EVALUATION OF CLIMATE ELASTICITY OF RUNOFF BASED ON OBSERVED RAINFALL/ STREAMFLOW DATA AND SIMULATED FUTURE STREAMFLOW USING SWAT MODEL IN KELANI GANGA BASIN

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Degree of Master of Science in
Water Resources Engineering and Management

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

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

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University of Moratuwa
Sri Lanka

July 2020

DECLARATION

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

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The above candidate has carried out research for the Masters thesis under my supervision.

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Dr. R. L. H. L. Rajapakse Date

Evaluation of Climate Elasticity of Runoff based on Observed Rainfall/ Streamflow Data and Simulated Future Streamflow using SWAT Model in Kelani Ganga Basin

Abstract

Kelani Ganga basin is the 7th largest watershed in Sri Lanka, spanning over 2,292 km^2, with a length of 145 km, and annually discharging 4,225 MCM flow to the sea. The annual average rainfall varies from 2000 mm to 5700 mm while annual average temperature (T_{avg}) varies from 28 ºC to 30 ºC in the basin. The basin currently hosts over 19 % of the country's population and is the primary source of drinking water to over 4 million people living in Greater Colombo. Hence, it is vital to investigate the potential effects of climate change on streamflow in the basin. The present study was undertaken to evaluate Climate Elasticity of runoff based on observed rainfall/ streamflow data and simulated future streamflow using SWAT Model in Kelani Ganga basin, targeting sustainable management of basin water resources in future.

Hydro-meteorological data were collected for 41 rainfall, 10 temperature, and 3 streamflow gauging stations in and around the basin. The initial data checking was carried out and gap filling was performed based on regression analysis for streamflow and Inverse Distance Weighting (IDW) for rainfall and temperature. Root-mean-squared errors (RMSE) were calculated for each month and each percentile to determine the most suitable combination of Alpha of both rainfall and temperature. The $\alpha = 1$ for rainfall and $\alpha = 5$ for temperature were obtained as optimum parameters for the IDW. Additional statistical tests were carried out to identify trends on Climate change using Innovative Trend Analysis (ITA), Mann-Kendall and Sen's Slope tests for rainfall, temperature and streamflow. Decadal averages and deviation from Mean were plotted for all rainfall stations in and around the basin. SWAT model was built to simulate streamflow for the selected duration of 1960 to 2016 and the model was calibrated and validated for the key hydrometric station at Glencourse. The runoff elasticity (ε) is assessed by two methods based on the impact assessment of climate change only and impacts of land surface and climate change, respectively for current and Future Pessimistic Climate Change Scenario for 2040 after incorporating the projected landuse for 2040.

Annual average flow is reduced by 14% from the period of 1960-2016 to the period of 1980-2016 at Glencourse. The runoff to rainfall ratio at Glencourse and Hanwella for the period of 1980 to 2016 are 53% and 55%, respectively. Among 41 rainfall stations, 20 exhibit positive trends, 17 show the negative trends for annual rainfall totals for the all three tests of ITA, Sen's Slope and Mann-Kendall tests. The all selected three hydrometric gauging stations exhibit significant downward trends for the period of 1980 to 2016. An 80 % of the rain gauges in the middle and Upper basin, show significant decreasing trends for high to low rainfall totals for Yala season as ITA analysis for the period of 1980 to 2016. The model calibration and validation were completed at Glencourse for the period 1970 to 1980 and 1982 to 1992, respectively. Mass balance performance Error (Er), Nash–Sutcliffe efficiency (NSE) and coefficient of determination (R^2) are used as multi-objective functions and 8.90 %, 0.65, 0.72 and 9.10 %, 0.69, 0.69 are obtained, respectively for the calibration and validation periods.

1 ºC of temperature increase causes 6.9 % and 7.4 % runoff decrease for current scenario and 0.4 % increase and 1.5 % decrease of runoff for Future Pessimistic Climate Change Scenario as evaluated by two methods, respectively. 1% of rainfall increase causes runoff increase of 0.002 % and 0.370 % for current scenario and runoff increase of 0.005 % and 0.360 % for 2040 as evaluated by two methods, respectively. The flow didn't show significant increase for 2040 with projected landuse at Glencourse gauging station. As the water extraction quantity is significantly high for the districts, namely Colombo and Gampaha, with the highest residential densities with a majority (78%) are living in Kelani Ganga basin, it is recommended to further analyse the water allocation model for better results with practical implementations by considering identified trend after 1995 in future researches for planning and management of water resources in future.

Keywords: Inverse Distance Weighting, Mann-Kendal test, Sen's Slope, Innovative Trend Analysis, Precipitation elasticity, Future Pessimistic Scenario

DEDICATION

Every challenging work needs self-effort as well as the guidance of elders especially those who are very close to our heart.

My humble efforts are dedicated to my loving

<u>father</u>

who is in heaven, was always watching over me and guiding hand of me forever

<u>mother & husband</u>

whose affection, love and encouragement of everyday allowed me to accomplish this success and honour.

Along with the above, this work is also dedicated to my committed and respected

<u>teachers</u>

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LIST OF ABBREVIATIONS

Abbreviation	Description
CC	Climate Change
CEB	Ceylon Electricity Board
DEM	Digital Elevation Model
DSWRPP	Dam Safety, Water Resources Planning Project
ET*o*	Evapotranspiration
FDC	Flow Duration Curve
FIM	First Inter Monsoon
FSL	Full Supply Level
FPM	FAO-56 Penman-Monteith equation
GCM	Globle Climatic Models
GIS	Geographic Information System
HG	Hargreaves equation
HRUs	Hydrological Response Units
ID	Irrigation Department
IDW	Inverse Distance Weighting
IPCC	Intergovernmental Panel on Climate Change
ITA	Innovative Trend Analysis
LHGu	Modified linear regression calibrated HG equations
LIDAR	Light Detecting And Ranging
LTA	Long term Average
LUPPD	Landuse Policy Planning Department

m AMSL	m Above Mean Sea Level
MOL	Minimum Operating Level
MCM	Million Cubic Meters
MK	Mann-Kendall test
NEM	North East Monsoon
NWSDB	National Water Supply and Drainage Board
PET	Potential Evapotranspiration
SD	Standard Deviation
SIM	Second Inter Monsoon
SSSSL	Soil Science Society of Sri Lanka
SSSSL	Soil Science Society of Sri Lanka
SWAT	Soil Water Assessment Tool
SWM	South West Monsoon
T_{avg}	Average Temperature
T_{max}	Maximum Temperature
T_{min}	Minimum Temperature
RCM	Regional Climatic Models
RCP	Regional Concentration Pathways
RMSE	Root-mean-squared errors
UNCED	UN conference on development and Environment
WMO	World Meteorological Organisation

1. INTRODUCTION

1.1 Overview of the Study

Degradation of biodiversity and ecosystems have been resulted in increasing pressure on water resources, empowering significant risk for sustainable development on the globe (Oki and Kanae, 2006; Biswas et al., 2009). Nevertheless, the rapidly growing population, increasing urbanization and industrial expansion also cause remarkable pressure on water resources. Climate Change is an additional driver on it in the 21st century (Uniyal et al., 2015). Climate change may affect water resources through long-term water balance and temperature changes, unusual spatio-temporal variability and sea-level rise, which leads insinuation for food security, water security, human livelihoods and health of human and ecosystems.

Surface temperature is projected to increase by 1.5°C in 2050, if the projected anthropogenic activities are increased at the current rate and it is currently increasing at 0.2°C per decade (Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C Approved by Governments — IPCC, 2019). Thus, climate change impacts will be a huge problem for the developing countries, as their poor adaptation and mitigation measures to climate change (Gosain et al., 2006). Sri Lanka is also in under this category, hence some effects may be irreversible or long-lasting, such as the loss of some ecosystems (Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C Approved by Governments — IPCC, 2019). Therefore, Climate trends analysis and climate elasticity of runoff are to be evaluated to identify potential effects of Climate Change on Water resources in Kelani Ganga basin in Sri Lanka.

1.1.1 Hydrological modelling

Hydrological models are very valuable tools to response for the issues in water resources planning and management (Kamran, 2017). One of the major concerns in hydrological studies is predicting streamflow variations in poorly-gauged or ungauged watersheds, especially in sparse or lack of data and the massive spatial variability regions of the hydrological environment (Abimbola et al., 2017). Hydrological models are an essential tool for water resources sustainable management (Devia et al., 2015). The best model's common concept is using the lesser model parameters and lesser model complexity, which directs the results close to reality (Devia et al., 2015).

1.1.1.2 Soil and Water Assessment Tool (SWAT)

Soil and Water Assessment Tool (SWAT) is a semi-distributed, physically-based rainfall-runoff model, which has confirmed that a useful tool, which assesses non-point source pollution and water resources problems for different environmental conditions across the world (Neitsch et al., 2011). It has become a powerful tool, which measures the effects of climate change on water resources planning and management in the recent past (Jha et al., 2006).

Calibrated SWAT model was used to simulate the streamflow for future scenario and calibrated and validated parameters will be compared with the other gauged catchment to evaluate the applicability of hydrological parameter transferability at other hydrometric stations. Then the potential effects of future climate change on streamflow can be analysed based on rainfall elasticity in Kelani River basin using SWAT model. This analysis ultimately facilitates a more efficient and sustainable water resources planning and management in future.

1.4 Problem Statement

Climate change impacts will intensify the water crisis as well as natural disasters in Kelani ganga basin in future, hence the climate trend analysis is essential, based on the hydro-meteorological parameters in the basin for current and future scenarios, as the highest population is located in Kelani Ganga and it is ranked as third (3^{rd}) in the country in terms of water resources.

Therefore, it is vital to evaluate Climate Elasticity of runoff based on observed rainfall/ streamflow data and simulated future streamflow using SWAT Model in Kelani Ganga basin to manage the Water Resources in Sri Lanka sustainably in future. This evaluation is a national requirement of Sri Lanka, as it contributes 38 % of the total hydropower production and it is the only water source to supply the drinking water demands over 19 % of the population in Sri Lanka.

1.5 Objectives

1.5.1 Overall objective

To evaluate the Climate trend analysis for the period of 1980 to 2016 with Climate Elasticity of runoff based on observed rainfall/ streamflow data and simulated future streamflow using SWAT Model in Kelani Ganga for planning and management of the Water Resources in Sri Lanka efficiently and sustainably in future, while assessing the applicability of hydrological parameter transferability.

1.5.2 Specific objectives

- To identify the present status of knowledge/research update/literature survey
- To analyse of the Climate trends of each hydro-meteorological parameter
- To develop a SWAT model and calibrate and validate it at key Monitoring station
- To evaluate the potential impacts of climate change on streamflow based on two-parameter Climate Elasticity for the present scenario
- To predict the potential effects of future climate change on streamflow based on two-parameter Climate Elasticity for pessimistic scenario in future with landuse change for 2040
- To derive conclusions and recommendations for effective future water management in the basin

1.6 Study Area

Although the Kelani is the largest river, which is only second to Mahaweli Ganga by volume of discharge in Sri Lanka (Arumugam, 1969), it is the seventh largest river basin in Sri Lanka with a watershed area of 2,292 km^2, which contributes 4225 MCM flow to the sea annually. Two reservoirs and five hydropower plants were constructed to contribute 38% of Sri Lanka's total hydropower production (Siyambalapitiya and Samarasinghe, 1993).

It is bounded to the north by the Attanagalu Oya and Maha Oya basins, and in the east, by Mahaweli Ganga basin. In the south, the Kelani basin is bounded by the Kalu Ganga basin. The Kelani basin is totally located in the "wet zone" with the highest annual rainfall in Sri Lanka, and the annual average rainfall is ranged in between from 2,000 mm to 5,700 mm. Rainfall varies considerably through the year and mean temperature varies little over the year, between 28 ^oC and 30 ^oC in the basin. It flows 145 km into the sea at Modara and elevation varies from 2500 m AMSL to 0 m AMSL.

The basin currently has a population of approximately 2.5 million. This amounts to more than 19 % of the total Sri Lanka population in less than 4 % of the total land extent of the country. The heavily populated part of the country is the Western Region and Sri Lanka's capital city of Colombo is located in Kelani Ganga basin. The population density is over 1,000 people per km^2 in the Kelani Basin, which is largely due to its position as part of the Colombo urban conurbation, or at least within its sphere of commercial influence, the population of the Kelani Basin will rise to 3.3 million by 2040, an increase of about 31% from 2016 (WS Atkins International Ltd, 2019).

Water supply from the Kelani Ganga will experience deficits by the year 2025, even corresponding to 2 year return period daily average low flow value (MWS&D, 2013). Low flows corresponding to a 30 year return period shows deficits even for the year 2012 demands. By 2040, the demand gap at Ambatale is estimated as 15.2 m^3/s (1.31 MCM/day).

Kelani Ganga basin extends over three provinces such as Western Province, covering 805 km^2 (34 %), Sabaragamuwa Province, covering 1100 km^2 (47 %), while Central Province covering 435 km^2 (19 %). The basin also contains parts of the Administrative Districts of Kegalle (1028.5 km^2 - 44 %), Colombo (458.5 km^2 - 19.6 %), Nuwara Eliya (431.4 km^2 - 18.4 %), Gampaha (334.9 km^2 - 14.3 %), Ratnapura (71.5 km^2 - 3 %), Kaluthara (11.4 km^2 - 0.5 %) and Kandy (3.9 km^2 - 0.2 %) as shown in These are listed in order of percentage of the entire District extent in the basin and it is apparent that Nearly about two third of the total area of Colombo District (64%) is in the Kelani Ganga basin (Table 1-1 and Figure 1-1).

Hence it is vital to evaluate Climate Elasticity of runoff based on observed rainfall/ streamflow data and simulated future streamflow using SWAT Model in Kelani Ganga, as the above given factors clearly illustrate the importance of the assessment of water resources in Kelani Ganga basin in Sri Lanka.

Table 1-1: District area and percentages in Kelani Ganga basin

District	**Total District Area (km^2)**	**District Area in the Kelani Basin (km^2)**	**District Area percentage in the Kelani Basin (%)**
Colombo	682	439	64.3
Kegalle	1662	1028	61.9
Nuwara Eliya	1738	427	24.6
Gampaha	1382	337	24.4
Ratnapura	3292	69	2.1
Kalutara	1647	10	0.6
Kandy	1934	4	0.2

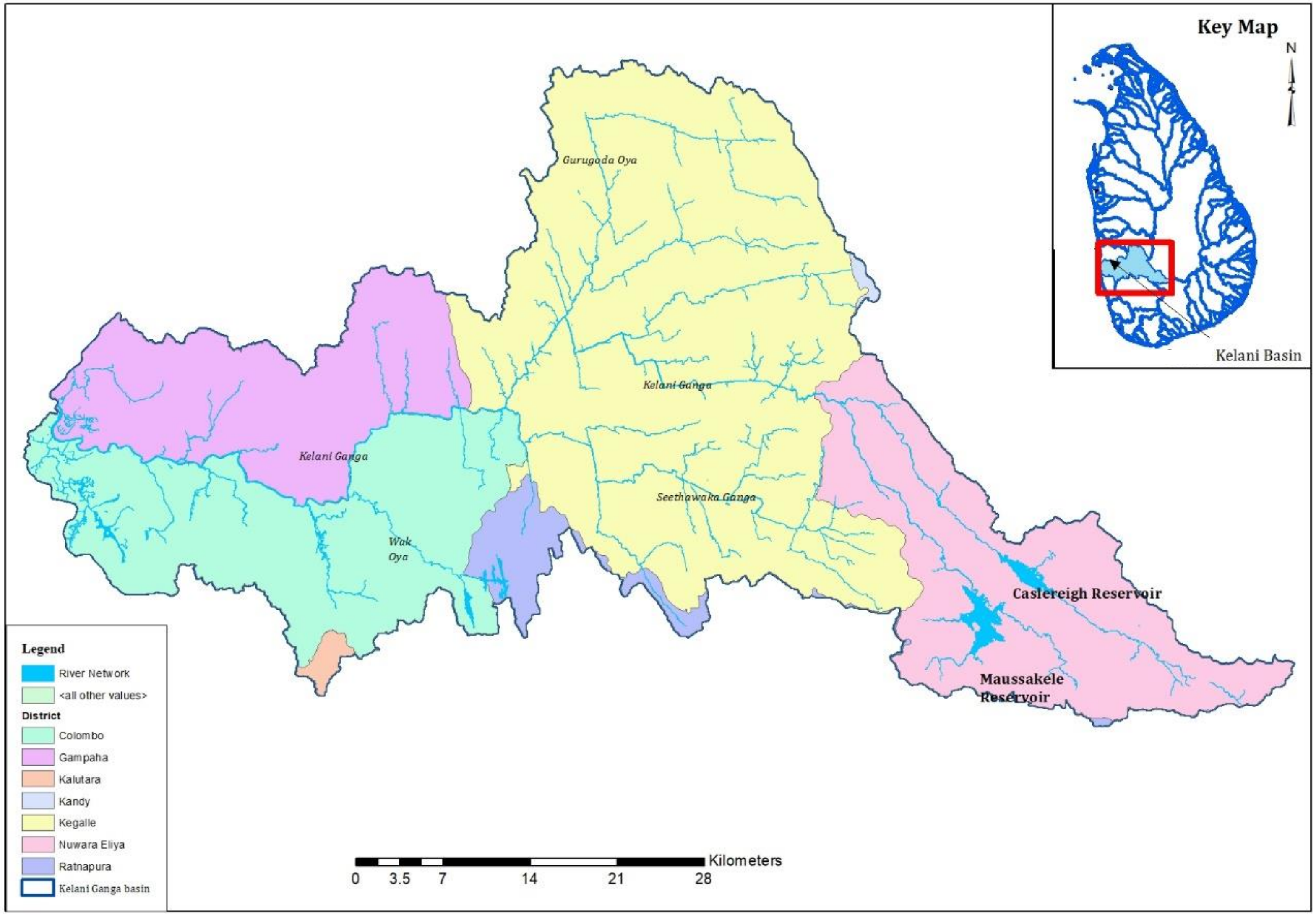


Figure 1-1: District Boundaries in Kelani Ganga basin

2 LITERATURE REVIEW

2.1 Overview

The total area of Sri Lanka is 65,268 km^2 and it has a tropical climate. It is the only country, which has a radial river distribution pattern. It mainly divided into three climatic zones such as Intermediate, Wet and Dry and Kelani Ganga is totally in the Wet Zone.

Modern hydrological techniques have been commonly employed in the water resources development and it was experienced that, various categories of numerical models can be utilized to simulate flow series in water resources planning projects in Sri Lanka (Dharmasena (Department of Irrigation), 1997). Therefore, it is vital to select the most suitable model for hydrological modelling of a watershed, which represents the actual conditions of the basin.

2.2 Climate Change

It was noted that the danger of climate change was first highlighted globally at the UN conference on development and Environment (UNCED) in Stockholm 1972 during the literature review. The number of researches has been carried out to identify the climate change in regionally as well as in globally. The number of General Circulation Models or Global climatic models (GCMs) and Regional climatic models (RCMs) have been developed to facilitate the analysis of climatic change. However, the situation related to Sri Lanka is quite different, since there are a number of research gaps with respect to the Sri Lankan context.

The regional hydrologic conditions and the impacts on water resource systems are being expected to change as a result of climate variability and change all over the world (Zhang et al., 2007). The future alterations in climate will adjust subsequently impacts of regional water resources and regional hydrologic conditions in terms of both quality and quantity (Gleick, 1989; Jyrkama and Sykes, 2007).

Quantitative assessments of the hydrological outcomes of climate change will be helpful in recognizing the possible water resource problems and to obtain better planning decisions. Potential effects may comprise changes in hydrological processes, hence research of global change on the hydrologic cycle plays a rising role (Zhang et al., 2007).

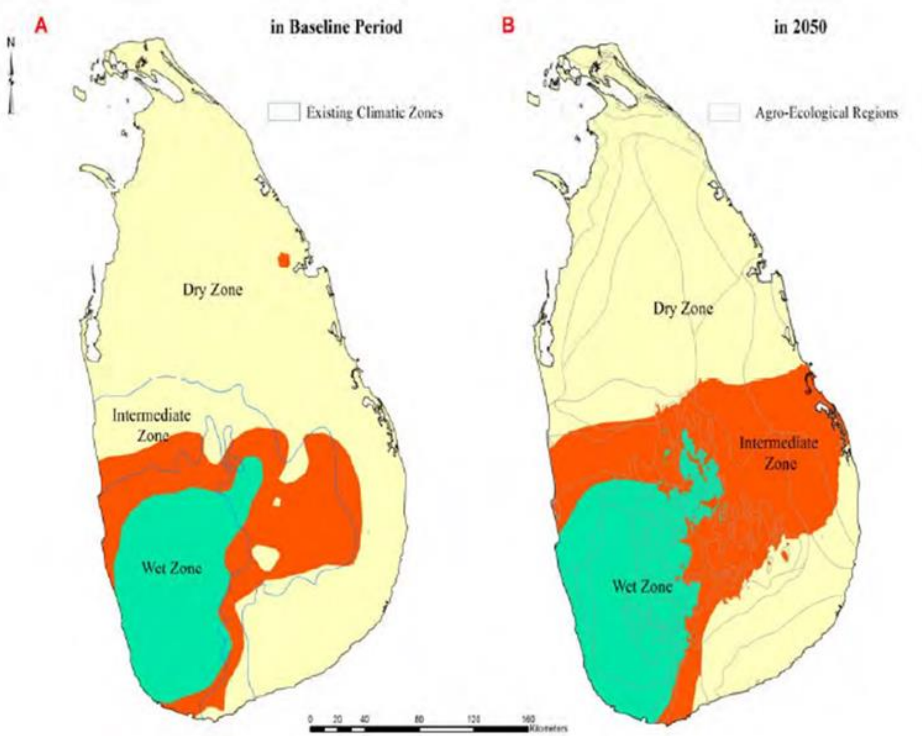
The IPCC confirms that the global warming will be increased by 1.5°C by 2050 (Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C approved by governments—IPCC, 2019).

Climate-related risks for human and natural systems at present will be increased and these risks depend on the implementation of adaptation and mitigation options, rate of warming and magnitude, vulnerability and levels of development and geographic location (Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C approved by governments—IPCC, 2019).

2.3 Climate Trend in Sri Lanka

Sri Lanka is consisted of mainly three climatic zones, such as Intermediate, Wet and dry. Most of the intermediate and dry zone agricultural activities are associated with, major, medium and minor irrigation systems. Climate change has been predicted to affect the pattern of rainfall, hence would change the timing of the receipt of reservoir inflows (Wijesekara, 2010). The reservoirs having larger spread areas would be greatly affected by the increase of evaporation as a result of temperature increment. In addition to that, irrigation systems have been deteriorated due to various reasons including lack of maintenance, which would be caused to increase the water stress in irrigation system together with climate change. The impact of climate impact would be spatially and temporally varied.

In additions to that, the climatic zones shifting would be expected due to Climate Change (CC) (Figure 2-1). There will be a significant expansion of dry areas of the country by 2050 due to CC thereby significant pressure on water resources (Jayathilaka, 2005).



Zone	Current	Baseline	2050	% change*
Dry	38,627	43,734	35,492	-8.1
Intermediate	14,212	11,866	17,312	21.8
Wet	12,696	10,278	12,793	0.03

* Changes of area compared to the current climatic zone map

WZ IZ – 1639 km²
DZ IZ – 5888 km²
IZ WZ – 1662 km²

Figure 2-1: The climatic zones shifting would be expected due to climate change

2.2.1 Temperature trend

The literature on Temperature variations due to Climate Change is given in Table 2-1.

Table 2-1: The Literature on Temperature variations due to Climate Change

Literature of Climate Change on temperature	References
Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate.	Stocker & Intergovernmental Panel on Climate Change (2019)
The average wet season temperature (the average of minimum and maximum air temperature) increases by 1.68 °C (A2) and 1.38 °C (B2) and the average reference evapotranspiration increases by 2% (A2).	De Silva, Weatherhead, Knox, & Rodriguez-Diaz (2007)
In particular, rice yield is sensitive to night-time minimum temperature with yield declining by 10% for each 1 °C increase in growing-season minimum temperature	Peng et al. (2004); Sivakumar and Stefanski (2010)
Changes in local extremes on daily and sub-daily time scales are expected to increase by roughly 5 to 10% per °C of warming.	Stocker & Intergovernmental Panel on Climate Change (2013)
Emissions Scenarios (SRES) downscaled GCMs A2 and B2 revealed that temperature by 2080 will likely increase by 2.5–4.5 °C under A2 and 2.5–3.25 °C under B2	Punyawardena et al. (2013)
Global Mean temperature increase by 2 °C for RCP 8.5 scenario by 2050	Stocker & Intergovernmental Panel on Climate Change (2013)

2.2.2 Rainfall trend

The literature on the effects of rainfall due to Climate Change is given in Table 2-2.

Table 2-2: The literature on the effects of rainfall due to Climate Change

Character	Literature of Climate Change on rainfall	References
Magnitude	Especially over land, there is a component of a '**wet-get-wetter**' and '**dry-get-drier**' response over oceans at the large scale.	Stocker & Intergovernmental Panel on Climate Change (2013)
	The mean annual average rainfall is projected to increase under A2 SRES scenarios by 14%, respectively, compared to the baseline period 1961–1990	De Silva, Weatherhead, Knox, & Rodriguez-Diaz (2007)

Character	Literature of Climate Change on rainfall	References
Intensity	Extreme precipitation will very likely be more intense and more frequent in a warmer world.	Stocker & Intergovernmental Panel on Climate Change (2013)
	Changes in local extremes on daily and sub-daily time scales are expected to increase by roughly 5 to 10% per °C of warming.	Stocker & Intergovernmental Panel on Climate Change (2013)
Shift	Especially on the South Asian Summer Monsoon, using RegCM3, also projects a weakened and delayed (by 5-15 days by the end of the twenty-first century) SWM over the majority of South Asia.	Eriyagama, Smakhtin, Chandrapala, and Fernando (2010)
	Inter-decadal variability of rainfall has increased over the recent decades compared to the past	Ranasinghe (2016)

2.2.3 Evaporation and evapotranspiration trends

The literature on the effects of evaporation and evapotranspiration due to Climate Change is given in Table 2-3.

Table 2-3: The literature on the effects of evaporation and evapotranspiration due to Climate Change

Literature for selection of Climate Change Scenario	References
Potential evapotranspiration increasing by 3.5% (A2), Consequently, the average paddy irrigation water requirement increases by 23% (A2)	De Silva et al. (2007)
Evaporation will be increased by 5.6% by 2050 due to 1°C rise on larger reservoirs	Helfer et al. (2012)

2.2.4 Other facts on Climate Change

It is essential to have a consistent base period to guarantee that national climate monitoring products (NCMPs) can be compared among countries and the base period is often pointed out as a climate normal. The World Meteorological Organization (WMO) guidelines on the standard climatological normal calculation endorses a rolling 30-year period, upgraded in every 10 years for operational climate monitoring (WMO, 2017).

The latest period for base year period is 1981 - 2010 (WMO Guidelines on Generating a Defined Set of Nati... | E-Library, 2017).

As the uncertainty associated with climate change scenarios, GCM outputs are essential to be sensibly assessed in future water policies and plans (Zhang et al., 2007). Climate Change damages could be highly dependent on the actual climate scenario, but it would be great in tropical developing countries (Seo et al., 2005).

As No-regret solutions are cost-effective for the range of future climate scenarios, Low-regret actions offer relatively large benefits and fairly low cost under predicted future climates. Adaptation is better than mitigation, in terms of Climate Change, when it is compared to the other social, economic and environmental policy benefits.

2.3 Data Checking

Several tests were performed during data checking and several method of data checking had been performed such as visual data checking, outlier checking, graphical checking Consistency and homogeneity checking. Summary describing the dataset and statistical results are given below;

- a time-series plot of the annual rainfall totals;
- a time-series plot of the normalised annual rainfall totals;
- a normal probability plot;
- single mass and double mass analysis plot; and

2.3.1. Test for absence of trend

To verify the absence of trend, Spearman’s rank-correlation method was used, as among its other attributes, it contains approximately equal power for linear and non-linear trends (Dahmen & Hall, 1990). The following values were calculated:

$$R_{sp} = 1 - \frac{6\sum_{i=1}^{n} {D_i}^2}{n(n^2-1)} \quad \ldots 1$$

where *n* is the total number of data; *D* is the difference (rank of variable minus the chronological order number of the observation); and *i* is the chronological order number.

2.3.2 Anderson-Darling test for normality

The normality of a data set is tested using Anderson-Darling's test statistic A2. A data set may be considered to be normally distributed if the p-value associated with A2 is greater than 0.05. The test makes use of the cumulative distribution function by applying the following formula:

$$AD = -n - \frac{1}{n}\sum_{i=1}^{n}(2i-1)[lnF(Xi) + \ln(1 - F(X_{n-i+1})] \ldots\ldots 2$$

where *n* = sample size; *F(X)* = cumulative distribution function for the specified distribution; and *i* = the i^{th} sample when the data is sorted in ascending order. For unknown mean and variance, the *AD* value is adjusted by (D'Augostino & Stephens, 1986):

$$AD^{*} = AD(1 + \frac{0.75}{n} + \frac{2.25}{n^2}) \ldots\ldots 3$$

Then, the *p* value is calculated by:

If AD*=>0.6, then p = exp(1.2937 - 5.709(AD*)+ 0.0186(AD*)2

If 0.34 < AD* < .6, then p = exp(0.9177 - 4.279(AD*) - 1.38(AD*)2

If 0.2 < AD* < 0.34, then p = 1 - exp(-8.318 + 42.796(AD*)- 59.938(AD*)2)

If AD* <= 0.2, then p = 1 - exp(-13.436 + 101.14(AD*)- 223.73(AD*)2)

2.3.3 Test for stability of variance and mean

The F-test for stability of variance

Instability of variance indicates non-stationarity. Two equal and non-overlapping sub-sets (1981-1997 and 1998-2016) and have been tested with the distribution of variance-ratio, known as Fisher or F distribution:

$$F_t = \frac{{s_1}^2}{{s_2}^2} \ldots\ldots 4$$

The *F* value needs to be between two bounded values for the 5% level of significance to be considered stable.

The t-test for stability of mean

The t-test requires the unknown variances of the two sub-sets to not statistically different, therefore it will always follow the F-test. The t-test can be applied to any frequency distribution, as long as the sub-sets length is equal:

$$t_t = \frac{x_{mean1} - x_{mean2}}{\sqrt{\left[\frac{(n_1-1)s_1^2+(n_2-1)s_2^2}{n_1+n_2-2}(\frac{1}{n_1}+\frac{1}{n_2})\right]}} \ldots\ldots 5$$

The number of degrees of freedom is $v = v_1+v_2$.

If the mean of the time series falls within the bounded values of the 5 % level of significance, then it is considered stable.

2.3.4 Test for absence of persistence

The serial-correlation coefficient verifies the independence of a time series, as if all lags other than zero are zero then the time series is completely random. The lag-1 serial-correlation coefficient for adjacent observations is computed according to Box and Jenkins (1970):

$$r_t = \frac{\sum_{i=1}^{n-1}(x_i - x_{mean})(x_{i+1} - x_{mean})}{\sum_{i=1}^{n}(x_i - x_{mean})} \quad \text{……..6}$$

If r_t is between the bounded values for the 5% level of significance, then there is no correlation between successive observations, Test for Absence of Persistence data is independent and there is no persistence in the time series.

2.4 Statistical tests for climate change impacts

Literature suggested that three (3) main tests are to be carried out to check the trends in each hydrometeorological parameter.

- Innovative Trend Analysis
- The Mann-Kendall Test
- Sen's Slope Estimator

2.4.1 Mann-Kendall test and Sen's Slope estimator

The Mann–Kendall test, proposed by Kendall (1938, 1970) and it is a non-parametric test, which is widely used most popular methods to detect trends in hydro-meteorological time series (Şen, 2012; Wu & Qian, 2017). Sen (1968) developed the slope of the trend using a non-parametric procedure in the sample of *N* pairs of data.

Though there are commonly used trend detection techniques, such as Mann-Kendall (MK) and Sen's Slope Estimator, their viability is feasible under a set of restraining assumptions (Şen, 2012).

2.4.2 Innovative Trend Analysis (ITA)

The ITA has avoided the limitations of Mann-Kendall and Sen's Slope estimator (Şen, 2012). Sen introduced "This new methodology on the basis of subsection time series plots derived from a given time series on a Cartesian coordinate system. In such a plot, trend free time-series subsections appear along the 45° straight-line. Increasing (decreasing) trends occupy upper (lower) triangular areas of the square area defined by the variation domain of the variable concerned".

2.5 The Climate Elasticity of Runoff

Climate elasticity of runoff can be defined as the proportional change in the runoff to the change in climatic variables such as Precipitation (P), Relative humidity (RH) and Temperature (T) etc.. (Tang et al., 2013). Chiew stated, "The rainfall elasticity of streamflow is strongly correlated to runoff coefficient and mean annual rainfall and streamflow, where streamflow is more sensitive to rainfall in drier catchments, and those with low runoff coefficients" (Chiew, 2006).

The nonparametric estimator is useful, where frequent evaluates the long-term streamflow sensitivity to climate are required because it is simple to estimate and use the elasticity from the past data (Chiew, 2006).

2.6 Hydrological Modelling

Hydrological models simply illustrate the actual hydrological processes. The commencement of mathematical modelling initiated when M. Darcy (1856) published his hydraulic conductivity analysis. Hydrological phenomena are highly non-linear, highly variable and extremely complex in space and time. Hence hydrological models are very useful kit for planning, design and management of water resources, but there are some constraints of all different model structures and the data availability, etc... (Mwakalila et al., 2001).

Classification of the various hydrological models are available and they are; conceptual models, physically-based models and empirical model; Lumped and distributed models; Stochastic and Deterministic models, etc. Among the different hydrological model classifications, the most vital classifications are empirical model, physically-based models and conceptual models (Devia et al., 2015).

2.6.1 Empirical models

It does not contain the physical processes of the catchment, but the mathematical equations have derived from simultaneous input and output time series. These models are effective only within the borders, based purely on observation (Devia et al., 2015). Unit hydrograph and rational formula are examples of this method. These models are also identified as Black box models.

2.6.2 Conceptual models

Devia et al. (2015) stated "Semi empirical equations are used in this method and the model parameters are assessed not only from field data but also through calibration. A large number of meteorological and hydrological records is required for calibration". These models use broad concepts to explain systems e.g. Tank model, Linear channel and Cascade models, Watershed/ water balance models, etc.

2.6.3. Physically based models

This is a simplified mathematically realistic illustration of physical processes e.g. Climate, hydrology, flow and energy gradients, remote sensing, geomorphology, etc. It uses variables and those are functions of both space and time and are measurable e.g. SWAT, MIKE BASIN, etc.. The finite difference equations represent the hydrological processes of water movement (Devia et al., 2015).

The assessment of Strength and weaknesses of these three rainfall-Runoff models are illustrated in Table 2-4.

Table 2-4: The assessment of Strength and weaknesses of these three rainfall-Runoff models

Criteria	Empirical model	Conceptual model	Physically based model
Other definitions	Data based or black box	Parametric or Grey box model	Mechanistic or white box model.
Typical Run time step	Can be daily, if daily flow from another gauge is used as a predictor variable. Otherwise typically only applied at annual (or longer) time's scale.	Daily, although shorter run time steps are possible if sufficient climatic data is available at this short time step	Minutes to hours to maintain numerical stability, although often forced with daily data and assumed patterns used to disaggregate to shorter time steps.
Typical no. of parameters	1 to 5	4 to 20	10 to 1000's
Which equations used	Use Mathematical equations	Based on modeling of storages along with the semi empirical equations	Based on special distribution, evaluation of parameter describing physical characteristics
	Cannot be used for other catchments	Can be used for other watersheds which has similar catchment parameters	Valid for wide range of situations, and it needs human expertise and computation capabilities, since its complexity.
Risk of over-parameterising the model	Low	Moderate	Very high
Need for high resolution spatial data layers	None to moderate	Low	Very high
Run time on typically available computer platforms for 100 years of daily data	<1 second	<1 to 60 seconds	1 minute to several hours
Models	ANN, Unit hydro graph, Rational Formula	HBV, TOPMODEL, Tank Model, Mike11	MIKESHE, SWAT, MIKEBASIN

2.7 Model Selection Criteria

After the identification of strengths and weaknesses of each model, model selection criteria was rationalized using 8 criteria as given in Table 2-5, as they are more sensible for model selection. Equal weightages were given for each criterion for the selection of the model and Ranking for model selection is given in Table 2-6**.**

Table 2-5: Model selection rational criteria

No.	Criteria	High	Medium	Low
1.	Model Application	Applied in Sri Lanka	Applied in Asian region	Applied in other regions
2.	Assessing the Climate change Impacts	Highly used	Moderately used	Rarely used
3.	Time of simulation	Continuous and event base	Continuous base	Event base
4.	Model accessibility	Freely available model	Freely available for education purpose	Fully commercial
5.	Physical process representation	Physics based model	Conceptual model	Empirical model
6.	Temporal resolution	sub daily, daily	Monthly	Annually
7.	Data requirement	Model runs with limited data availability	Model runs with moderate limited data availability	Model runs with more data availability
8.	Availability of manuals and quick guides	freely available user guides and manuals	Commercially available user guides and manuals	None availability of manuals and guides

Table 2-6: Ranking for model selection

Criteria	SWAT	TOPMODEL/ BTOPMC	MIKE 11/ NAM	TANK	HEC-HMS	ABCD
Criteria 1	H (3)	H (3)	H (3)	H (3)	H (3)	L (1)
Criteria 2	H (3)	L (1)	L (1)	L (1)	L (1)	L (1)
Criteria 3	H (3)	L (1)	M (2)	M (2)	H (3)	M (2)
Criteria 4	H (3)	H (3)	M (2)	M (2)	H (3)	H (3)
Criteria 5	H (3)	M (2)	M (2)	M (2)	H (3)	L (1)
Criteria 6	H (3)	H (3)	H (3)	H (3)	H (3)	H (3)
Criteria 7	M (2)	L (1)	H (3)	H (3)	H (3)	L (1)
Criteria 8	H (3)	L (1)	H (3)	L (1)	H (3)	H (3)
Total	**24**	**15**	**16**	**17**	**19**	**18**

The SWAT model is ranked the highest score for the model selection criteria, hence SWAT was selected for the analysis.

