Apr	539.44	539.44	539.82	539.82	540.67	539.43
May	543.49	543.49	543.87	543.87	544.27	543.40
Jun	546.09	546.09	546.40	546.40	546.73	546.01
Jul	545.62	545.62	546.23	546.23	546.67	545.72
Aug	543.54	543.54	544.05	544.05	544.49	543.53
Sep	544.12	544.12	544.56	544.56	544.97	544.08
Min	515.65	515.65	505.09	505.09	520.44	516.52
Avg	534.70	534.70	529.52	529.52	537.16	535.12
Max	546.09	546.09	546.40	546.40	546.73	546.01

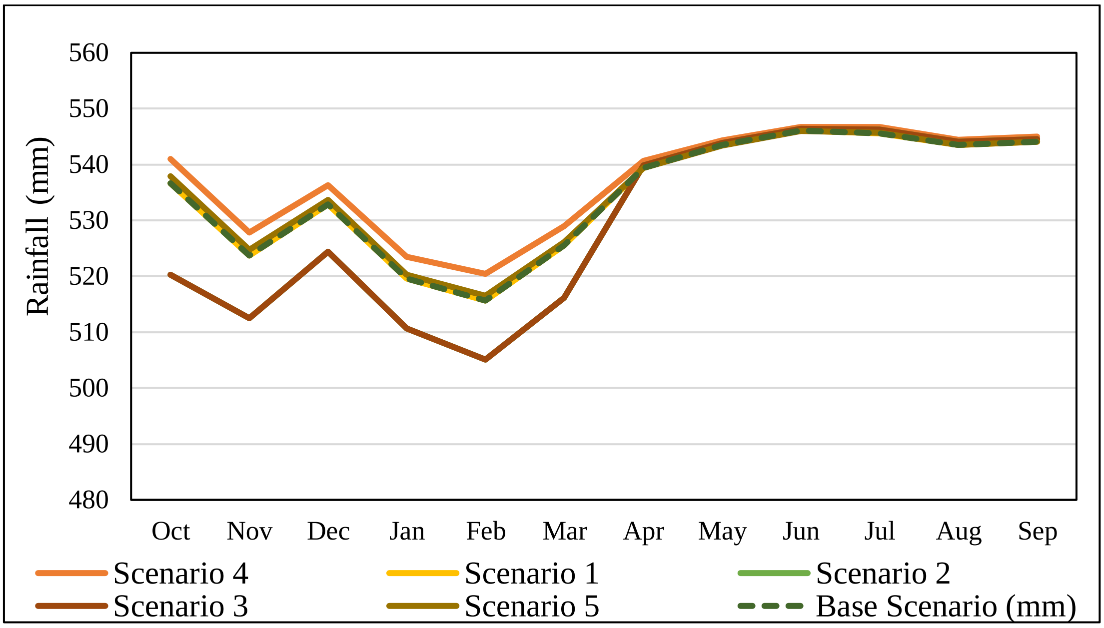


Figure 4-63: Soil moisture content with climate change (Nawalapitiya)

Table 4-9: Groundwater storage scenarios (Nawalapitiya)

Estimated Groundwater Storage (mm/Month						
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Month	Base Scenario (mm)	Projected GW (mm)	Projected GW (mm)	Projected GW (mm)	Projected GW (mm)	Projected GW (mm)
Oct	208.22	195.66	165.77	110.50	328.35	267.14
Nov	141.73	129.94	115.59	76.97	158.65	144.99
Dec	103.49	90.32	113.71	56.59	180.62	157.57
Jan	74.38	63.17	80.18	47.36	117.04	104.26
Feb	55.01	45.17	64.81	60.97	101.01	88.03
Mar	47.35	35.79	79.06	247.74	144.48	121.24
Apr	58.19	60.62	256.44	356.96	294.35	248.30
May	75.31	91.87	360.61	437.07	393.76	335.33
Jun	94.13	122.59	439.03	341.71	476.38	406.42
Jul	94.54	125.93	343.36	339.06	371.98	317.79
Aug	94.37	127.53	340.48	368.90	368.39	314.52
Sep	97.19	132.73	367.27	297.02	397.11	338.67
Min	47.35	35.79	64.81	47.36	101.01	88.03
Avg	95.32	101.78	227.19	228.40	277.68	237.02
Max	208.22	195.66	439.03	437.07	476.38	406.42

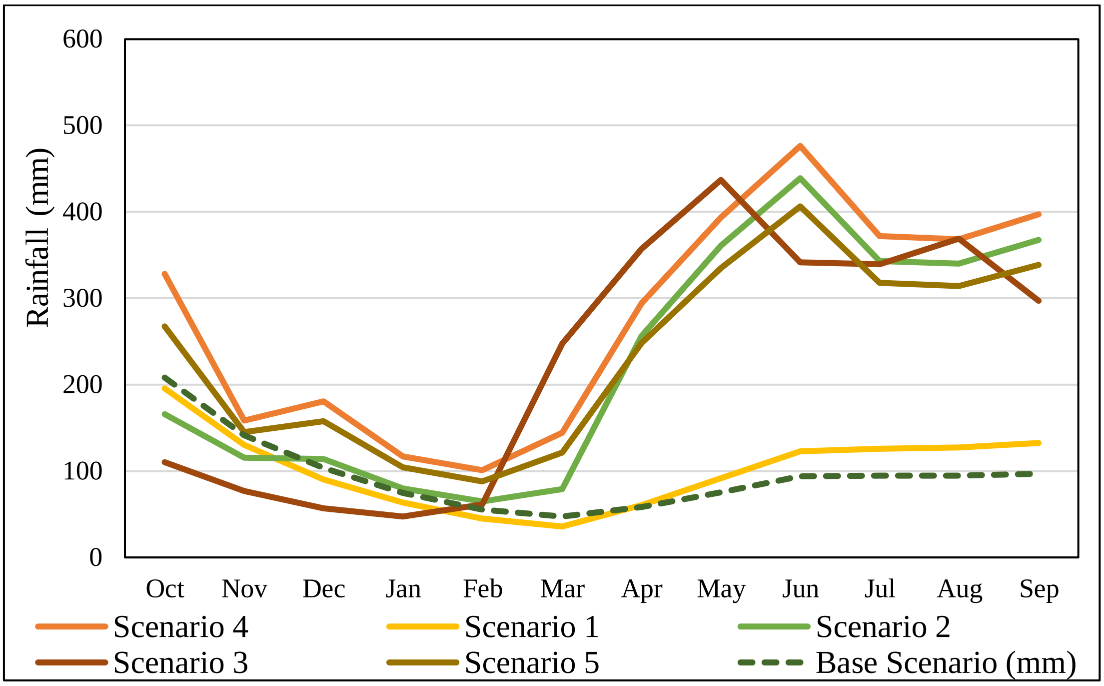


Figure 4-64: Groundwater storage with climate change

5 DISCUSSION

The “abcd” model was applied to Nawalapitiya,Thaldena and Padiyatalawa watersheds in Mahaweli Ganga and Maduru Oya basins respectively and the model input data, model performance, behavior of model parameters, parameter sensitivity, challenges in the Modeling work and the model limitations have been discussed herewith with reference to the related literature.

5.1 Model inputs

As the input of the model isohyetal averaged rainfall has been chosen as this is the main input of “abcd” hydrological model. For good representation of the rainfall for model input WMO (2009) guidelines used for all the three sub-catchments.

5.1.1 Isohyetal averaged rainfall

For selected data period average rainfall from selected stations in each catchment is calculated by isohyetal rainfall method.The annual average rainfall recorded at Thaldena, Nawalapitiya and Padiyatalawa catchments area 2320 mm/year,4595 mm/year and 1782 mm/year respectively. 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 moreclear image of the rainfall over the basin. This method is more suited for hilly areas and all the selected catchments area upper catchments on the tributaries to avoid reservoirs in the catchment.Hence isohyetal method was appropriate method for estimating the average rainfall for Modeling of the catchments.The accuracy is largely dependent on the skill of the person performing the analysis and the number of gauges. If simple linear interpolation between stations is used for drawing the contours, the results will be essentially the same as those obtained by the Thiessen method.

5.1.2 Stream flow

The average annual streamflow of Nawalapitiya and Thaldena had recorded as 3270 mm/year and 791 mm/year whereas Padiyatalawa was 1014 mm/year, average monthly stream flow had recorded as 275 mm/month for Nawalapitiya and 63 mm/month for Thaldena and 77 mm/year to Padiyatalawa catchment. and average In

Thaldena,Nawalapitiya and Padiyatalawa watershed, highest standard deviation was observed in June for stream flow data which was the same observation for rainfall data while observing the minimum in February which was January in the rainfall data set. For the watershed, highest standard deviation for stream flow data was observed in June while observing the minimum in February. But the corresponding months for the rainfall data are September and January respectively which may have affected the Modeling process of Thaldena watershed.

5.1.3 Evaporation

Annual average evaporation calculated from selected stations of each catchment.The annual pan evaporation of Nawalapitiya was1061 mm/year and1487 mm/year for Padiyatalawa whereas Thaldena annual evaporation was 748mm/year.In general March had high evaporation and December contains low evaporation.

5.2 Rainfall Trend Over Three Climatic Zones of Mahaweli Basin

The MK test and Sen's slope estimator were applied to the time-series data from 1988 to 2018 in Mahaweli basin. The statistics from tests for the annual rainfall data demonstrate that only seven rain gauge stations show positive potential trends for rainfall in the entire basin. While this is noteworthy, it is interesting to observe the locations and topography of the surrounding area.

In wet zone, only Ambewela rain gauge station shows a positive trend whereas the rest three stations have negative trends. This may be due to the site-specific topographical conditions. The area is a plateau which could have affected such spatial variation.

A recent study on Kelani Basin which lies in wet zone of Sri Lanka also indicates similar decreasing annual rainfall trend (Dissanayaka and Rajapakse 2018). In Intermediate zone, Kurundu Oya and Ducwary gauge stations showed negative rainfall trend, presumably due to the fact that they lie in the immediate proximity of wet zone boundary and elevations are nearly similar to wet zone topography. The other stations in Intermediate Zone show a positive rainfall trend.

Several previous studies have indicated the positive trends in Dry and Intermediate zones. Hence, most appropriate adaptation measures needed to be identified based on the key decisive factors. The increased rainfall will have serious effects on infrastructure as well as urban settings which are built by filling the marshy lands and paddy fields. The reason for the decrease in rainfall in Wet zone station cannot be properly evaluated without a proper knowledge about changes in long term temperature, humidity, and orographic and cumulus cloud patterns that produce rainfall over the Central Highlands. A ground-based cloud observation system is not available in Sri Lanka. Such a system must be established in order to study cloud patterns and their movements over Sri Lanka. The observed long-term trends in temperature can be used to evaluate the impact on stream flow variability in each climatic zone and their associated watersheds and sub-watersheds by applying the ABCD lumped parameter, monthly water balance hydrologic model

5.3 Model performance

Model perform well for all the three sub-catchments in Mahaweli Ganga and Maduru Oya basin with monthly hydro climatological datasets which are available with an average MRAE 0.128 and Nash-Sutcliffe efficiency 0.56. Monthly precipitation and evaporation seem to be sufficient for evaluation of climate change impacts on the streamflow. The correlation between the observed stream flow and simulated stream flow was observed for all watersheds considering overall data as shown in Figure 5-1. In all watersheds, low flows have been slightly over estimated while very high flows have been underestimated. But a balance distribution of simulated flow results can be observed in intermediate flows. Comparatively high dispersion of simulation results can be observed in Thaldena watershed than Padiyatalawa watershed. For further interpretation, graphs were regenerated with simulated flows verses observed flows for calibration and validation periods separately as shown in Figure 5-51 and Figure 5-54. In Mahaweli Basin basin specially for validation period, the high flows have underestimated while low flows have overestimated, and high dispersion of simulated results were observed in validation period than in calibration period. In MaduruOya basin, same kind of over estimations in low flows and under estimates in high flows in validation period were observed but relatively low in comparing with Mahweli Ganga. Both watersheds showed excellent performance in their calibration with low dispersion with respect to line. The dispersion of points was observed to be further scattered when the flow was increasing.