2.7.1 SWAT modelling

Soil and Water Assessment Tool (SWAT) evaluates the uncertainty in streamflow prediction and climate change impacts, which is in combination with SWAT. The potential effects of climate change on surface runoff is estimated by Zang et al. (2007) and Kalogerophoulous and Chalkias (2012) at a basin scale.

The flood and drought severity will be amplified and surface runoff was discovered to normally decline as a result of the climate change projections. The reviews of SWAT components and researches reported in over 1,000 published peer-reviewed articles (Gassman et al., 2007); Soil and Water Assessment Tool (SWAT) applications. Most SWAT parameters can be assessed automatically using the weather information and the databases of internal model and GIS interface (Zhang et al., 2008; Srinivasan et al., 1998). Governing equation in SWAT is given below (Neitsch et al., 2011).

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \qquad \text{……………………....7}$$

SW_t = Final soil water content (mm)
SW_0 = Initial soil water content on day i (mm)
R_{day} = Amount of precipitation on day i (mm)
Q_{surf} = Amount of surface runoff on day i (mm)
E_a = Amount of evapotranspiration on day i (mm)
W_{seep} = Amount of water entering the vadose zone from the soil profile on day i (mm)
Q_{gw} = Amount of return flow on day i (mm)

2.7.1.1 Input data

Digital elevation model (DEM), land use/land cover map and soil map, time series of rainfall, temperature and streamflow data are mainly required as the model inputs (Neitsch et al., 2011). Though the stream network can be delineated from the DEM, it has to be checked with the available river network by Survey Department.

2.7.1.2 Calculating potential evapotranspiration

SWAT, the rainfall-runoff model described in the corresponding chapter of this Volume, offers three options for calculating potential evapotranspiration (PET): Priestly-Taylor (Priestley & Taylor, 1972), Penman-Monteith (Monteith, 1965) and Hargreaves (Hargreaves George H. & Allen Richard G., 2003). The model can also read in daily PET values, allowing the user to apply a different PET method. The three methods differ in the amount of input data compulsory to run simulations. The Priestly-Taylor method needs solar radiation, air temperature and relative humidity, while the Penman-Monteith method involves solar radiation, air temperature, relative humidity and wind speed and the Hargreaves method needs temperature only.

The improved Hargreaves equation (1985) that is incorporated in the SWAT model is:

$$ET_o = 0.0023 * RA * (T_{max} - T_{min})^{0.5} * (T_{av} + 17.8) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...8$$

where ET_o is the potential evapotranspiration (mm/day), RA is the extraterrestrial radiation (mm/day), T_{max} is the maximum air temperature for a given day (^oC), T_{min} is the minimum air temperature for a given day (^oC), and T_{avg} is the mean air temperature for a given day (^oC).

As the literature suggests, "the 1985 Hargreaves method is often used to provide ET_o predictions for weekly or longer periods for use in regional planning, reservoir operation studies, canal design capacities, regional requirements for irrigation and/or drainage, potentials for rain-fed agricultural production, and, under some situations, for irrigation scheduling".

2.7.1.3 Selection of Parameters

The rules for parameter regionalization (Abbaspour, 2015) was used to optimize objective functions for the selected Hydrometric station given in Table 2-7 in Figure 2-2 and summary of the parameter selection is given in Table 2-7 as Abbaspour (2015).

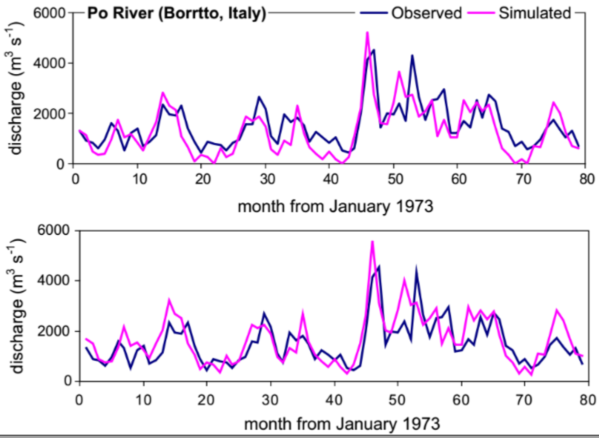
Simulated condition and significant parameters	Before (top) and after (below) parameter regionalization
– **Base flow too low** –**Evapotranspiration too high** GWQMN.gw ↓ GW_REVAP.gw ↓ REVAMPM.gw ↑	

Figure 2-2: Rules for parameter regionalization. ↑ indicates parameter should increase, ↓ indicates parameter should decrease

Source: Abbaspour (2015)

Table 2-7: The rules for parameter regionalization (Abbaspour, 2015) for parameter optimisation

No.	Simulated condition	Significant parameters
1	Base flow too low	GWQMN.gw ↓
	Evapotranspiration too high	GW_REVAP.gw ↓
		REVAMPM.gw ↑
2	Peak flow too low	CN2.mgt ↑
		SOL_AWC.sol ↓
		ESCO.hru ↓
3	Discharge shift to the right	HRU_SLP ↑
		OV_N.hru ↓
		SLSUBBSN.hru ↓
4	Base flow too high	CN2.mgt ↑
	Peaks too low	SOL_AWC.sol ↓
		ESCO.hru ↓
		GWQMN.gw ↑
		GW_REVAP.gw ↑
		REVAMPM.gw ↓
5	Nitrate load too high	SHALLST_N.gw ↓
		RCN.bsn ↓
		NPERO.bsn ↓
		CMN.bsn ↓
		SOL_NO3.chm ↓
		FRT_SURFACE.mgt ↓

Source: Abbaspour (2015)

2.7.1.4 Objective function

The Nash–Sutcliffe efficiency (*NSE*), Relative Error (*Er*) and coefficient of determination (R^2) were used to assess the SWAT model performance by lots of researchers Quinn et al. (1991) and White & Chaubey (2005).

The statistics of streamflow can be considered as highly applicable, when NSE is higher than 75%, RE values are lower than 20%, and R^2 is close to one (Motovilov et al., 1999) Some researches use only Nash–Sutcliffe efficiency (*NSE*) to evaluate the SWAT model performance (Shi et al., 2011).

$$E_r = \frac{S_i - O_i}{O_i} x\ 100\% \quad \ldots\ldots 9$$

$$E_{NS} = 1 \frac{\sum_{i=1}^{N} (O_i - S_i)^2}{\sum_{i=1}^{N} (O_i - \overline{O})^2}, \quad \ldots\ldots 10$$

$$R^2 = \left(\frac{\sum_{i=1}^{n} \left(O_i - O_{avg}\right)\left(P_i - P_{avg}\right)}{\left[\sum_{i=1}^{n} \left(O_i - O_{avg}\right)^2 \sum_{i=1}^{n} \left(P_i - P_{avg}\right)^2 \right]^{0.5}} \right)^2 \quad \text{……..……....................................} 11$$

3 MATERIALS AND METHODS

3.1 Methodology

The methodology carried out during this research is explained in this chapter and the Methodology Flow chart is shown in Figure 3-1. The methodology is carried out during the study is briefly described in below.

- During the literature review, research gaps, the extents to analysis and prevailing issues were identified. As a result of that, the research objectives and specific objectives were originated.
- The study area was selected based on the research gaps and other identified issues during the literature survey.
- After identifying the study area, data collection was initiated.
- Data checking was carried out for all meteorological and hydrological data series and missing data threshold is taken as less than 10% for all time series.
- Gap-filling was carried out for all 5 alpha parameters for rainfall and temperature data using IDW.
- Three (3) streamflow (hydrometric) stations were selected among 6 hydrometric stations based on the data quality. Gap filling of streamflow was carried out using linear interpolation and nearby station's records.
- Root-mean-squared errors were calculated for each month and each percentile to determine the most suitable combination of power value (α) for both rainfall and temperature time series in the analysis.
- The statistical tests were carried out for the optimized alpha parameter to identify consistency and homogeneity of the data series as well as to identify trends of Climate change for the duration for 1980 to 2016 using ITA, Mann-Kendall test and Sen's Slope test.
- Decadal averages and deviation from mean were estimated for all rainfall stations in and around the basin for optimized alpha parameter.
- The SWAT model is selected based on Model selection rational criteria and model was built to simulate the streamflow for the selected duration of 1960 to 2016.

- The SWAT model was calibrated for 1970-1980 period, while the validation was carried out for the period of 1982-1992 at Key hydrometric station at Glencourse.
- The applicability of same hydrological parameters, which were used for Glencourse was also evaluated for Hanwella and Kitulgala gauging stations in the basin.
- Future rainfall and temperature series already derived for pessimistic Climate Change scenarios and landuse for 2040 (WS Atkins International Ltd, 2019) were used to simulate the future flow series in the Kelani Ganga basin using SWAT model for 2040.
- The runoff elasticity (ε) is assessed by two methods based on the assessment of impacts of climate change only and impacts of climate and land surface change on the streamflow, as evaluated by Sankarasubramanian et al. (2001) and Zheng et al. (2009), respectively for current and the future pessimistic Climate change scenario for 2040.

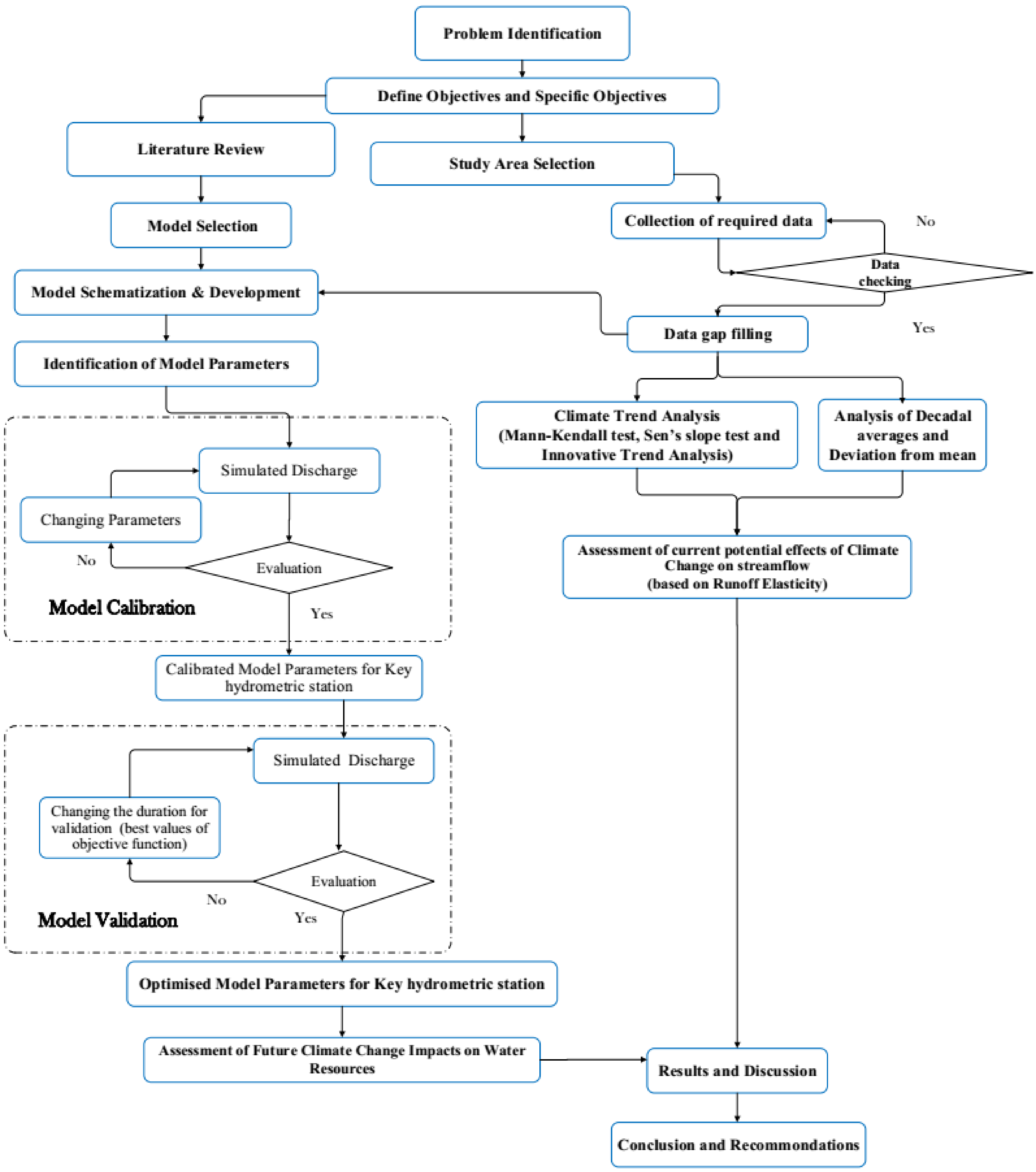


Figure 3-1: Methodology Flow Chart of the study

3.2 Data and Data Checking

3.2.1 Data sources and data resolution

Daily data were collected for the period of fifty-six years starting from 1960/61 water year to 2015/2016 water year. From the selected 41 rainfall stations, 17 rainfall stations are located within the Kelani Ganga basin, while 24 rainfall stations are located surrounding of the Kelani Ganga basin, which were used to process for gap-filling using Inverse Distance Weighting (IDW).

Accordingly, rainfall, evaporation, temperature data were collected from Department of Meteorology, while streamflow data and spatial information on hydrometric stations were collected from Department of Irrigation and other GIS data is collected from survey Department. Land use data was collected from the Land Use Policy Planning Department (LUPPD) and other related data was collected from different mandatory organizations, respectively.

The hydrological and meteorological stations were selected considering spatial and temporal distribution of each gauging stations located within or near the Kelani Ganga basin and data were collected for the aforementioned reference period including rainfall, streamflow, Maximum and Minimum temperature, evaporation etc.

Table 3-1, summaries the details of data Availability for the analysis.

Table 3-1: Data Requirement and Availability for the analysis

No.	Data	Layer/ Data type	Spatial Resolution/ time step	Source/ Availability/ Accessibility
01.	Rainfall data	Vector/ Time series	1:10,000/ Daily time step	Department of Meteorology
02.	Temperature data	Vector/ Time series	1:10,000/ Daily time step	Department of Meteorology
03.	Evaporation data	Vector/ Time series	1:10,000/ Daily time step	Department of Meteorology
04.	DEM	Raster	30 m	Survey Department
05.	Soil data	Vector	1: 250,000	Soil Science Society of Sri Lanka (SSSSL)
06.	Landuse data	Vector	1: 10,000	Landuse Policy Planning Department (LUPPD)

No.	Data	Layer/ Data type	Spatial Resolution/ time step	Source/ Availability/ Accessibility
07.	Basin Boundaries	Vector	1: 10,000	DSWRPP
08.	Stream paths	Vector	1: 10,000	Department of Survey
09.	Reservoir data	Vector / timeseries	1:10,000/ Daily time step	Ceylon Electricity Board
10.	Agro-ecological zones	Vector	1: 500,000	Department of Agriculture

All the collected data were pre-processed to restructure the raw data into time series during the initial stage of data collection. Data inconsistencies, missing data, and outliers were assessed visually for the collected Hydro-meteorological data including streamflow, rainfall, and Maximum Temperature (T_{max}) and Minimum Temperature (T_{min}) data. Furthermore, the Double mass curves and annual water balance were also used to identify the data consistencies and homogeneity.

During the literature review, it was identified that there are different methods can be applied for data gap filling such as Inverse Distance Weighting (IDW), Thiessen Polygon Method, Cokriging and Kriging. IDW method was used to gap fill the rainfall and temperature data, while long term average used to gap fill the streamflow data.

The IDW infilling process applied the following formula:

$$u(x) = \frac{\sum_{i=1}^{N} w_i(x) u_i}{\sum_{i=1}^{N} w_i(x)} \quad \ldots\ldots 12$$

where $w_i(x) = \frac{1}{d(x,x_i)^{\alpha}}$

Based on values suggested by literature for the application of the IDW method on rainfall data, ensuring a sufficient number of stations to use in the IDW process, and ensuring that distant stations are not utilized where rainfall patterns are potentially dissimilar, the IDW parameter values (α) were tested using data from selected rain gauges within and near the target basin (Chen & Liu, 2012). The following IDW parameter values were tested for both temperature and rainfall daily time series:

- Power value α = [1, 2, 3, 4, 5]; and
- Radius of influence R = [25, 30] km

Specific power values (α) and radii of influence (R) were selected per basin given the distribution of stations used in the analysis. The power value (α) is optimized, which gives the minimum Root-mean-squared errors for each month and each percentile of the rainfall and temperature data.

3.2.2 Rainfall gauging stations selection

Among 200 Rainfall stations, 42 stations were screened, which are located in 30 km buffer zone in and around Kelani Ganga basin, but Nawalapitiya rainfall gauging station is removed during visual checking of annual totals, which shows an outlier. Therefore 41 rainfall stations were selected for further analysis (Table 3-2 and Figure 3-3). Table 3-4 shows average rainfall (LTA) and Standard Deviation (SD) for annual, Yala and Maha seasons for Kelani Ganga basin.

Table 3-2: Selected of Rainfall gauging stations for gap-filling in and around Kelani Ganga basin

Name	X Coordinate	Y Coordinate	Missing data Percentages for the duration of 1980 to 2016	Elevation in m AMSL
Alupolla Group	479065	468593	1%	925
Ambewela	503017	487019	7%	1857
Angoda mental hospital	405404	492635	2%	7
Avissawella Estate	434871	490746	10%	107
Avissawella Hospital	438559	494428	5%	25
Balangoda Post Office	491961	461218	3%	527
Bandarawela	524400	482187	1%	1227
Bopatthalawa	493807	481490	2%	1729
Campion Estate	491964	475962	1%	1427
Canyon	473547	487026	7%	1283
Castlereigh	477230	485181	7%	1109
Chesterford	434892	507334	7%	190
Colombo	399757	488949	0%	8
Digalla Estate	447767	494418	10%	193
Dunedin Estate	445935	503635	9%	29

Name	X Coordinate	Y Coordinate	Missing data Percentages for the duration of 1980 to 2016	Elevation in m AMSL
Dyrabba Estate	517752	487022	6%	1130
Galatura Estate	445897	466774	3%	39
Hakgala Botanical Grdns	504858	490705	3%	2030
Hanwella Group	427498	487070	2%	68
Hapugastenna Estate	471695	468597	4%	461
Holmwood Estate	493807	483333	2%	1544
Kalatuwawa	436704	483372	3%	142
Katugastota	484499	536774	0%	447
Katunayaka	401655	518437	0%	7
Kenilworth Strathellie	468029	499930	2%	720
Labugama Tank	434859	481531	2%	186
Labukelle	493809	501763	4%	1654
Laxapana	471706	488870	7%	1050
Maliboda	462495	487033	12%	381
Maussakelle	475387	483339	7%	1203
Negombo	396699	523812	3%	2
Nuwara Eliya	499219	496225	0%	1883
Pasyala	429381	516557	3%	34
Ratmalana	401582	479729	0%	6
Ratnapura	458680	464910	0%	21
Sandringham Estate	497491	483333	7%	1501
Undugoda	455152	514685	4%	339
Wagolla	457282	532056	3%	92
Walpita	420281	529361	5%	48
Welimada Group	514068	488864	4%	1113
Weweltalawa Estate	456985	505468	3%	859

The primary screening and secondary screening of the rainfall stations selection process were carried out for 30 km radius of influence (R) distance and the stations were selected, which are more than 90 % for the period of 1980 to 2016, as the gap-filling threshold value is 10 % (Subramanya, 2013). The power value (α) is optimized, which gives the minimum Root-mean-squared errors for each month and each percentile of the rainfall and temperature data and $\alpha = 1$ for rainfall and $\alpha = 5$ for temperature is obtained as optimized power values (α) for IDW, respectively.

As Bandarawela, Badulla, Dyrabba Estate, Welimada Group, Negombo, Hakgala Botanical Gardens, Katugasthota and Nuwara Eliya are far away to Kelani ganga basin, they were not used to calculate the rainfall variability in the basin as well as for SWAT modelling. Those stations were used only for gap-filling of other nearby stations using IDW, as it is a spatial averaging method. Therefore, average annual rainfall variation in the basin are given without considering those 5 stations were given above. The annual average rainfall is varied from 1760 mm to 5680 mm, while rainfall totals varied from 760 mm to 1850 mm and from 920 mm to 3920 mm in the basin for Maha and Yala seasons respectively for the duration of 1980 to 2016.

Though Nawalapitiya and Maliboda were in among the pass stations in the primary and secondary screening tests, its annual totals show unbelievably lower outliers in raw data for the period of 1990/91 to 1992/93 water years, about 889 mm, 997 mm and 1575 mm correspondingly for Nawalapitiya and 1981/82 water year for Maliboda station, respectively, which are not shown in any other stations nearby. Therefore, those durations were considered as missing values, hence the raw data percentage became less than 90 % for both stations.

But Maliboda station is selected for the further analysis, though its raw percentage became about 88 % after removing the outliers, as it is one of the stations which shows the highest long term averages (LTA) of rainfall among the four stations within and three other stations nearby to the basin, respectively (Table 3-3 and Figure 3-1). Therefore finally, 41 rainfall stations were selected for further analysis and 17 rainfall stations are located within the Kelani Ganga basin, while the 24 rainfall stations are located near to the Kelani Ganga basin among the 41 stations, which were used for gap filling process using Inverse Distance Weighting (IDW) again.

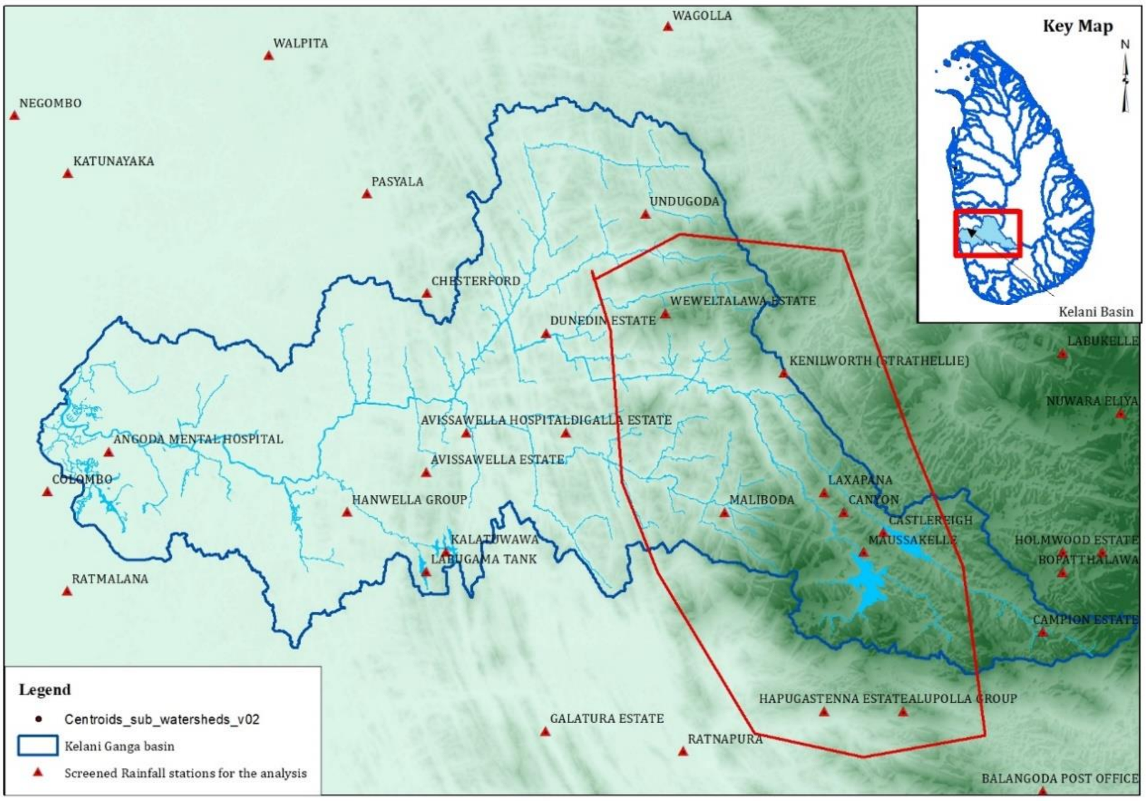


Figure 3-1: Spatial distribution of rainfall gauging stations, which shows the highest rainfall within and nearby to the Kelani Ganga basin

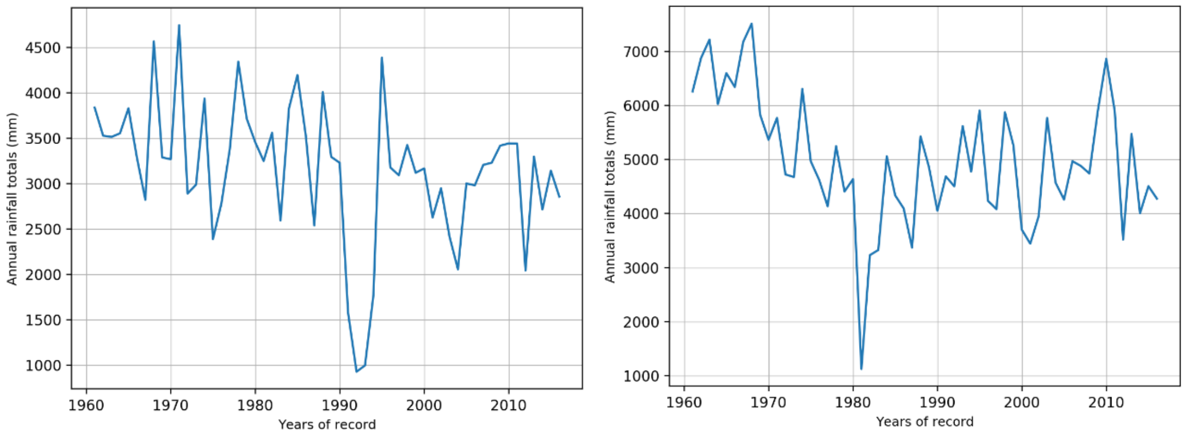


Figure 3-2: Annual rainfall totals for Nawalapitiya and Maliboda rainfall stations with outliers

Table 3-3: The highest rainfall long term averages (LTA) within the basin among the four stations and three other stations in and nearby to the basin

Name of the Rainfall station	LTA for 1980 to 2016 duration (mm)
Alupolla Group	4154.53
Kenilworth Strathellie	5704.01
Laxapana	4643.82
Maliboda	4700.03
Weweltalawa Estate	4648.17
Galatura Estate	4084.33
Hapugastenna Estate	4671.23

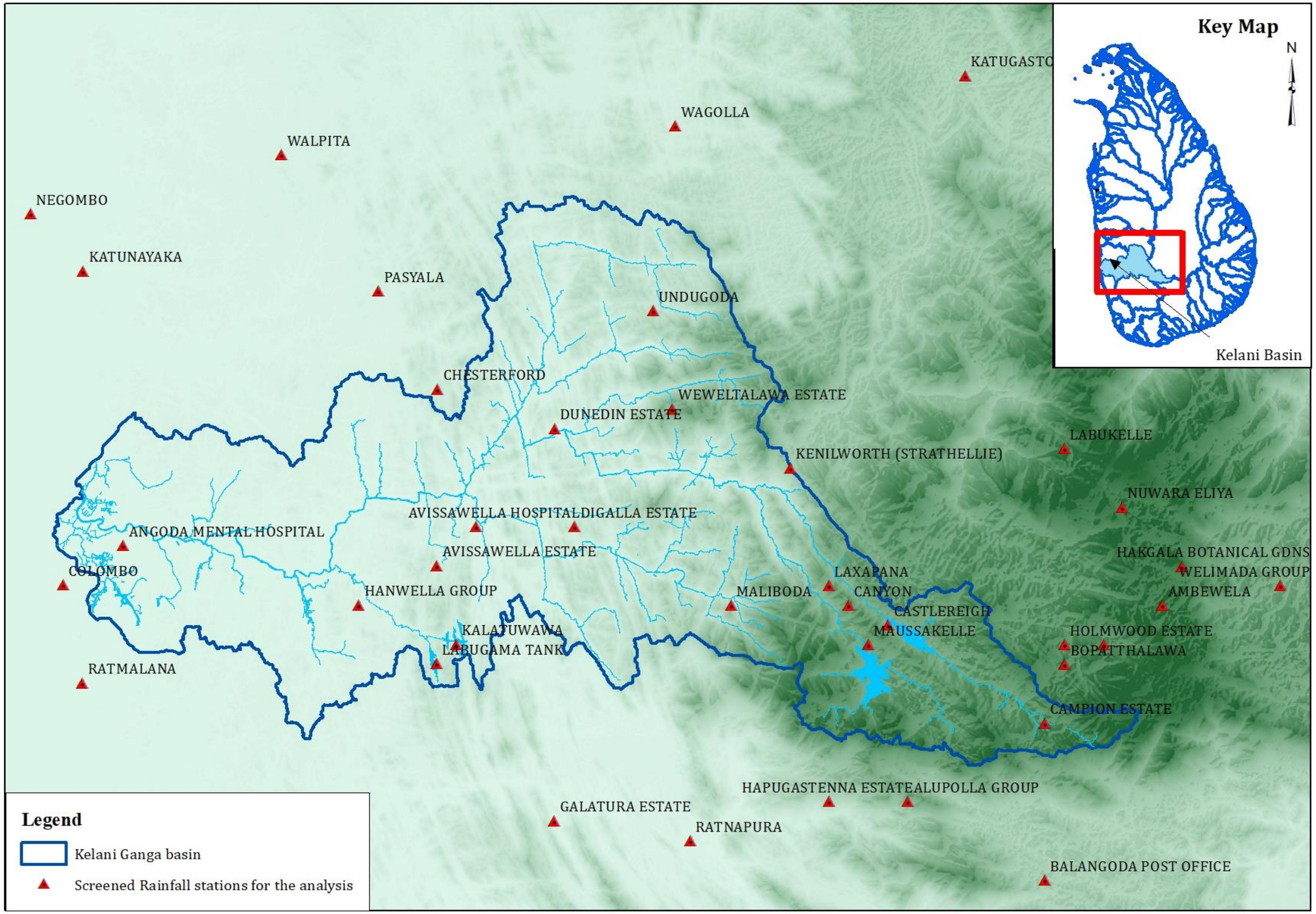


Figure 3-3: Selected Rainfall stations for the analysis in Kelani Ganga basin

Table 3-4: Summary of annual averages (LTA) and Standard Deviation (SD) variation for annual, Maha season and Yala season in selected rainfall stations

Name of the Rainfall station	Annual rainfall totals (mm)				Rainfall totals for Maha season (mm)				Rainfall totals for Yala season (mm)			
	LTA from 1960 to 2016	SD from 1960 to 2016	LTA from 1980 to 2016	SD from 1980 to 2016	LTA from 1960 to 2016	SD from 1960 to 2016	LTA from 1980 to 2016	SD from 1980 to 2016	LTA from 1960 to 2016	SD from 1960 to 2016	LTA from 1980 to 2016	SD from 1980 to 2016
Alupolla Group	4322	943	4221	779	1914	474	1853	440	2418	688	2367	561
Ambewela	2246	488	2117	497	1057	276	1008	307	1202	384	1125	366
Angoda mental hospital	2465	558	2335	518	1112	342	1056	346	1358	374	1282	344
Avissawella Estate	3536	837	3268	846	1540	498	1445	557	2005	523	1829	473
Avissawella Hospital	3765	635	3611	658	1669	409	1630	456	2098	454	1968	395
Balangoda Post Office	2243	426	2214	458	1289	320	1282	364	952	250	923	232
Bandarawela	1585	276	1585	308	988	226	977	248	603	135	618	142
Bopatthalawa	2043	435	1922	419	885	268	844	289	1170	337	1091	297
Campion Estate	2339	425	2349	494	1156	301	1152	343	1184	297	1194	310
Canyon	3981	656	3836	696	1193	268	1125	279	2805	599	2728	635
Castlereigh	3528	691	3409	786	1119	302	1069	344	2424	569	2355	623
Chesterford	3428	642	3388	662	1509	440	1520	483	1923	441	1854	438
Colombo	2397	433	2315	368	1120	319	1085	321	1280	293	1227	242
Digalla Estate	3909	685	3766	751	1582	358	1541	380	2326	528	2218	544
Dunedin Estate	3765	619	3662	685	1601	422	1584	462	2151	438	2057	446
Dyrabba Estate	1579	332	1553	390	974	263	976	311	607	195	588	208
Galatura Estate	4021	691	4044	806	1591	390	1636	452	2431	531	2405	575
Hakgala Botanical Grdns	1897	418	1793	445	1133	334	1076	372	771	205	722	169
Hanwella Group	3131	622	3106	664	1415	398	1427	434	1728	404	1693	405
Hapugastenna Estate	4658	681	4613	731	1816	377	1823	408	2852	587	2805	601

Name of the Rainfall station	Annual rainfall totals (mm)				Rainfall totals for Maha season (mm)				Rainfall totals for Yala season (mm)			
	LTA from 1960 to 2016	SD from 1960 to 2016	LTA from 1980 to 2016	SD from 1980 to 2016	LTA from 1960 to 2016	SD from 1960 to 2016	LTA from 1980 to 2016	SD from 1980 to 2016	LTA from 1960 to 2016	SD from 1960 to 2016	LTA from 1980 to 2016	SD from 1980 to 2016
Holmwood Estate	1966	509	1756	437	830	277	760	279	1151	335	1002	251
Kalatuwawa	3950	508	3889	550	1716	370	1737	414	2240	405	2158	399
Katugastota	1863	323	1860	367	1039	307	1054	366	827	190	809	180
Katunayaka	2168	463	2065	406	1072	334	1034	338	1107	277	1036	234
Kenilworth Strathellie	5436	1151	5681	1246	1675	496	1763	533	3783	903	3916	964
Labugama Tank	3839	568	3720	553	1690	388	1686	426	2157	440	2035	405
Labukelle	3171	636	3111	697	1296	351	1288	412	1896	488	1840	491
Laxapana	4765	794	4570	837	1542	325	1466	336	3241	724	3119	764
Maliboda	5058	1050	4685	876	1796	496	1662	460	3287	806	3042	706
Maussakelle	3071	515	2986	579	1033	223	994	245	2050	460	2002	505
Negombo	1744	531	1591	403	889	352	816	309	865	298	779	222
Nuwara Eliya	1881	358	1856	384	912	250	910	279	981	253	957	252
Pasyala	2772	490	2663	463	1304	339	1277	361	1473	355	1387	331
Ratmalana	2486	428	2440	398	1159	320	1145	336	1328	288	1298	248
Ratnapura	3720	459	3736	495	1507	327	1542	351	2217	380	2193	395
Sandringham Estate	2016	456	1868	397	867	263	820	254	1164	337	1077	285
Undugoda	3381	638	3309	742	1431	446	1443	523	1950	440	1877	444
Wagolla	2074	427	1957	440	1045	277	1010	299	1036	295	962	282
Walpita	2175	445	2139	381	1028	306	1016	303	1147	250	1101	218
Welimada Group	1285	242	1295	288	809	203	817	236	478	164	480	186
Weweltalawa Estate	4971	1023	4648	1006	1880	508	1728	453	3089	782	2904	787

3.2.2.2 Statistical analysis for daily rainfall stations for data checking

Anderson Darling Normality test, Spearman Rank Correlation test, F test, t test, Serial correlation tests and double mass analysis were performed for the optimized alpha parameter, which gives the least Root-mean-squared errors (RMSE) for each month and each percentile of the monthly rainfall. Alpha 1 is optimized for daily rainfall, which has given the least RMSE.

Hence gap-filled rainfall values are used to perform several statistical analysis, which are illustrated below (see Table 3-5 and Figure 3-4).

- a station summary describing the dataset and statistical results (Table 3-5);
- a time-series plot of the annual rainfall totals;
- a time-series plot of the normalized annual rainfall totals;
- a normal probability plot;
- a double mass analysis plot; and

This analysis were carried out for 41 rainfall stations and those plots for Avissawella Estate and Angoda mental hospital are given in Figure 3-4 and Figure 3-5, respectively and Appendix A.

Table 3-5: Summary of statistical results for 41 gap-filled rainfall stations

Station	**Normality**	**Trend analysis**	**Stability of mean**	**Stability of variance**	**Serial correlation**
	p	Spearman	t	F	r
Alupolla Group	Normal	Ok	Ok	Ok	Ok
Ambewela	Normal	Ok	Ok	Ok	Ok
Angoda mental hospital	Not normal	Trend	Trend	Ok	Ok
Avissawella Estate	Normal	Ok	Ok	Ok	Ok
Avissawella Hospital	Normal	Ok	Ok	Ok	Ok
Balangoda Post Office	Normal	Ok	Ok	Ok	Ok
Bandarawela	Normal	Ok	Ok	Ok	Ok
Bopatthalawa	Normal	Ok	Ok	Ok	Ok
Campion Estate	Not normal	Ok	Ok	Ok	Ok
Canyon	Normal	Ok	Ok	Ok	Ok

Station	Normality	Trend analysis	Stability of mean	Stability of variance	Serial correlation
	p	Spearman	t	F	r
Castlereigh	Normal	Ok	Ok	Ok	Correlated
Chesterford	Normal	Trend	Trend	Ok	Ok
Colombo	Normal	Ok	Ok	Ok	Ok
Digalla Estate	Not normal	Ok	Ok	Unstable	Ok
Dunedin Estate	Normal	Ok	Ok	Ok	Ok
Dyrabba Estate	Not normal	Ok	Ok	Ok	Ok
Galatura Estate	Not normal	Ok	Ok	Ok	Ok
Hakgala Botanical Grdns	Normal	Ok	Ok	Ok	Ok
Hanwella Group	Normal	Ok	Ok	Ok	Ok
Hapugastenna Estate	Normal	Ok	Ok	Ok	Ok
Holmwood Estate	Not normal	Ok	Ok	Unstable	Ok
Kalatuwawa	Normal	Ok	Ok	Ok	Ok
Katugastota	Normal	Ok	Ok	Unstable	Ok
Katunayaka	Normal	Ok	Ok	Unstable	Ok
Kenilworth Strathellie	Normal	Ok	Ok	Ok	Ok
Labugama Tank	Normal	Ok	Ok	Ok	Ok
Labukelle	Normal	Ok	Ok	Ok	Ok
Laxapana	Normal	Trend	Trend	Ok	Ok
Maliboda	Normal	Ok	Ok	Ok	Ok
Maussakelle	Normal	Ok	Ok	Ok	Ok
Negombo	Not normal	Trend	Trend	Ok	Ok
Nuwara Eliya	Normal	Ok	Ok	Ok	Ok
Pasyala	Normal	Trend	Ok	Ok	Ok
Ratmalana	Normal	Ok	Ok	Ok	Ok
Ratnapura	Normal	Ok	Ok	Ok	Ok
Sandringham Estate	Normal	Ok	Ok	Ok	Ok
Undugoda	Normal	Ok	Ok	Ok	Ok
Wagolla	Normal	Trend	Trend	Ok	Ok
Walpita	Normal	Ok	Ok	Ok	Ok
Welimada Group	Not normal	Trend	Trend	Ok	Ok
Weweltalawa Estate	Normal	Ok	Ok	Ok	Ok

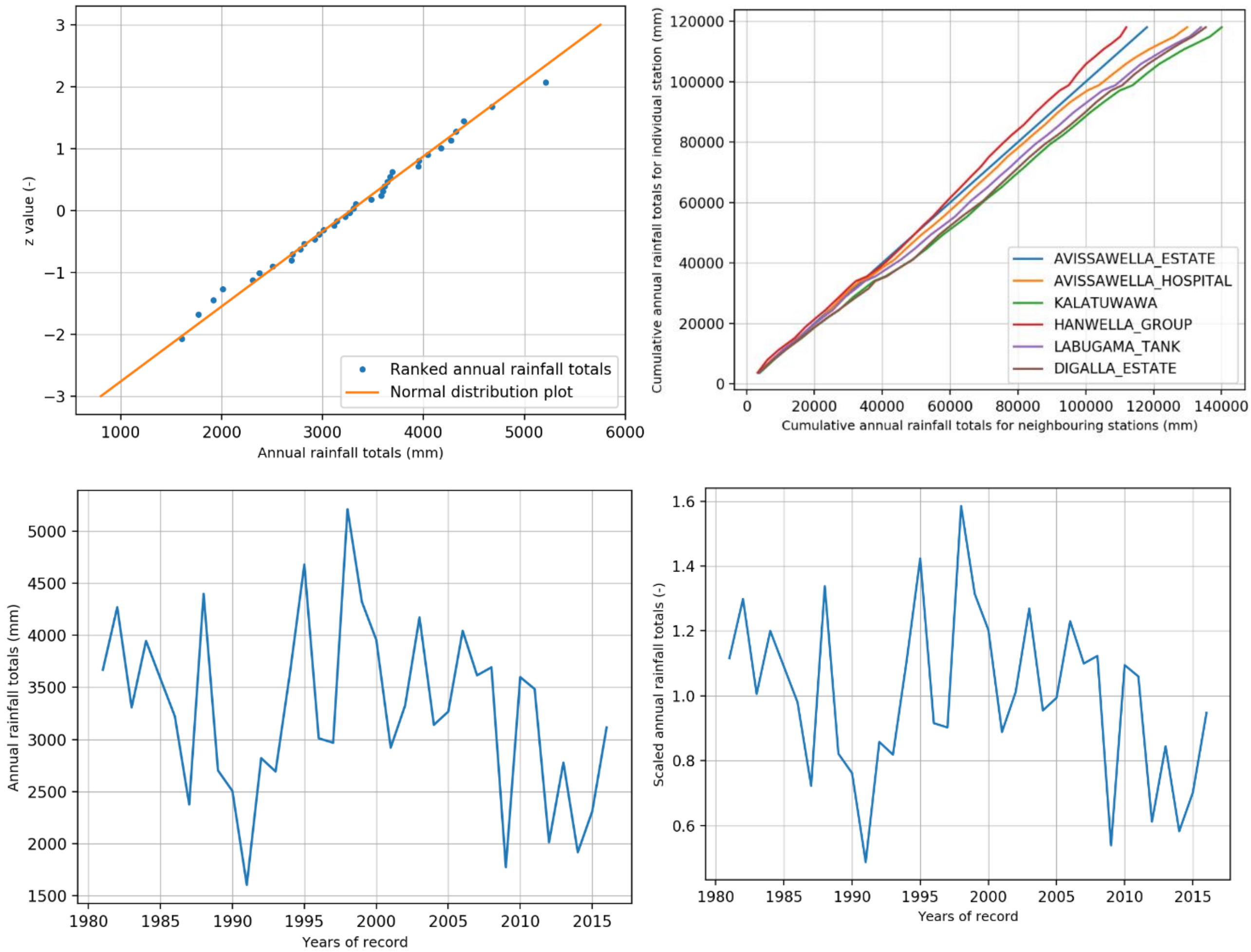
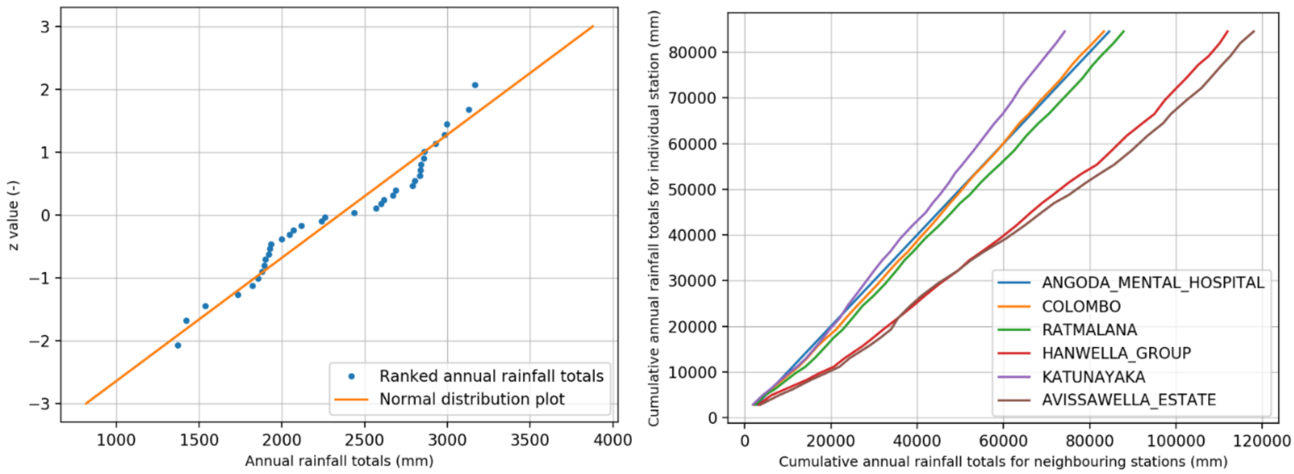


Figure 3-4: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of normalized annual rainfall totals (bottom right) for Avissawella Estate rainfall station



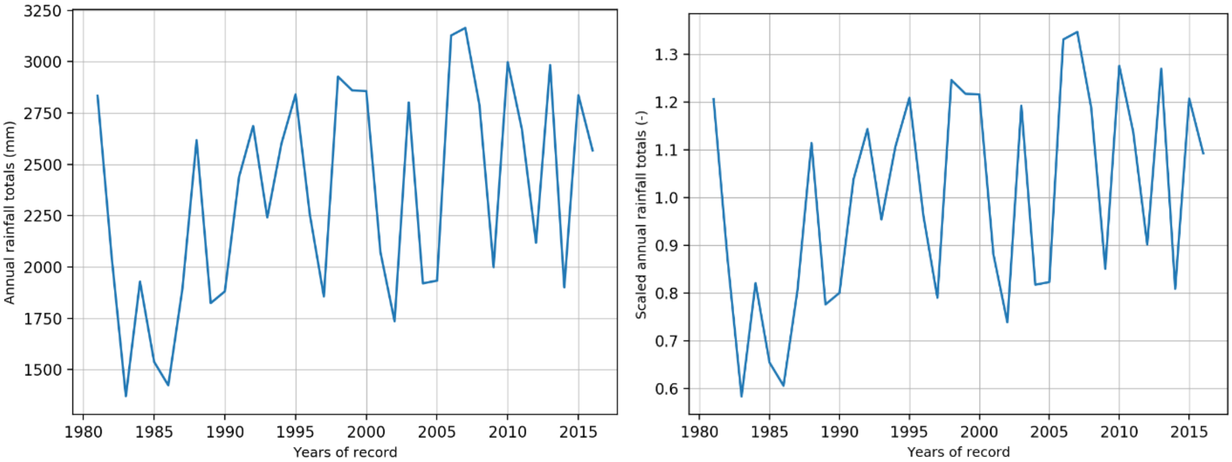


Figure 3-5: Normal Distribution (top left), Double mass analysis (top right) and variation of annual rainfall totals (bottom left) and variation of normalized annual rainfall totals (bottom right) for Angoda mental hospital rainfall station

3.2.2.1 Agroecological zones in the basin

Though the Kelani Ganga basin is situated totally in the wet zone, it has eight (8) Agroecological regions in the basin (Figure 3-6).

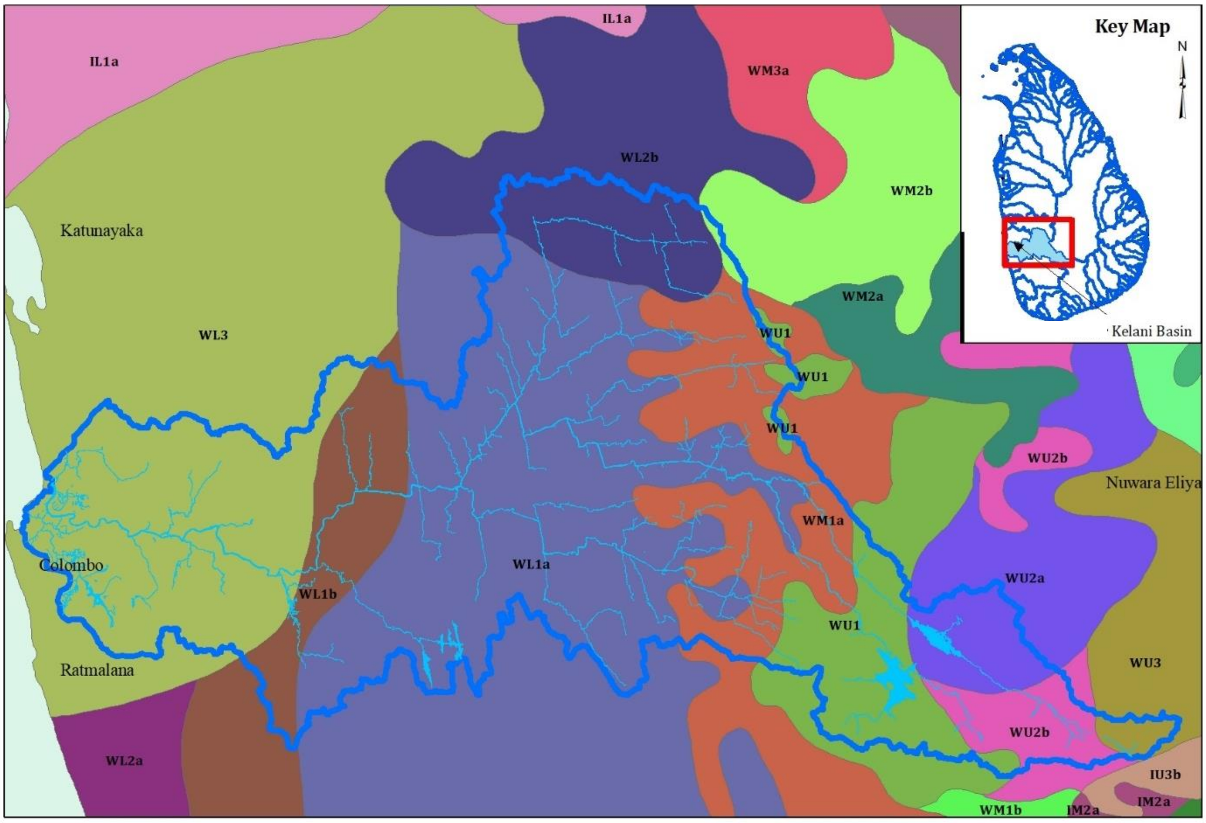


Figure 3-6: Agroecological Zones in Kelani Ganga basin

Source : Department of Agriculture

3.2.3 Temperature gauging stations selection

Among 10 Temperature stations, 10 stations were screened, which are located in 30 km buffer zone in and around Kelani Ganga basin. Among the daily Temperature stations, none of the stations within the Kelani Ganga basin and all 10 stations surrounding the Kelani Ganga basin were processed for gap-filling (Table 3-6 and Figure 3-7) using IDW. Gap filling of pre-processed daily temperature series has been undertaken to provide ‘full record’ temperature data series is taken for data analysis. Accordingly, gap filling has been undertaken for the period of 1960 to 2016. Summary of the raw percentages for each temperature gauging stations is given below.

Table 3-6: Temperature stations were selected for the gap-filling process

Name	X Coordinate	Y Coordinate	Missing data Percentages for the duration of 1980 to 2016		Elevation (m AMSL)
			Tmax	Tmin	
Badulla	530639	498086	0.1%	0.1%	684
Bandarawela	522795	481117	1.4%	1.4%	1114
Colombo	399757	488949	0.2%	0.4%	8
Katugastota	484499	536774	0.4%	0.5%	447
Katunayaka	401655	518437	0.5%	0.5%	7
Kurunegala	455071	551537	0.3%	0.4%	124
Nuwara Eliya	499219	496225	1.3%	0.1%	1883
Ratmalana	401582	479730	5.2%	5.1%	6
Ratnapura	458680	464910	0.2%	1.4%	21
Seetha Eliya	502900	492170	9.1%	8.4%	1826

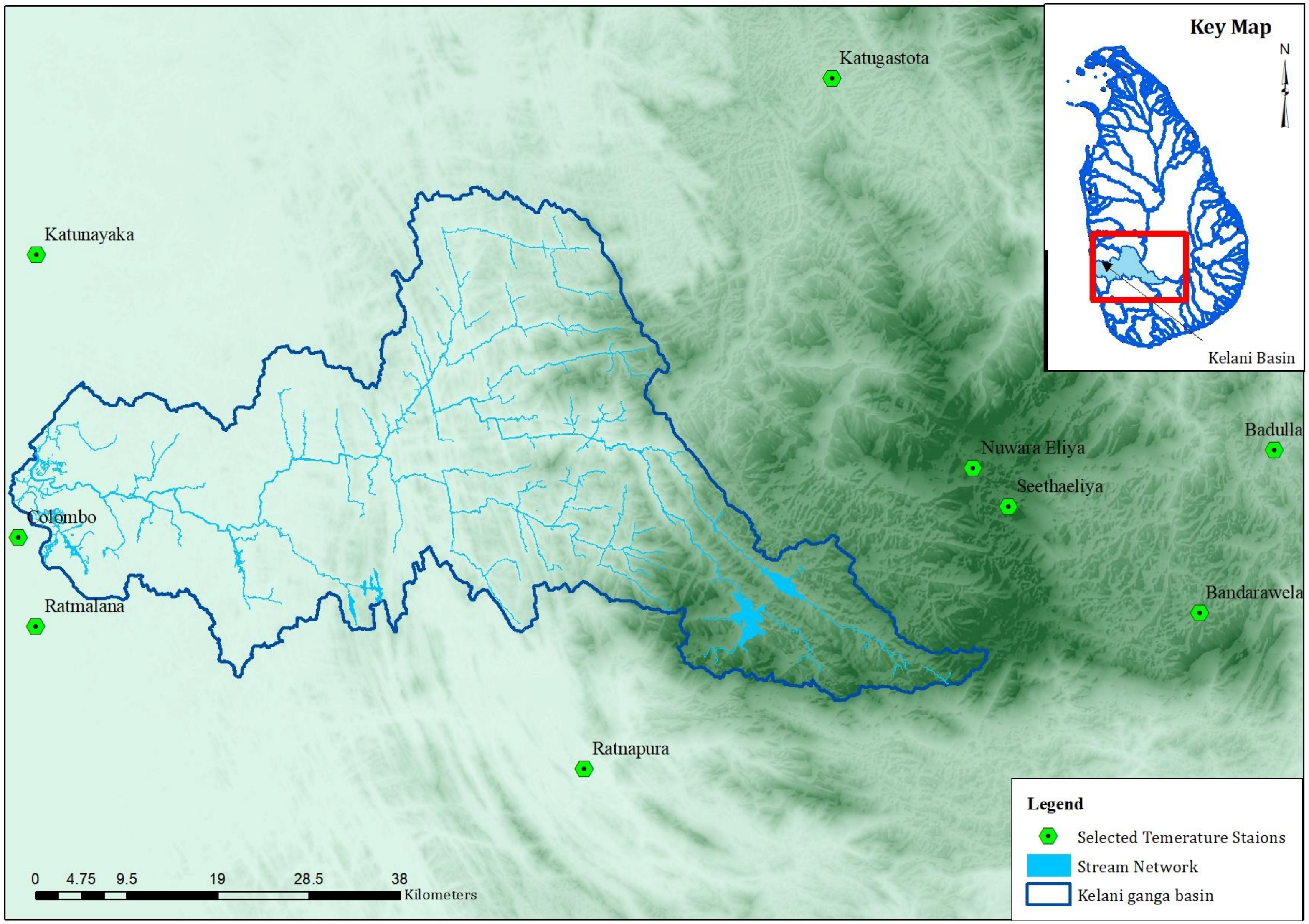


Figure 3-7: Selected Temperature gauging stations in the Kelani Ganga basin

3.2.3.1 Data checking and statistical test results for temperature stations

Summary of annual averages (LTA) and Standard Deviation (SD) variation for annual, Maha season and Yala season in selected temperature gauging stations are given in Table 3-7.

Table 3-8 shows the summary of statistical results of Anderson Darling Normality test, Spearman rank Correlation test, F test, t test, Serial correlation tests for T_{max} and T_{min} time series of 10 gap-filled temperature gauging stations, which were analyzed separately, hence the results are shown in separately. Normal Distribution, Double mass analysis and variation of annual average temperature were potted for 10 temperature gauging stations and those are given in Figure 3-8 for T_{max} and T_{min}, respectively for Colombo temperature gauging station.

Table 3-7: Summary of annual averages (LTA) and Standard Deviation (SD) variation for annual, Maha season and Yala season in selected temperature gauging stations

Name of the Temperature station	Average Temperature (T_{avg})											
	Annual average Temperature (°C)				Average temperature for Maha season (°C)				Average temperature for Yala season (°C)			
	LTA from 1960 to 2016	Standard Deviation from 1960 to 2016	LTA from 1980 to 2016	Standard Deviation from 1980 to 2016	LTA from 1960 to 2016	Standard Deviation from 1960 to 2016	LTA from 1980 to 2016	Standard Deviation from 1980 to 2016	LTA from 1960 to 2016	Standard Deviation from 1960 to 2016	LTA from 1980 to 2016	Standard Deviation from 1980 to 2016
Badulla	23.8	0.52	24	0.54	22.7	0.61	22.9	0.65	24.8	0.54	25	0.55
Bandarawela	20.6	0.52	20.8	0.47	19.6	0.54	19.8	0.51	21.5	0.58	21.8	0.54
Colombo	27.6	0.42	27.8	0.36	27.2	0.51	27.4	0.46	28.0	0.41	28.2	0.33
Katugastota	24.8	0.44	24.9	0.43	24.4	0.57	24.5	0.56	25.1	0.45	25.3	0.42
Katunayaka	27.6	0.42	27.8	0.36	27.2	0.50	27.4	0.45	28.0	0.42	28.1	0.34
Kurunegala	27.4	0.50	27.5	0.51	26.9	0.60	27	0.63	27.9	0.52	28	0.53
Nuwara Eliya	16.0	0.45	16.1	0.42	15.6	0.57	15.8	0.54	16.4	0.45	16.5	0.43
Ratmalana	27.7	0.59	28.1	0.38	27.3	0.63	27.6	0.44	28.2	0.58	28.5	0.38
Ratnapura	26.9	0.35	27	0.29	26.6	0.42	26.8	0.36	27.1	0.34	27.3	0.29
Seetha Eliya	16.0	0.49	16.1	0.49	15.6	0.58	15.7	0.58	16.4	0.51	16.5	0.52

Table 3-8: Summary of statistical results for 10 gap-filled temperature gauging stations

Station	Maximum Temperature (T_{max})				Minimum Temperature (T_{min})				
	Normality	Trend analysis	Stability of mean	Serial correlation	Normality	Trend analysis	Stability of mean	Stability of variance	Serial correlation
	p	Spearman	t	r	p	Spearman	t	F	r
Badulla	Normal	Ok	Ok	Correlated	Normal	Ok	Ok	Ok	Ok
Bandarawela	Normal	Ok	Ok	Ok	Not Normal	Trend	Trend	Ok	Correlated
Colombo	Normal	Ok	Ok	Ok	Normal	Trend	Trend	Ok	Correlated
Katugastota	Normal	Ok	Ok	Ok	Normal	Trend	Trend	Ok	Ok
Katunayaka	Not Normal	Trend	Trend	Ok	Normal	Trend	Trend	Ok	Correlated
Kurunegala	Normal	Ok	Ok	Ok	Normal	Trend	Trend	Ok	Correlated
Nuwara Eliya	Not Normal	Ok	Ok	Ok	Normal	Trend	Trend	Ok	Correlated
Ratmalana	Normal	Ok	Ok	Correlated	Normal	Trend	Trend	Ok	Correlated
Ratnapura	Normal	Ok	Ok	Ok	Normal	Ok	Ok	Ok	Ok
Seetha Elia	Normal	Ok	Ok	Correlated	Not Normal	Trend	Trend	Ok	Correlated

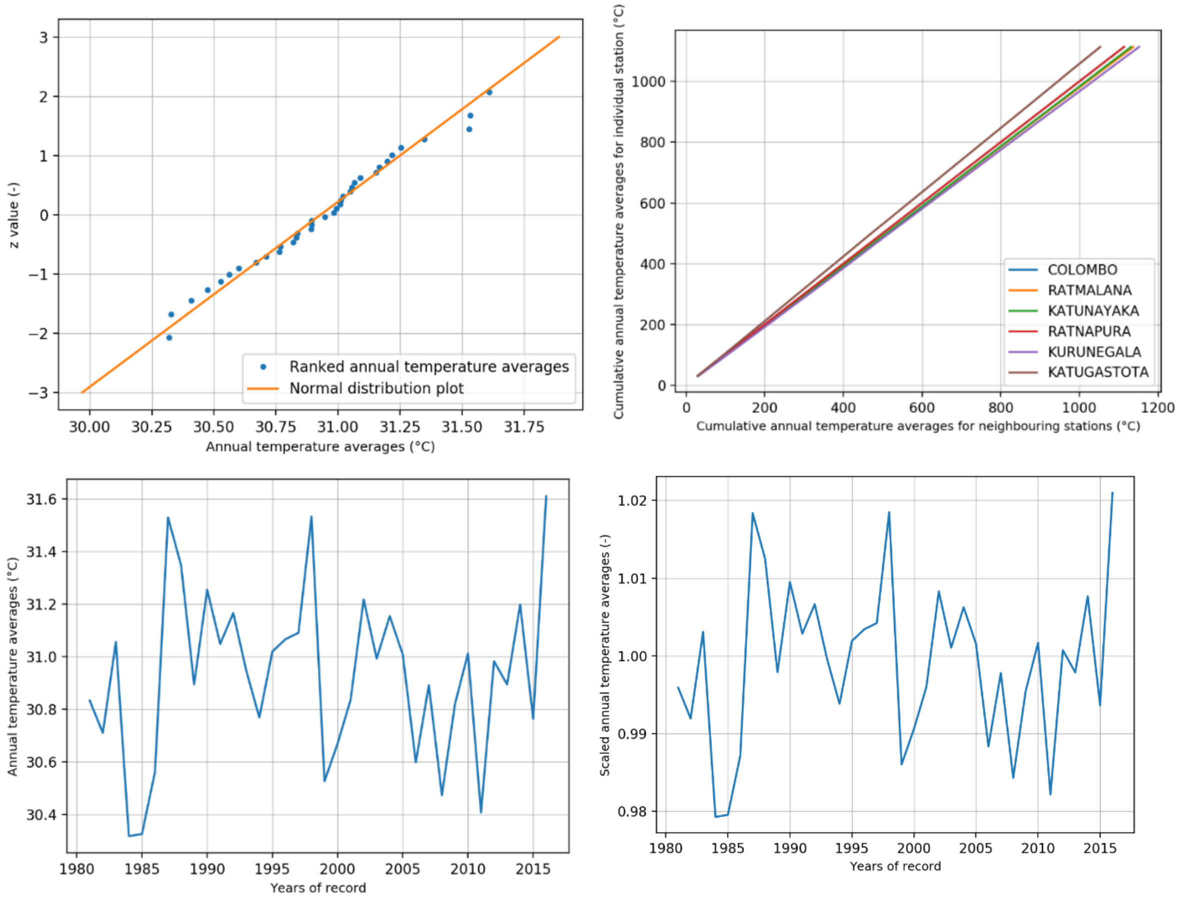
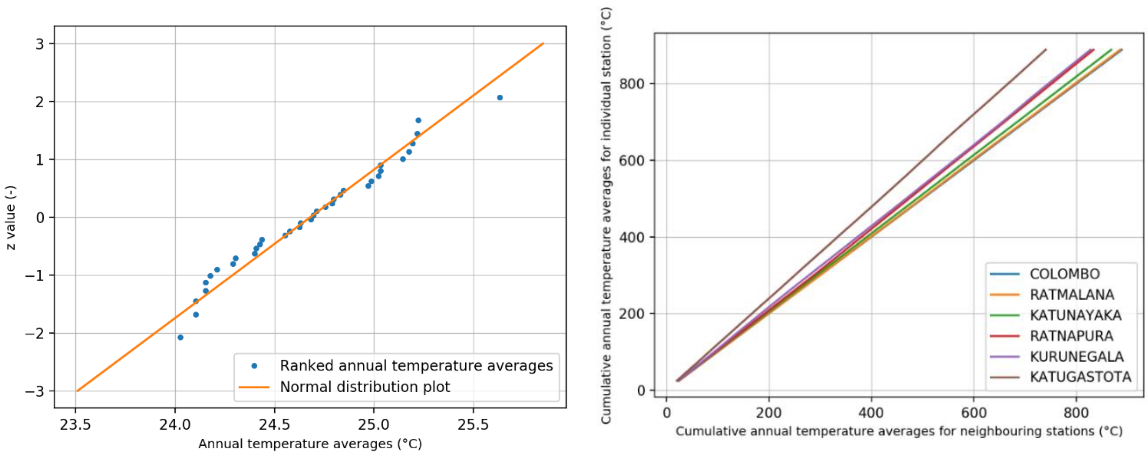


Figure 3-8: Normal Distribution (top left), Double mass analysis (top right) and variation of annual averages (bottom left) and variation of normalized annual averages (bottom right) of Maximum temperature of Colombo temperature gauging station



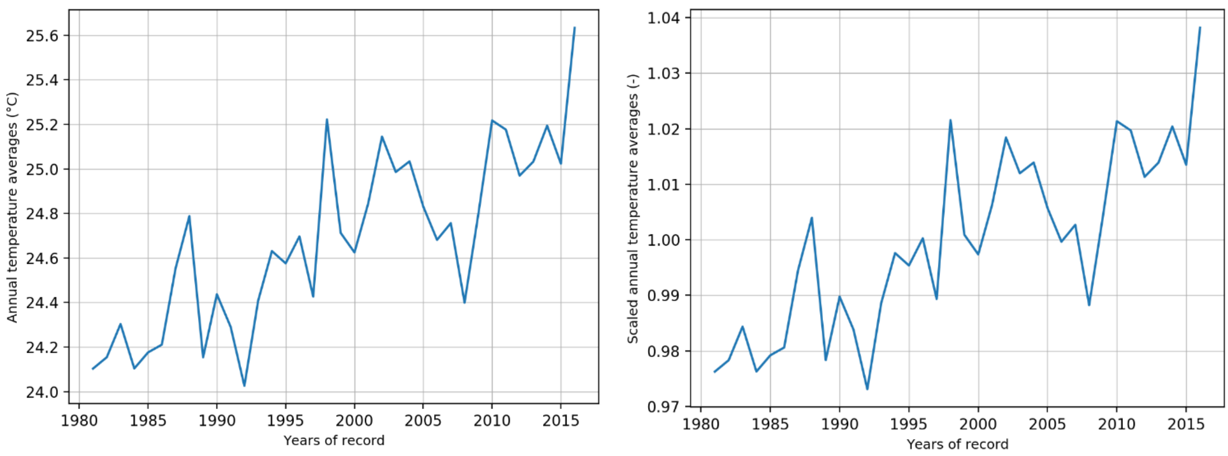


Figure 3-9: Normal Distribution (top left), Double mass analysis (top right) and variation of annual averages (bottom left) and variation of normalized annual averages (bottom right) of Minimum temperature for Colombo temperature gauging station

3.3.4 Hydrometric stations selection

Though there are six (6) hydrometric stations are located in Kelani Ganga basin, only three (3) stations were considered for the analysis, which are located in the main Kelani Ganga. Among the 3 stations, SWAT model is calibrated for Glencourse gauging station, as it is located in the middle of the basin and it has better quality data comparatively other gauging stations, hence it is considered as key monitoring station. Spatial distribution of the catchment areas of each selected gauging station are shown in Figure 3-10 and Table 3-9.

Table 3-9: Catchment Area of each selected gauging station

Station Name	**X Coordinate**	**Y Coordinate**	**Missing data Percentages for the duration of 1980 to 2016**	**Catchment Area (km^2)**
Kitulgala	460819	498925	0.0%	426.5
Glencourse	435657	497646	0.0%	1525.9
Hanwella	423667	490018	3.5%	1835.2

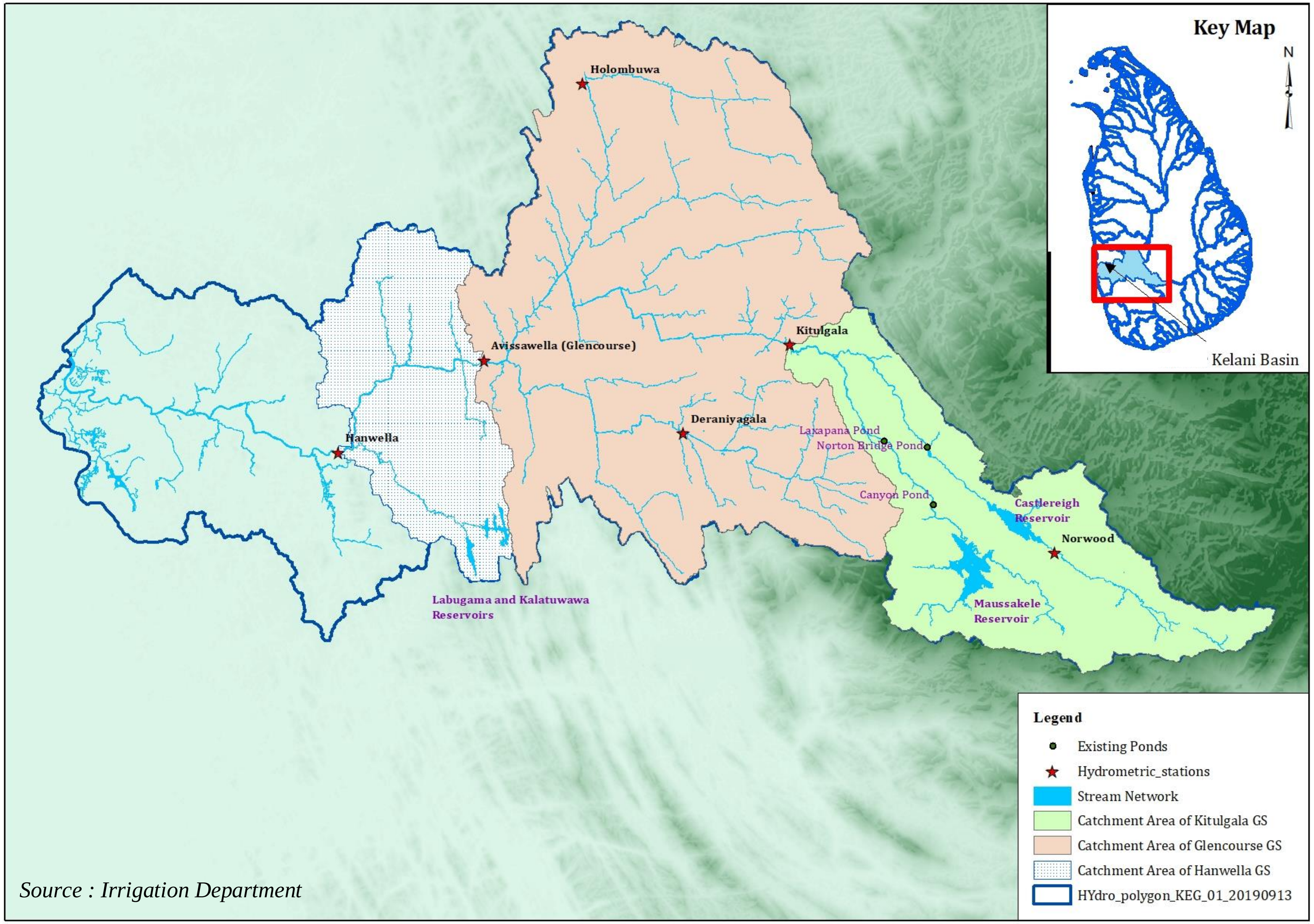


Figure 3-10: Spatial distribution of each hydrometric stations and Reservoirs in the basin

3.3.4.1 Analysis of selected 3 hydrometric stations

Summary of averages (LTA) and Standard Deviation (SD) variation for annual, Maha season and Yala season for selected hydrometric stations are given in Table 3-10 and Table 3-11, respectively. Single mass curves and double mass curves were plotted for annual average flows for selected Glencourse, Hanwella and Kitulgala hydrometric stations and the plots are given in Figure 3-11, respectively.

If the missing data is available in the flow records, the Gap filling is carried out using 2 methods.