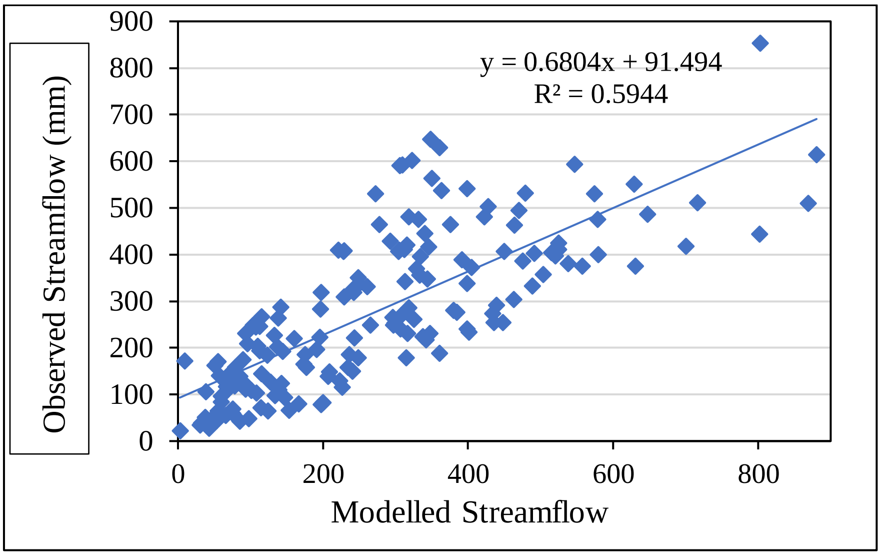


Figure 5-1: Observed Flow Vs Simulated Flow for Padiyatalawa Catchment

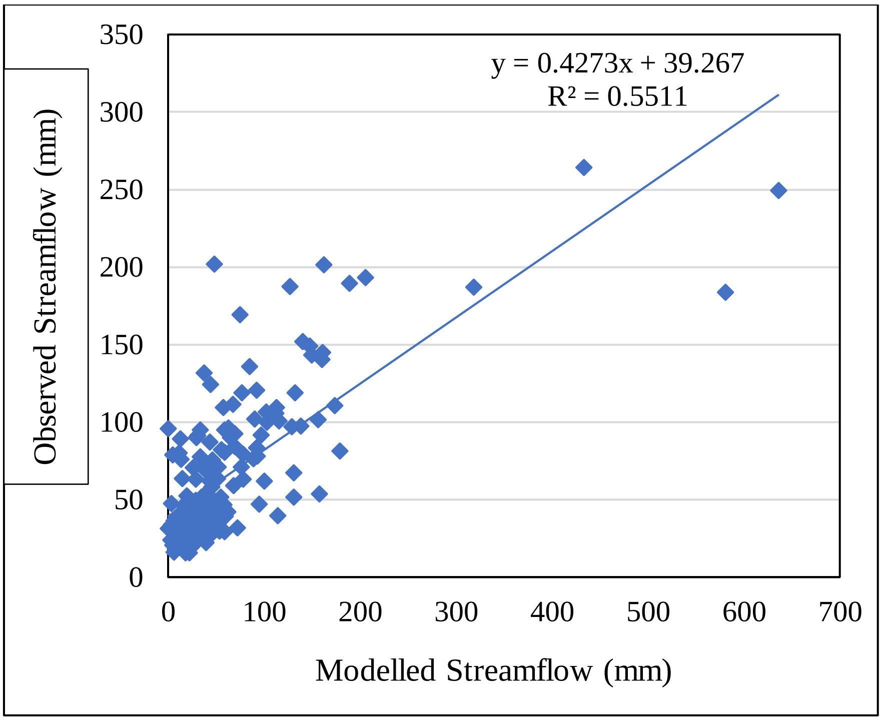


Figure 5-2: Observed Flow Vs Simulated Flow for Thaldena Catchment

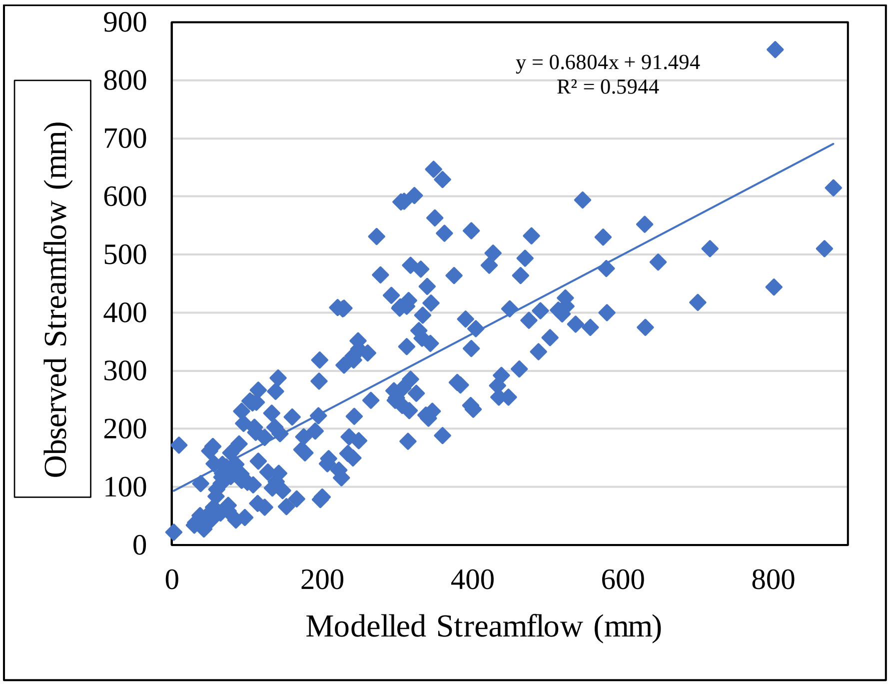


Figure 5-3: Observed Flow Vs Simulated Flow for Nawalapitiya Catchment

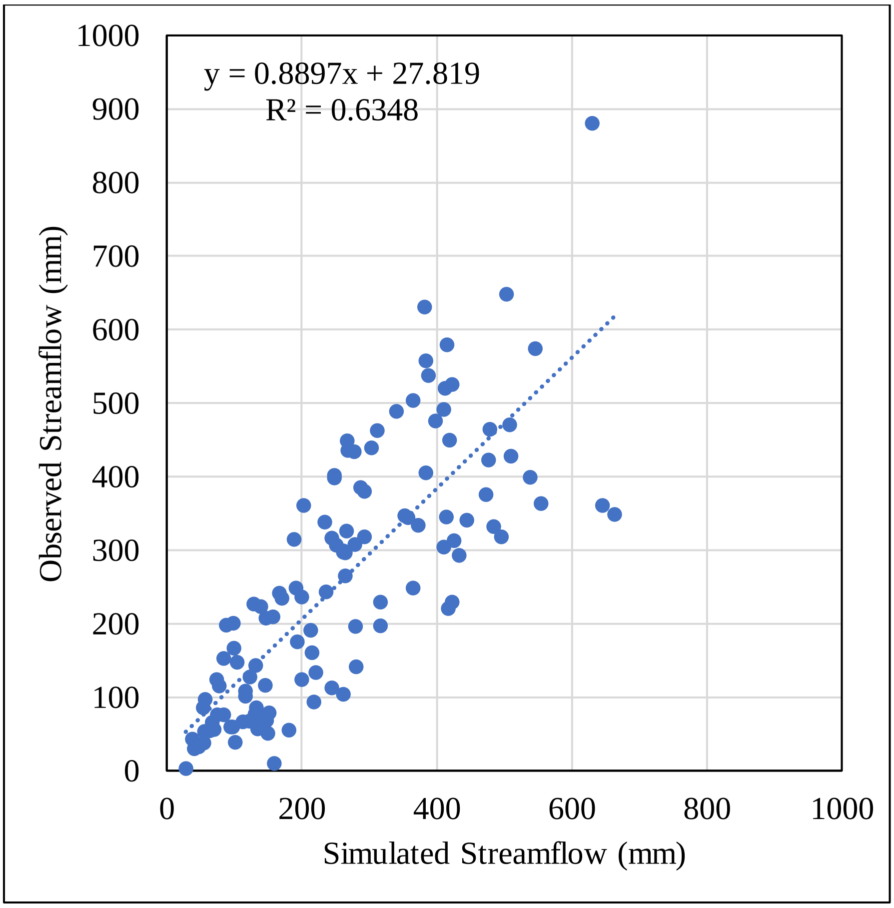


Figure 5-4: Simulated flow Vs Observed flow in Nawalapitiya for calibration period

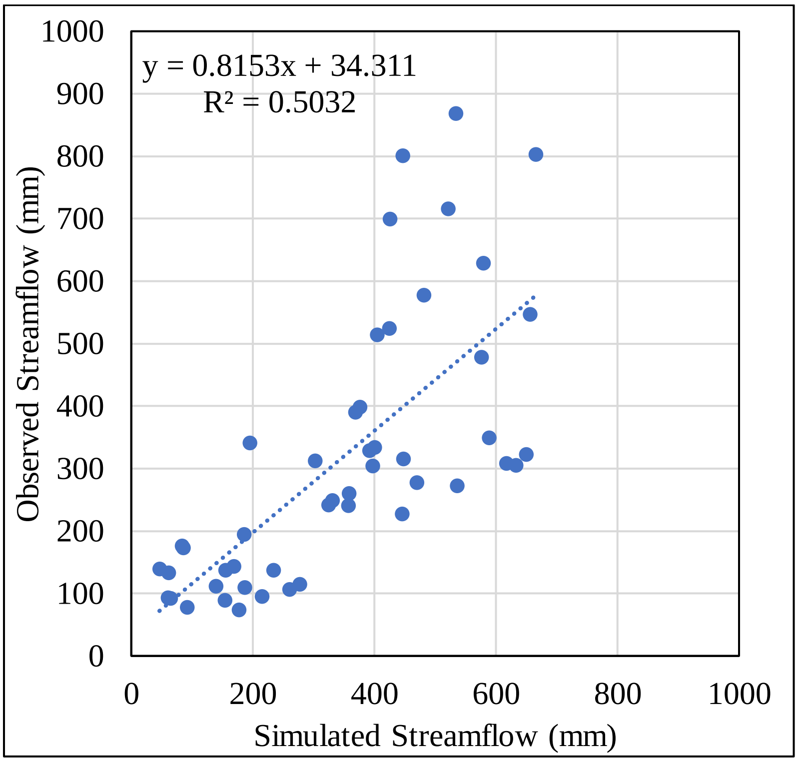


Figure 5-5: Simulated flow Vs Observed flow in Nawalapitiya for Validation Period