1. Using linear interpolation
2. Using nearby station's records.

Linear interpolation was used, if the missing data is less than consecutive five days. If the missing data has high record length, then the gaps were filled using the following equation given below using nearby station's records.

$$\left.\begin{array}{l}\text{Flow record of the day}\\ \text{of missing data of X station}\end{array}\right\} = \begin{array}{l}\text{Available record}\\ \text{of the same day}\\ \text{flow record of the}\\ \text{nearby Y station}\end{array} \times \frac{\text{Catchment area of X station}}{\text{Catchment area of Y station}} \quad \text{........13}$$

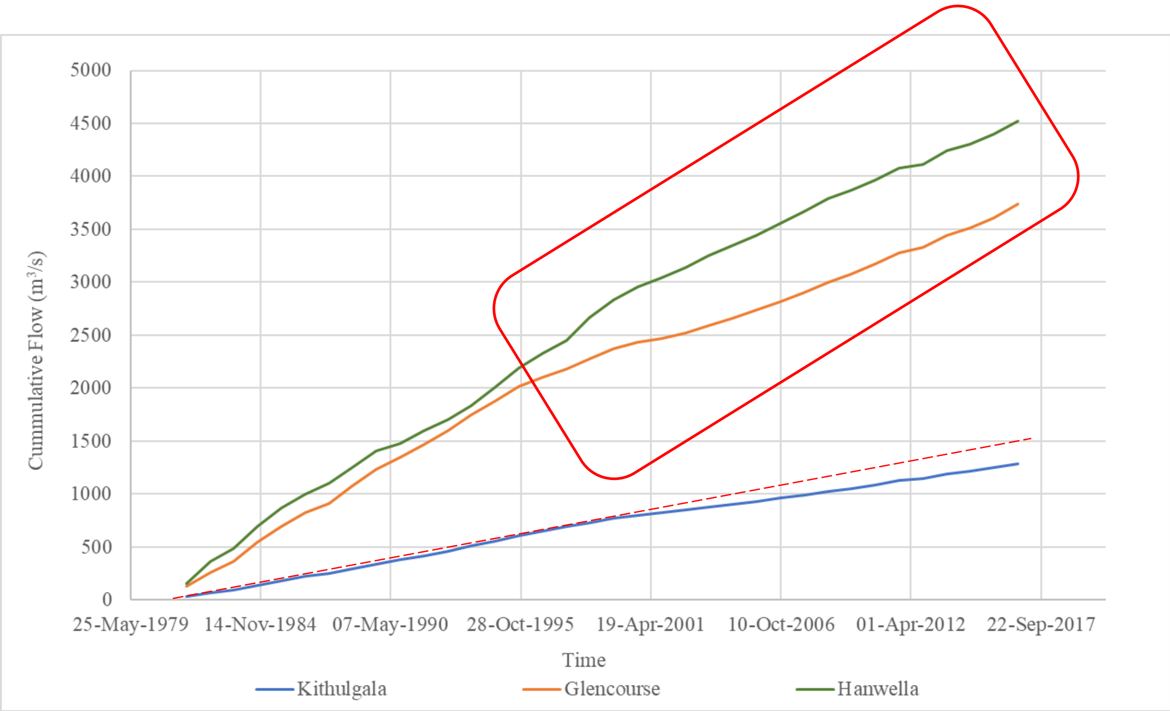
As uncertainties associated with record length, observed water level data and the rating equations for all hydrometric stations due to lots of reasons such as rating equations were not updated properly by considering bed lowering effect in the river as a result of sand mining in Kelani Ganga (Wijesinghe, 2010), the overall uncertainty associated with observed flow records in the Kelani Ganga basin. Though Kitulgala shows two trends, other two stations don't show it, basically the uncertainties in the streamflow records.

Table 3-10: Summary of annual averages (LTA) and Standard Deviation (SD) variation of streamflow for selected hydrometric stations

Name of the Hydrometric station	**Annual average streamflow**					
	LTA from 1960 to 2016 (m^3/s)	**Standard Deviation from 1960 to 2016 (m^3/s)**	**LTA from 1980 to 2016 (m^3/s)**	**Standard Deviation from 1980 to 2016 (m^3/s)**	**LTA from 1960 to 2016 (MCM)**	**LTA from 1980 to 2016 (MCM)**
Glencourse	121.0	39.0	103.8	34.8	3814.6	3272.7
Kitulgala	36.8	7.8	35.7	8.5	1159.2	1126.4
Hanwella	-	-	125.4	39.8	-	3954.6

Table 3-11: Summary of averages (LTA) and Standard Deviation (SD) variation for Maha season and Yala season for the selected hydrometric stations

Name of the Hydrometric station	For Maha season						For Yala Season					
	LTA from 1960 to 2016 (m^3/s)	SD from 1960 to 2016 (m^3/s)	LTA from 1980 to 2016 (m^3/s)	SD from 1980 to 2016 (m^3/s)	LTA from 1960 to 2016 (MCM)	LTA from 1980 to 2016 (MCM)	LTA from 1960 to 2016 (m^3/s)	SD from 1960 to 2016 (m^3/s)	LTA from 1980 to 2016 (m^3/s)	SD from 1980 to 2016 (m^3/s)	LTA from 1960 to 2016 (MCM)	LTA from 1980 to 2016 (MCM)
Glencourse	99.6	37.0	85.8	27.7	1566.2	1341.5	142.3	29.5	121.8	36.7	2250.2	1925.3
Kitulgala	31.0	5.7	30.9	4.9	487.9	483.1	42.5	7.2	40.5	8.4	671.8	641.1
Hanwella	-	-	112.1	27.0	-	1752.5	-	-	138.7	28.0	-	2193.6



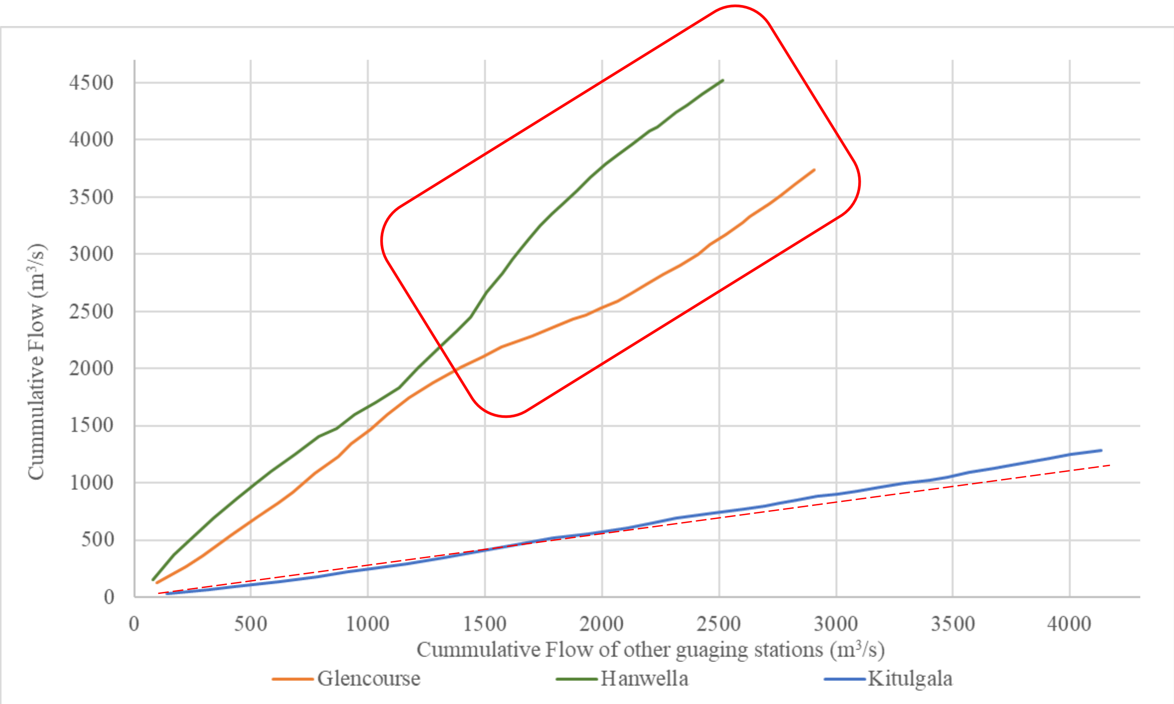


Figure 3-11: Single mass curves (top) and double mass curves (bottom) for annual average flows for selected Glencourse, Hanwella and Kitulgala hydrometric stations

3.3.5 Evaporation stations selection

Two evaporation stations around the Kelani Ganga basin are selected to compare the calculated ET_0 by Hargreaves method in SWAT modelling and the data availability of those two stations are given in Table 3-12.

Table 3-12: Data availability of the two stations of Evaporation

Evaporation station name	X Coordinate	Y Coordinate	Missing data Percentages for the duration of 1980 to 2016
Colombo	399757	488949	17.4%
Seetha Eliya	502900	492170	20.4%

3.3.5.1 Data checking and Analysis of Evaporation data

Summary of annual averages (LTA) and Standard Deviation (SD) variation of calculated ET_0 for annual for selected Evaporation gauging stations are given in Table 3-13.

Figure 3-12 and Figure 3-13 shows the comparison, which was undertaken of Hargreaves derived estimates of PET against actual evaporation data obtained from two stations near the Kelani Ganga basin for Colombo and Seetha Eliya gauging stations, respectively. Extra-terrestrial radiation for each day of the year in the same units of equivalent water evaporation was estimated for station latitude, based on solar constant, solar declination and time of the year, as FAO documentation (Chapter 2 - FAO Penman-Monteith Equation, 202).

Table 3-13: Summary of annual averages (LTA) and Standard Deviation (SD) variation of calculated ET_0 for annual for selected Evaporation gauging stations

Name of the Evaporation station	For Annual averages (mm)	
	LTA from 1980 to 2016	SD from 1980 to 2016
Colombo	3.8	0.41
Seetha Eliya	3.1	0.41

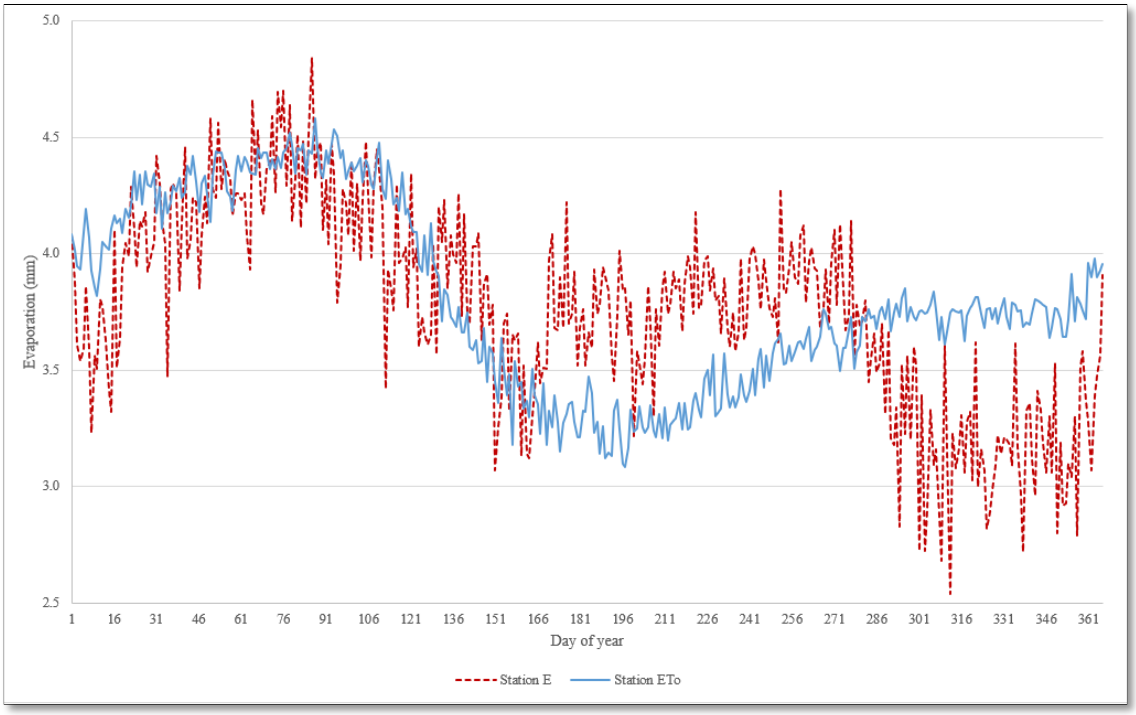


Figure 3-12: Comparison of estimated PET by Hargreaves method and observed Evaporation data for Colombo station

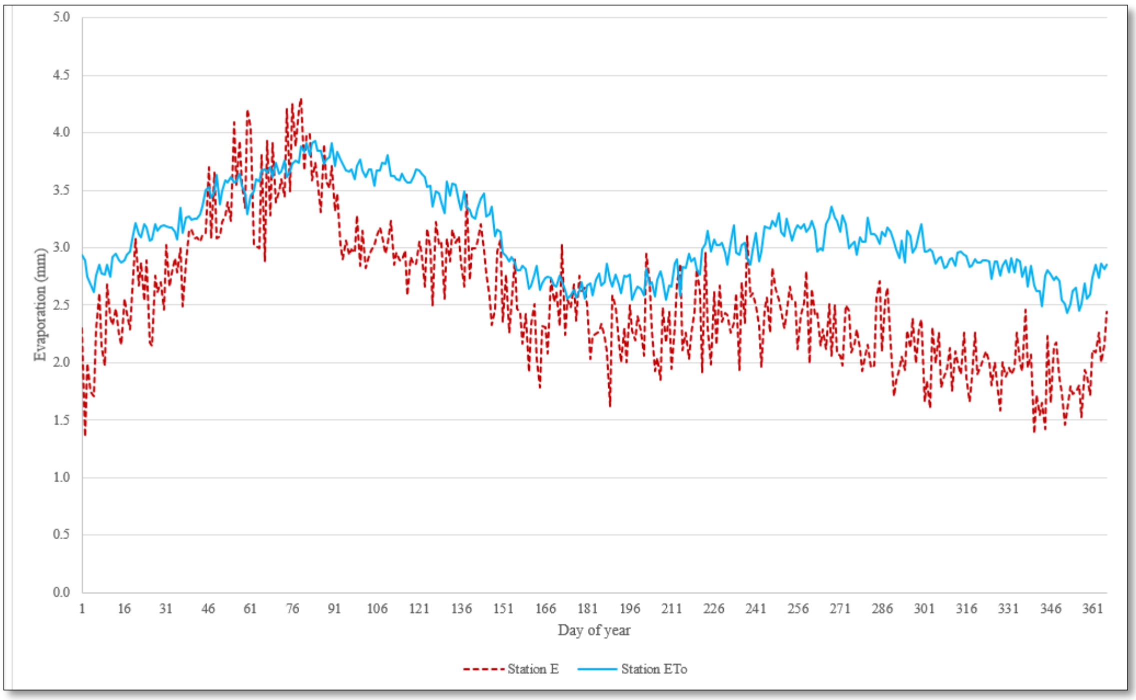


Figure 3-13: Comparison of estimated PET by Hargreaves method and observed Evaporation data for Seetha Eliya station

3.3.6 Reservoirs in the basin

There are 4 existing reservoirs and 3 ponds in the upper reaches of the Kelani Ganga basin (Figure 3-10), utilized 5 for power generation, while 02 utilized for drinking water. The 2 reservoirs and 3 ponds for power generation are: Maussakelle reservoir; Castlereigh reservoir; Canyon reservoir; Norton Bridge reservoir; and Laxapana reservoir. Additional 2 existing reservoirs in the lower reaches of the Kelani Ganga basin, utilized for drinking water supply: Kalatuwawa reservoir; and Labugama reservoir. Castlereigh reservoir started operating in 1958 and Maussakelle reservoir became operational in 1969.

The reservoir parameters (Table 3-14) and observed daily power flow and daily spill flow were obtained by the Mahaweli Authority of Sri Lanka (MASL) and the Ceylon Electricity Board (CEB). There is some uncertainty in the physical characteristics of the reservoirs as there is conflicting information between the various sources about the surface area and volume. Two major Reservoir outflows were used in the SWAT model, while other reservoirs and ponds information were used to feed the SWAT model appropriately.

Table 3-14: Reservoir/ Pond parameters

Name of Reservoir/ Pond	Surface area (ha)	Reservoir volume (MCM)	MOL (m AMSL)	FSL level (m AMSL)	Annual Average Output (GWh/yr)
Castlereigh Reservoir	396	59.7	1076.4	1095.5	117
Maussakele Reservoir	760	114.7	1145.4	1167.4	197
Canyon reservoir	14	1.2	953.4	962.3	490
Norton Bridge reservoir	15	0.4	863.8	866.9	265
Laxapana reservoir	3	0.2	374.3	380.1	420

3.3 Method of Analysis of Climate Change Impacts

Literature suggested that 3 main tests are to be analysed to check the trends in each hydrometeorological parameters such as rainfall, temperature and flow and given below. These tests were carried out for optimized gap-filled parameter (α) for rainfall and temperature time series.

- Innovative Trend Analysis (ITA)
- Mann-Kendall Test
- Sen’s Slope Test

These methods were used to analyse trends in annual and seasonal variations in each parameter. The four seasons were defined as: First Inter Monsoon (FIM) (March - April), South West Monsoon (SWM) (May - September), Second Inter Monsoon (SIM) (October - November) and North East Monsoon (NEM) (December - February). These tests were used to analyse Maha (October to April) and Yala (May to September) seasons as well. Mann-Kendall and Sen’s Slope were used to verify the results of Innovative Trend Analysis (ITA). Following mentioned test were carried out to analysis of Climate Change impacts on hydrometeorological parameters.

Other than the above mentioned tests, decadal averages (Collins, 2002) were plotted with Long term averages (LTA) with respect to the whole duration of 5 decades (from 1960 to 2010) and LTA for the reference period of 1980 to 2016. Decadal averages were analyzed for annual and seasonal rainfall series, whether the trends, standard deviation are significant in the time series.

Deviation from mean is plotted to each time series from 1960 to 2016 to analysis the variation of time series and compare it with decadal averages plots.

3.3.1 Innovative Trend Analysis (ITA)

Innovative Trend Analysis (ITA) is an innovative or novel technique suggested by Şen (2012, 2014). Trends are best suited for the time series through the well-known regression methodology, which frequently observed and identified as linear lines.

The time-series is sub-divided into two parts, so that trend presence can be compared between these two parts. The steps are executed to reach at a graph that shows potential partial trends for “low”, “medium” and “high” precipitation values (Şen, 2012, 2014) as given below.

1) The main time series is divided into two similar sub-sets,

2) Each sub-set are sorted into ascending order and plot the most recent one sub-set on the horizontal axis against the others on a Cartesian coordinate system,

3) A 45^o straight line is drawn on the same Cartesian coordinate system.

4) The scatter points are examined by identifying the trends in the scatter diagram,

5) The time-series do not have significant trend, if the scatter of points are close to 45° line within ±10 % error, otherwise, the time series shows the noteworthy increasing or decreasing trend.

The ITA values can be compared with Mann-Kendall (MK) trend test using the trend indicator, which is given by:

$$D = \frac{1}{n}\sum_{i=1}^{n} 10\,\frac{(y_i - x_i)}{\bar{x}} \quad \text{.....14}$$

where *D* is the trend indicator, and a negative value indicates a decreasing trend, whereas a positive value for *D* indicates an increasing trend; *n* is the number of observations of each sub-sets and *x* is the average of the first sub-set. If the original time series has odd observations, the first observation is discarded before dividing to make full use of the latest data (Wu & Qian, 2017).

3.3.2 Mann-Kendall (MK) test

The Mann–Kendall test, proposed by Kendall (1938, 1970) and it is a non-parametric test, which is widely used most popular methods to detect trends in hydro-meteorological time series (Şen, 2012; Wu & Qian, 2017). The significance of a trend was assessed at the 0.1%, 1%, 5% and 10% significance levels for the Mann–Kendall test. The test statistic S is given by

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sgn\,(x_j - x_i) \quad \text{.....15}$$

where *n* is the number of observations, x_i and x_j are the i^{th} and j^{th} $(j > i)$ observations in the time series, respectively and sgn$(x_j - x_i)$ is the sign function as:

$$\text{sgn}(x_j - x_i) = \begin{Bmatrix} +1\,,\ if\ (x_i - x_j) > 0 \\ 0\,,\ if\ (x_i - x_j) = 0 \\ -1\,,\ if\ (x_i - x_j) < 0 \end{Bmatrix} \quad \text{.....16}$$

when n is greater than 10, the distribution of statistic S tends to normality. The variance can be calculated as follows:

$$\mathrm{Var}(S) = \frac{\boldsymbol{n\,(n-1)\,(2n+5)} - \sum_{k=1}^{m}(t_k - 1)(2t_k + 5)}{18} \quad \text{……………………………………..………17}$$

where m is the number of tied groups, t_k is the number of ties of extent k. The standard normal test statistic Z used for detecting a significant trend is expressed as,

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & if\ S > 0 \\ 0, & if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & if\ S < 0 \end{cases} \quad \text{………………………………………………………………18}$$

A positive value of Z indicates an upward trend, while a negative value of Z indicates a downward trend.

3.3.3 Sen's Slope test

Sen (1968) developed the slope of the trend using a non-parametric procedure in the sample of N pairs of data:

$$Q_i = \frac{x_j - x_k}{j-k} \text{ for } i = 1,\ldots,N \quad \text{………………………………………………………………..19}$$

where x_j and x_k are the data values at times j and k $(j>k)$, respectively. If there is only one datum in each time period, then $N = \frac{n(n-1)}{2}$; where n is the number of time periods. If there are multiple observations in one or more time periods, then $N < \frac{n(n-1)}{2}$; where n is the total number of observations. The N values of Q_i are ranked from smallest to largest and the median of slope or Sen's slope estimator is computed as

$$Q_{med} = \begin{cases} Q_{\left[\frac{N+1}{2}\right]}, & if\ N\ is\ odd \\ \frac{[Q[(N+2)/2] + Q[(N+2)/2]]}{2}, & if\ N\ is\ even \end{cases} \quad \text{……………………………….……………..…20}$$

The Q_{med} sign reflects data trend reflection, while its value indicates the steepness of the trend.

3.4 Analysis the current Potential Effects of Climate Change on Streamflow based on Runoff Elasticity

The two-parameter climate elasticity as introduced by Fu et al. (2007); Yang and Yang

(2011), as;

$$\frac{dR}{R} = \varepsilon_a \frac{dP}{P} + \varepsilon_b \frac{dT}{T} \quad \text{..........21}$$

The *ε* is defined as lots of literature as Chiew (2006); (Sankarasubramanian et al., 2001); (Niemann & Eltahir, 2005);

$$\varepsilon = \text{median}\left[\frac{(R_i - \bar{R}) / \bar{R}}{(X_i - \bar{X}) / \bar{X}}\right] \quad \text{..........22}$$

But recently,(Zheng et al., 2009) suggested that the concept of climate elasticity was used to assess the impacts of climate and land surface change on the streamflow and they described *ε* as following,

$$\varepsilon = \frac{\bar{X}}{\bar{R}} \frac{\sum(X_i - \bar{X})(R_i - \bar{R})}{\sum(X_i - \bar{X})^2} \quad \text{..........23}$$

where *X* represents the climatic variables (e.g., *P*, and *T*), and *R* and *X* represent the mean annual runoff and any climatic variable, respectively. During the study, the runoff elasticity is calculated from 1980 to 2016 period.

3.5.2. Hydro-meteorological inputs and reservoir inputs

During the model schematisation, weather data and reservoir inputs are added to the model. The model includes the two major reservoirs at the upper reaches of the Kelani Ganga basin – Castlereigh and Maussakelle as reservoirs, while other 5 tanks were fed as ponds to the model.

3.5 SWAT Modelling

The rainfall-runoff modelling has been undertaken in order to simulate the streamflow in the Kelani Ganga basin for future scenario and to evaluate the parameter transferability. Governing equation in SWAT is given in section 2.7.1 (Neitsch et al., 2011).

3.5.1 Key components and State variables

Key components of the SWAT model are weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading, and water transfer and those are given in Figure 3-14 (Neitsch et al., 2011). There are more than 50 state variables are given in the SWAT manual (Neitsch et al., 2017) and among those variables, the key state variables, which can be used for calibration and validation, are given in Table 3-15.

Table 3-15: The key state variables of SWAT model

HYDROLOGIC CYCLE

Potential and Actual Evapotranspiration

Variable	File	
IPET	.cod	Chapter 4
PETFILE	file.cio	Chapter 3
ESCO	.bsn, .hru	Chapter 5, 19
EPCO	.bsn, .hru	Chapter 5, 19
PET_MEAS	.pet	Chapter 12
ELEV	.sub	Chapter 6
CANMX	.hru	Chapter 19
SOL_ALB	.sol	Chapter 22
GW_REVAP	.gw	Chapter 24
REVAPMN	.gw	Chapter 24

Surface Runoff

Variable	File	
IEVENT	.cod	Chapter 4
SURLAG	.bsn	Chapter 5
CN2	.mgt	Chapter 20
CNOP (***plant operation***)	.mgt	Chapter 20
CNOP (***harv & kill op***)	.mgt	Chapter 20
CNOP (***tillage operation***)	.mgt	Chapter 20

Time of Concentration

Variable	File	
CH_L(1)	.sub	Chapter 6
CH_S(1)	.sub	Chapter 6
CH_N(1)	.sub	Chapter 6
SLSUBBSN	.hru	Chapter 19
OV_N	.hru	Chapter 19

Crack Flow

Variable	File	
ICRK	.cod	Chapter 4
SOL_CRK	.sol	Chapter 22

Transmission Losses from Surface Runoff

Variable	File	
CH_L(1)	.sub	Chapter 6
CH_W(1)	.sub	Chapter 6
CH_K(1)	.sub	Chapter 6

Soil Water

Variable	File	
FFCB	.bsn	Chapter 5
SOL_Z	.sol	Chapter 22
SOL_BD	.sol	Chapter 22
SOL_AWC	.sol	Chapter 22
SOL_K	.sol	Chapter 22
irrigation operation	.mgt	Chapter 20
auto-irrigation operation	.mgt	Chapter 20

Source : SWAT User Manual, 2017

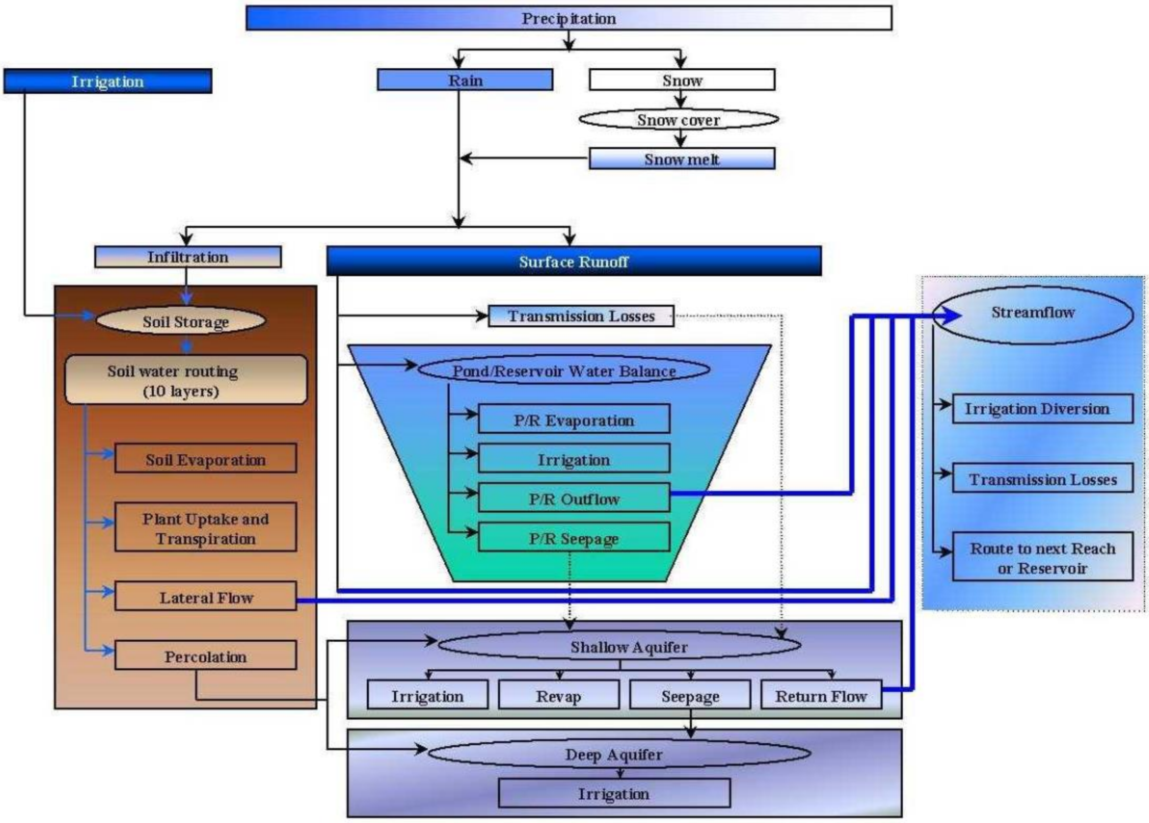


Figure 3-14: Key components of the SWAT model

Source: SWAT User Manual, 2017

3.5.2. Modelling process, inputs and Outputs

SWAT Modelling process and parameterisation includes the following main processes:

- Delineate watershed and sub-basins;
- Define hydrological response units (HRUs); and
- Parameterise "artificial" features eg: Reservoirs, ponds, etc..

3.5.2.1 Delineate watershed and sub-basins

The schematization of the Kelani Ganga SWAT model is based on the use of a catchment digital elevation model, supplemented by a defined river network and the locations of basin inlets, outlets and existing on-line reservoirs (Figure 3-15).

3.5.2.2 Digital Elevation Model (DEM)

A 4m grid cell size DEM of the Kelani Ganga basin, itself derived from a combination of LiDAR and aerial photography, has been developed as part of the Kelani Ganga basin GIS data processing. Based on this cell resolution, aggregated versions of the DEM were created in ArcGIS for 16 m, 32 m and 64 m grid cell resolutions to obtain DEM for the analysis.

Assessments were undertaken using the ArcGIS Arc Hydro tool (ESRI, USA) to assess the impact of selecting different resolution grids for defining the watershed and sub-basins. Considering the current basin-scale requirements of the SWAT model, the 64 m DEM was considered appropriate to be used as the primary input to SWAT.

3.5.2.3. River network

The ArcGIS Arc Hydro tool was also used to define the river network of the Kelani Ganga basin based on 4 m DEM. Various different 'catchment threshold' values were assessed during the development of the stream network: 5 km^2, 10 km^2, 10 km^2 and 25 km^2 and 35 km^2.

Accordingly, it was decided to select the 4 m DEM 35 km^2 catchment threshold river network for use in QSWAT and use this to 'burn-in' the river network into the 64 m DEM to help ensure the appropriate definition of sub-basins after confirmation and validation of the delineated river networks was undertaken using Google Earth imagery. 49 sub-basins were delineated from 64 m resolution DEM for the Kelani Ganga basin.

3.6.2.4. Inlets, outlets and reservoirs

The SWAT model of the Kelani Ganga basin is schematised to cover the whole of the basin. Therefore, no 'inlets' to the model are defined. The 'outlet' of the watershed was placed appropriately based on examination of the derived river network, the DEM, aerial photography and local knowledge.

There are 4 existing reservoirs and 3 ponds in the upper reaches of the Kelani Ganga basin, as described in Chapter 3.3.6. Additional 2 existing reservoirs in the lower reaches of the Kelani Ganga basin, utilised for drinking water supply: Kalatuwawa reservoir; and Labugama reservoir. These are two relatively small reservoirs located in tributary headwaters not represented by the 4 m DEM 35 km^2 catchment threshold river network. Accordingly, within the selected schematisation, they have been merged into one single (in-line) pseudo-reservoir.

3.6.2.5. Hydrological Response Units (HRUs)

The hydrological response units (HRUs) within sub-basins determines the rainfall-runoff processes with each sub-basin. Land use data, soil data and topography are the key factors that determine the definition of HRUs.

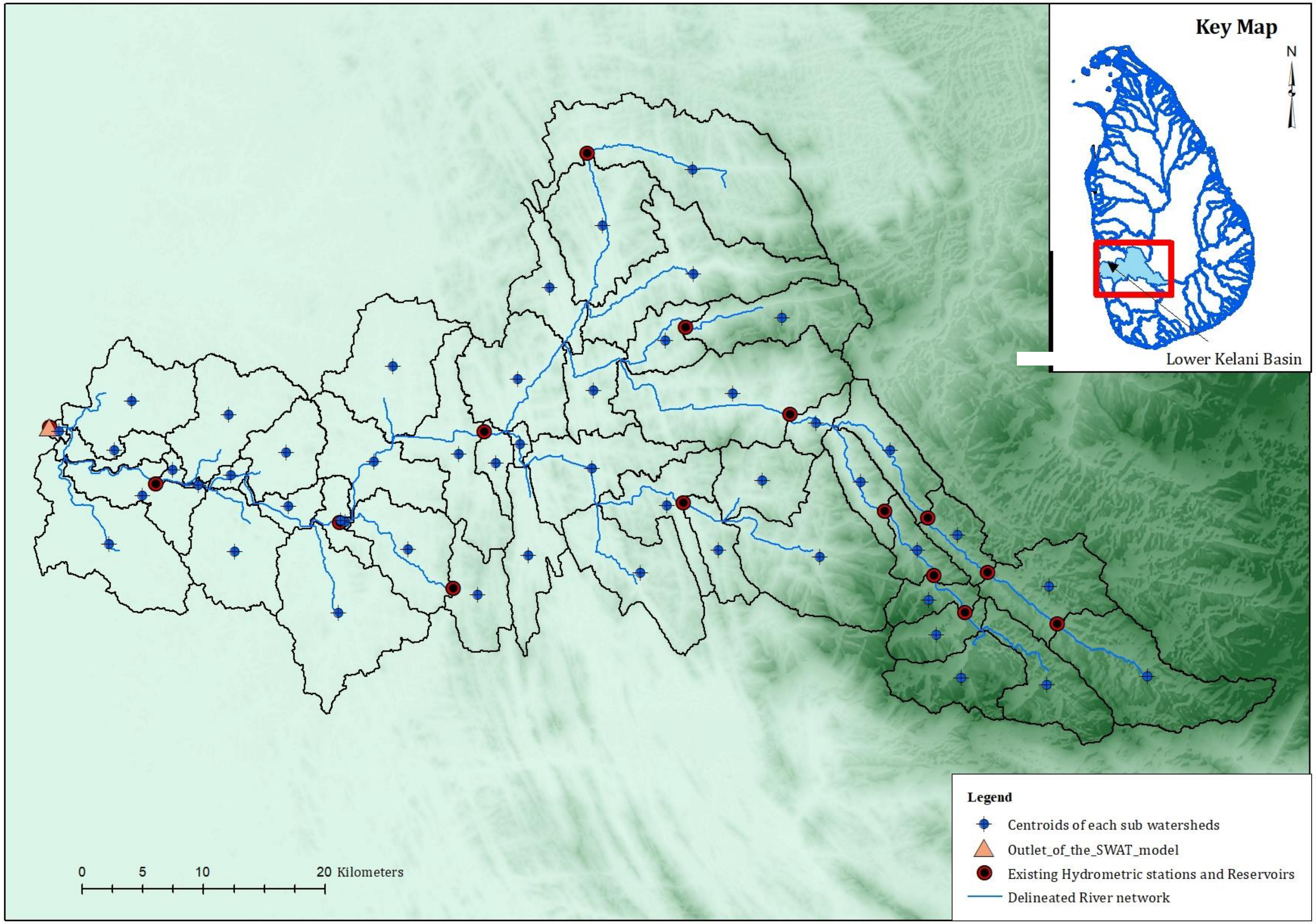


Figure 3-15: SWAT Model Schematisation for Kelani Ganga basin

3.5.2.5.1 Land use

3.5.2.5.1.1 Current Landuse

Table 3-16 and Figure 3-16 shows the distribution of land-use within the Kelani Ganga basin based on the use of the LUPPD dataset. Some land-use types were verified using Google Earth (Google Inc., USA).

Table 3-16: Summary Statistics of Pre-processed Land use Types

Landuse Type	Area in ha	Coverage (%)
Barren Land	52.7	0.0%
Built up Land	18755.5	8.0%
Cemetery	22.3	0.0%
Chena	4.0	0.0%
Coconut	5435.3	2.3%
Forest	26338.4	11.3%
Forest Plantation	2005.7	0.9%
Grass Land	3076.2	1.3%
Home Garden	58360.3	24.9%
Marsh	34.8	0.0%
Other	4335.0	1.9%
Other Field Crops	490.7	0.2%
Paddy	14098.4	6.0%
Park	2.3	0.0%
Playground	89.2	0.0%
Rock	520.7	0.2%
Rubber	63412.9	27.1%
Scrub	6568.9	2.8%
Tea	26214.5	11.2%
Water Bodies	4199.6	1.8%

The dominant land-use classes in the pre-processed land use data are ‘Rubber’ (27.1 %) and ‘Home Garden’ (24.9 %). ‘Tea’ (11.2 %), ‘Forest’ (11.3 %), ‘Built up Land’ (8 %) and ‘Paddy’ (6.0 %), covers over 88.5 % of the basin.

Additionally, ‘Home Garden’ has been identified as a composite land-use type. Based on technical discussions with the LUPPD, aerial photography, expert judgement and local knowledge, this land-use type has been split into three separate classes, based on the population density of Grama Niladari Division as 2012 census data.

- If Population Density > 10,000, then the ‘home garden’ has been reclassified as ‘high density urban’ (URHD);

- If the Population Density in-between 3,500 and 10,000, then the ‘home garden’ has been reclassified as ‘medium density urban’ (URMD); and

- If the Population Density less than 3,500, then the ‘home garden’ has been reclassified as ‘low density urban’ (URLD).

It can be seen that following processing, ‘Rubber’ remains the dominant land-use class (27.1 %), whereas due to disaggregation, ‘Home Garden’ is split into three smaller land-use classes (URLD – 3.8%; URMD – 6.4 %; and URHD – 1.9 %). Accordingly, ‘tea’, ‘Home garden’ and ‘forest’ become relatively more important as land use types in the basin.

3.5.2.5.1.2 Future Landuse for 2040

Future landuse for 2040 is taken based on the Flood and Drought Risk Assessment report for Kelani Ganga basin (WS Atkins International Ltd, 2019). Population growth between the present day and 2040 will not be spatially uniform and will be influenced by several factors, namely political, economic, environmental, topographic and infrastructure development. The proximity of growth locations has been based on planned infrastructure and urban developments outlined in the NPP (National Physical Planning Dept, 2011) and the WRMMP to guide the spatial distribution of projected population growth changes to 2040.

To predict the spatial distribution of population growth in 2040, the following assumptions have been made:

- There will be significant growth in towns with ‘Mega Projects’ earmarked for future development and expansion (e.g. Plantation City (Avissawella) and The Aero Maritime Trade Hub (Colombo port to Negombo including Ja Ela and Katunayaka));
- Growth will also concentrate along existing and planned key transport corridors including:
    - Existing expressway and trunk roads, plus proposed extensions to the expressway network and road upgrades;
    - Railway interventions including upgrades to existing lines and the proposed railway between Kelaniya and Kosgama; and
    - Improvements to the existing water transport network.
- There will be growth around key transport hubs, including road, rail, sea, air and multimodal hubs;

- There will be limited or no growth in protected areas such as forests and conservation areas and the Central Fragile Area (CFA), limiting the expansion of settlements in these areas; and
- Restrictions on urban sprawl outside of these assumptions (e.g. planning restrictions or unfavorable building conditions) were not considered.

Using the LUPPD land use mapping and the growth and constraint factors developed as part of the population growth analysis, the existing land use maps were updated to represent the projected land use change in 2040 (WS Atkins International Ltd, 2019).

A summary of the land use changes made are shown in Table 3-17 and illustrated in Figure 3-17. Landuse for 2040 is used for simulate flow to obtain runoff elasticity for 2040.

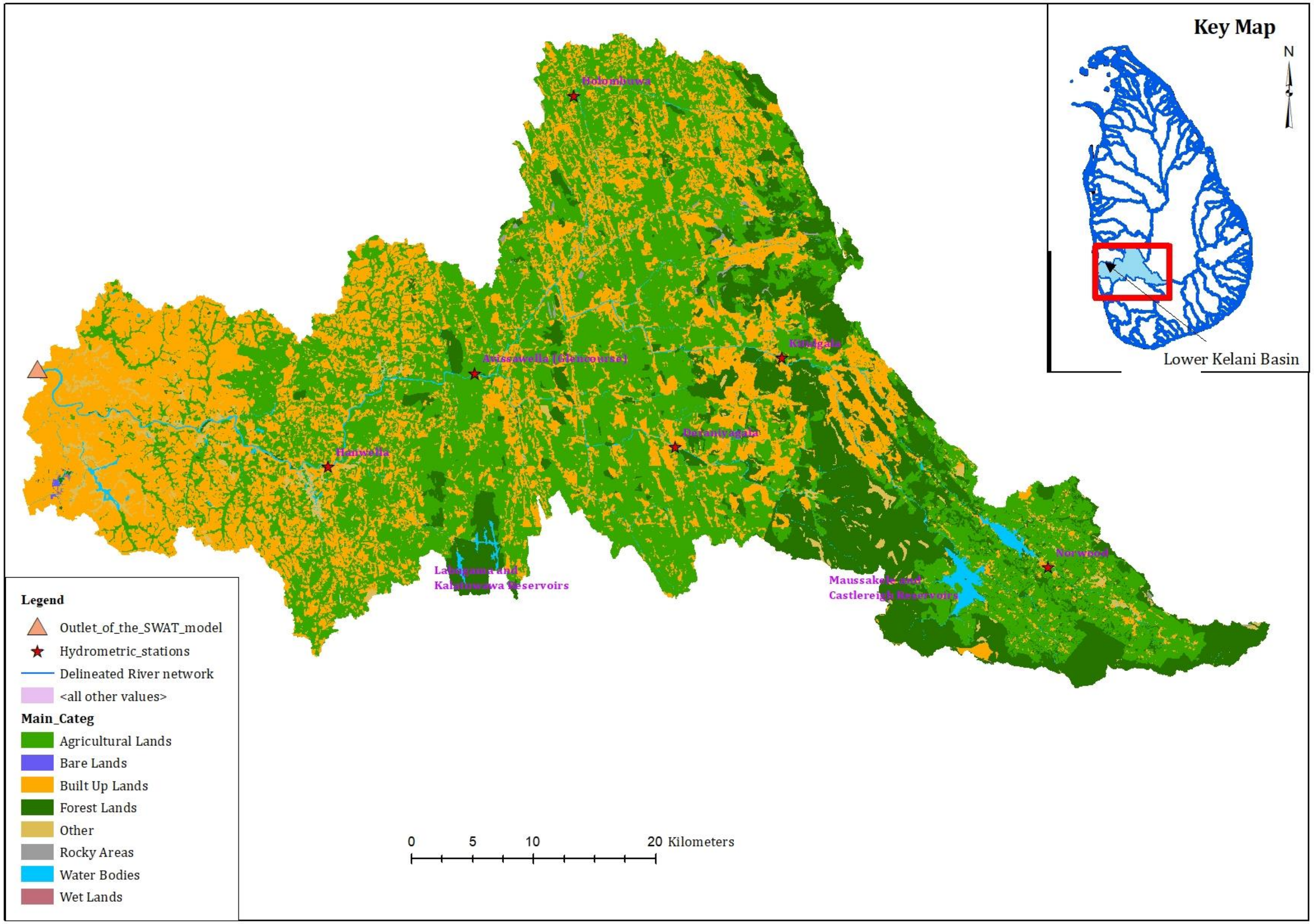
Table 3-17: Future land use changes in the Kelani Ganga basin

Current land use	**Land use change**
Urban Area High Density (URHD)	Urban Area High Density (URHD)*
Urban Area Medium Density (URMD)	Urban Area High Density (URHD)
Urban Area Low Density (URLD)	Urban Area Medium Density (URMD)
Home gardens at Lower Kelani (HGLK)	Urban Area Medium Density (URMD) or Urban Area Lower Density (URLD) depending on location
Rubber (RUBR)	Replaced by Medium Density Urban Areas (URMD) or Home Gardens (HGLK) at locations near existing urban centres or at Colombo
Paddy (RICE)	Replaced by Medium Density Urban Areas (URMD) or Home Gardens (HGLK) at locations near existing urban centres or at Colombo
Tea Estates (AGRR)	Expected to decline in the upper reaches of Kelani and be replaced by with forest, otherwise leave as abandoned. Tea on steepest slopes is most likely to be abandoned
Coconut (COCO)	Replaced by Medium Density Urban Areas (URMD) or Home Gardens (HGLK) at locations near existing urban centres or at Colombo

*No change is expected as this is already a high density urban area

3.5.2.5.2. Soils

The final mapping of soil association / soil complex data to SWAT soil classes is presented in Figure 3-18.



Source: LUPPD

Figure 3-16: Land Use Types in Kelani Ganga basin

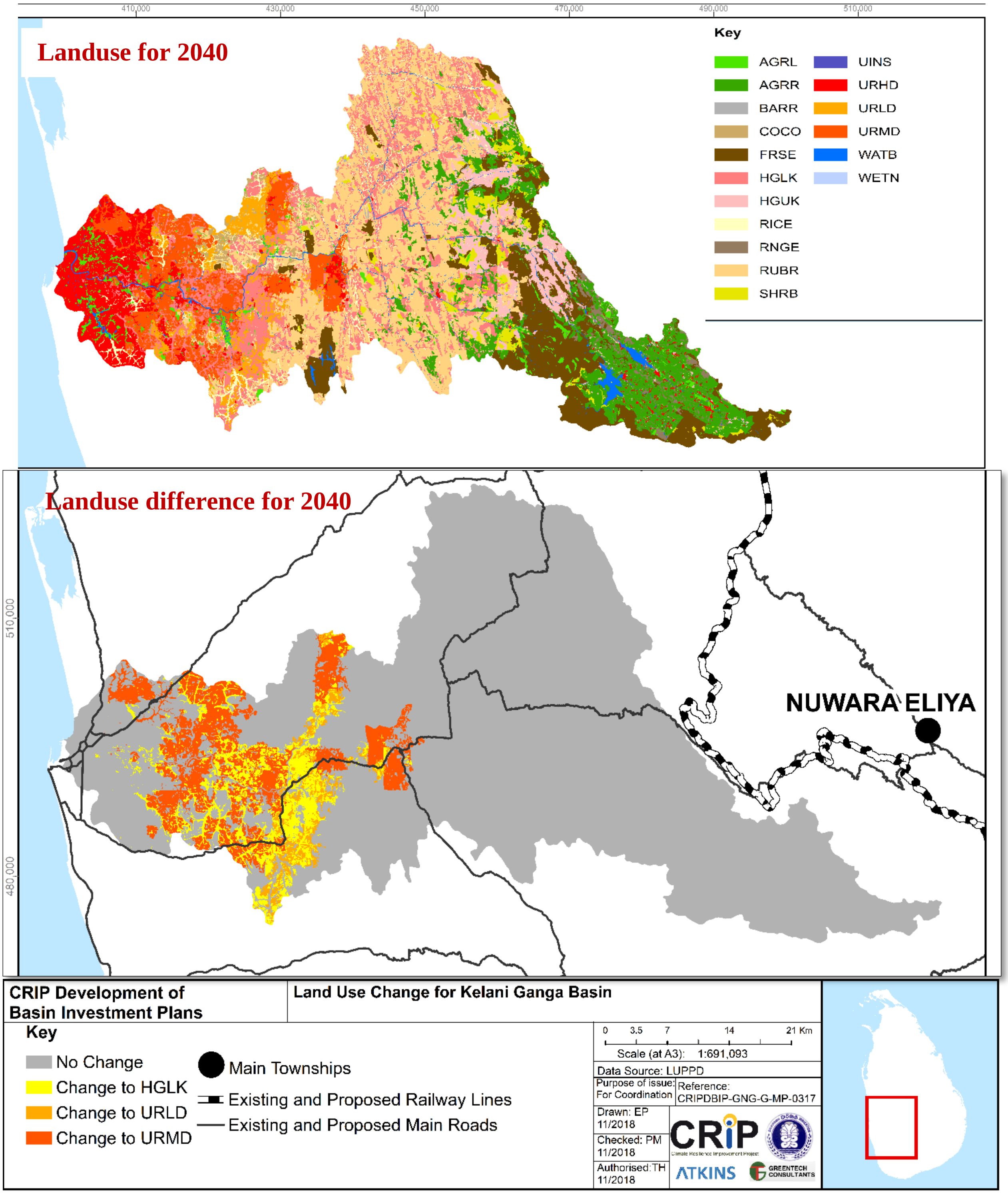


Figure 3-17: Land Use for 2040 (top) and Land Use difference from current to 2040 (bottom)

Source: FDRAR for Kelani Ganga basin-WS Atkins International Ltd, 2019

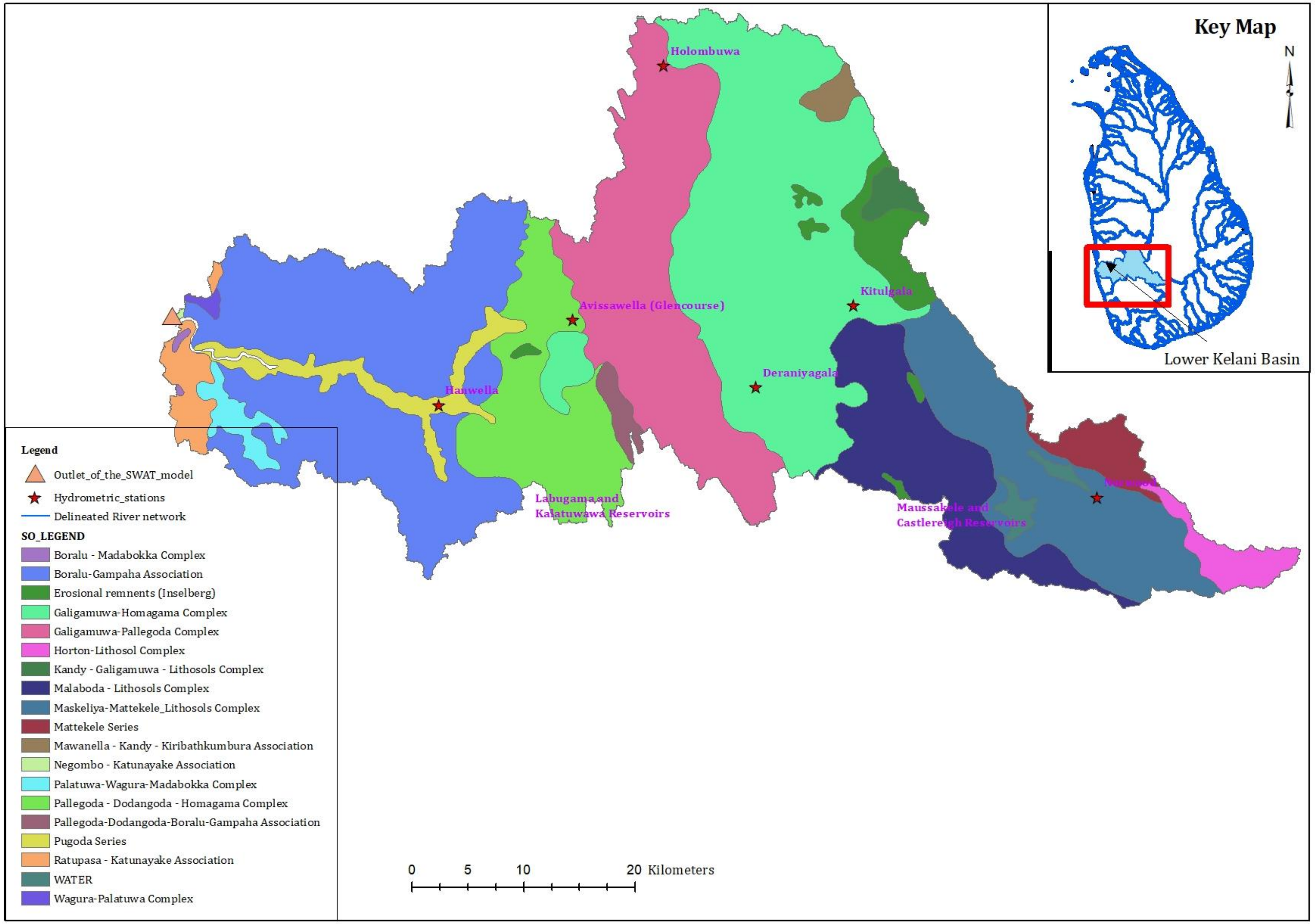


Figure 3-18: Soil Types in Kelani Ganga basin

Source: SSSSL

3.5.2.5.3. HRUs

HRUs within the Kelani Ganga basin have been defined based on unique combinations of land use and soil. This resulted in the creation of 411 HRUs in the watershed (Figure 3-19), an average of approximately 8 HRs per sub-basin.

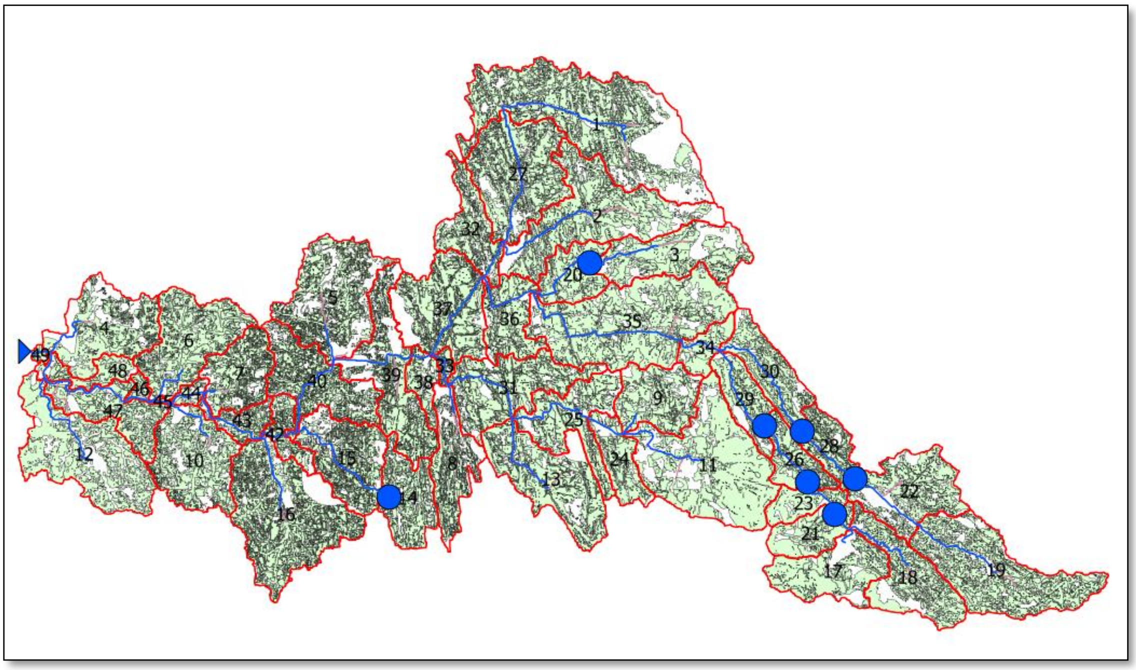


Figure 3-19: Dominant HRUs in Kelani Ganga Basin Scale

3.5.2.5.4 Outputs

SWAT outputs can be displayed in sub-basin wise (Figure 3-20), HRU wise and river reach wise. The main outputs can be displayed in sub-basin wise are Evapotranspiration, Groundwater flow, Lateral flow, etc… The main outputs of river reach are flow in to sub-basin, Flow out from the sub-basin, etc…

1	PRECIP: Average total precipitation on subbasin (mm H_2O)
2	SNOMELT: Snow melt (mm H_2O)
3	PET: Potential evapotranspiration (mm H_2O)
4	ET: Actual evapotranspiration (mm H_2O)
5	SW: Soil water content (mm H_2O)
6	PERC: Amount of water percolating out of root zone (mm H_2O)
7	SURQ: Surface runoff (mm H_2O)
8	GW_Q: Groundwater discharge into reach (mm H_2O)
9	WYLD: Net water yield to reach (mm H_2O)
10	SYLD: Sediment yield (metric tons/ha)
11	ORGN: Organic N released into reach (kg/ha)
12	ORGP: Organic P released into reach (kg/ha)
13	NSURQ: Nitrate released into reach (kg/ha)
14	SOLP: Soluble P released into reach (kg/ha)
15	SEDP: Mineral P attached to sediment released into reach (kg/ha)

Figure 3-20: SWAT outputs, which can be displayed in sub-basin wise

Source: SWAT User Manual, 2017

3.5.2.5.4.1 Method of comparing output of PET with observed evaporation

SWAT model uses several equations to calculate potential evapo-transpiration (PET) to obtain runoff and those methods are Priestley – Taylor equation, Penman Monteith and Hargreaves method. Though the most common method to calculate potential evapotranspiration is Penman Monteith, it requires the Relative Humidity, Solar radiation, temperature, etc.. As the limited data availability, Hargreaves method (1985) is used to calculate potential evapo-transpiration in Kelani Ganga basin and the improved Hargreaves equation (1985) that is incorporated in the SWAT model is given as equation 8 in section 2.7.1.2.

The spatial variability of rainfall and temperature within the Kelani Ganga basin were discussed already during the rainfall and temperature gauging selection process. To assess the suitability of the Hargreaves method, a comparison was undertaken of Hargreaves derived estimates of PET against actual evaporation data obtained from two stations near the Kelani Ganga basin – Colombo and Seetha Eliya and results are shown in Chapter 3.3.5.

As described in 3.2.2 and 3.2.3, gap-filled daily rainfall records at 41 rain gauges and gap-filled daily temperature records at 10 weather stations within and near the Kelani Ganga basin were used in rainfall-runoff modelling to obtain pseudo rainfall and temperature values were created at each sub-basin centroid using IDW spatial averaging method (Figure 3-21). The radius for rainfall was set to 25 km and for the temperature to 40 km to ensure that all sub-basins are covered by at least one meteorological station.

3.5.3 Calibration and validation

The model is calibrated and validated at Glencourse key hydrometric station by minimizing Relative Error (*E*r*)* and maximizing both Nash–Sutcliffe efficiency (*NSE)* and coefficient of determination *(R^2).*

As the calibration and validation were undertaken at Glencourse and the calibrated the same parameters (Table 4-14) were checked with another hydrometric stations named Hanwella and Kitulgala.

The calibrated SWAT model is used to evaluate Climate Elasticity of runoff based on simulated future streamflow in Kelani Ganga basin with landuse change using daily rainfall and temperature values derived by WS Atkins International Ltd (2019), downscaling to the basins through the Marksim Stochastic Weather Generation Tool and then applying a Spatial Rainfall Generation tool to generate spatially coherent stochastic daily rainfall data for 99 years considering future Climate scenario for 2040.

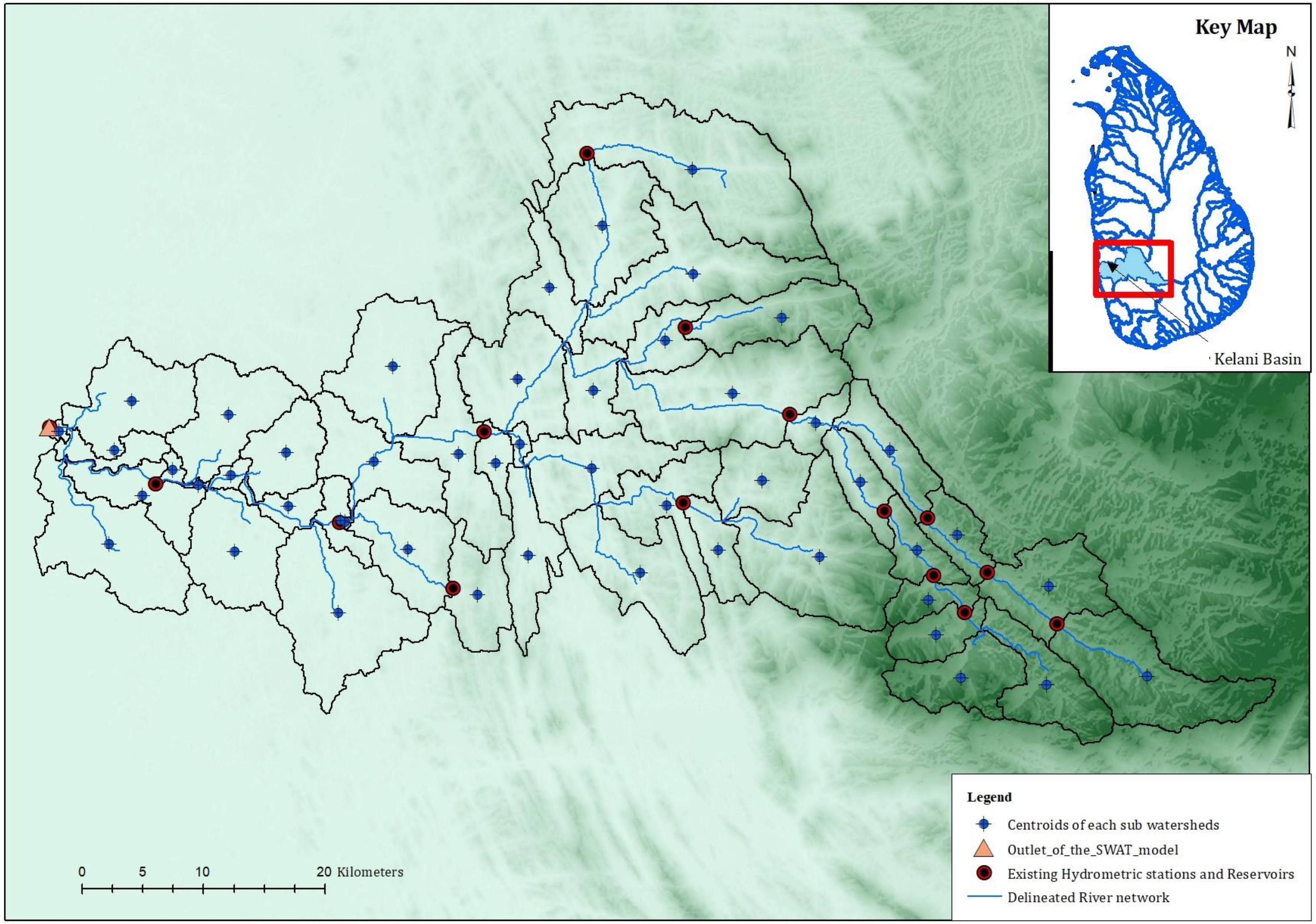


Figure 3-21: Pseudo rainfall and temperature values were created at each sub basin centroid using IDW spatial averaging method

3.5.3.1 Incorporating the Major Reservoirs and ponds to SWAT model

Two major reservoirs such as Castlereigh and Maussakelle are located at the upper reaches of the Kelani Ganga basin. Those two reservoirs are used for hydropower generation and have significant storage variation and release patterns that affect the natural flow regime in the Kelani Ganga basin.

Castlereigh reservoir started operating in 1958, therefore in the model, it was set to start operating at the beginning of the simulation period. Maussakelle reservoir became operational in 1969. The maximum capacity of the power discharge facility was selected as the maximum allowed daily outflow for each month.

The physical parameters of the reservoirs that were selected for the model simulation are listed in Table 3-18.

Table 3-18: Maussakelle and Castlereigh Reservoir Characteristics

Parameter	Maussakelle	Castlereigh
Surface area at emergency spillway level – RES_ESA (ha)	760	320
Volume at emergency spillway level – RES_EVOL (10^4 m^3)	14,400	5,000
Surface area at principal spillway level – RES_PSA (ha)	730	300
Volume at principal spillway level – RES_PVOL (10^4 m^3)	12,360	4,380
Initial reservoir volume – RES_VOL (10^4 m^3)	300	370
Maximum daily outflow – OFLOWMX (month)	19.8	29.7

As daily power flow data was made available for both reservoirs by the MASL for January 1984 to May 2016 period, a gap-filling method was applied to obtain data for the entire 1960-2016 record. The long-term average for each day of the month was calculated and applied to days that were missing.

3.6 Analysis of the Future Potential Effects of Climate Change on Streamflow based on Runoff Elasticity

Volume 1 of Flood and Drought Risk Assessment Report for the Kelani Ganga basin (WS Atkins International Ltd, 2019) is suggested that future climate data (rainfall and temperature) based on 10 GCM / RCP (5 GCMs with 2 RCPs) combinations using stochastic weather generation tool Kelani Ganga basin and those combinations are given below. The overall weather generation needs to incorporate a process of bias correction, spatial data generation and long-term persistence allowances before it can satisfy the output specifications. The basic MarksimGCM weather generation and these modification processes are therefore incorporated into a Stochastic Weather Generation Tool.

- RCP6_CSIRO_MK3_6_0
- RCP6_FIO_ESM
- RCP6_GISS_E2_H
- RCP6_IPSL_CM5A_MR
- RCP6_MIROC5
- RCP8.5_CSIRO_MK3_6_0
- RCP8.5_FIO_ESM
- RCP8.5_GISS_E2_H
- RCP8.5_IPSL_CM5A_MR
- RCP8.5_MIROC5

As the report, the pessimistic scenario is identified as both RCP6_FIO_ESM and RCP6_GISS_E2_H for the rainfall and RCP 8.5_IPSL_CM5A_MR for temperature, hence RCP6_FIO_ESM for the rainfall and RCP 8.5_IPSL_CM5A_MR for temperature were taken for this study.

Those selected time-series data for 99 years is inputted to the calibrated SWAT model and analyse the future runoff elasticity in Kelani ganga basin.

3.6.1 Objective function of Runoff elasticity based on two-parameter climate elasticity

Two parameter elasticity was checked for current scenario and for the future scenario respectively. The equations used during the analysis are given below.

The two-parameter climate elasticity by Fu et al. (2007); Yang & Yang, (2011);

$$\frac{dR}{R} = \varepsilon_a \frac{dP}{P} + \varepsilon_b \frac{dT}{T} \qquad \text{...25}$$

The ε is defined as lots of literature as Chiew (2006); Sankarasubramanian et al. (2001); (Niemann & Eltahir, 2005); $\varepsilon = \text{median}\left[\frac{(R_i - \bar{R}) / \bar{R}}{(X_i - \bar{X}) / \bar{X}}\right]$

But recently, Zheng et al. (2009) suggested that the climate elasticity was used to assess the influences of climate and land surface change on the streamflow and they described *ε* as following,

$$\varepsilon = \frac{\bar{X}}{\bar{R}} \frac{\sum(X_i - \bar{X})(R_i - \bar{R})}{\sum(X_i - \bar{X})^2}$$

where *X* represents the climatic variables (e.g., *P* and *T*), and *R* and *X* represent the mean annual runoff and any climatic variable, respectively. During the study, the runoff elasticity is calculated from 1980 to 2016 period.

4 RESULTS AND ANALYSIS

4.1 Decadal Averages for Annual Rainfall Totals

Decadal averages of optimized α parameter for rainfall were plotted for the selected 41 rainfall stations with Long term averages (LTA) and standard deviation (SD) with respect to the whole duration of 5 decades (from 1960 to 2010) and for the reference period from1980 to 2010 to compare trends visually in terms of Decadal averages. The decadal average plots for some key rainfall stations for annual rainfall totals are given in Figure 4-1. The decadal average plots for some key rainfall stations for rainfall totals for Maha and Yala are given in Figure 4-2 and Figure 4-3, respectively.

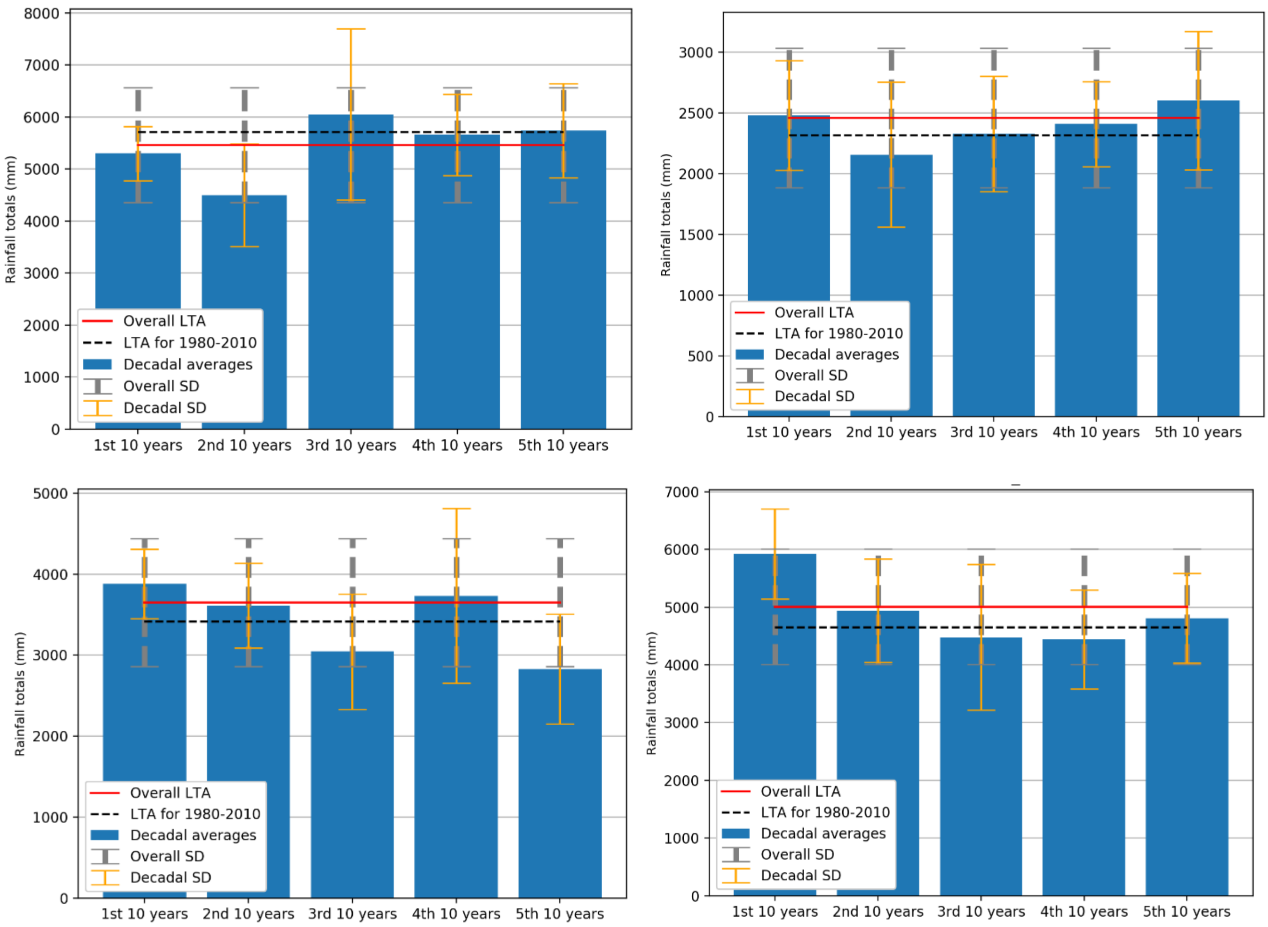


Figure 4-1: The decadal average plots for Kenilworth_Strathellie (top left), Angoda mental hospital (top right), Avissawella Estate (bottom left) and Weweltalawa Estate (bottom right) key rainfall stations for annual rainfall totals

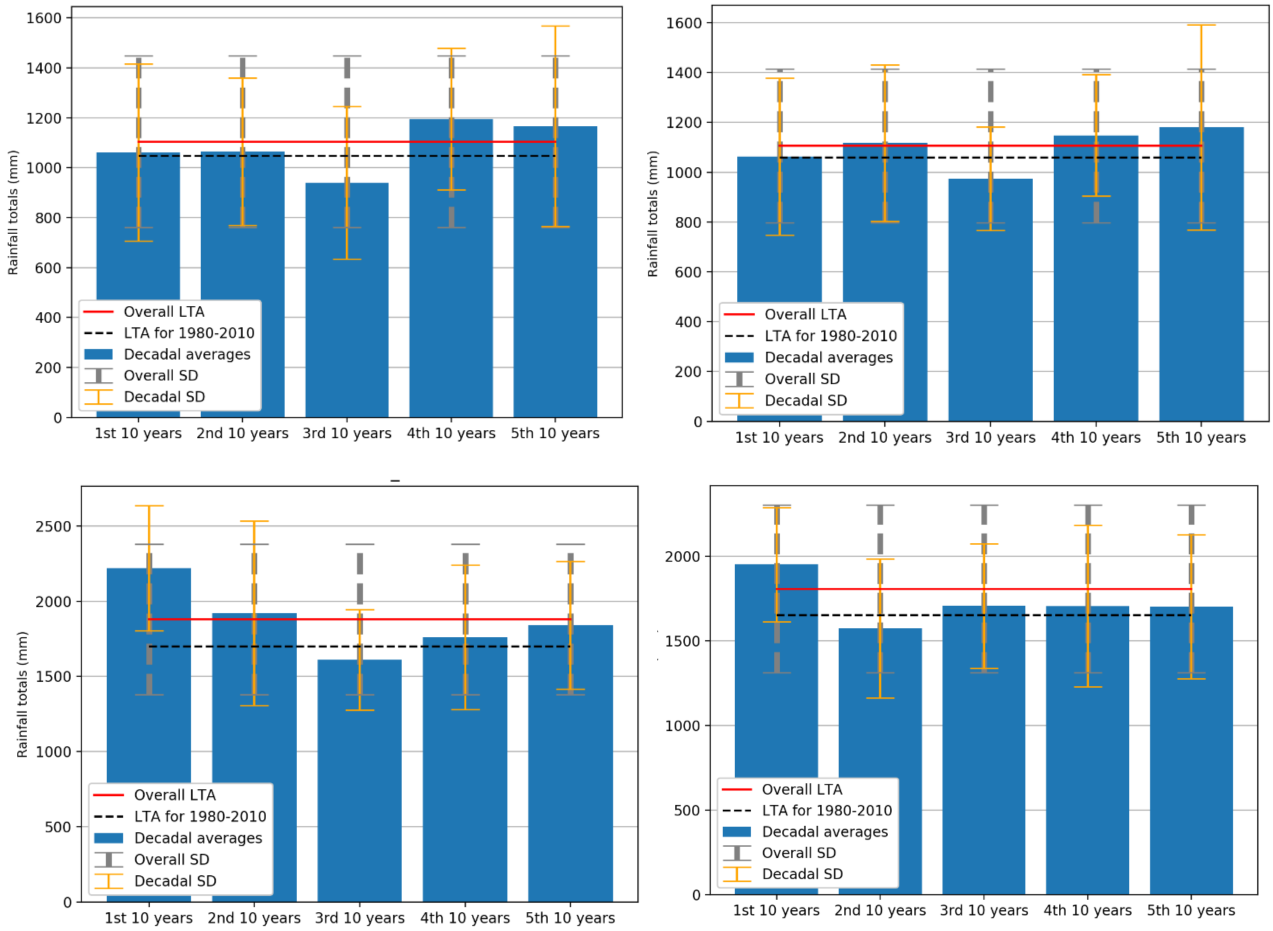


Figure 4-2: The decadal average plots for Angoda mental hospital (top left), Colombo (top right), Weweltalawa Estate (bottom left) and Maliboda (bottom right) key rainfall stations for annual rainfall totals for Maha Season