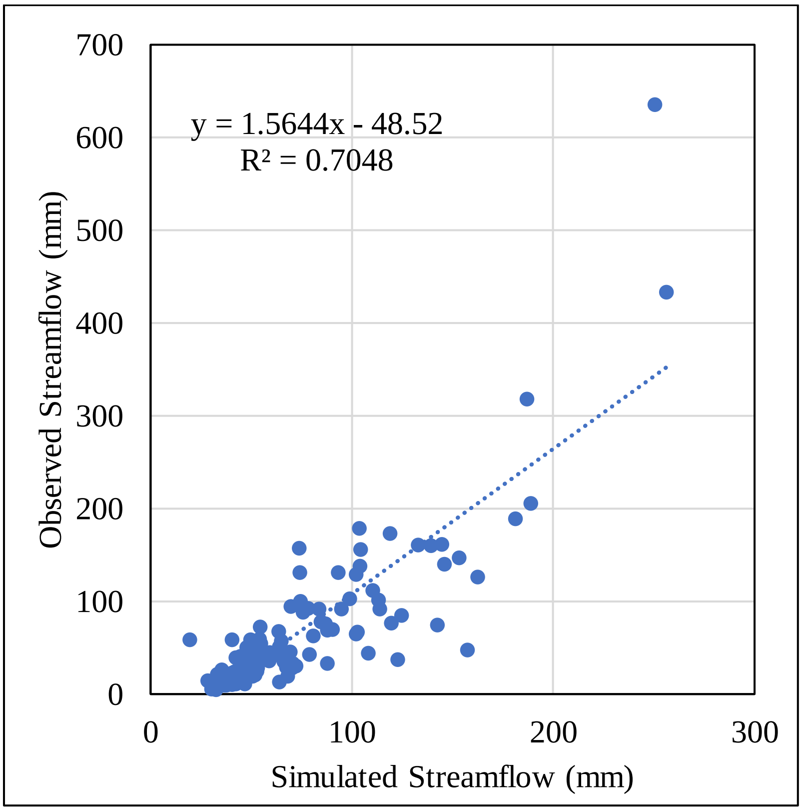


Figure 5-6: Simulated flow Vs Observed flow in Thaldena for calibration

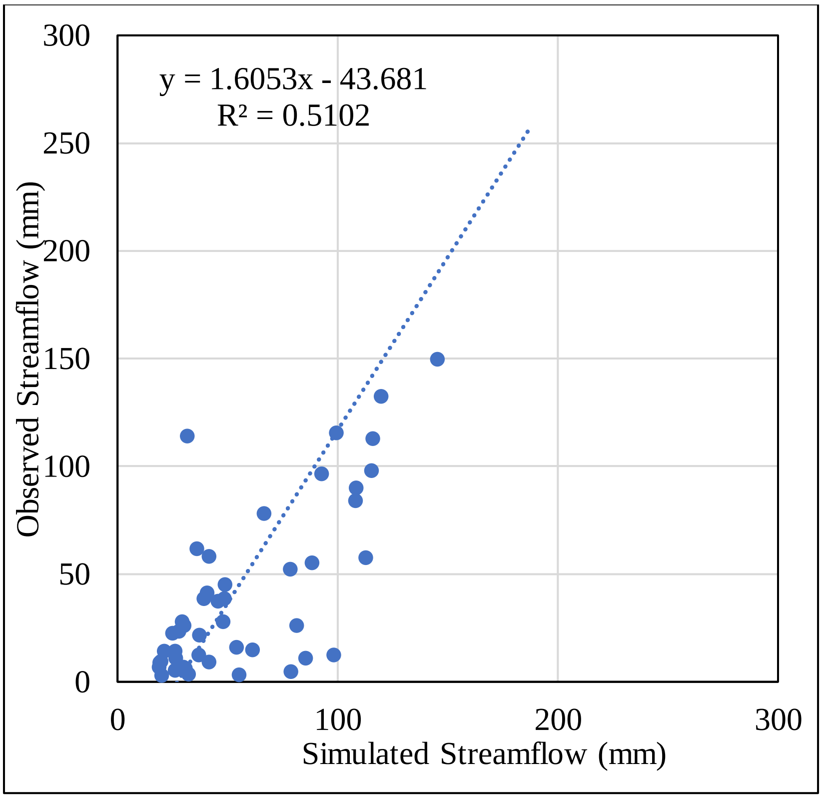


Figure 5-7: Simulated flow Vs Observed flow in Thaldena for validation

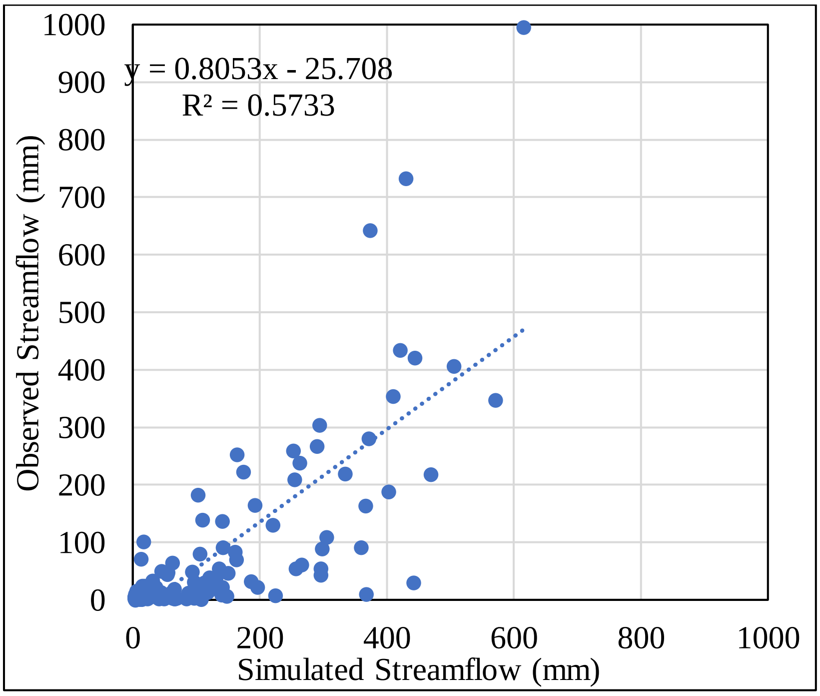


Figure 5-8: Simulated flow Vs Observed flow in Padiyatalawa for calibration

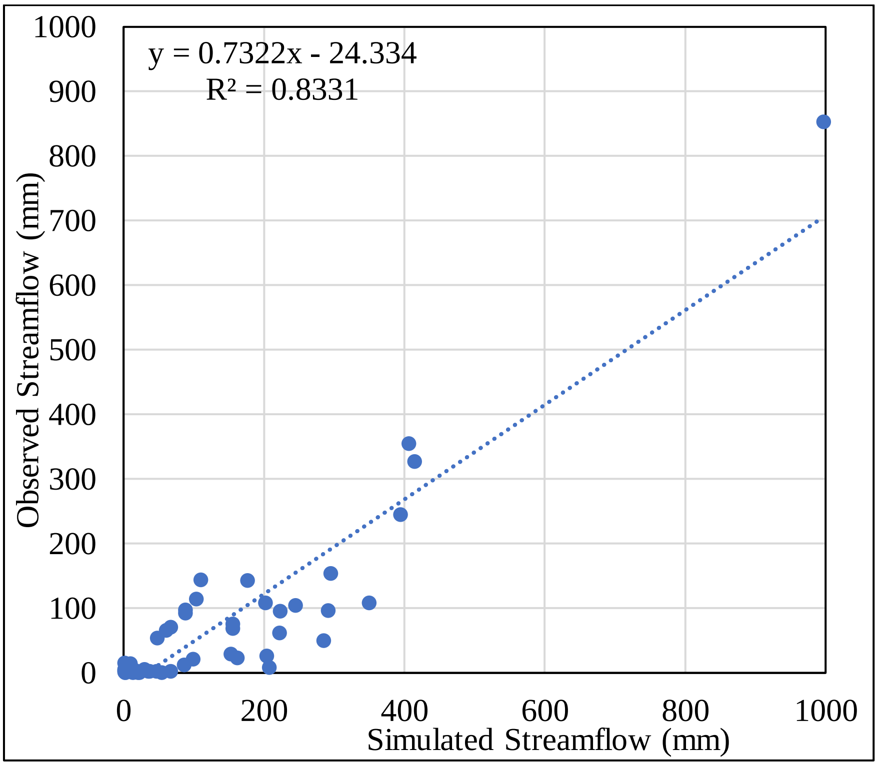
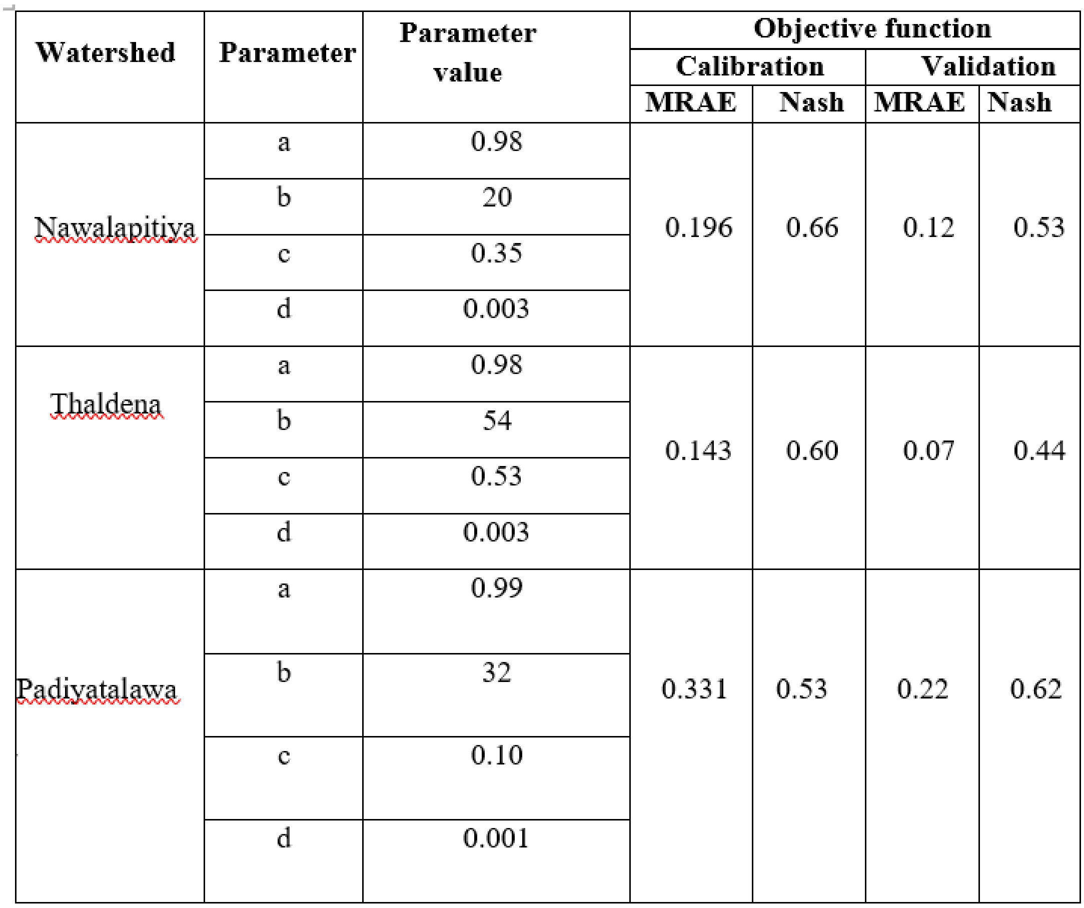


Figure 5-9: Simulated flow Vs Observed flow in Padiyatalawa for validation

Even in the flow duration curve analysis, the same scenario was clearly observed which have been shown in Figure 4-30, Figure 4-32, Figure 4-34 and Figure 4-36. Specially these underestimations in high flow regimes and over estimations in low regimes are dramatically observed in validation periods in both watersheds.

The overall performance of the model was measured by using the MRAE, which is an objective function especially suitable for low and moderate flows. But for the comparison purposes, Nash Sutcliff Efficiency value was used which is especially suitable to evaluate high flows. As a consensus, MRAE values close to zero and Nash Sutcliff Efficiency values close to one are considered as good simulations.

Table 5-1: Parameters and objective function values



Watershed	Parameter	Parameter value	Objective function			
			Calibration		Validation	
			MRAE	Nash	MRAE	Nash
Nawalapitiya	a	0.98	0.196	0.66	0.12	0.53
	b	20				
	c	0.35				
	d	0.003				
Thaldena	a	0.98	0.143	0.60	0.07	0.44
	b	54				
	c	0.53				
	d	0.003				
Padiyatalawa	a	0.99	0.331	0.53	0.22	0.62
	b	32				
	c	0.10				
	d	0.001				

It shows the optimized MRAE and Nash values for calibration and validations in corresponding watersheds. The MRAE in calibration and validation of ‘abcd’ model for Thaldena watershed are 0.143 and 0.07which can be considered as an excellent performance. But the corresponding MRAE values for Nawalapitya watershed are 0.196 and 0.12 which shows relatively better performance than Thaldena watershed but also can be considered as a satisfactory referring to previous Modeling work in literature. Padiyatalawa watershed shows satisfactory MRAE values ie .331 and .22 for calibration and validation respectively. The Nash Sutcliffe efficiency values in calibration and validation of ‘abcd’ model for Thaldena watershed are 0.60 and 0.44, which can be considered as a satisfactory performance while the corresponding values for Nawalapaitiya watershed are 0.66 and 0.53, which also can be considered as satisfactory.Padiyatalawa watershed also shows satisfactory result for NSE ie .53 and .62. In overall comparison of all watersheds, it can be concluded that ‘abcd’ model for

Nawalapitiya watershed shows better performance than other two catchment in dry and intermediate zones.

The model performance was checked separating the high, medium and low flows in the data set separately for calibration and validation. The high, medium and low flow regimes were identified by using the sudden deflection points in the flow duration curves and the results have been summarized in Table 5-7. The probability exceedance values of regime changing points were not same for calibration and validation data sets even though it is expected from a parent data set, but was in a satisfactory range.

In the model application for separate regimes, satisfactory performance was shown with relatively low MRAE values for high flows and medium flows while showing relatively low performance for low flows specially in validation periods as shown in Table 4-8. This observation, specially related to intermediate and low flows are well illustrated with visual comparisons, flow duration curve analysis and the plot between observed verses simulated flows.

Therefore, by considering the above facts, it can be concluded that the overall performance of the “abcd” model is satisfactory for the considered watersheds

5.4 Challenges faced in Modeling

Whenever hydrologic data is temporally aggregated (lumped), valuable information is lost regarding the timing of precipitation and evapotranspiration. This is most pronounced between the daily and monthly time scales, but dramatically increases at the annual scale, where seasonality is no longer evident. For example, at the monthly time scale (using monthly data as input to a hydrologic model), prediction errors can occur when a significant fraction of the daily precipitation occurs late in the month (Thomas, 1981). To represent the loss of this significant fluctuation at bigger time scales, it is normal to speak to the partition of accessible water to evapotranspiration preceding or simultaneously with surface runoff. At shorter time scales, in any case, it is increasingly proper to isolate the precipitation between the soil and surface runoff first. At that point, soil water portion can be part among evapotranspiration and baseflow requests. while evapotranspiration, in a sense, still completes surface runoff by bringing down the water level in the soil dampness for the next time span. In a recurrence investigation of streamflow, low frequency variability (i.e. low streamflow variation or "slow flow") is more probable to be associated with baseflow while high frequency variability ("quick flow") is mainly the outcome of direct precipitation (i.e. sum of interflow and surface runoff) (Eckhardt, 2005). However, interflow, which is sub-surface flow through the unsaturated zone, has a quick element and slow element, and consequently quick interflow is interpreted as direct runoff while slow interflow is lumped with baseflow (Xu & Singh, 1998). This shows a test in demonstrating overflow at bigger than-every day time scales on the grounds that as time scales increment, the inconstancy in streamflow, precipitation, and evapotranspiration lessens, which will in general decrease the measure of reenacted prompt runoff. A model created on a one-time scale to simulate baseflow and direct runoff procedures will need to be able to simulate a greater part of baseflow happening on bigger time scales.

Usually routing is conducted to solve with this issue. Each routing method, however, often needs an extra parameter. It should be observed that routing is also essential to delay the reaction of runoff in big catchments, although routing procedures typically account for this impact along with the impact of temporal lumping on input information simultaneously. Another problem with climate change hydrological modeling is how the complete spectrum of climate change situations can be captured. There are a number of distinct ways of constructing climate change scenarios, including techniques using climate analogues, synthetic scenarios, and scenarios of the general circulation model (GCM) (Carter et al., 1995).

5.5 Difficulties with data

The issues identified with information can be isolated into two classes as information accessibility and the information precision. In determination of precipitation stations and dissipation stations, the underlying concern was to choose the stations inside the catchment which could clearly mirror the careful precipitation conditions. In any case, lamentably, information was not accessible persistently for number of years for a portion of the stations which falls inside the watersheds. Certain precipitation stations had begun as of late and a portion of the stations were not working. In any case, for the Thaldena watershed, every one of the stations were found inside the catchment while Nawalapitiya and Padiyatalawa is having just one station which is Ekiriyankumbura inside the catchment. The various three stations are situated outside of the catchment. Notwithstanding that, there were missing estimations of precipitation information for specific stations which can influence the model execution and the missing information rate was kept beneath 10% for each station to lessen introductory information mutilation. The precipitation missing qualities were filled by utilizing the linear regression technique which is considered as one of the acknowledged strategies in hydrological contemplates while filling the missing estimations of stream and skillet vanishing information by utilizing month to month mean estimations of 30 years information. The chose evaporation station for the watersheds area Kotmalle, Padiyatalawa and Girandurukotte and which is situated outside the catchments. Despite the fact that stations are arranged outside of Catchment ,it was utilized thinking about the information accessibility, information cost, palatable water balance and other comparable climatic conditions. In any case, still there may be a blunder because of this far off nearness yet it is dared to minorly affect the model because of the low commitment of evaporation to the water balance.

Considering these limitations on data availability, data accuracy, time and cost, 15 years data (2004-2018) was used for all sub-catchments. But still this data period is enough for a monthly model, according to Martinez and Gupta (2010).

5.6 Initial conditions for the model

Warm up period for the model was initital as it needs to set initial values for the soil moisture (S_t-1) and ground water storage (G_t-1) for getting the parameter values of abcd model which was little difficult.Initial values for soil moisture and ground water were assumed as like other modelers while keeping the mean values in literature for a,b,c,d parameters. After running the model for several times the soil moisture and ground water values comes to quasi steady state.

5.7 Limitations of “abcd” model

One of the real necessities in the utilization of "abcd" model isn't to have any huge water storages and stream administrative structures in the watershed which will influence the reaction of the stream to the precipitation. For the chosen watersheds, it was seen that there are no such huge water storages and this reality was confirmed in the visual information check by watching a fitting reaction of stream to precipitation without having an impressive slack aside from a couple of months which had rained in the most recent day of the month. Notwithstanding that, as indicated by Martinez and Gupta (2010), model does not perform well with its regular model structure for the catchments which has snow falling and the model structure should be adjusted likewise. The reason might be the slack that is made in the runoff of snow. This was not an issue for the chose watersheds, since snow isn't a method of precipitation in Sri Lanka.

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusions

1. The "abcd" monthly water balance model can be used successfully to represent the catchment hydrology and to investigate the water resources of the three climatic zone watersheds, Nawalapitya (Wet),Thaldena (Intermediate) and Padiyatalawa (Dry zone) in Mahaweli Basin.
2. The optimized average *a*, *b*, *c*, *d* parameter values considering Nawalapitiya, Thaldena and Padiyatalawa watersheds are 0.980, 45, 0.008, 0.01 with corresponding average MRAE and Nash–Sutcliffe efficiency values of 0.24, 0.69 ,0.33, 0.57 and .23, 0.56 in the calibration and validation, respectively.
3. Nawalapitiya watershed shows better performance than Thaldena and Padiyatalawa sub-catchments in calibration and validation, in the presence of MRAE and NSE as objective functions.
4. The "abcd" model shows better performance for high and intermediate flows than low flows when the Pearson correlation is used as the objective function.
5. The parameter "*d*" and "*b*" are the most sensitive parameters.
6. Streamflow elasticity of each catchment was identified as 1 means 10% change in rainfall will introduce 10% variation in streamflow.
7. The dry zone of the country which was earlier observed by previous researchers to be experiencing declining rainfall trend is now witnessing a more favourable conditions for the selected basins.

6.2 Recommendations

1. The “abcd” hydrologic model can be recommended to use for streamflow simulations and water resources investigations in monthly temporal resolution for the watersheds which are having similar characteristics with parameter values of a (0.961-0.998), b (0-150), c (0.001-0.7), d (0.001-0.1) under climatic change conditions.
2. It is recommended to apply the “abcd” model for several additional climatic zone sub-catchments and confirm the behavior of *a*, *b*, *c* and *d* parameters.
3. It is recommended to apply the “abcd” model for several micro agro ecological watersheds and confirm the behavior of *a*, *b*, *c* and *d* parameters under climate change conditions.
4. The model is recommended to apply only for the watersheds which are free from large water bodies (and snow).
5. It is recommended to do verifications for soil moisture storage and groundwater storage which are given as out puts from the model, by conducting appropriate field tests.
6. It is also recommended to have more data for calibration and verification for more accuracy of model predictions of results.
7. Policy makers can take advantage of this increasing rainfall trend in dry zone part of the basin by creating more storage.
8. Most appropriate adaptation measures needed to be identified based on the key decisive factors. The increased rainfall will have serious effects on infrastructure as well as urban settings which are built by filling the marshy lands and paddy fields.
9. The findings of the research will be useful for better water resources management targeting impending climate change impacts in the basin.

REFERENCES

Achleitner, S., Schöber, J., Rinderer, M., Leonhardt, G., Schöberl, F., Kirnbauer, R., & Schönlaub, H. (2012). Analyzing the operational performance of the hydrological models in an alpine flood forecasting system. *Journal of Hydrology*, *412–413*(January), 90–100. https://doi.org/10.1016/j.jhydrol.2011.07.047.

Ajami, N. K., Hornberger, G. M., & Sunding, D. L. (2008). Sustainable water resource management under hydrological uncertainty. *Water Resources Research*, *44*(11), 1–10. https://doi.org/10.1029/2007WR006736.

Anthony G, B. (1992). *Correspondence among the Correlation, RMSE, and Heidke Forcast Verification Measures; Refinement of the Heidke Score*.

Booij, M. J., Cluckie, I. D., & Babovic, V. (2009). *Identification of an appropriate low flow forecast model for the Meuse River Identification of an appropriate low flow forecast model for the Meuse River*. (September). https://doi.org/10.13140/RG.2.1.3163.6242.

Boyle, D. P., Gupta, H. V., & Sorooshian, S. (2011). *Multicriteria calibration of hydrologic models*. (May 2015), 185–196. https://doi.org/10.1029/ws006p0185.

Brigode, P., Oudin, L., & Perrin, C. (2013). Hydrological model parameter instability: A source of additional uncertainty in estimating the hydrological impacts of climate change? *Journal of Hydrology*, *476*, 410–425. https://doi.org/10.1016/j.jhydrol.2012.11.012.

Brirhet, H., & Benaabidate, L. (2016). Comparison Of Two Hydrological Models (Lumped And Distributed) Over A Pilot Area Of The Issen Watershed In The Souss Basin, Morocco. *European Scientific Journal, ESJ*, *12*(18), 347. https://doi.org/10.19044/esj.2016.v12n18p347.

Caldera, H. P. G. M., Piyathisse, V. R. P. C., & Nandalal, K. D. W. (2016). A Comparison of Methods of Estimating Missing Daily Rainfall Data. *Engineer: Journal of the Institution of Engineers, Sri Lanka*, *49*(4), 1. https://doi.org/10.4038/engineer.v49i4.7232.

Carpenter, T. M., & Georgakakos, K. P. (2006). Intercomparison of lumped versus distributed hydrologic model ensemble simulations on operational forecast scales. *Journal of Hydrology*, *329*(1–2), 174–185. https://doi.org/10.1016/j.jhydrol.2006.02.013.

Chu, X., & Steinman, A. (2009). Event and Continuous Hydrologic Modeling with HEC-HMS. *Journal of Irrigation and Drainage Engineering*, *135*(1), 119–124. https://doi.org/10.1061/(asce)0733-9437(2009)135:1(119).

Collet, L., Ruelland, D., Estupina, V. B., Dezetter, A., & Servat, E. (2015). Water supply sustainability and adaptation strategies under anthropogenic and climatic changes of a meso-scale Mediterranean catchment. *Science of the Total Environment*, *536*(January), 589–602. https://doi.org/10.1016/j.scitotenv.2015.07.093.

Cosgrove, W. J., & Loucks, D. P. (2007). Water management: Current and future challenges and research directions. *Journal of the American Water Resources Association*, *5*(3), 2–2. https://doi.org/10.1111/j.1752-1688.1969.tb04897.

Daggupati, P., Pai, N., Ale, S., Zeckoski, R. W., Jeong, J., Parajuli, P. B., … Youssef, M. A. (2015). A Recommended Calibration and Validation Strategy for Hydrologic and Water Quality Models. *Transactions of the ASABE*, *58*(6), 1705–1719. https://doi.org/10.13031/trans.58.10712.

Desai, P. V, & Ukarande, S. K. (2016). *Watershed Modeling- A Case Study*. 61–64.

Devia, G. K., Ganasri, B. P., & Dwarakish, G. S. (2015). A Review on Hydrological Models. *Aquatic Procedia*, *4*(Icwrcoe), 1001–1007. https://doi.org/10.1016/j.aqpro.2015.02.126.

Diskin, M. H., & Simon, E. (1977). A procedure for the selection of objective functions for hydrologic simulation models. *Journal of Hydrology*, *34*(1–2), 129–149. https://doi.org/10.1016/0022-1694(77)90066-X.

Donald E, W., & P. Golder, A. (1997). *GUIDELINES FOR TAILINGS BASIN WATER BALANCE MODELING AND WATBAL MANUAL*. (April).

Ekenberg, M. (2016). *Using a lumped conceptual hydrological model for five different catchments in Sweden*.

EPA. (2007). An Approach for Using Load Duration Curves in the Development of

TMDLs. *U.S. Environmental Protection Agency*, 68.

Eruola et al, A. o. (2015). Determination of areal rainfall using estimation methods in a tropical wet and dry climate. *Merit Research Journal of Environmental Science and Toxicology*, *3*(7), 79–82.

Ezekiel, P., & Nyanchaga, N. (2017). Effectiveness of the Implementation of the Sub-Catchment Management Plan- A case study of Awach Kano Water Resources Users Association. *International Journal of Innovative Studies in Sciences and Engineering Technology*, *4863*(June), 9–15.

Fabre, J., Ruelland, D., Dezetter, A., & Grouillet, B. (2015). Accounting for hydro-climatic and water use variability in the assessment of past and future water balance at the basin scale. *IAHS-AISH Proceedings and Reports*, *371*, 43–48. https://doi.org/10.5194/piahs-371-43-2015.

Frone, D.-F., & Frone, S. (2015). The Importance of Water Security for Sustainable Development in the Romanian Agri-Food Sector. *Agriculture and Agricultural Science Procedia*, *6*, 674–681. https://doi.org/10.1016/j.aaspro.2015.08.120.

Gitau, M. W., & Chaubey, I. (2010a). Regionalization of SWAT model parameters for use in ungauged watersheds. *Water (Switzerland)*, *2*(4), 849–871. https://doi.org/10.3390/w2040849.

Gitau, M. W., & Chaubey, I. (2010b). Regionalization of SWAT model parameters for use in ungauged watersheds. *Water (Switzerland)*, *2*(4), 849–871. https://doi.org/10.3390/w2040849.

Green, I. R. A., & Stephenson, D. (1986). Criteria for comparison of single event models. *Hydrological Sciences Journal*, *31*(3), 395–411. https://doi.org/10.1080/02626668609491056.

Gupta, K., Sharma, G., Jethoo, A., Tyagi, J., & Gupta, N. (2015). A critical review of hydrological models. *II Roorkee, Water Resources and River Engineering*, *1*(December), 17–19.

Heuvelmans, G., Muys, B., & Feyen, J. (2004). Analysis of the spatial variation in the parameters of the SWAT model with application in Flanders , Northern.

Hydrology and Earth System Sciences Dis- Cussions, European Geosciences Union, 2004, 8 (5), Pp.931-939.

Hoad, K. (2008). *AUTOMATING WARM-UP LENGTH ESTIMATION*. (2004), 532–540.

Hong, N., HAMA, T., KITAJIMA, T., AQILI, S. W., HUANG, X., WEI, Q., & KAWAGOSHI, Y. (2015). Simulation of Groundwater Levels Using Tank Model with Consideration of Mixed Hydrological Structure in Kumamoto City. *Journal of Water and Environment Technology*, *13*(4), 313–324. https://doi.org/10.2965/jwet.2015.313.

Hwang, S. H., Ham, D. H., & Kim, J. H. (2012). *A new measure for assessing the efficiency of hydrological data-driven forecasting models A new measure for assessing the efficiency of hydrological data-driven*. *6667.* https://doi.org/10.1080/02626667.2012.710335.

Jajarmizadeh, M., Harun, S., & Salarpour, M. (2012). A review on Theoretical Consideration and Types of Models in Hydrology. *Journal of Environmental Science and Technology*, Vol. 5, pp. 249–261.