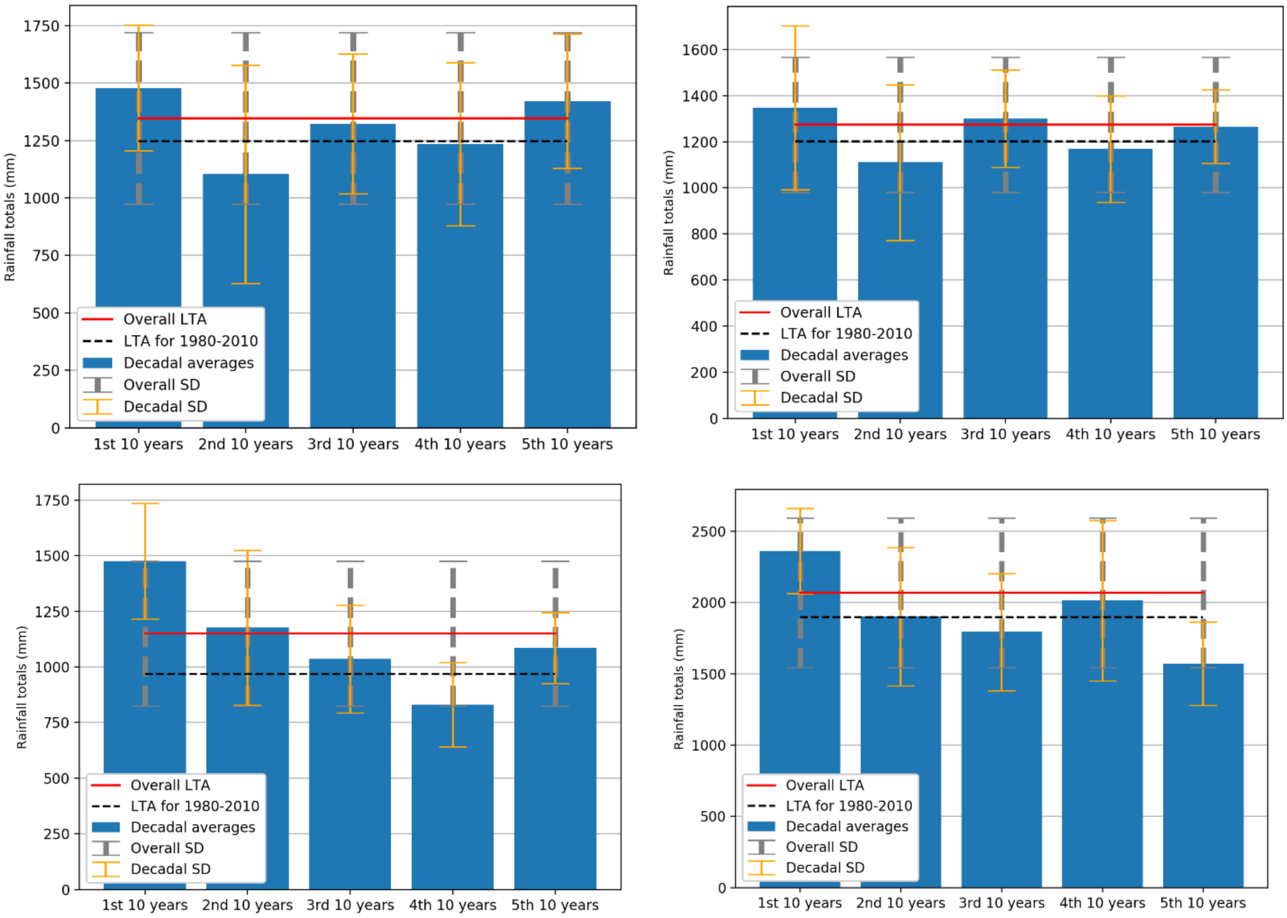


Figure 4-3: The decadal average plots for Angoda mental hospital (top left), Colombo (top right), Holomwood Estate (bottom left) and Avissawella Estate (bottom right) key rainfall stations for annual rainfall totals for Yala Season

4.2 Deviation from Mean

Deviation from mean is plotted for annual totals, Maha and Yala for the selected 41 rainfall stations for the duration of 1960 to 2016 and some plots for key stations are shown in Figure 4-4, Figure 4-5 and Figure 4-6, respectively.

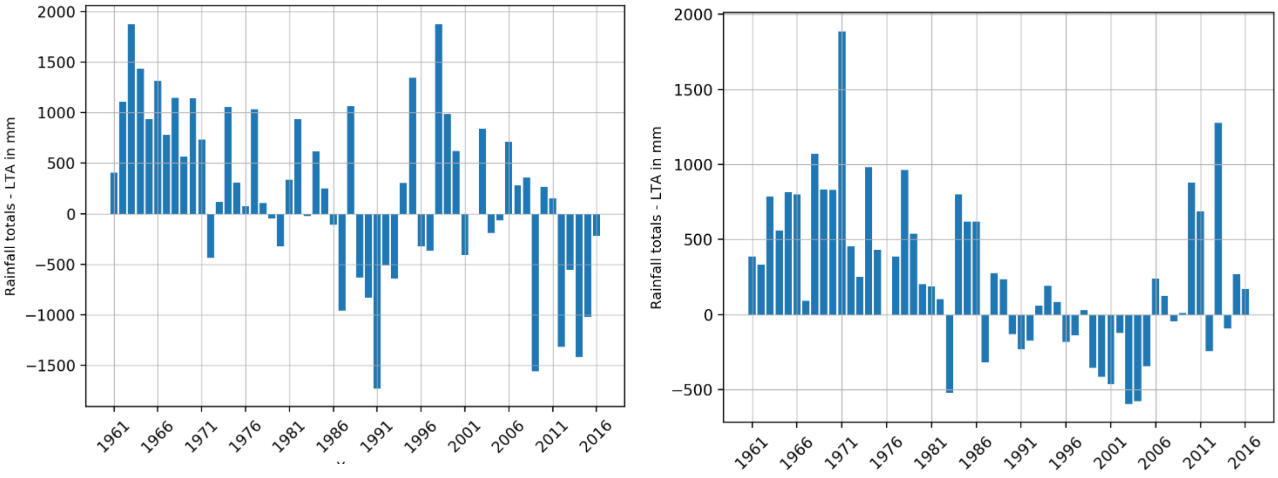


Figure 4-4: Deviation from mean plots for annual totals for Avissawella Estate (left) and Maliboda (right) for the duration of 1960 to 2016

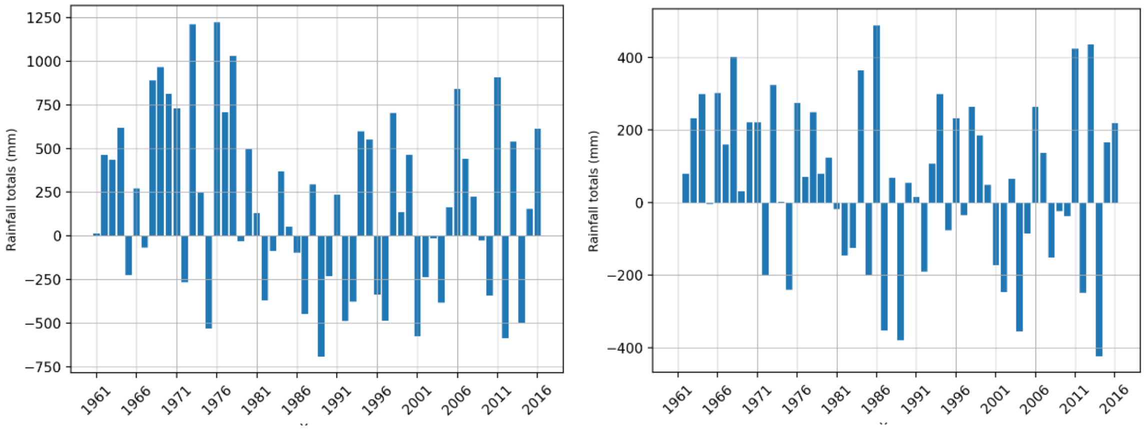


Figure 4-5: Deviation from mean plots for rainfall totals for Maha season for Wewelthalawa Estate (left) and Maussakele (right) for the duration of 1960 to 2016

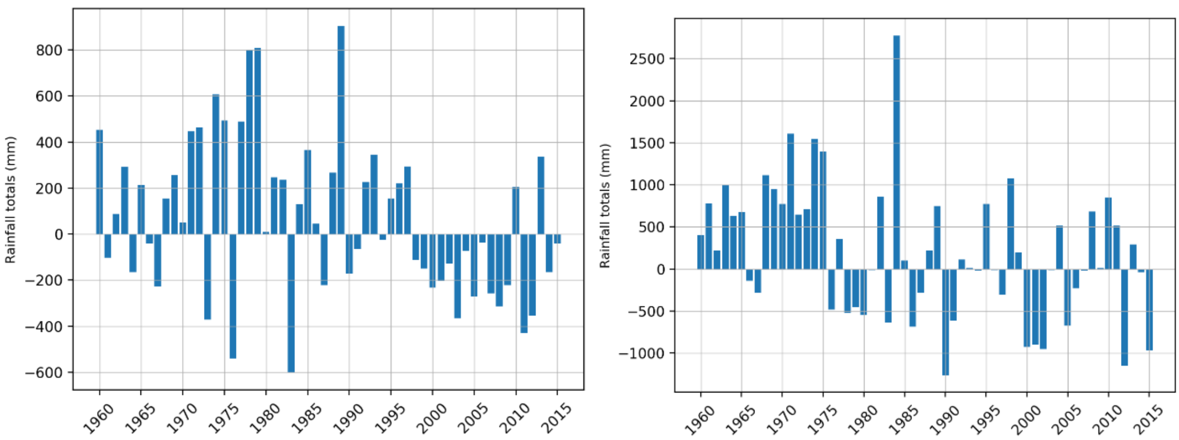


Figure 4-6: Deviation from mean plots for rainfall totals for Maha season for Wewelthalawa Estate (left) and Maussakele (right) for the duration of 1960 to 2016

4.3 Innovative Trends Analysis (ITA)

4.3.1 Rainfall stations

Innovative Trends Analysis (ITA) are plotted for annual totals, Maha and Yala for the selected 41 rainfall stations and some plots for the stations are shown in Figure 4-7, Figure 4-8 and Figure 4-9, respectively.

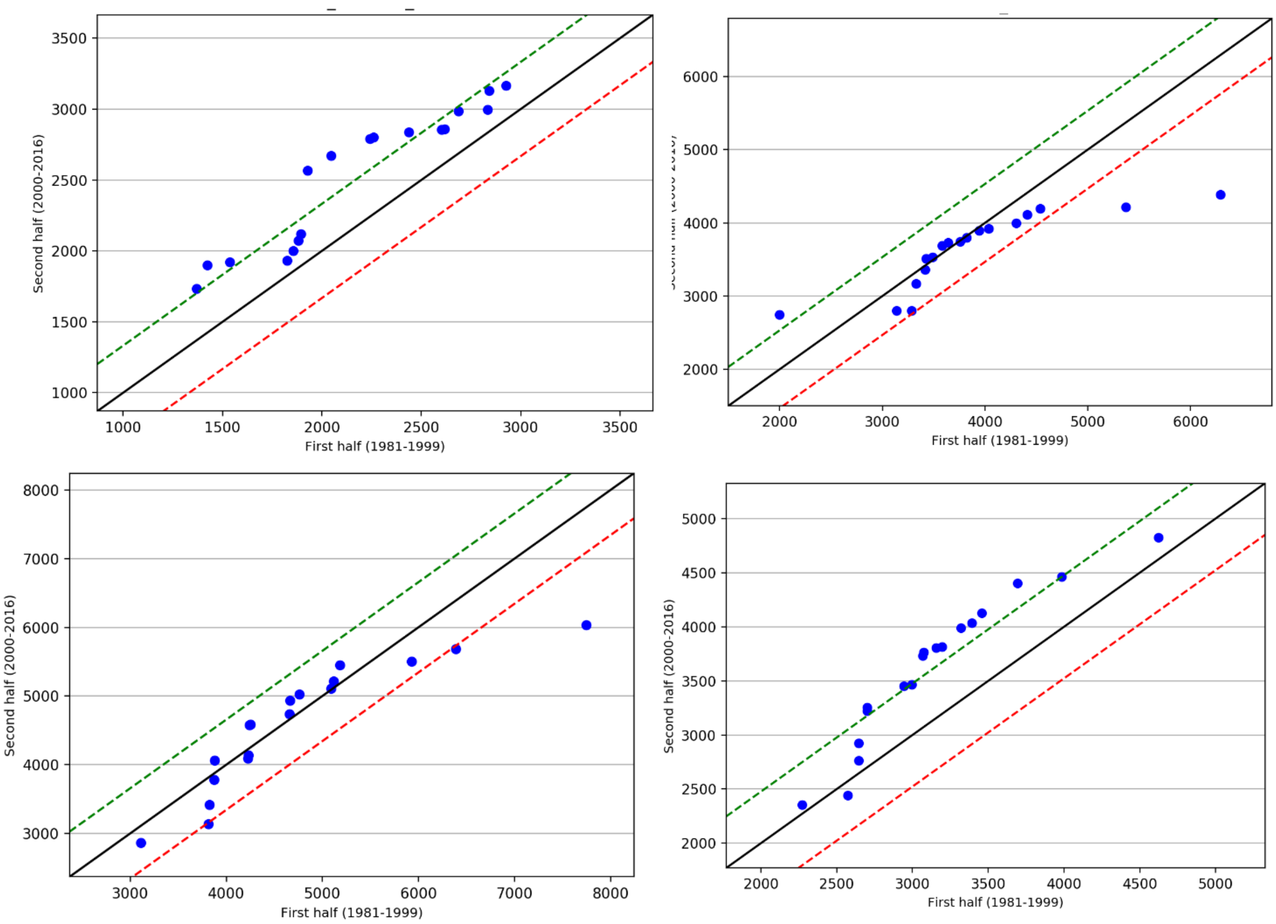


Figure 4-7: Innovative Trends Analysis (ITA) plots for annual totals for Angoda mental hospital (top left), Digalla Estate (top right), Weweltalawa Estate (bottom left) and Chesterford (bottom right)stations

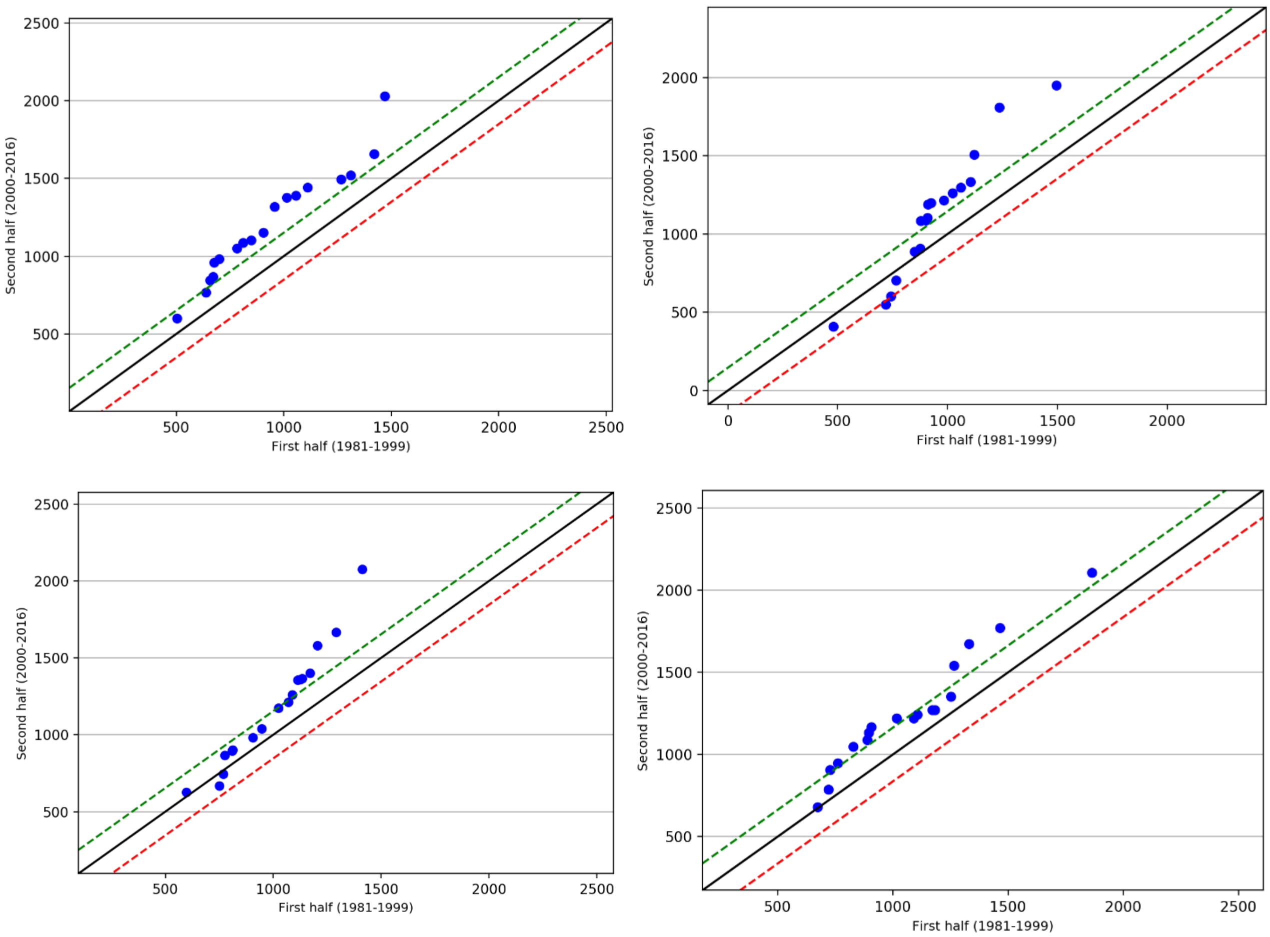


Figure 4-8: Innovative Trends Analysis (ITA) plots for annual totals for Angoda mental hospital (top left), Katunayaka (top right), Colombo (bottom left) and Campion Estate (bottom right) stations for Maha Season

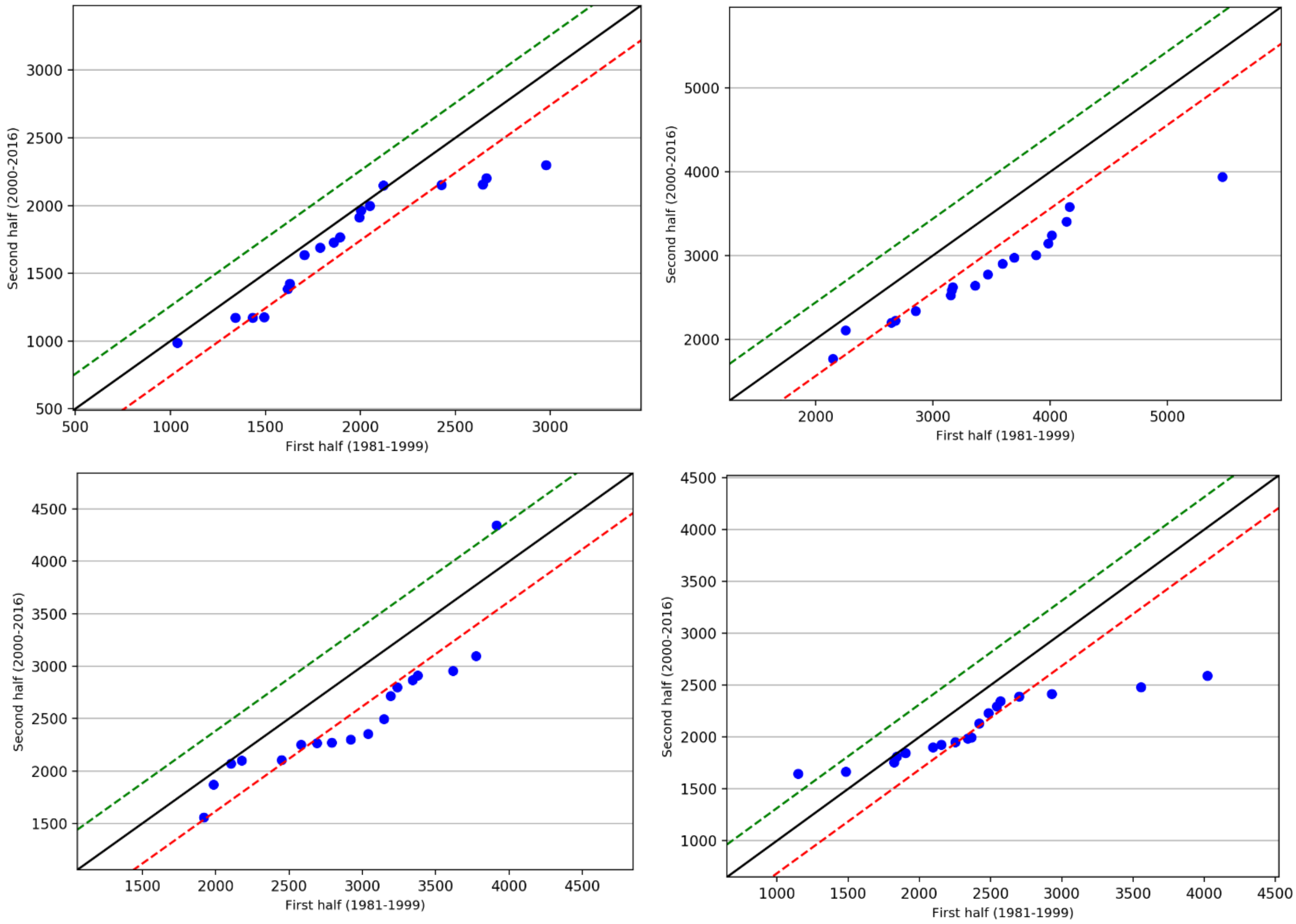


Figure 4-9: Innovative Trends Analysis (ITA) plots for annual totals for Avissawella Estate (top left), Laxapana (top right), Canyon (bottom left) and Digalla Estate (bottom right) stations for Yala Season

As described in Chapter 3.3, the ITA values were compared with Mann-Kendall (MK) trend test using the trend indicator; D and the obtained D values for annual rainfall totals, Maha and Yala seasons are shown in Table 4-1 with its sign of + or -; which indicates the positive or negative trends, respectively. Orange and Green colours were used to show positive and negative signs, respectively.

Table 4-1: ITA trend indicator D values for annual rainfall totals, Maha and Yala seasons

Name of Rainfall Station	Innovative Trend Analysis		
	D value for Annual Totals	D value for Maha Totals	D value for Yala Totals
Alupolla Group	0.66	1.21	0.25
Ambewela	-0.93	1.53	-2.70
Angoda mental hospital	1.56	2.89	0.57
Avissawella Estate	-0.52	0.20	-1.06
Avissawella Hospital	0.55	1.41	-0.12
Balangoda Post Office	0.00	1.09	-1.34
Bandarawela	0.43	0.71	0.02
Bopatthalawa	-1.13	0.68	-2.33
Campion Estate	0.14	1.73	-1.19
Canyon	-0.79	0.63	-1.32
Castlereigh	0.19	2.48	-0.70
Chesterford	1.49	1.79	1.25
Colombo	0.57	1.77	-0.39
Digalla Estate	-0.60	0.40	-1.23
Dunedin Estate	-0.29	0.62	-0.94
Dyrabba Estate	-0.75	0.35	-2.34
Galatura Estate	-0.23	0.40	-0.63
Hakgala Botanical Grdns	0.24	1.38	-1.26
Hanwella Group	-1.09	-0.60	-1.49
Hapugastenna Estate	-0.52	0.52	-1.14
Holmwood Estate	-0.34	0.89	-1.19
Kalatuwawa	-0.02	0.62	-0.51
Katugastota	0.62	2.20	-1.13
Katunayaka	0.57	1.84	-0.57
Kenilworth Strathellie	0.37	1.73	-0.19
Labugama Tank	0.25	1.03	-0.36
Labukelle	-1.18	0.59	-2.25
Laxapana	-1.40	-0.23	-1.91
Maliboda	0.35	0.72	0.15
Maussakelle	-1.14	-0.12	-1.61
Negombo	2.17	3.65	0.81
Nuwara Eliya	-0.80	1.09	-2.30
Pasyala	1.15	1.73	0.65
Ratmalana	0.99	2.35	-0.08
Ratnapura	-0.08	0.52	-0.49
Sandringham Estate	-1.27	0.17	-2.25
Undugoda	-1.26	-0.55	-1.78
Wagolla	-1.63	-0.39	-2.78
Walpita	1.27	1.64	0.95
Welimada Group	1.60	1.87	1.15
Weweltalawa Estate	-0.31	0.83	-0.93

4.3.2 Temperature stations

4.3.2.1 T_{max}

Innovative Trends Analysis (ITA) are plotted for annual averages, averages for Maha and Yala for the selected 10 temperature gauging stations. The trend indicator (D) values for annual average maximum temperature (T_{max}), Average values for Maha and Yala seasons are shown in Table 4-2 with its sign of + or -; which indicates the positive or negative trends, respectively. Orange and Green colours were used to show positive and negative signs, respectively.

Table 4-2: The trend indicator (D) values for annual average Tmax, Average values for Maha and Yala seasons

Temperature Station's Name	Innovative Trend Analysis		
	D value for Annual averages	D value for averages for Maha	D value for averages for Yala
Badulla	-0.11	-0.14	-0.04
Bandarawela	0.07	0.01	0.12
Colombo	-0.03	-0.05	0.00
Katugastota	0.01	-0.03	0.07
Katunayaka	-0.10	-0.15	-0.05
Kurunegala	0.00	-0.05	0.03
Nuwara Eliya	-0.06	-0.09	0.01
Ratmalana	0.00	-0.02	0.05
Ratnapura	-0.02	-0.04	0.00
Seetha Eliya	0.00	0.01	0.03

7.8.2.2 T_{min}

Innovative Trends Analysis (ITA) are plotted for annual, Maha and Yala averages for the selected 10 temperature gauging stations. The trend indicator (D) values for annual average minimum temperature (T_{min}), average values for Maha and Yala seasons are shown in Table 4-3. Orange and Green colours were used to show positive and negative signs, respectively.

Table 4-3: The trend indicator (D) values for annual average T_{min}, Average values for Maha and Yala seasons

Temperature Station's Name	Innovative Trend Analysis		
	D value for Annual averages	D value for averages for Maha	D value for averages for Yala
Badulla	-0.01	-0.14	-0.01
Bandarawela	0.49	0.01	0.49
Colombo	0.18	-0.05	0.18
Katugastota	0.13	-0.03	0.13
Katunayaka	0.18	-0.15	0.18
Kurunegala	0.15	-0.05	0.15
Nuwara Eliya	0.27	-0.09	0.27
Ratmalana	0.18	-0.02	0.18
Ratnapura	-0.06	-0.04	-0.06
Seetha Eliya	0.49	0.01	0.49

4.3.3 Streamflow stations

Innovative Trends Analysis (ITA) are plotted for annual average flows, average flows for Maha and Yala seasons for the selected 3 hydrometric stations and ITA plots for annual average flows, average flows for Maha and Yala seasons are shown in Figure 4-10, Figure 4-11 and Figure 4-12, respectively. Orange and Green colours were used to show positive and negative signs, respectively.

The trend indicator (D) values for annual average annual flows, average values for Maha and Yala seasons are shown in Table 4-4.

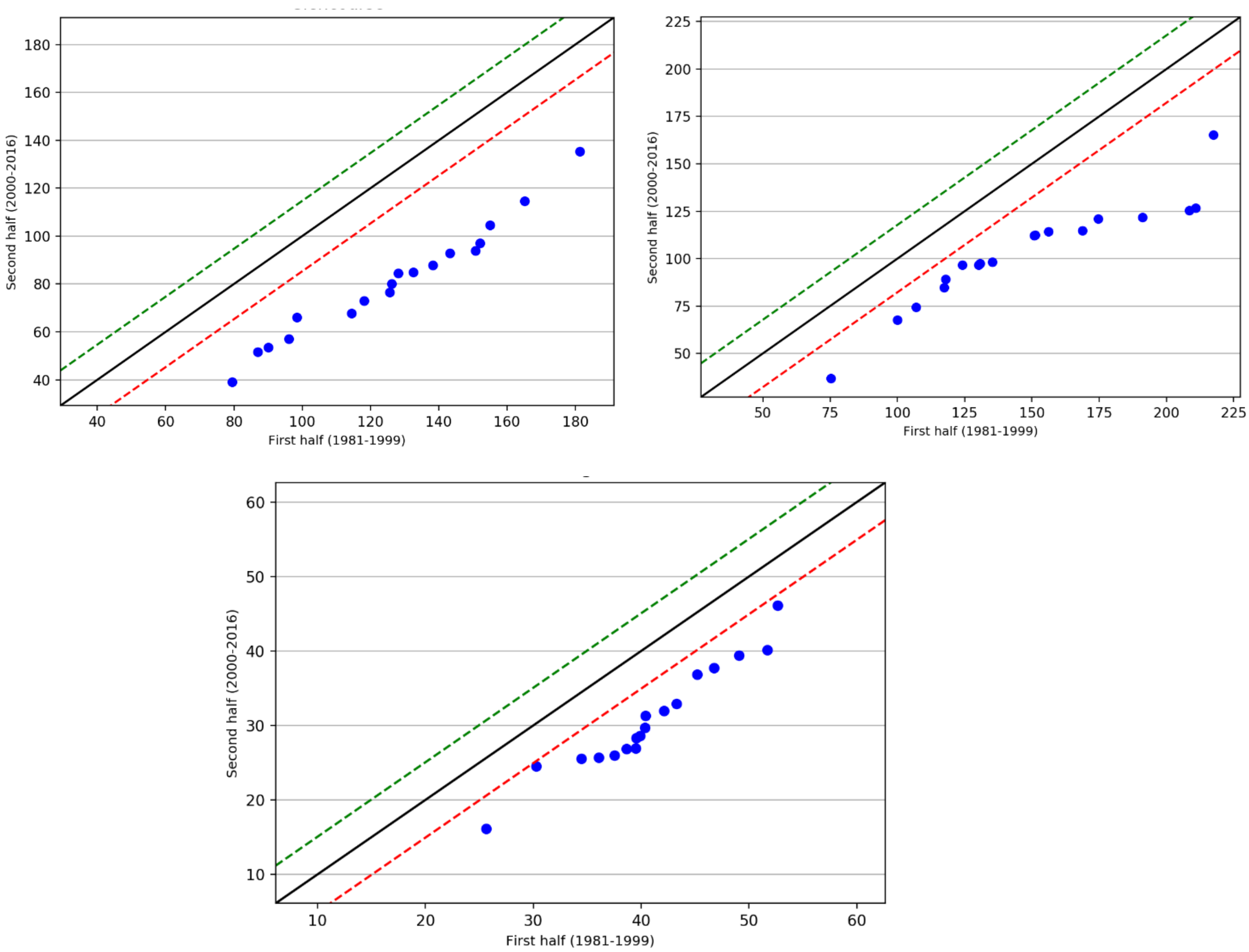
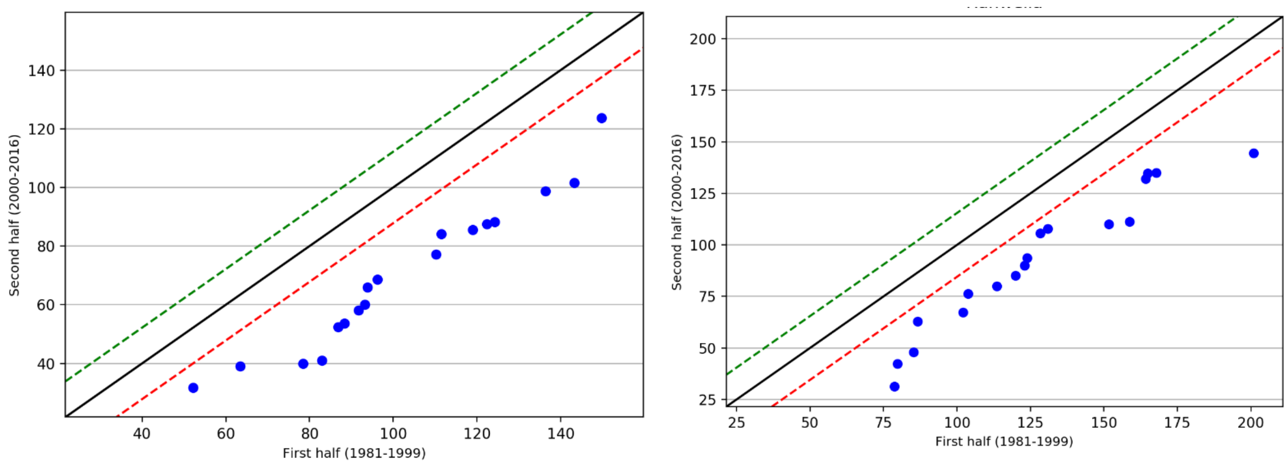


Figure 4-10: ITA plots for annual average flows for Glencourse (top left), Hanwella (top right) and Kitulgala (bottom) hydrometric stations



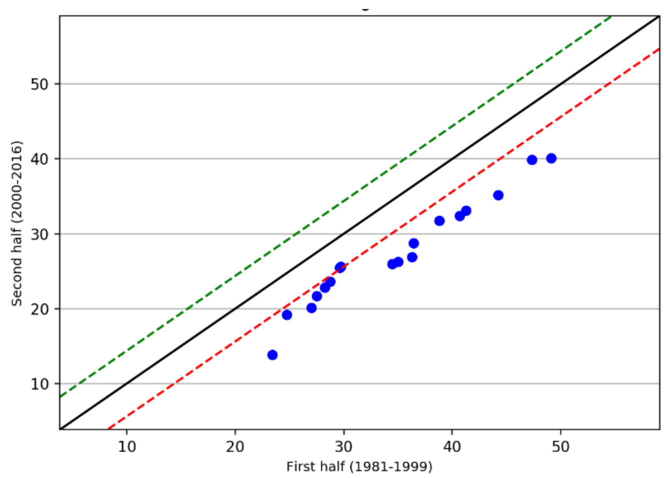


Figure 4-11: ITA plots for average flows for Maha season for Glencourse (top left), Hanwella (top right) and Kitulgala (bottom) hydrometric stations

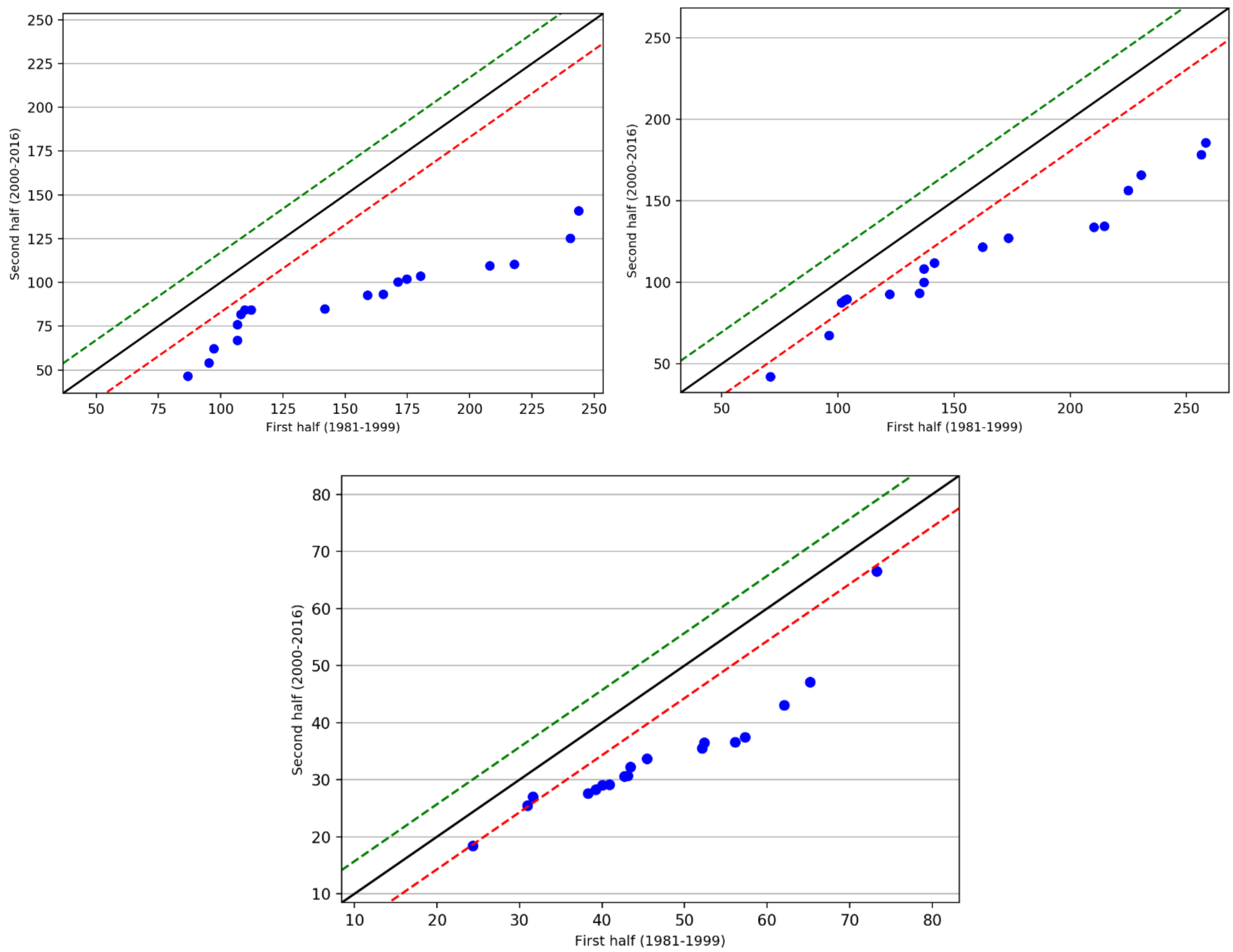


Figure 4-12: ITA plots for average flows for Yala season for Glencourse (top left), Hanwella (top right) and Kitulgala (bottom) hydrometric stations

Table 4-4: The trend indicator (D) values for annual average flows, Average values for Maha and Yala seasons

Hydrometric Station Name	Innovative Trend Analysis		
	D value for Annual Averages	D value for Maha Averages	D value for Yala Averages
Kitulgala	-2.43	-2.09	-2.67
Glencourse	-3.60	-3.18	-4.06
Hanwella	-3.04	-2.74	-2.75

4.4 Mann-Kendall Test results

A positive value of Z indicates an upward trend, while a negative value of Z indicates a downward trend, hence Z is calculated for rainfall, Maximum and minimum temperature and flows, respectively.