Jan , Chris , Rajbir , Kurt , Muluken, B. (2017). *An Overview of Rainfall-Runoff Model Types An Overview of Rainfall-Runoff Model Types*. (September), 0–29.

Jayasinghe, S. N., & Rajapakse, R. L. H. L. (2017). *Hydrological Modeling Approach for Flood and Water Pollution Control in an Ungauged Catchment - A Case Study in Erewwala Catchment in Bolgoda River Basin , Sri Lanka*. (Grade II), 111–116.

Jeffrey, M. (2016). Scale Implications of Integrated Water Resource Management Politics: Lessons from New Zealand. *Environmental Policy and Governance, 26*(4), 306–319. https://doi.org/10.1002/eet.1719.

José, J., Moreno, M., Pol, A. P., Abad, A. S., Blasco, B. C., José, J., … Blasco, B. C. (2013). *Using the R-MAPE index as a resistant measure of forecast accuracy*. *25*(4), 500–506. https://doi.org/10.7334/psicothema2013.23.

Kim, K. B., Kwon, H. H., & Han, D. (2018). Exploration of warm-up period in conceptual hydrological Modeling. *Journal of Hydrology*, *556*(November 2017), 194–210. https://doi.org/10.1016/j.jhydrol.2017.11.015.

Knapp, H. V., Durgunoglu, A., & Ortel, T. W. (1991). A Review of Rainfall-Runoff Modeling for Stormwater Management. *U.S. Geological Survey, Illinois District*, (October), 96.

Krause, P., & Boyle, D. P. (2005). *Advances in Geosciences Comparison of different efficiency criteria for hydrological model assessment*. 89–97.

Kumarasamy, K., & Belmont, P. (2018). Calibration parameter selection and watershed hydrology model evaluation in time and frequency domains. *Water (Switzerland)*, *10*(6). https://doi.org/10.3390/w10060710.

Kuok, K. K., Harun, S., & Chiu, P. (2011). *Investigation Best Number of Tanks for Hydrological Tank Model for Rural Catchment in Humid Region*. (1957), 1–11.

Li, Ji, Chen, Y., Wang, H., Qin, J., Li, J., & Chiao, S. (2017). *Extending flood forecasting lead time in a large watershed by coupling WRF QPF with a distributed hydrological model*. 1279–1294. https://doi.org/10.5194/hess-21-1279-2017.

Li, Jin. (2017). *Assessing the accuracy of predictive models for numerical data : Not r nor r 2 , why not ? Then what ?* 1–16.

Littlewood, I. G., Down, K., Parker, J. R., & Post, D. A. (2003). *Catchment-scale rainfall - streamflow Modeling (PC version) Version 1.0 April 1997. 1997*(September).

Loukas, A., & Vasiliades, L. (2014). Streamflow simulation methods for ungauged and poorly gauged watersheds. *Natural Hazards and Earth System Sciences*, *14*(7), 1641–1661. https://doi.org/10.5194/nhess-14-1641-2014.

Mahajan, P. S., & Ingalls, R. G. (2005). *Evaluation of Methods Used to Detect Warm-Up Period in Steady State Simulation*. 651–659. https://doi.org/10.1109/wsc.2004.1371374.

Mango, L. M., Melesse, A. M., McClain, M. E., Gann, D., & Setegn, S. G. (2011). Land use and climate change impacts on the hydrology of the upper Mara River Basin, Kenya: Results of a modeling study to support better resource management. *Hydrology and Earth System Sciences*, *15*(7), 2245–2258. https://doi.org/10.5194/hess-15-2245-2011.

Martinec, J., Rango, A., & Roberts, R. (2008). *Snowmelt Runoff Model (SRM) User ' s Manual*.

Merritt, W. S., Croke, B. F. W., Jakeman, A. J., Letcher, R. A., & Perez, P. (2004). A Biophysical Toolbox for assessment and management of land and water resources in rural catchments in Northern Thailand. *Ecological Modeling*, *171*(3), 279–300. https://doi.org/10.1016/j.ecolmodel.2003.08.010.

Moradkhani, H., & Sorooshian, S. (2008). General Review of Rainfall-Runoff Modeling: Model Calibration, Data Assimilation, and Uncertainty Analysis. *Hydrological Modeling and the Water Cycle*, 1–24. https://doi.org/10.1007/978-3-540-77843-1_1.

Moriasi, D. N., Arnold, J. G., Liew, M. W. Van, Bingner, R. L., Harmel, R. D., & Veith, T. L. (2007). *M e g s q a w s*. *50*(3), 885–900.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., & Veith, T. L. (2008). Conduction between left superior pulmonary vein and left atria and atria fibrillation under cervical vagal trunk stimulation. *Colombia Medica*, *39*(3), 227–234. https://doi.org/10.1234/590.

Mwakalila, S. (2003). *Estimation of stream flows of ungauged catchments for river basin management*. *28*, 935–942. https://doi.org/10.1016/j.pce.2003.08.039.

Myttenaere, A. De, & Golden, B. (2017). *Mean Absolute Percentage Error for Regression Models*.

Nallaperuma, S., & Wijesekera, T. (2016). *Wijesekera, N.T.S. and Rajapakse, R.L.H.L., Mathematical Modeling of Watershed Wetland Crossings for Flood Mitigation and Groundwater Enhancement - Case of the Attnagalu Oya River...* (February).

Nandagiri, L. (2007). Calibrating hydrological models in unguaged basins: possible use of areal evapotranspiration instead of streamflows. *Predictions In Ungauged Basins: PUB Kick-off ...*, (November 2002), 20–22.

Nash, J. E., & Sutcliffe, J. V. (1970). ’ L ~ E Empirical or Analytical Approaeb. *Journal of Hydrology*, *10*(3), 282–290. https://doi.org/10.1016/0022-1694(70)90255-6.

Nicolle, P., Pushpalatha, R., Perrin, C., François, D., Thiéry, D., Mathevet, T., … Lorraine, D. (2014). *Benchmarking hydrological models for low-flow simulation and forecasting on French catchments*. 2829–2857. https://doi.org/10.5194/hess-18-2829-2014.

Ou, X., Gharabaghi, B., McBean, E., & Doherty, C. (2017). Investigation of the Tank Model for Urban Storm Water Management. *Https://Doi.Org/10.14796/JWMM.C421*, (2001), 1–5. https://doi.org/10.14796/JWMM.C421.

Oudin, L., Andréassian, V., Perrin, C., Michel, C., & Le Moine, N. (2008). Spatial proximity, physical similarity, regression and ungaged catchments: A comparison of regionalization approaches based on 913 French catchments. *Water Resources Research*, *44*(3), 1–15. https://doi.org/10.1029/2007WR006240.

Patil, S. (2011a). Information transfer for hydrologic prediction in ungauged river basins. *Tese*, (December).

Patil, S. (2011b). *INFORMATION TRANSFER FOR HYDROLOGIC PREDICTION IN UNGAUGED RIVER BASINS INFORMATION TRANSFER FOR HYDROLOGIC PREDICTION IN UNGAUGED RIVER BASINS*. (December).

Patry, G. G., & Mario, M. A. (1983). *Journal of Hydrology, 66 (1983) 227--244. 66*.

Pechlivanidis, I., Meteorological, S., Jackson, B., & Mcintyre, N. (2018). Catchment scale hydrological Modeling: A review of model types, calibration approaches and uncertainty analysis methods in the context of recent developments in technology and applications. *Global NEST JournalGlobal NEST: The International Journal*, *13*(3), 193–214. https://doi.org/10.30955/gnj.000778.

Perrin, C., Michel, C., & Andreassian, V. (2001). Does a large number of parameters enhance model performance? Comparative assessment …. *Journal of Hydrology*, *242*(3–4), 275–301.

Phien, H. N., & Pradhan, P. S. S. (1983). the Tank Model in Rainfall-Runoff Modeling. *Water SA*, *9*(3), 93–102.

Phuong, H. T., Tien, N. X., Chikamori, H., & Okubo, K. (2018). A Hydrological Tank Model Assessing Historical Runoff Variation in the Hieu River Basin. *Asian Journal of Water, Environment and Pollution*, *15*(1), 75–86. https://doi.org/10.3233/AJW-180008.

Project, N. H. (2017). Hydrological Modeling – Current Status and Future Directions. *Environmental Earth Sciences*, *77*(July), 1–19. https://doi.org/10.1007/s12665-018-7317-6.

Risley et al, J. (2008). Estimating flow-duration and low-flow frequency statistics for unregulated streams in Oregon. *Usgs*, (June).

Searcy, J. K. (2005). Flow-Duration Curves. *Water Encyclopedia*. https://doi.org/10.1002/047147844x.sw321.

Seibert, J., & McDonnell, J. J. (2010). Impacts de l'occupation du sol sur les écoulements en rivière: Une approche de détection de changement par modélisation qui inclut les incertitudes sur les paramètres. *Hydrological Sciences Journal*, *55*(3), 316–332. https://doi.org/10.1080/02626661003683264.

Sellami, H., La Jeunesse, I., Benabdallah, S., Baghdadi, N., & Vanclooster, M. (2014). Uncertainty analysis in model parameters regionalization: A case study involving the SWAT model in Mediterranean catchments (Southern France). *Hydrology and Earth System Sciences*, *18*(6), 2393–2413. https://doi.org/10.5194/hess-18-2393-2014.

Servat, E., & Dezetter, A. (1991). Sélection de fonctions critères dans le cadre d%une modélisation pluie-débit en zone de savane soudanaise. *Hydrological Sciences Journal*, *36*(4), 307–330. https://doi.org/10.1080/02626669109492517

Setiawan, B. I. (2002). *Hydrological models for cidanau watershed*. (May 2013), 1–10.

Setiawan, B. I., Fukuda, T., & Nakano, Y. (2003). Developing Procedures for Optimization of Tank Model's Parameters. *Agricultural Engineering*, 1–13.

Shakti, P., Shrestha, N., & Gurung, P. (1970). Step wise Multi-criteria Performance Evaluation of Rainfall-Runoff Models using WETSPRO. *Journal of Hydrology and Meteorology*, *7*(1), 18–29. https://doi.org/10.3126/jhm.v7i1.5613.

Shalamu, A., Chunliang, C., Muattar, S., & James Phillip, K. (2012). Application of snowmelt runoff model (SRM) in mountainous watersheds: A review. *Water Science and Engineering*, *5*(April), 123–136. https://doi.org/10.3882/j.issn.1674-2370.2012.02.001.

Silva, R. P. De, Dayawansa, N. D. K., & Ratnasiri, M. D. (2007). A COMPARISON OF METHODS USED IN ESTIMATING MISSING RAINFALL DATA R. P. De Silva 1 , N.D.K. Dayawansa 1 and M. D. Ratnasiri 1. *University of Peradeniya*, (May), 101–108.

Singh, V. P., & Birsoy, Y. K. (1975). Comparison of the Methods of Estimating Mean Areal Rainfall. *Nord Hydrol*, *6*(4), 222–241. https://doi.org/10.2166/nh.1975.0015.

Singh, V. P., & Chowdhury, P. K. (1986). Comparing Some Methods of Estimating Mean Areal Rainfall. *JAWRA Journal of the American Water Resources Association*, *22*(2), 275–282. https://doi.org/10.1111/j.1752-1688.1986.tb01884.x.

Sivakumar, B., & Berndtsson, R. (2010). Model calibration in watershed hydrology. In *Advances in Data-Based Approaches for Hydrologic Modeling and Forecasting*. https://doi.org/10.1142/9789814307987.

Sivapalan, M., Takeuchi, K., Franks, S. W., Gupta, V. K., Karambiri, H., Lakshmi, V., … Zehe, E. (2003). IAHS Decade on Predictions in Ungauged Basins (PUB), 2003-2012: Shaping an exciting future for the hydrological sciences. *Hydrological Sciences Journal*, *48*(6), 857–880. https://doi.org/10.1623/hysj.48.6.857.51421.

Skøien, J. O., Blöschl, G., & Western, A. W. (2003). Characteristic space scales and timescales in hydrology. *Water Resources Research*, *39*(10). https://doi.org/10.1029/2002WR001736.

Smakhtin, V. U. (2001). Low flow hydrology: a review V.U. Smakhtin. *Journal of HydrologyJournal of Hydrology, 240,* 147–186. https://doi.org/10.1016/S0022-1694(00)00340-1.

Surya, R., Yanuar Purwanto, M. J., & Sapei, A. (2014). Tank Model to See The Effect of Land Use Changes on Runoff, Infiltration and Groundwater in Sub Watershed of Konaweha South East Sulawesi Indonesia. *Journal of Environment and Earth Science*, *4*(14).

TAKEUCHI, K., SCHERTZER, D., O'CONNELL, P. E., LIANG, X., KARAMBIRI, H., ZEHE, E., … OKI, T. (2005). IAHS Decade on Predictions in Ungauged Basins (PUB), 2003–2012: Shaping an exciting future for the hydrological sciences. *Hydrological Sciences Journal, 48*(6), 857–880. https://doi.org/10.1623/hysj.48.6.857.51421.

Tessema, S. M. (2011). Hydrological modeling as a tool for sustainable water resources management: a case study of the Awash River Basin. In *Trita-LWR. LIC NV - 2056.*

Thapa, G., & Wijesekera, N. T. S. (2017). *Computation and Optimization of Snyder's Synthetic Unit Hydrograph Parameters*. (January), 83–88. https://doi.org/10.31705/umcsawm.12.

Tofallis, C. (2017). *A better measure of relative prediction accuracy for model selection and model estimation*. (March 2015). https://doi.org/10.1057/jors.2014.124.

Van Liew, M. W., Arnold, J. G., & Bosch, D. D. (2005). Problems and potential of autocalibrating a hydrologic model. *Transactions of the American Society of Agricultural Engineers*, *48*(3), 1025–1040. https://doi.org/10.13031/2013.18514

Wagener, T., Boyle, D. P., Lees, M. J., Wheater, H. S., Gupta, H. V., & Sorooshian, S. (2001). A framework for development and application of hydrological models. *Hydrology and Earth System Sciences, 5*(1), 13–26. https://doi.org/10.5194/hess-5-13-2001.

Wan Ismail, W. N., & Wan Ibrahim, W. Z. W. Z. (2017). Estimation of rainfall and stream flow missing data for Terengganu, Malaysia by using interpolation technique methods. *Malaysian Journal of Fundamental and Applied Sciences, 13*(3), 213–217. https://doi.org/10.11113/mjfas.v13n3.578.

Wang, G., Mang, S., Cai, H., Liu, S., Zhang, Z., Wang, L., & Innes, J. L. (2016). Integrated watershed management : evolution , development and emerging trends. *Journal of Forestry Research*, *27*(5), 967–994. https://doi.org/10.1007/s11676-016-0293-3.

Wijesekera, N. T. . (2010). Water resources and climate change. *Encyclopedia of Earth Sciences Series*, (February), 731–733. https://doi.org/10.1007/978-94-017-8801-4_288.

Wijesekera, N. T. S. (2018). *Classification of Streamflow Observations for Water Management*. (February). https://doi.org/10.13140/RG.2.2.23605.58089.

Wijesekera, N. T. S., & Musiake, K. (1990). Streamflow Modeling of Sri Lankan Catchments (2) - Kalu River Catchment at Putupaula. *Seisan Kenkyu*, *42*(11), 645–648.

Winsemius, H. C., Schaefli, B., Montanari, A., & Savenije, H. H. G. (2009). On the calibration of hydrological models in ungauged basins: A framework for integrating hard and soft hydrological information. *Water Resources Research*, *45*(1). https://doi.org/10.1029/2009WR007706.

WMO. (1975). Intercomparison of conceptual models used in operational hydrological forecasting. *Operational Hydrology Report*, (7), 198.

Yates, D. (1994). WatBal - An integrated water balance model for climate impact assessment of river basin runoff. *Iahr.Tandfonline.Com*.

Yilmaz, K. K., Gupta, H. V., & Wagener, T. (2008). A process-based diagnostic approach to model evaluation: Application to the NWS distributed hydrologic model. *Water Resources Research*, *44*(9), 1–18. https://doi.org/10.1029/2007WR006716.

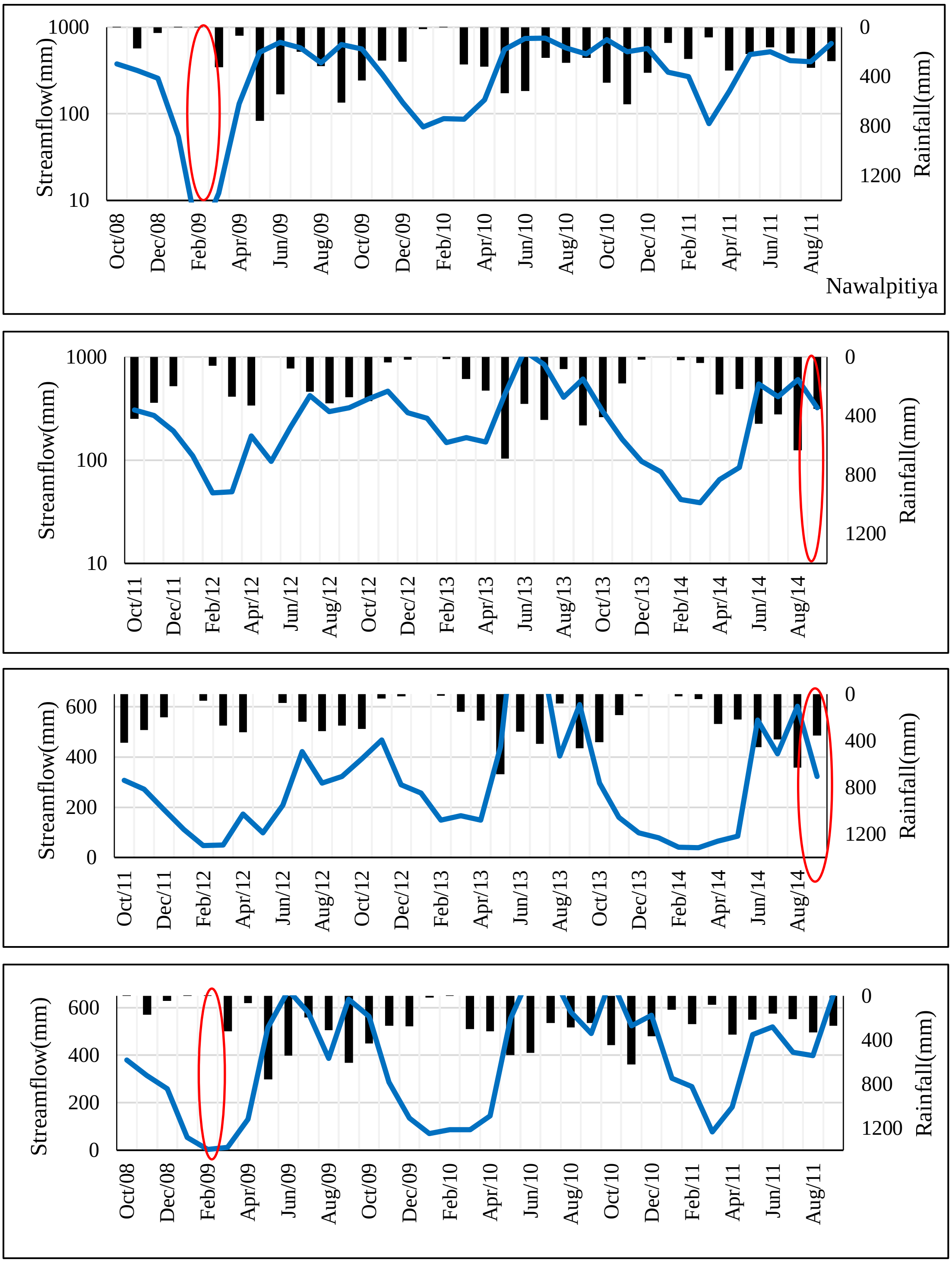
Zeiger, S., & Hubbart, J. (2017). An assessment of mean areal precipitation methods on simulated stream flow: A SWAT model performance assessment. *Water*

(Switzerland), *9*(7). https://doi.org/10.3390/w9070459.

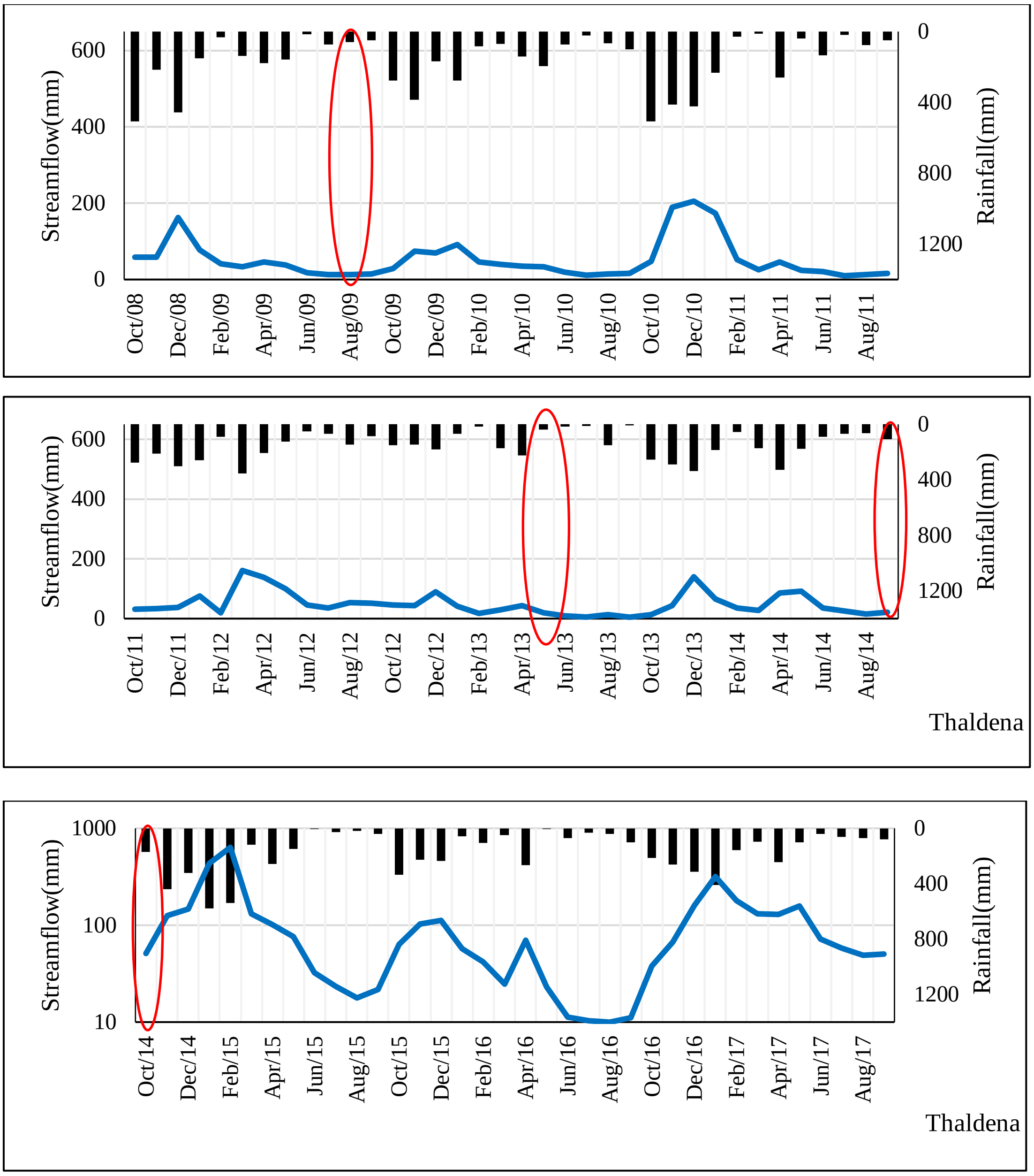
Zhang, Y. Q., & Chiew, F. H. S. (2009). Evaluation of regionalisation methods for predicting runoff in ungauged catchments in southeast Australia. *18th World IMACS Congress and MODSIM09 International Congress on Modeling and Simulation: Interfacing Modeling and Simulation with Mathematical and Computational Sciences, Proceedings*, (July), 3442–3448.