4.4.1 Rainfall stations

Summary results of Z values, which are obtained from Mann-Kendall test for annual rainfall totals, four rainfall seasons and totals for Maha and Yala seasons for the selected 41 rainfall gauging stations are given in Table 4-6. The significance of a trend was assessed at the 0.1 %, 1 %, 5 % and 10 % for the Mann–Kendall test and the colours used to show the significance of trends are given in Table 4-5.

Table 4-5: The colours used to show the significance of trends

trend at 0.001 significant level	
trend at 0.01 significant level	
trend at 0.05 significant level	
trend at 0.1 significant level	

Table 4-6: Summary results of *Z* values for annual rainfall totals, four rainfall seasons and totals for Maha and Yala seasons for the selected 41 rainfall gauging stations

Name of the Rainfall Station	Mann-Kendal Test Results						
	Z value for Annual totals	Z value for FIM-I	Z value for SWM-II	Z value for SIM-III	Z value for NEM-IV	Z value for Maha totals	Z value for Yala totals
Alupolla Group	0.99	0.72	0.97	2.17	0.50	0.51	0.13
Ambewela	-0.29	0.97	-2.22	2.52	1.10	2.06	-0.50
Angoda mental hospital	2.38	1.83	0.91	1.24	1.78	2.00	3.01
Avissawella Estate	-1.27	0.12	-2.06	-0.95	-0.42	-0.75	-0.56
Avissawella Hospital	1.21	1.73	0.01	0.56	0.75	0.96	1.74
Balangoda Post Office	0.18	0.94	-1.65	0.64	1.43	0.94	0.15
Bandarawela	0.91	1.91	-0.69	0.80	1.29	1.11	0.17
Bopatthalawa	-1.57	1.73	-3.50	0.12	0.72	1.02	-1.46
Campion Estate	0.80	1.21	-0.91	1.02	2.55	2.30	1.19
Canyon	-1.51	1.16	-1.73	0.12	1.35	0.67	-1.10
Castlereigh	0.26	1.32	-0.69	0.40	1.81	0.99	-1.29
Chesterford	2.68	2.41	1.78	1.05	0.78	0.88	2.04
Colombo	1.73	2.08	-0.37	1.16	1.54	1.38	1.87
Digalla Estate	-0.86	-0.16	-1.02	-0.10	0.23	0.01	-0.37
Dunedin Estate	0.00	0.94	-1.21	0.07	0.37	1.41	1.26
Dyrabba Estate	0.15	0.20	-2.14	1.29	0.42	1.07	-0.21
Galatura Estate	-0.23	0.59	-0.78	-1.02	1.29	0.32	-0.36
Hakgala Botanical Grdns	1.35	1.29	-1.21	2.36	1.27	1.56	0.99
Hanwella Group	-1.92	-0.20	-2.11	-0.80	-1.16	-1.41	-2.68
Hapugastenna Estate	-1.02	0.12	-1.65	0.83	0.45	-0.84	-1.63
Holmwood Estate	-0.12	1.51	-1.32	-0.42	1.35	1.89	0.99
Kalatuwawa	0.04	2.00	-0.59	-0.31	0.37	0.66	0.36
Katugastota	1.10	1.42	-2.44	1.78	1.32	1.71	0.96
Katunayaka	0.31	0.94	-0.86	0.61	0.97	0.77	0.32
Kenilworth Strathellie	0.64	1.65	0.50	0.89	0.86	1.43	0.42
Labugama Tank	0.69	1.81	-0.40	0.23	0.75	1.18	0.47
Labukelle	-0.89	-0.20	-1.48	0.89	1.46	0.39	-0.96
Laxapana	-2.11	0.00	-2.03	-0.64	0.45	-0.43	-2.79
Maliboda	1.05	1.65	0.34	0.34	1.05	-0.21	-0.02
Maussakelle	-2.03	0.29	-2.11	0.15	0.83	0.24	-2.38
Negombo	1.92	1.65	-0.59	1.43	1.62	2.23	2.61
Nuwara Eliya	-0.86	1.38	-2.08	0.83	1.46	1.26	-1.26
Pasyala	2.30	2.49	0.97	1.13	0.99	2.08	1.48

Name of the Rainfall Station	Mann-Kendal Test Results						
	Z value for Annual totals	Z value for FIM-I	Z value for SWM-II	Z value for SIM-III	Z value for NEM-IV	Z value for Maha totals	Z value for Yala totals
Ratmalana	1.29	1.40	-0.18	0.61	0.91	0.99	1.18
Ratnapura	-0.01	2.00	-0.59	0.64	0.42	0.47	-0.24
Sandringham Estate	-1.65	0.12	-2.47	0.34	0.48	0.66	-0.96
Undugoda	-0.91	-1.13	-1.65	-0.20	0.20	0.32	-0.51
Wagolla	-2.22	0.15	-3.72	-1.05	0.64	-1.26	-2.42
Walpita	1.89	2.00	0.72	0.83	1.87	0.92	1.93
Welimada Group	2.66	1.65	-0.94	2.60	1.38	2.19	1.48
Weweltalawa Estate	0.50	0.48	-0.18	0.50	1.54	0.77	0.69

4.4.2 Temperature stations

4.4.2.1 Maximum temperature (T_{max})

Summary results of Z values, which are obtained from Mann-Kendall test for T_{max} values for the selected 10 temperature gauging stations for annual averages, averages for four rainfall seasons and averages for Maha and Yala seasons are given in Table 4-7. The significance of a trend was assessed at the 0.1 %, 1 %, 5 % and 10 % for the Mann–Kendall test and the colours used to show the significance of trends are given in Table 4-5.

Table 4-7: Summary results of Z values for T_{max} values for the selected 10 temperature gauging stations for annual averages, averages for four rainfall seasons and averages for Maha and Yala seasons

Name of the Temperature Station	Mann-Kendal Test Results						
	Z value for Annual totals	Z value for FIM-I	Z value for SWM-II	Z value for SIM-III	Z value for NEM-IV	Z value for Maha totals	Z value for Yala totals
Badulla	-0.78	-0.72	0.04	-1.29	-1.73	-1.48	-1.40
Bandarawela	1.24	-0.91	2.27	0.01	-0.18	-0.26	0.91
Colombo	0.07	-1.14	0.50	0.86	-0.01	-0.07	0.23
Katugastota	1.02	-0.67	2.49	1.46	-0.80	-0.31	1.24
Katunayaka	-1.87	-3.02	-0.48	-1.24	-2.38	-2.49	-1.55
Kurunegala	0.61	-1.08	1.02	0.99	-0.61	-0.31	1.02
Nuwara Eliya	0.72	-1.57	1.95	1.13	-0.69	-0.53	0.78
Ratmalana	1.19	0.34	2.11	2.22	0.18	0.59	0.94
Ratnapura	0.31	-1.14	0.42	0.89	0.04	0.04	0.48

Name of the Temperature Station	Mann-Kendal Test Results						
	Z value for Annual totals	Z value for FIM-I	Z value for SWM-II	Z value for SIM-III	Z value for NEM-IV	Z value for Maha totals	Z value for Yala totals
Seetha Eliya	0.72	0.69	1.70	1.73	-0.15	0.31	0.61

4.4.2.2 Minimum temperature (T_{min})

Summary results of Z values, which are obtained from Mann-Kendall test for the selected 10 temperature gauging stations for annual averages, averages for four rainfall seasons and averages for Maha and Yala seasons are given in Table 4-8. The significance of a trend was assessed at the 0.1 %, 1 %, 5 % and 10 % for the Mann–Kendall test and the colours used to show the significance of trends are given in Table 4-5.

Table 4-8: Summary results of Z values for Tmin values for the selected 10 temperature gauging stations for annual averages, averages for four rainfall seasons and averages for Maha and Yala seasons

Name of the Temperature Station	Mann-Kendal Test Results						
	Z value for Annual averages	Z value for FIM-I	Z value for SWM-II	Z value for SIM-III	Z value for NEM-IV	Z value for Maha averages	Z value for Yala averages
Badulla	0.07	-1.89	-0.20	0.04	0.29	0.00	-0.45
Bandarawela	1.24	-0.91	2.27	0.01	-0.18	-0.26	0.91
Colombo	0.07	-1.14	0.50	0.86	-0.01	-0.07	0.23
Katugastota	1.02	-0.67	2.49	1.46	-0.80	-0.31	1.24
Katunayaka	-1.87	-3.02	-0.48	-1.24	-2.38	-2.49	-1.55
Kurunegala	0.61	-1.08	1.02	0.99	-0.61	-0.31	1.02
Nuwara Eliya	0.72	-1.57	1.95	1.13	-0.69	-0.53	0.78
Ratmalana	1.19	0.34	2.11	2.22	0.18	0.59	0.94
Ratnapura	0.31	-1.14	0.42	0.89	0.04	0.04	0.48
Seetha Eliya	0.72	0.69	1.70	1.73	-0.15	0.31	0.61

4.4.3 Streamflow

Summary results of Z values, which are obtained from Mann-Kendall test for flow values for the selected 3 hydrometric stations for annual averages, averages for four rainfall seasons and averages for Maha and Yala seasons are given in Table 4-9. The significance of a trend was assessed at the 0.1 %, 1 %, 5 % and 10 % for the Mann–Kendall test and the colours used to show the significance of trends are given in Table 4-5.

Table 4-9: Summary results of Z values for flow values for the selected 3 hydrometric stations for annual averages, averages for four rainfall seasons and averages for Maha and Yala seasons

Name of the selected Hydrometric Station	Mann-Kendal Test Results						
	Z value for Annual Averages	Z value for FIM-I	Z value for SWM-II	Z value for SIM-III	Z value for NEM-IV	Z value for Maha Averages	Z value for Yala Averages
Kitulgala	-1.65	-1.29	-1.87	-0.23	-0.91	-0.97	-2.17
Glencourse	-3.04	-0.12	-2.85	-2.30	-0.86	-2.19	-2.93
Hanwella	-3.39	-1.98	-2.63	-1.68	-2.68	-2.66	-3.28

4.5 Sen's Slope test

The Q_{med} sign reflects data trend reflection, while its value indicates the steepness of the trend, hence Q_{med} is calculated for rainfall, Maximum and minimum temperature and flows, respectively. Orange and Green colours were used to show positive and negative signs of the values, respectively.

4.5.1 Rainfall stations

Summary results of Q_{med} values, which are obtained from Sen's Slope test for annual rainfall totals, four rainfall seasons and totals for Maha and Yala seasons for the selected 41 rainfall gauging stations are given in Table 4-10.

Table 4-10: Summary results of Q_{med} values, which are obtained from Sen's Slope test for annual rainfall totals, four rainfall seasons and totals for Maha and Yala seasons for the selected 41 rainfall gauging stations

Name of the Rainfall Station	Sen's Slope Estimates						
	Q_{med} for Annual totals	Q_{med} for FIM-I	Q_{med} for SWM-II	Q_{med} for SIM-III	Q_{med} for NEM-IV	Q_{med} for Maha totals	Q_{med} for Yala totals
Alupolla Group	12.90	2.46	7.81	8.61	1.80	5.17	3.85
Ambewela	-2.54	2.22	-13.28	7.21	3.32	11.90	-6.23
Angoda mental hospital	19.65	4.94	4.15	6.81	4.75	12.39	20.83
Avissawella Estate	-18.68	0.70	-12.22	-5.10	-1.73	-7.79	-8.82
Avissawella Hospital	13.57	6.14	0.23	2.09	3.18	12.58	19.95
Balangoda Post Office	1.27	3.76	-6.33	2.04	4.25	6.40	1.08
Bandarawela	4.08	3.01	-1.79	2.33	3.36	6.81	1.64
Bopatthalawa	-10.11	4.72	-13.45	0.49	1.70	4.42	-9.58

Name of the Rainfall Station	Sen's Slope Estimates						
	Q_{med} for Annual totals	Q_{med} for FIM-I	Q_{med} for SWM-II	Q_{med} for SIM-III	Q_{med} for NEM-IV	Q_{med} for Maha totals	Q_{med} for Yala totals
Campion Estate	7.02	3.55	-4.43	3.03	6.41	12.91	8.72
Canyon	-17.46	2.91	-17.66	0.25	2.38	2.53	-14.14
Castlereigh	2.91	3.72	-8.52	1.39	3.19	8.97	-20.92
Chesterford	30.01	7.84	8.40	6.97	4.13	10.01	28.78
Colombo	11.25	5.47	-2.03	3.30	4.14	7.38	10.60
Digalla Estate	-8.21	-0.37	-6.73	-0.51	0.60	0.35	-4.57
Dunedin Estate	-0.21	2.81	-7.43	1.23	1.62	12.91	17.99
Dyrabba Estate	0.91	0.60	-4.71	2.97	1.48	6.17	-2.71
Galatura Estate	-2.66	2.32	-6.04	-2.56	4.92	3.10	-5.17
Hakgala Botanical Gdns	11.90	3.05	-3.82	6.51	6.21	14.14	12.63
Hanwella Group	-22.88	-0.59	-12.21	-4.60	-4.56	-12.04	-32.61
Hapugastenna Estate	-14.17	0.30	-13.78	3.26	1.60	-10.47	-29.84
Holmwood Estate	-1.16	4.36	-6.68	-1.43	2.82	12.17	5.63
Kalatuwawa	0.73	7.69	-3.07	-1.19	1.23	6.42	3.99
Katugastota	8.24	1.92	-6.54	6.03	4.48	14.55	6.51
Katunayaka	1.81	1.81	-3.27	1.63	2.66	6.56	3.38
Kenilworth Strathellie	14.03	7.27	10.52	5.27	2.97	14.87	9.86
Labugama Tank	5.97	7.89	-2.41	0.85	2.07	10.79	3.68
Labukelle	-13.63	-0.40	-12.82	2.27	6.01	4.47	-18.37
Laxapana	-30.16	0.02	-24.06	-2.61	0.79	-4.10	-45.59
Maliboda	14.40	6.76	5.20	1.93	3.86	-3.53	-1.91
Maussakelle	-19.10	0.85	-19.29	0.43	2.22	2.48	-30.43
Negombo	12.01	3.53	-2.45	5.55	4.66	16.51	17.79
Nuwara Eliya	-6.41	2.63	-9.52	1.72	5.00	8.23	-8.92
Pasyala	16.34	6.66	3.85	4.36	2.86	15.89	13.00
Rathmalana	8.66	3.96	-0.63	1.75	2.64	7.68	9.73
Rathnapura	-0.23	4.80	-3.38	2.05	1.28	5.04	-3.94
Sandringham Estate	-9.72	0.44	-10.86	0.57	0.84	3.68	-10.90
Undugoda	-10.57	-3.99	-12.28	-1.07	1.40	6.16	-8.97
Wagolla	-15.72	0.32	-13.57	-4.49	1.11	-8.25	-16.83
Walpita	13.44	4.45	2.74	2.77	4.30	6.62	12.75
Welimada Group	9.39	3.01	-1.43	5.42	3.95	11.45	7.60
Weweltalawa Estate	8.58	2.31	-1.59	2.32	5.83	12.13	17.11

4.5.2 Temperature stations

4.5.2.1 T_{max}

Summary results of Q_{med} values, which are obtained from Sen's Slope test for annual average maximum temperature (T_{max}), four rainfall seasons and annual averages for Maha and Yala seasons for the selected 10 temperature gauging stations are given in Table 4-11.

Table 4-11: Summary results of Q_{med} values, which are obtained from Sen's Slope test for annual average maximum Temperature (T_{max}), four rainfall seasons and annual averages for Maha and Yala seasons for the selected 10 temperature gauging stations

Temperature Station's Name	Sen's Slope Results						
	Q_{med} for Annual averages	Q_{med} for FIM-I	Q_{med} for SWM-II	Q_{med} for SIM-III	Q_{med} for NEM-IV	Q_{med} for Maha averages	Q_{med} for Yala averages
Badulla	-0.011	-0.019	0.002	-0.015	-0.025	-0.020	-0.021
Bandarawela	0.009	-0.007	0.021	0.000	-0.002	-0.002	0.007
Colombo	0.001	-0.009	0.003	0.006	-0.001	-0.001	0.002
Katugastota	0.007	-0.012	0.019	0.011	-0.010	-0.003	0.011
Katunayaka	-0.011	-0.029	-0.003	-0.011	-0.027	-0.020	-0.011
Kurunegala	0.004	-0.016	0.009	0.012	-0.010	-0.004	0.006
Nuwara Eliya	0.004	-0.018	0.016	0.010	-0.008	-0.003	0.007
Ratmalana	0.008	0.005	0.015	0.017	0.001	0.004	0.007
Ratnapura	0.002	-0.009	0.002	0.006	0.000	0.000	0.003
Seetha Eliya	0.007	0.011	0.018	0.017	-0.002	0.005	0.006

4.5.2.2 T_{min}

Summary results of Q_{med} values, which are obtained from Sen's Slope test for annual average minimum temperature (T_{min}), four rainfall seasons and annual averages for Maha and Yala seasons for the selected 10 temperature gauging stations are given in Table 4-12.

Table 4-12: Summary results of Q_{med} values, which are obtained from Sen's Slope test for annual average minimum Temperature (T_{min}), four rainfall seasons and annual averages for Maha and Yala seasons for the selected 10 temperature gauging stations

Temperature Station's Name	Sen's Slope Results						
	Q_{med} for Annual averages	Q_{med} for FIM-I	Q_{med} for SWM-II	Q_{med} for SIM-III	Q_{med} for NEM-IV	Q_{med} for Maha averages	Q_{med} for Yala averages
Badulla	0.000	-0.020	-0.001	0.001	0.004	0.000	-0.003
Bandarawela	0.009	-0.007	0.021	0.000	-0.002	-0.002	0.007
Colombo	0.001	-0.009	0.003	0.006	-0.001	-0.001	0.002
Katugastota	0.007	-0.012	0.019	0.011	-0.010	-0.003	0.011
Katunayaka	0.028	0.009	0.029	0.027	0.026	0.029	0.024
Kurunegala	0.004	-0.016	0.009	0.012	-0.010	-0.004	0.006
Nuwara Eliya	0.004	-0.018	0.016	0.010	-0.008	-0.003	0.007
Ratmalana	0.030	0.026	0.025	0.020	0.034	0.033	0.030
Ratnapura	0.002	-0.009	0.002	0.006	0.000	0.000	0.003
Seetha Eliya	0.007	0.011	0.018	0.017	-0.002	0.005	0.006

4.5.3 Streamflow

Summary results of Q_{med} values, which are obtained from Sen's Slope test for annual average flow, four rainfall seasons and annual averages for Maha and Yala seasons for the selected 3 hydrometric stations are given in Table 4-13.

Table 4-13: Summary results of Q_{med} values, which are obtained from Sen's Slope test for annual average flow, four rainfall seasons and annual averages for Maha and Yala seasons for the selected 3 hydrometric stations

Name of the selected Hydrometric Station	Sen's Slope Estimates						
	Q_{med} for Annual averages	Q_{med} for FIM-I	Q_{med} for SWM-II	Q_{med} for SIM-III	Q_{med} for NEM-IV	Q_{med} for Maha averages	Q_{med} for Yala averages
Kitulgala	-0.27	-0.16	-0.45	-0.09	-0.10	-0.13	-0.31
Glencourse	-1.77	-0.10	-2.41	-2.69	-0.34	-1.12	-1.83
Hanwella	-2.01	-1.09	-2.63	-2.35	-1.11	-1.67	-2.15

4.6 SWAT Modelling

4.6.1 Sensitivity analysis for calibration and verification at Glencourse hydrometric station

Sensitivity Analysis was carried out to optimise the calibration parameters using SWAT-CUP software. SUFI-2 is used for parallel processing and iterations are reduced the parameter uncertainties.

4.6.1.1 Parameter estimation

A lot of sensitivity runs were performed to optimize objective functions by changing about seven (7) parameters initially and finalised for four (4) parameters. The optimised four (4) parameters for Glencourse hydrometric station were given in Table 4-14.

Table 4-14: Four parameters are mainly used to optimization at Glencourse hydrometric station

Parameters used during Calibration in SWAT CUP	Method used	Optimsed Parameters from SWAT CUP	Optimsed Parameters for SWAT
CN2.mgt	Relative	-0.206	0.795
GWQMN.gw	Relative	-0.187	0.813
SOL_AWC().sol	Relative	0.926	1.926
ESCO.bsn	Relative	0.030	1.030

4.6.2 Calibration and validation of SWAT model at Glencourse gauging station

The SWAT model is calibrated and validated at Glencourse, as it shows fewer uncertainties at observed flows when compared with the other gauging stations in Kelani ganga basin.

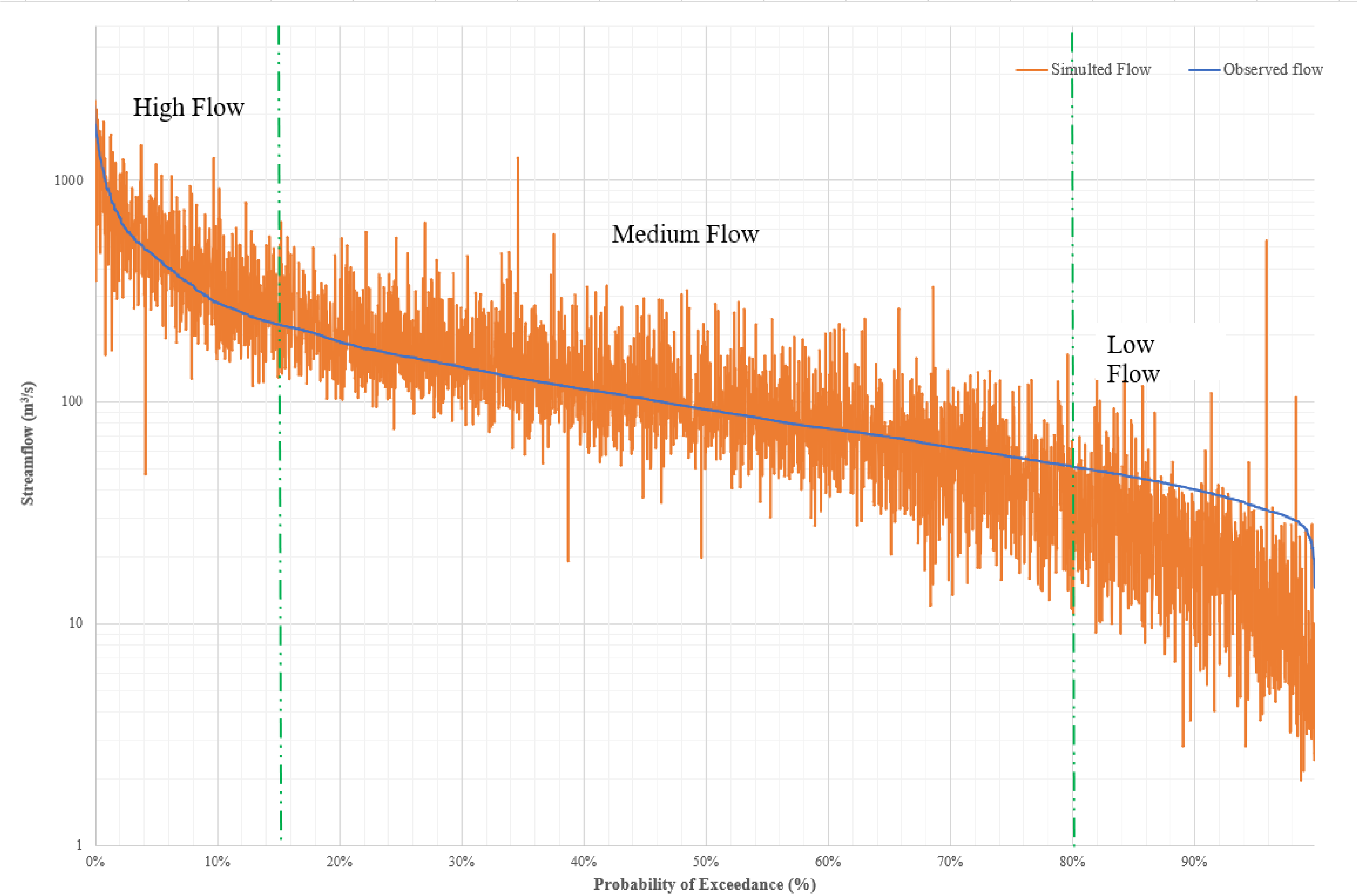
Mass balance performance, Nash and Sutcliffe coefficient and coefficient of determination is performed in daily time step has been undertaken for the annual average observed and simulated flows for the calibration and validation periods at the Glencourse hydrometric station.

Calibration was carried out for the period of 1970 to 1980, while the validation was carried out for the period of 1982 to 1992. Flow Duration Curves (FDC) for the unsorted simulated flow vs sorted observed flow are plotted and given in Figure 4-13 for both calibration and validation. Flow Duration Curves (FDC) for sorted simulated flow vs sorted observed flow are plotted for calibration and validation period are given in Figure

4-14. Identified Low flow/ medium flow and high flow thresholds is shown in the Figure 4-13 and Figure 4-14.

The optimised values for objectives functions during calibration and validation are given in Table 4-15, while R^2 plots for both Calibration and validation durations for Glencourse gauging station are given in Figure 4-15.

Comparison of the daily observed flow and modelled flows for the durations of calibration period and validation period for the Glencourse hydrometric station in actual scale and in logrithmic scale is shown in Figure 4-18 and Figure 4-19 respectively and also in Appendix E.



High Flow
Medium Flow
Low Flow
Simulted Flow
Observed flow
Streamflow (m³/s)
1000
100
10
1
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
Probability of Exceedance (%)

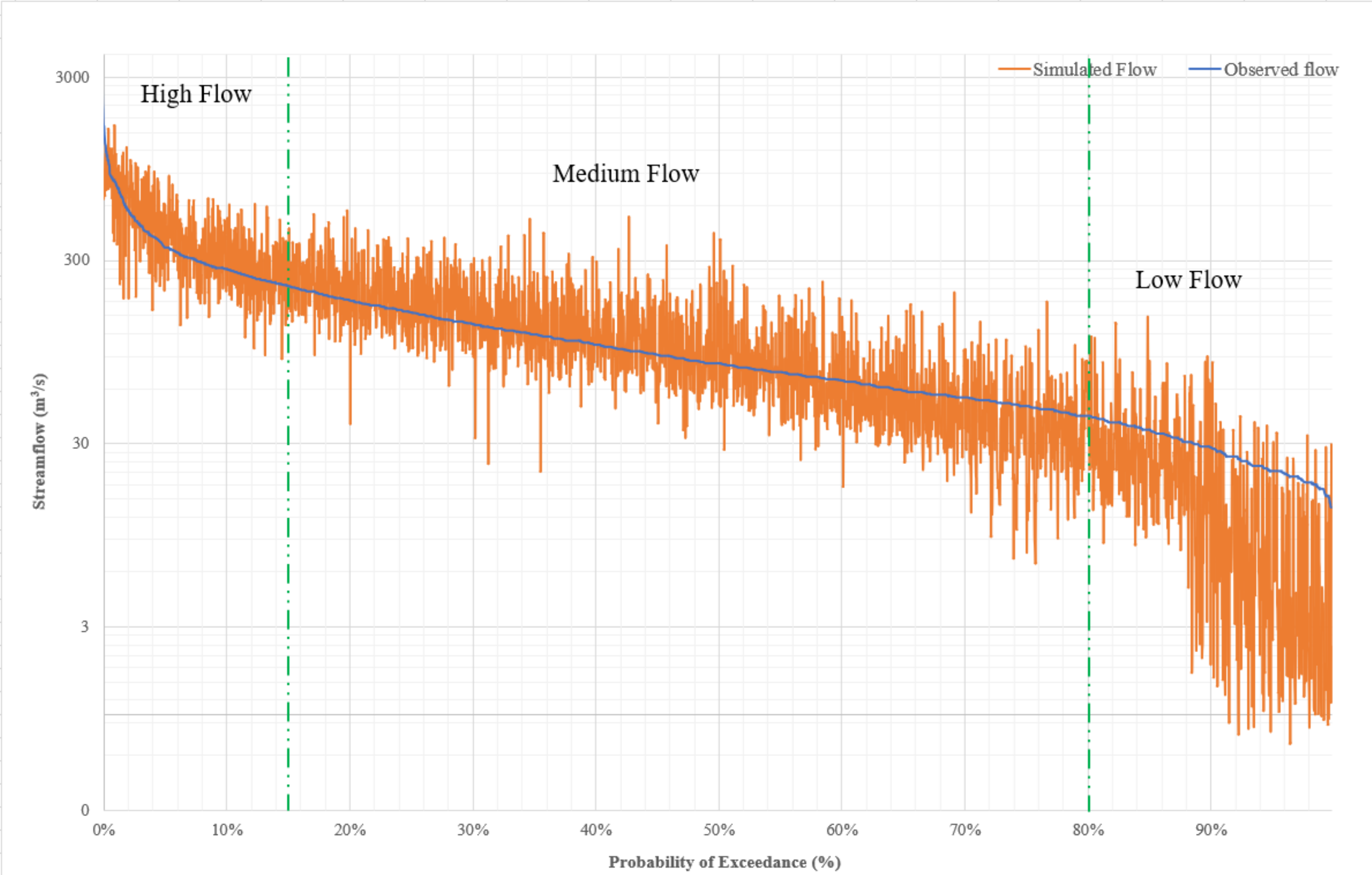
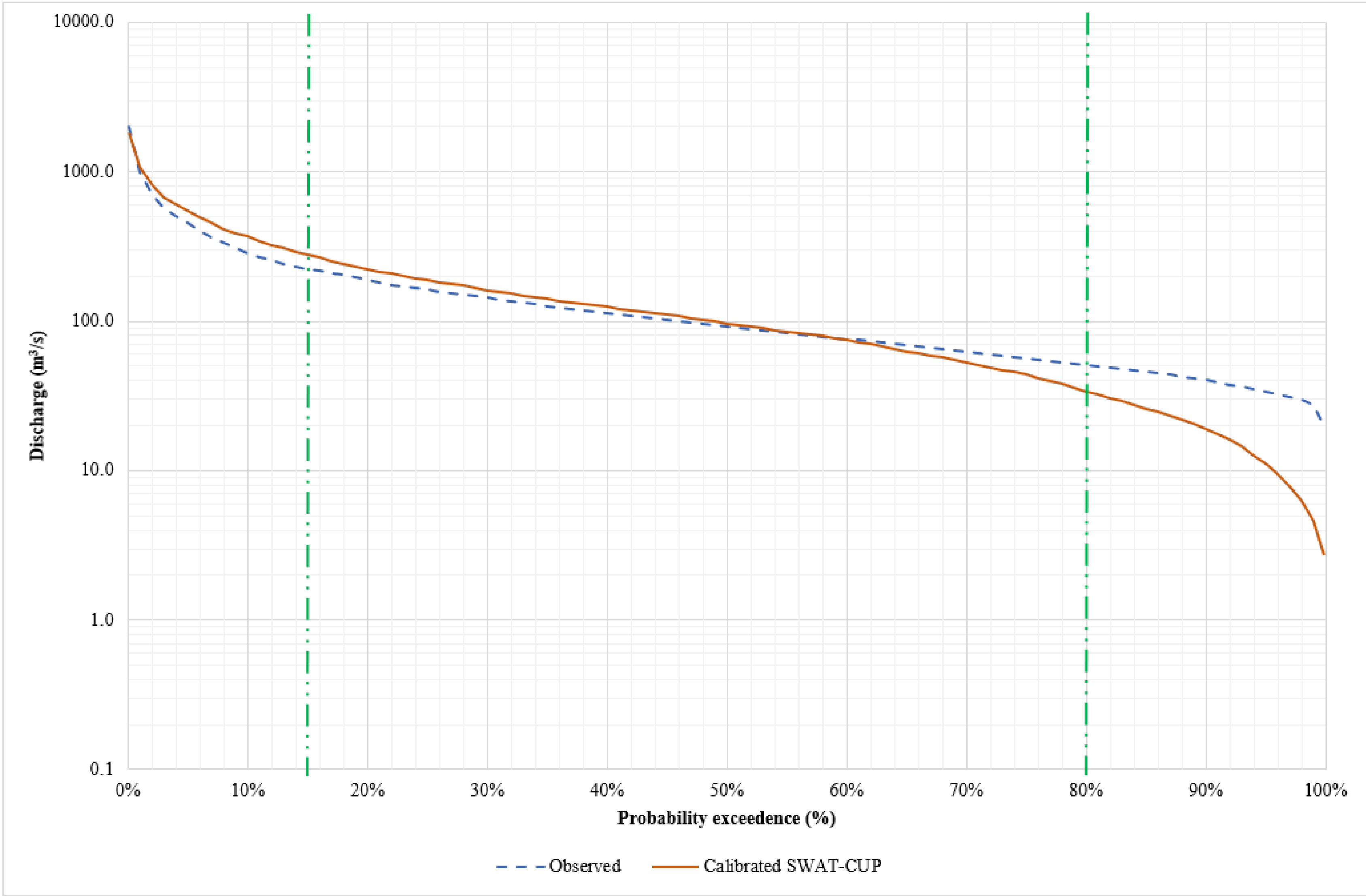


Figure 4-13: Flow Duration Curve (FDC) for the unsorted simulated flow vs sorted observed flow for the calibration period of 1970 to 1980 (top) and for validation period of 1982 to 1992 (bottom) for Glencourse Gauging station