APPENDIX-A
DATA CHECKING

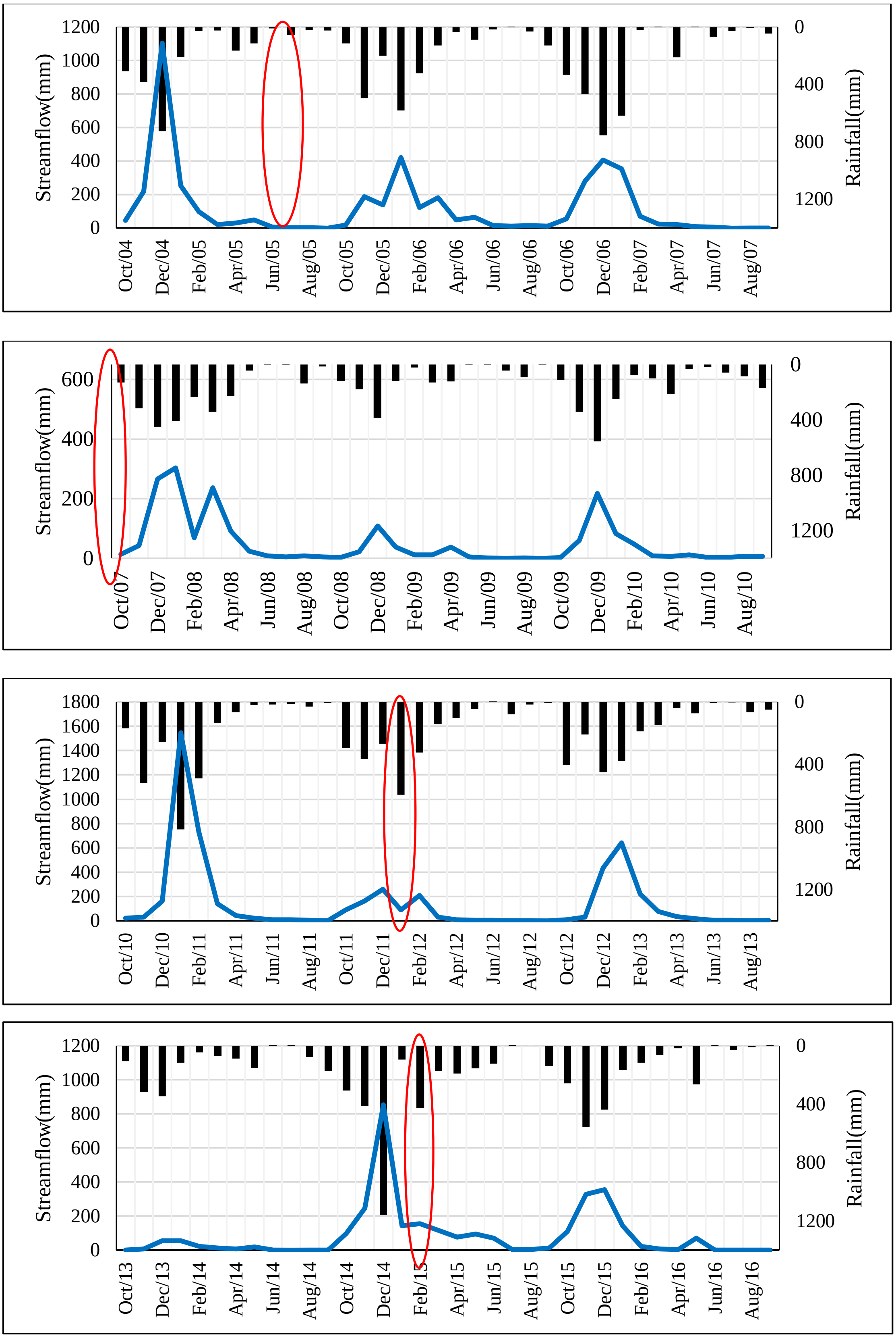
Figure A-1: Data checking graphs for Nawalapitiya catchment



FigureA-2: Data checking graphs for Thaldena catchment

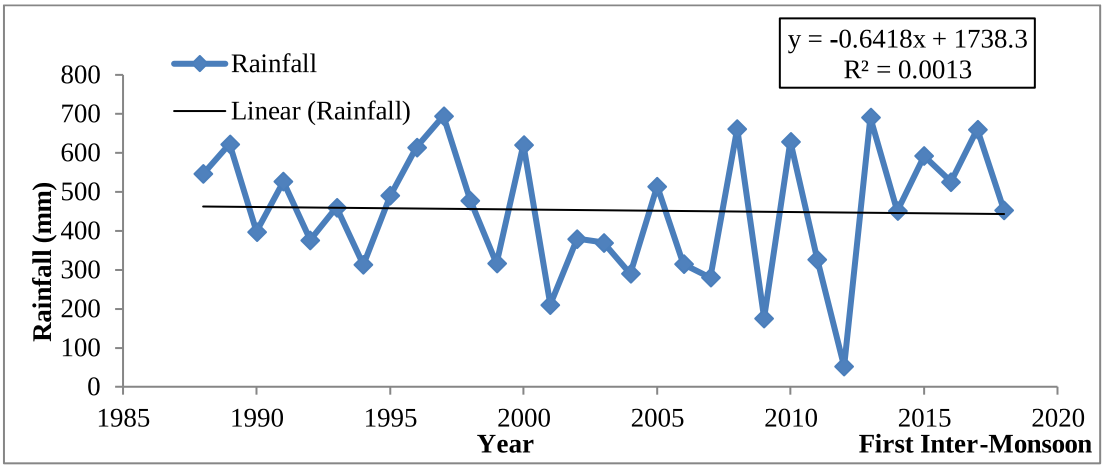


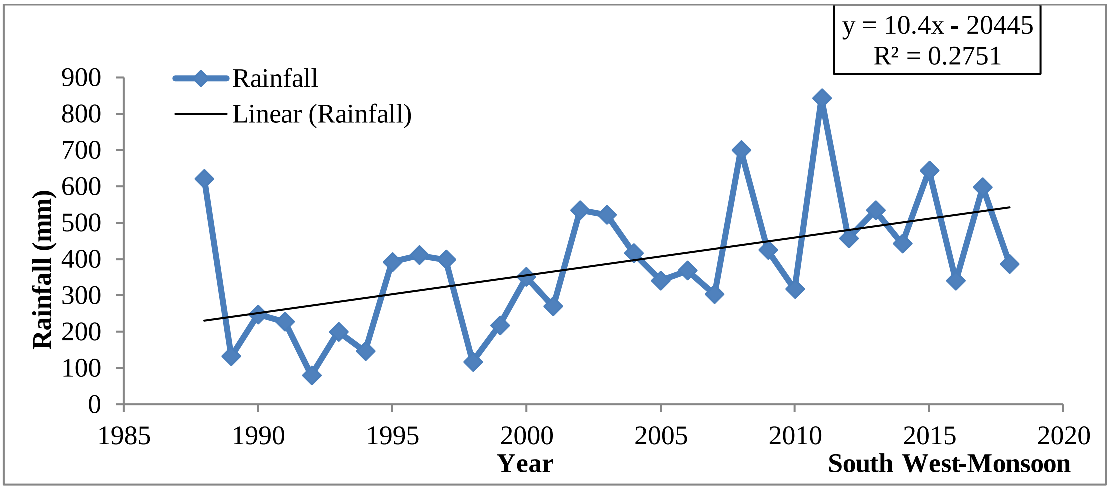
FigureA-3: Data checking graphs for Padiyatalawa catchment

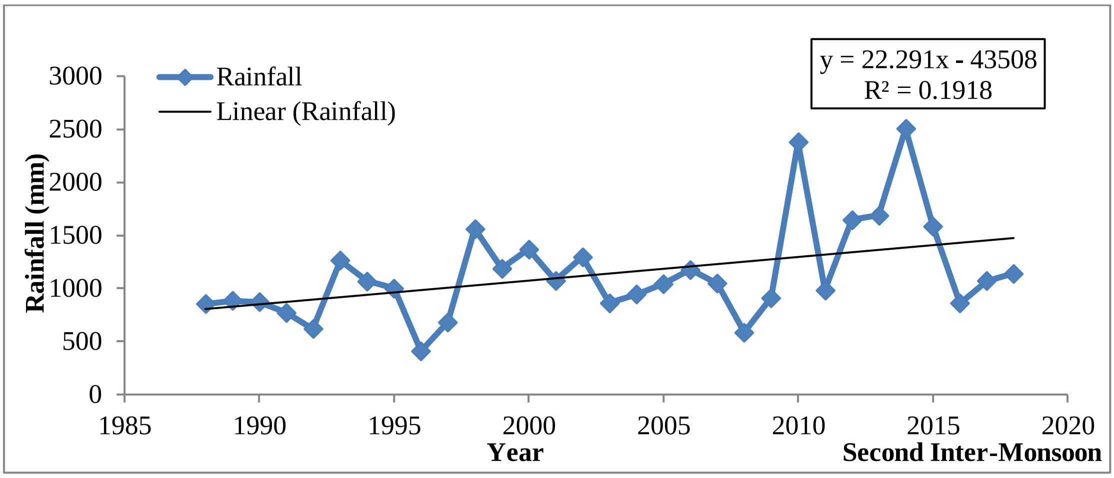


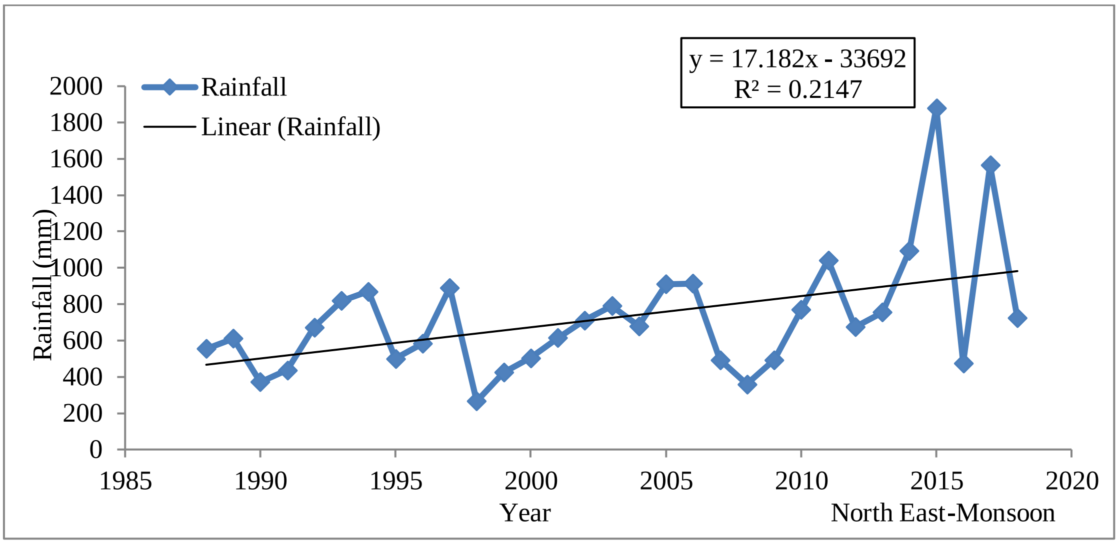
APPENDIX-B
TREND ANALYSIS RESULTS

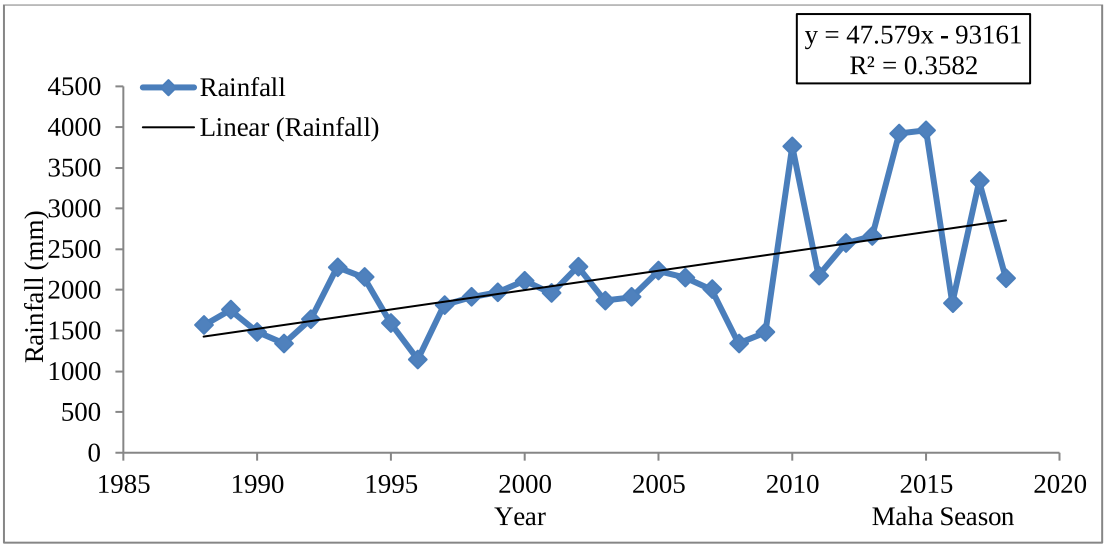
FigureB-1:Seasonal Trend of Kirklees Station (Intermediate Zone)

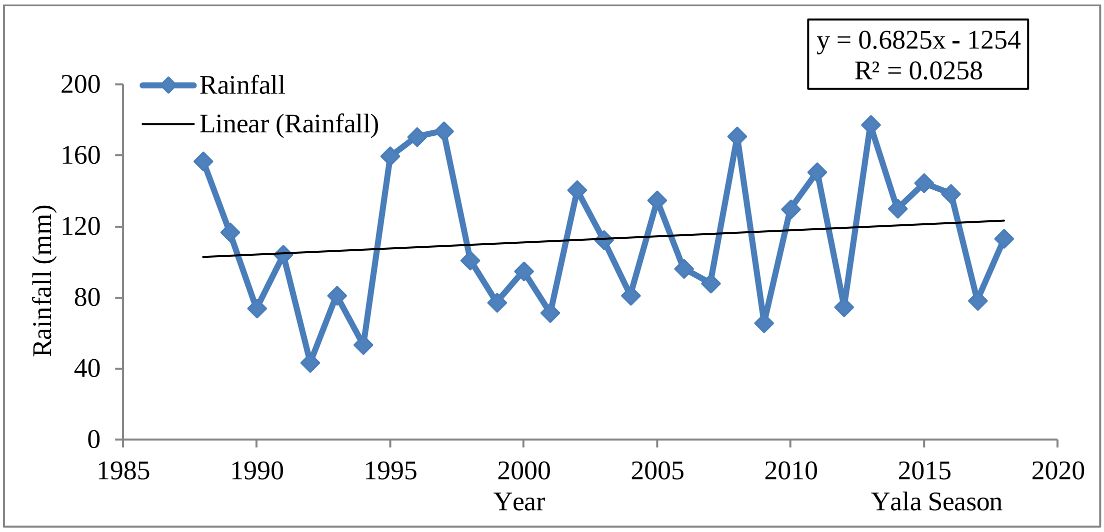




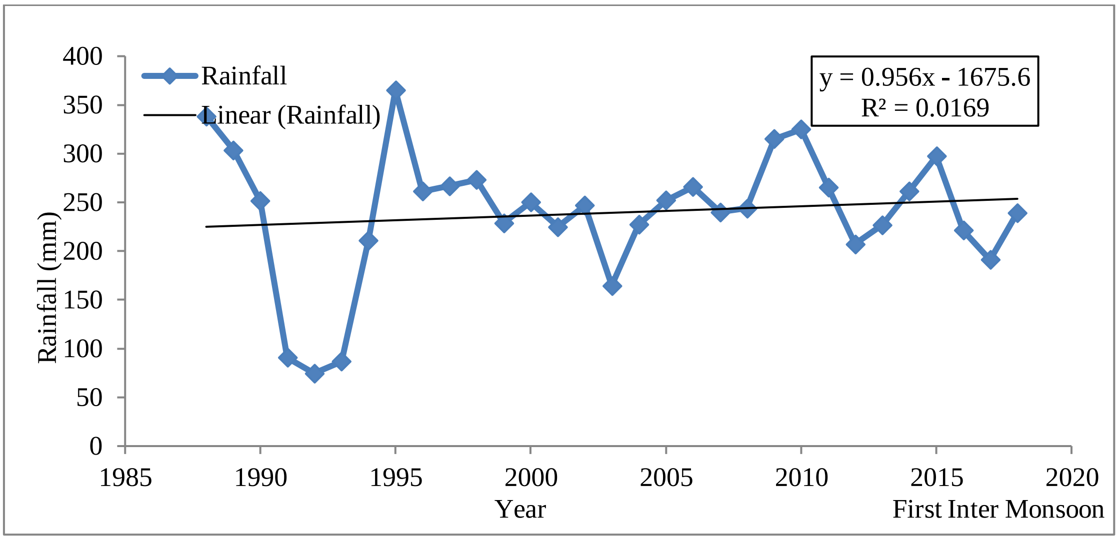

y = 22.291x - 43508
R² = 0.1918
Rainfall
Linear (Rainfall)
Rainfall (mm)
3000
2500
2000
1500
1000
500
0
1985
1990
1995
2000
2005
2010
2015
2020
Year
Second Inter-Monsoon

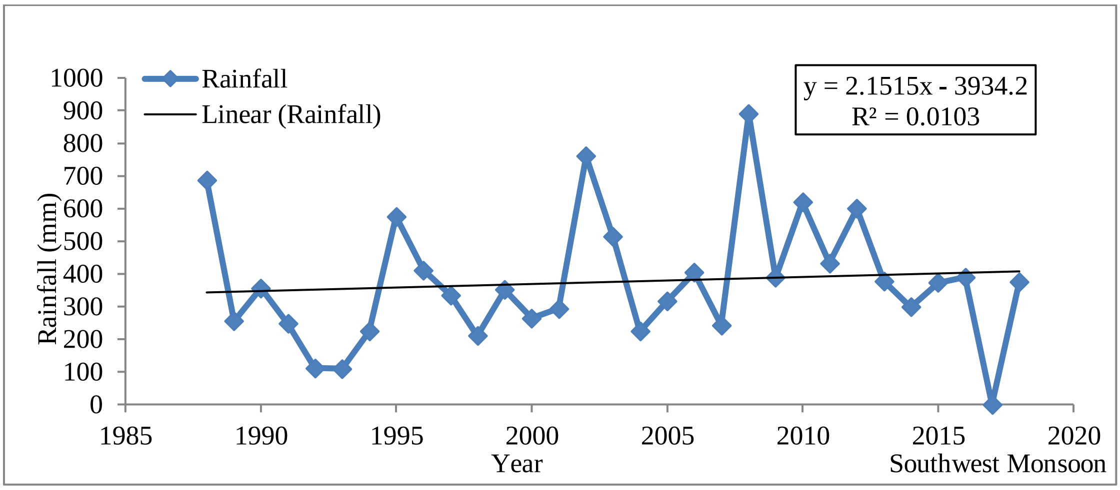

y = 17.182x - 33692
R² = 0.2147
Rainfall
Linear (Rainfall)
Rainfall (mm)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1985
1990
1995
2000
2005
2010
2015
2020
Year
North East-Monsoon

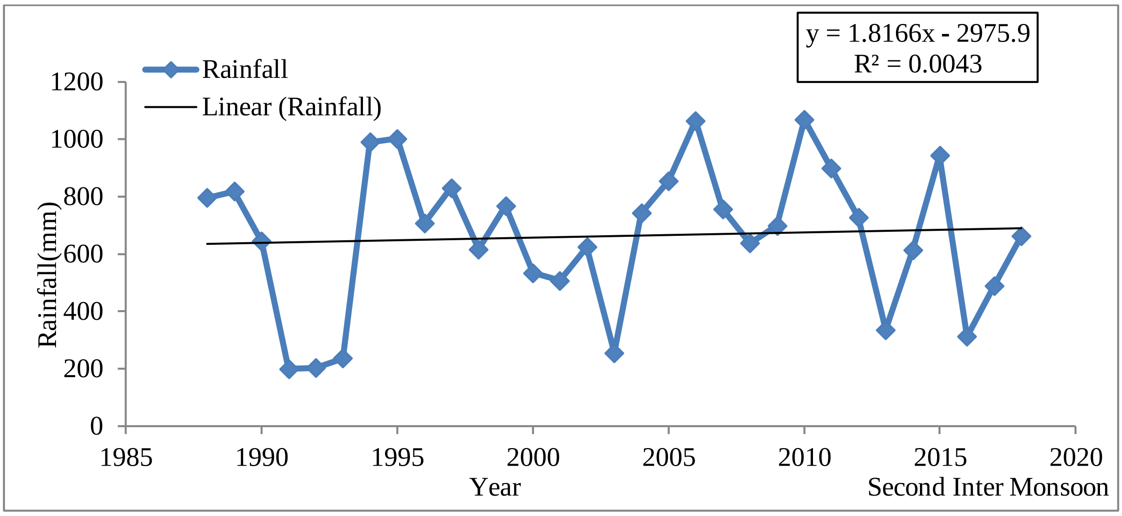

y = 47.579x - 93161
R² = 0.3582
Rainfall
Linear (Rainfall)
Rainfall (mm)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1985
1990
1995
2000
2005
2010
2015
2020
Year
Maha Season

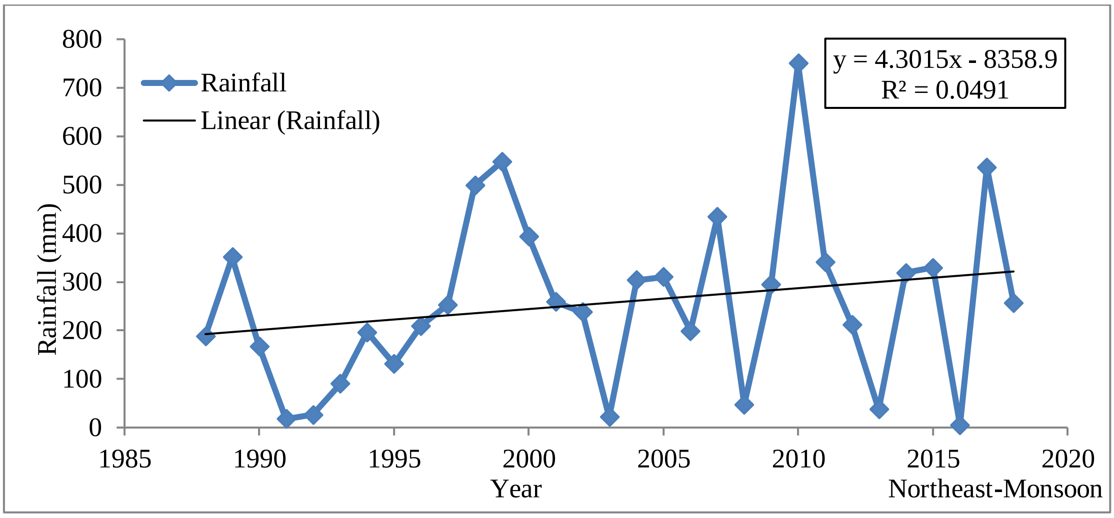


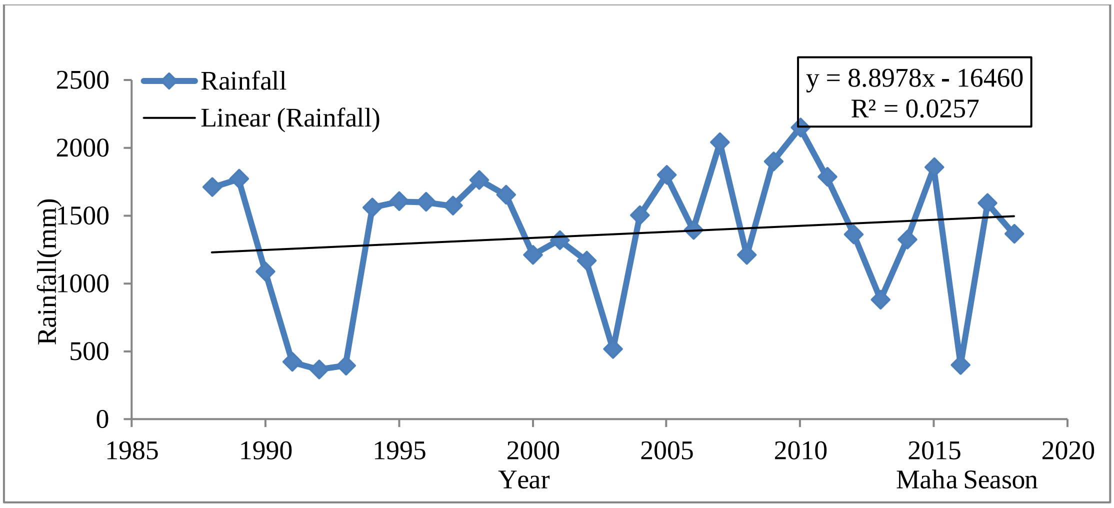
FigureB-2:Seasonal Trend of Nawalapitiya Station (Wet Zone)

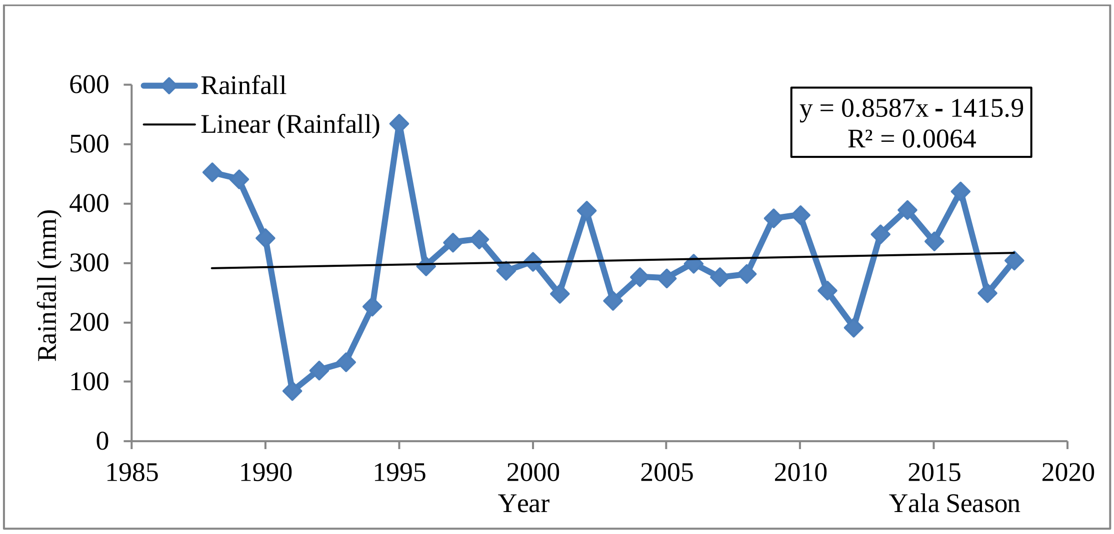





y = 1.8166x - 2975.9
R² = 0.0043
Rainfall
Linear (Rainfall)
Rainfall(mm)
0
200
400
600
800
1000
1200
1985
1990
1995
2000
2005
2010
2015
2020
Year
Second Inter Monsoon


y = 4.3015x - 8358.9
R² = 0.0491
Rainfall
Linear (Rainfall)
Rainfall (mm)
0
100
200
300
400
500
600
700
800
1985
1990
1995
2000
2005
2010
2015
2020
Year
Northeast-Monsoon


y = 8.8978x - 16460
R² = 0.0257
Rainfall
Linear (Rainfall)
Rainfall(mm)
0
500
1000
1500
2000
2500
1985
1990
1995
2000
2005
2010
2015
2020
Year
Maha Season


600
500
400
300
200
100
0
Rainfall (mm)
Rainfall
Linear (Rainfall)
y = 0.8587x - 1415.9
R² = 0.0064
1985
1990
1995
2000
2005
2010
2015
2020
Year
Yala Season

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