10000.0
1000.0
100.0
10.0
1.0
0.1
Discharge (m³/s)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Probability exceedence (%)
Observed
Calibrated SWAT-CUP

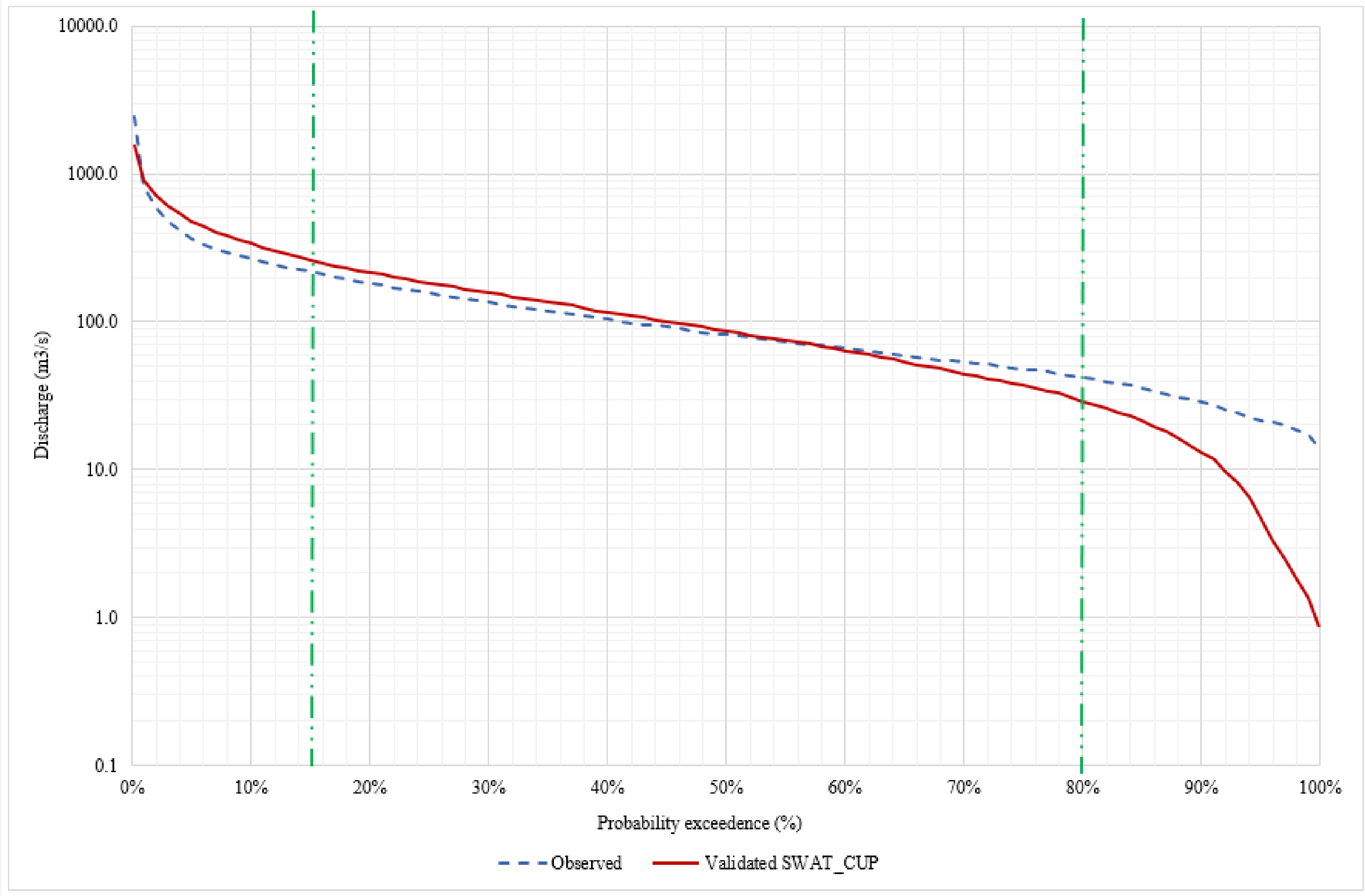
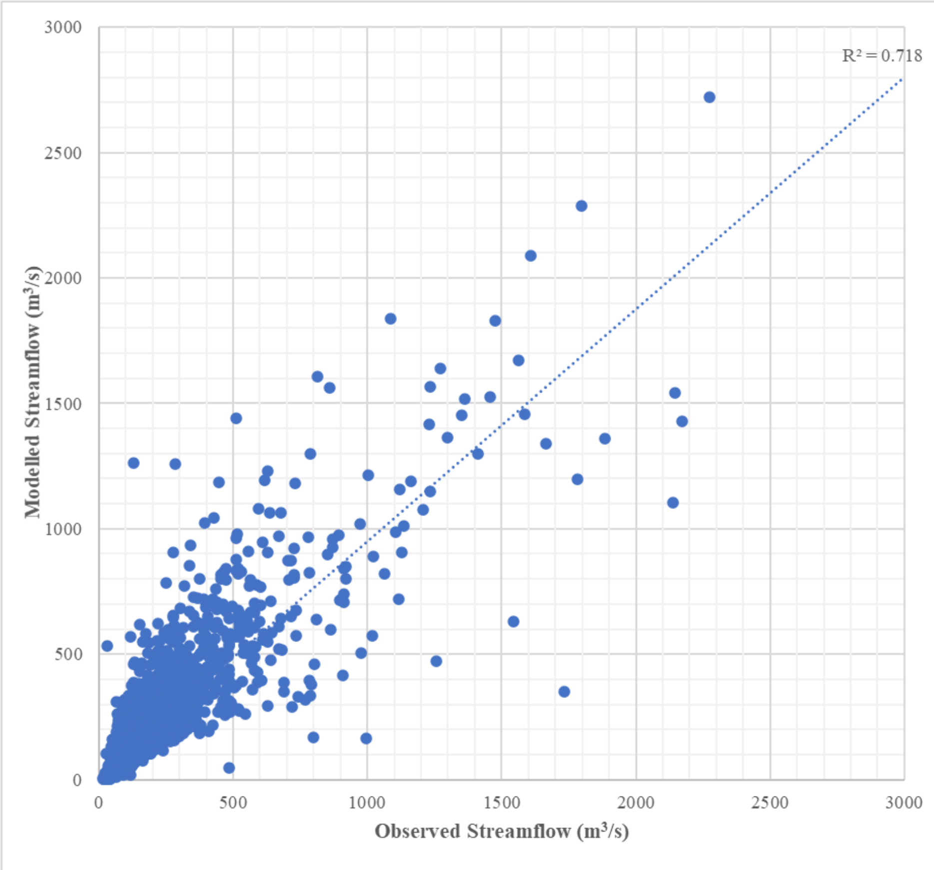


Figure 4-14: Sorted simulated flow vs sorted observed flow are plotted in Flow Duration Curve (FDC) for the calibration period (top) and validation period (bottom)



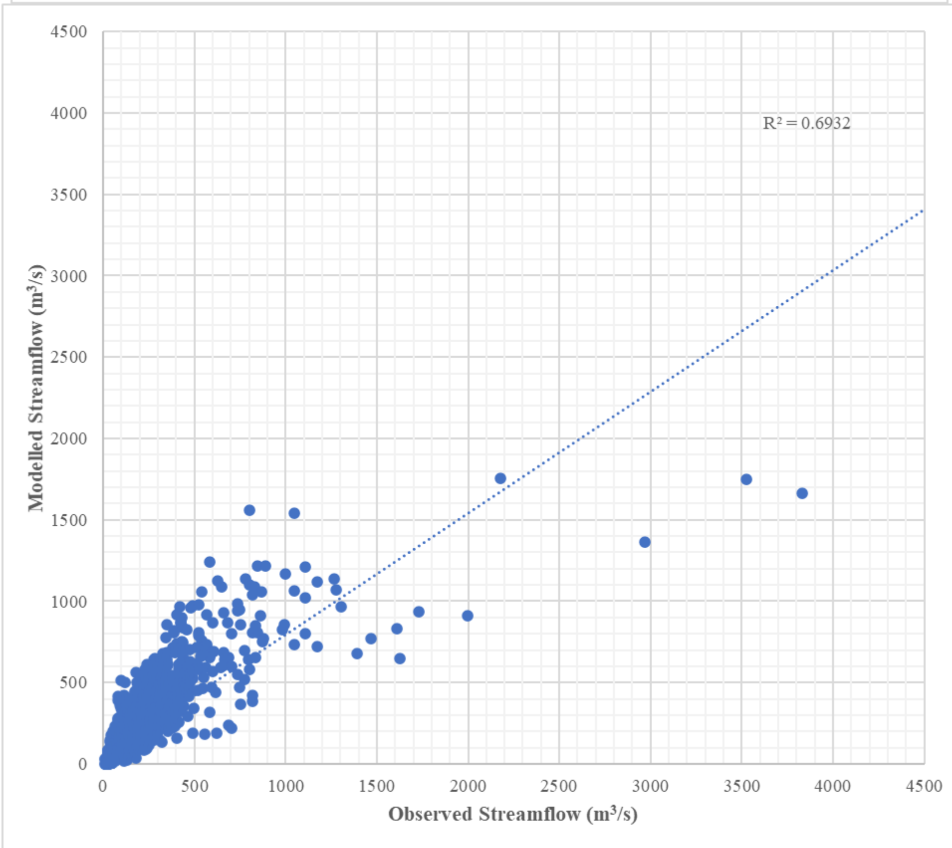


Figure 4-15: R^2 plots for Calibration (top) and validation (bottom) durations for Glencourse gauging station

Table 4-15: The optimised values for objectives functions during calibration and validation for Glencourse gauging station

Objective functions	Calibration period of 1970 to 1980	Validation period of 1982 to 1992
Mass balance performance Error (*Er*)	8.9%	9.1%
Coefficient of determination (R^2)	0.72	0.69
Nash–Sutcliffe efficiency (*NSE*)	0.65	0.69

After optimizing the parameters, the simulated flows vs observed flow is plotted for Glencourse gauging station for the water years for the period of 1960 to 2016 and the both discharges in actual scale and logarithmic scale are given in Figure 4-16 and Figure 4-17.

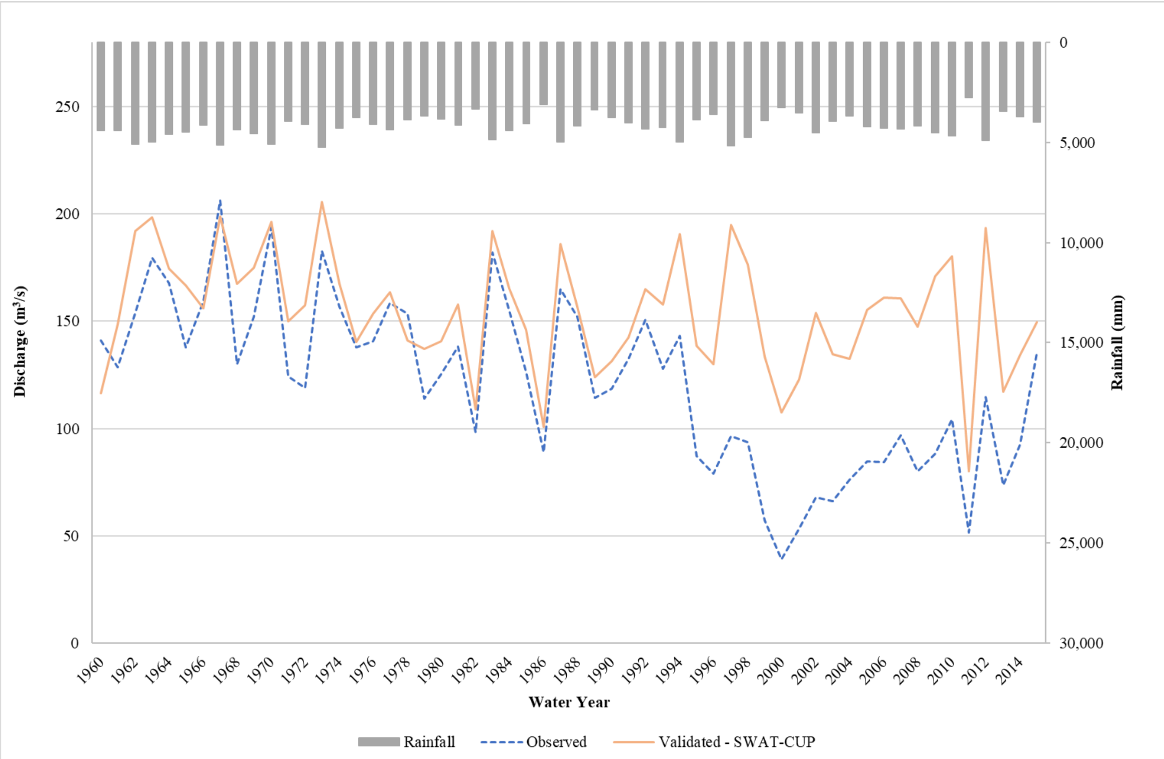


Figure 4-16: Comparison of the annual average observed and modelled flows in actual scale for water years for the period of 1960 to 2016 for the Glencourse hydrometric station

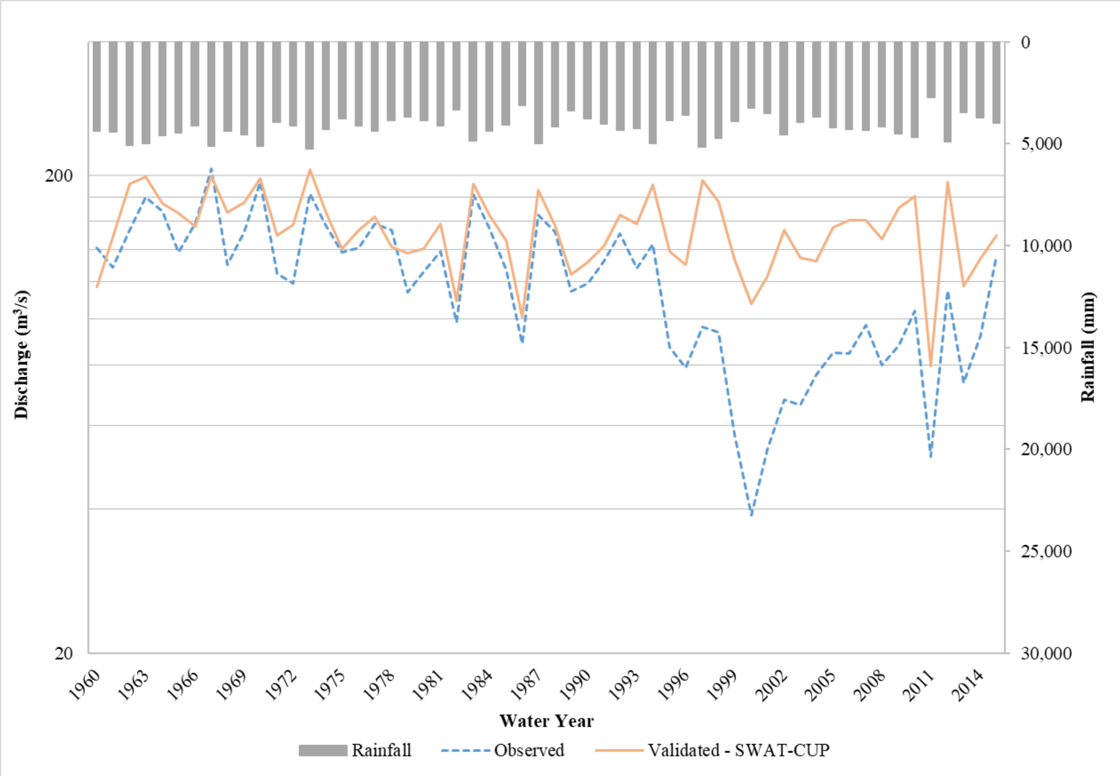
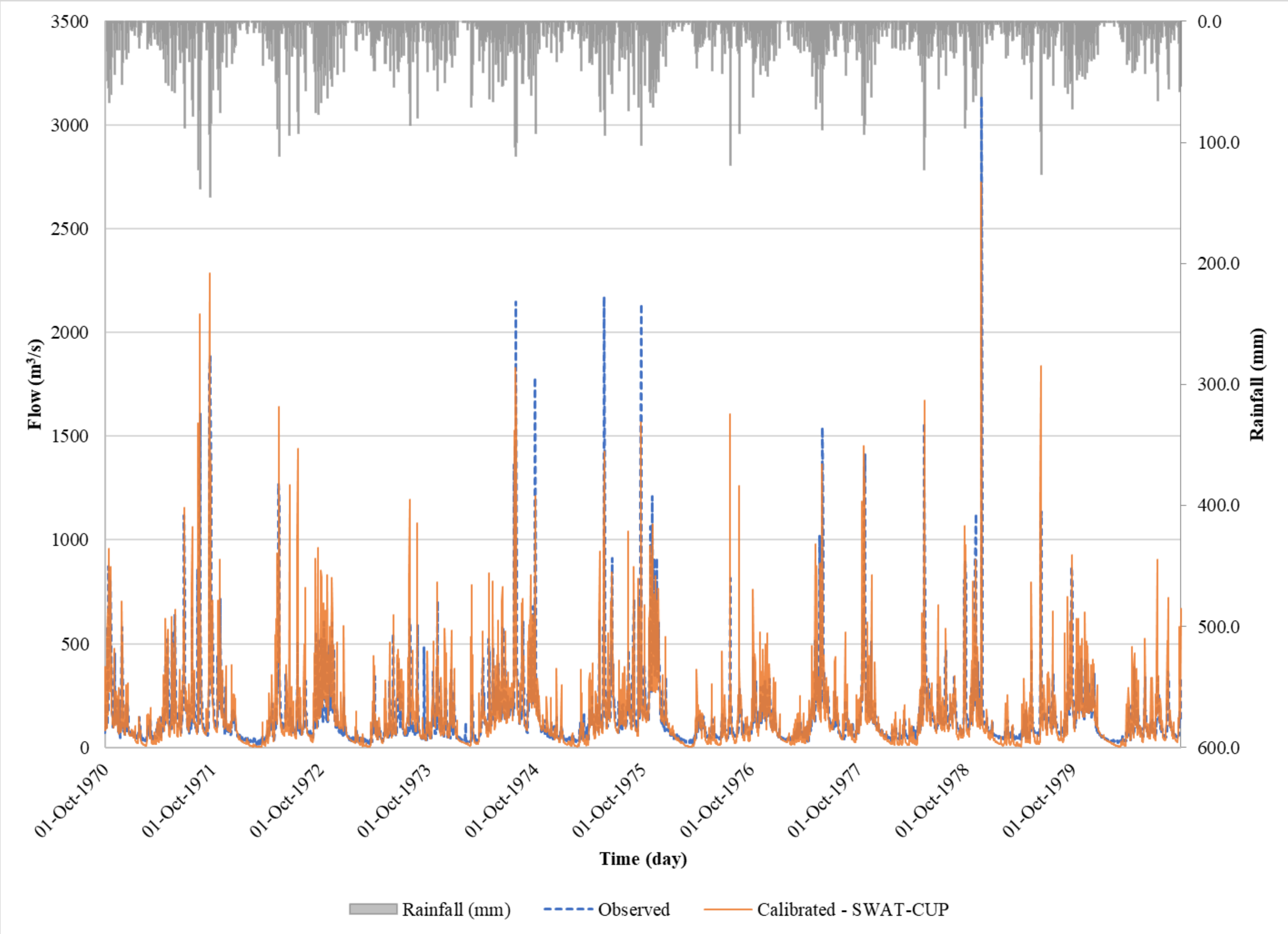


Figure 4-17: Comparison of the annual average observed and modelled flows for water years for the period of 1960 to 2016 in log scale for the Glencourse hydrometric station


3500
3000
2500
2000
1500
1000
500
0
Flow (m³/s)
0.0
100.0
200.0
300.0
400.0
500.0
600.0
Rainfall (mm)
01-Oct-1970
01-Oct-1971
01-Oct-1972
01-Oct-1973
01-Oct-1974
01-Oct-1975
01-Oct-1976
01-Oct-1977
01-Oct-1978
01-Oct-1979
Time (day)
Rainfall (mm)
Observed
Calibrated - SWAT-CUP

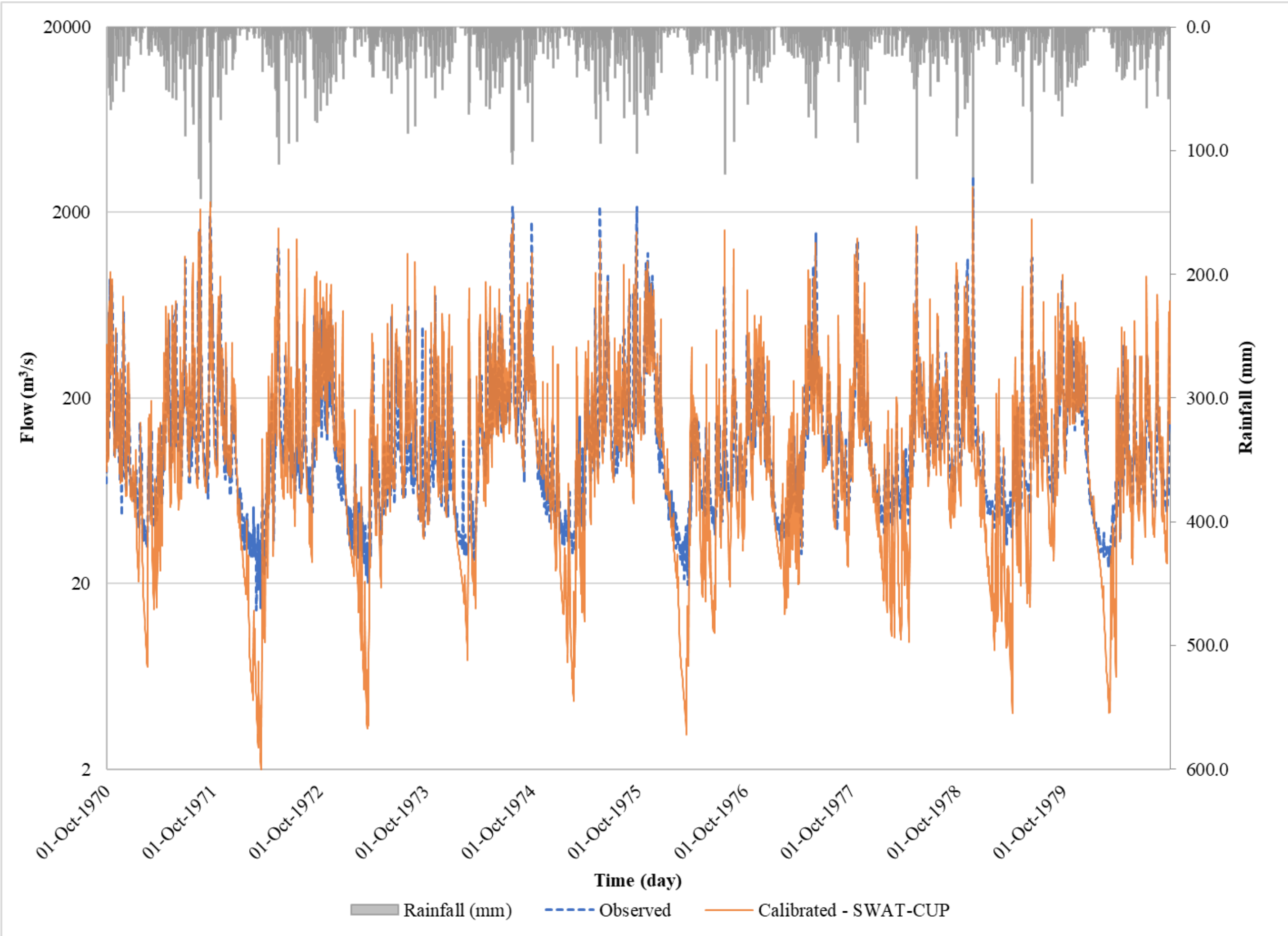
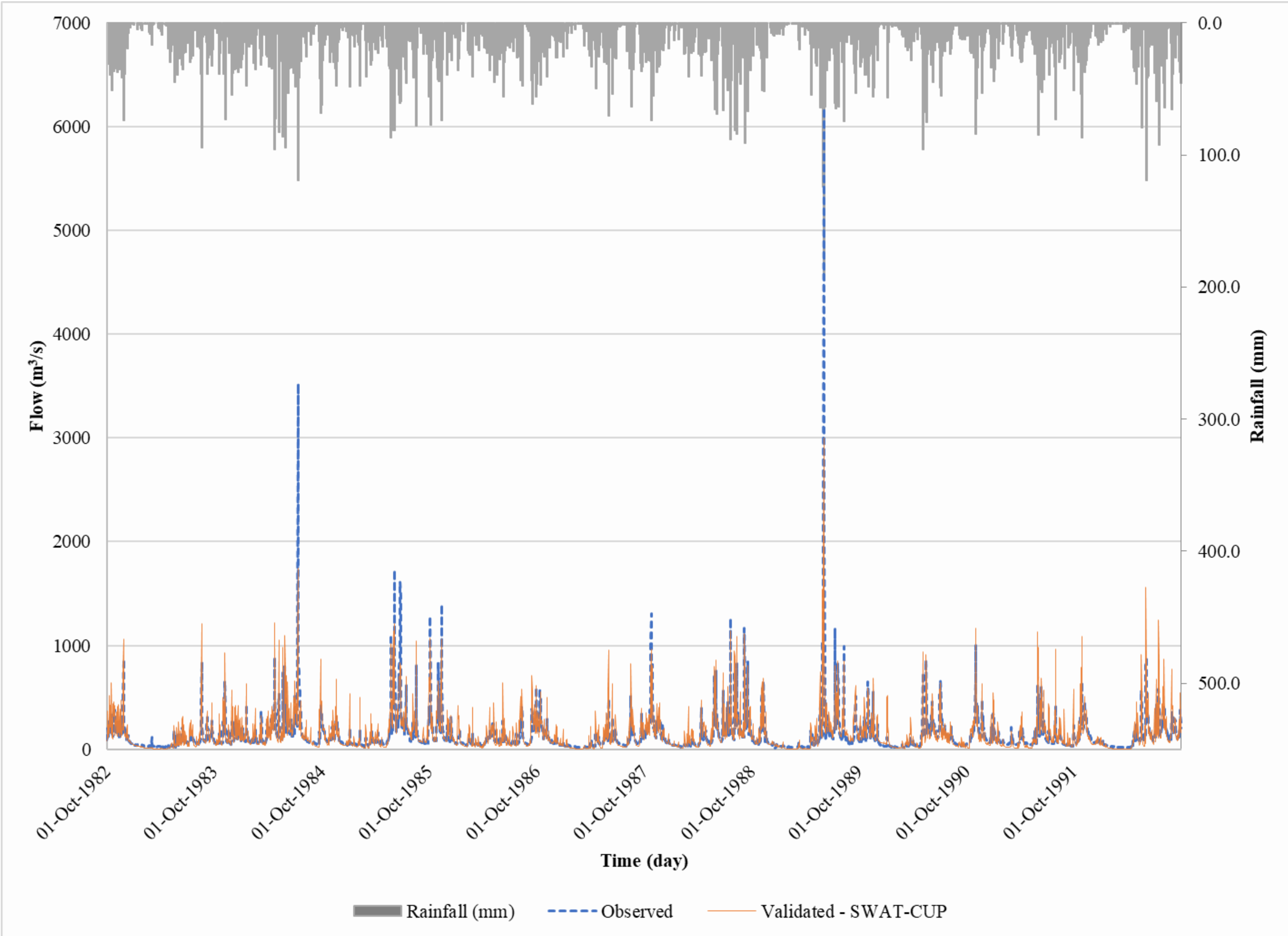


Figure 4-18: Comparison of the daily observed flow and modelled flows for the duration of calibration period in actual scale (top) in log scale (bottom) for the Glencourse hydrometric station



7000
6000
5000
4000
3000
2000
1000
0
Flow (m³/s)
0.0
100.0
200.0
300.0
400.0
500.0
Rainfall (mm)
01-Oct-1982
01-Oct-1983
01-Oct-1984
01-Oct-1985
01-Oct-1986
01-Oct-1987
01-Oct-1988
01-Oct-1989
01-Oct-1990
01-Oct-1991
Time (day)
Rainfall (mm)
Observed
Validated - SWAT-CUP

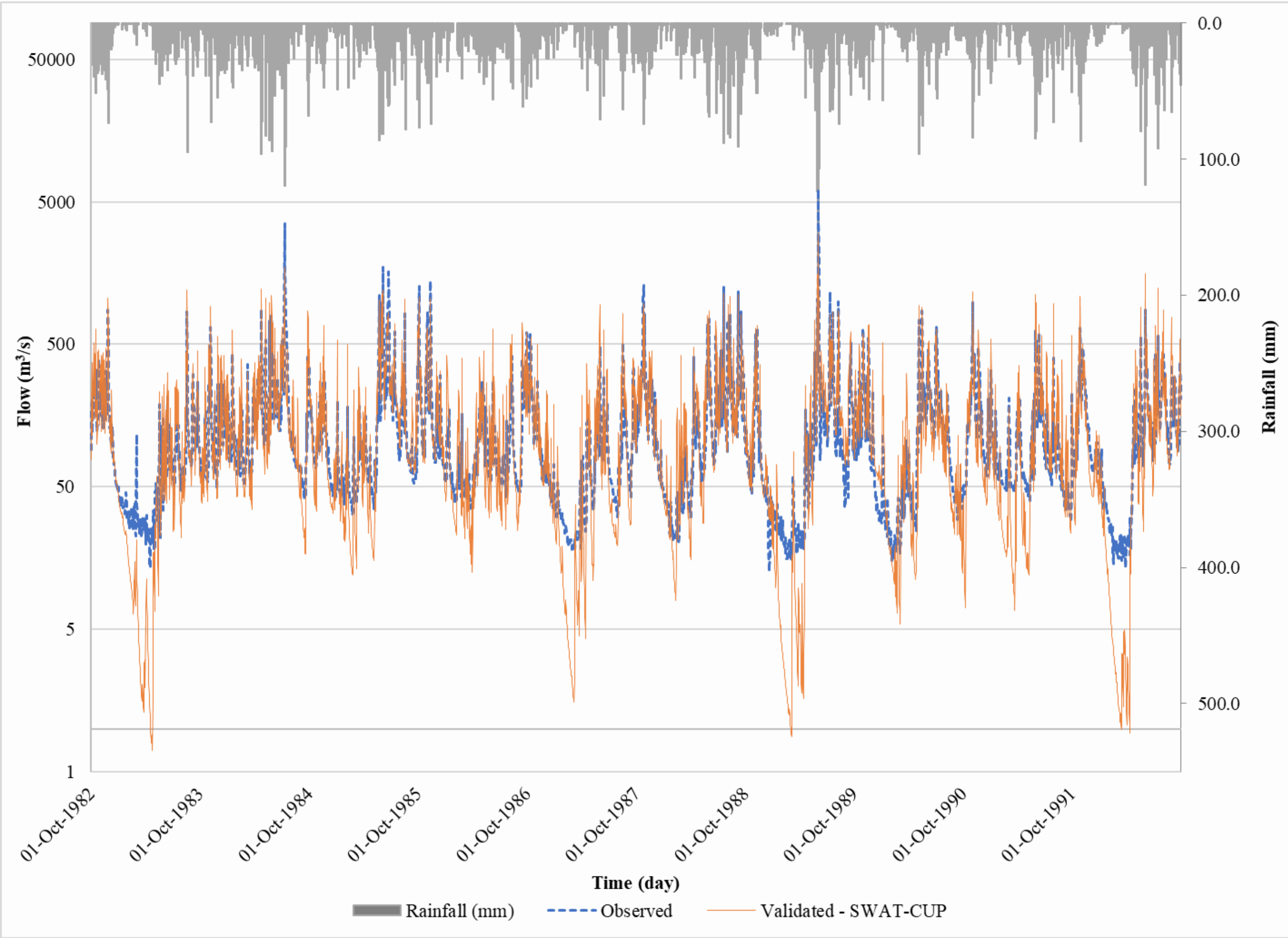


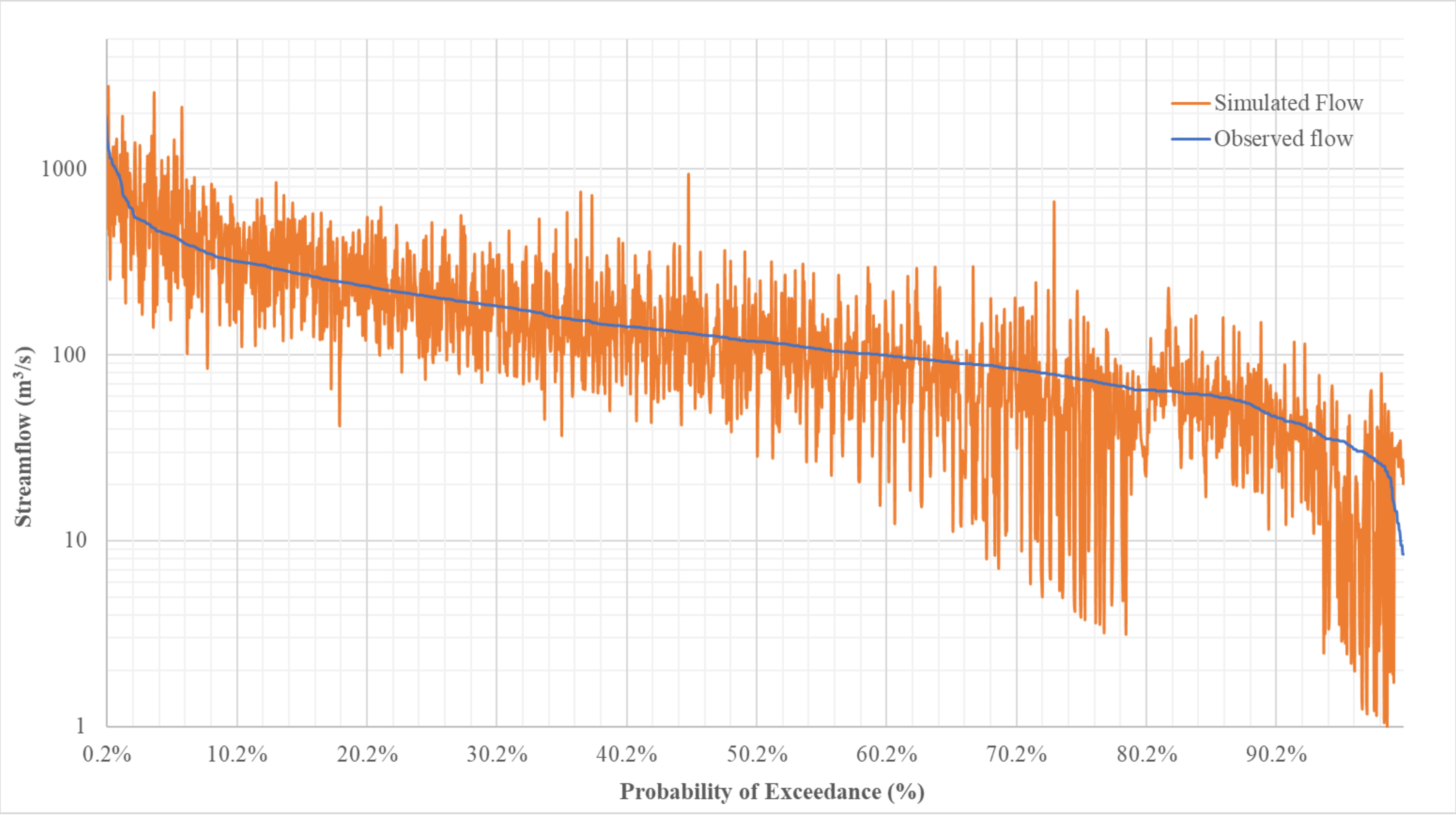
Figure 4-19: Comparison of the daily observed flow and modelled flows for the duration of validation period in actual scale (top) in log scale (bottom) for the Glencourse hydrometric station

4.6.3 Calibration and validation Results for Hanwella Catchment

Calibration was carried out for the period of 1980 to 1986, while the validation was done for the period of 1973 to 1980. Flow Duration Curves (FDC) for the unsorted simulated flow vs sorted observed flow are plotted in and it is given in Figure 4-20 for both calibration and validation. The optimised values for objectives functions during calibration and validation are given in Table 4-16 .

Table 4-16: The optimised values for objectives functions during the calibration and the validation for Hanwella gauging station

Objective functions	Calibration period of 1980 to 1986	Validation period of 1973 to 1980
Mass balance performance Error (*E*r)	7.3 %	0.5 %
Coefficient of determination (R^2)	0.58	0.51
Nash–Sutcliffe efficiency (*NSE*)	0.23	0.48



Simulated Flow
Observed flow
1000
100
10
1
Streamflow (m³/s)
0.2%
10.2%
20.2%
30.2%
40.2%
50.2%
60.2%
70.2%
80.2%
90.2%
Probability of Exceedance (%)

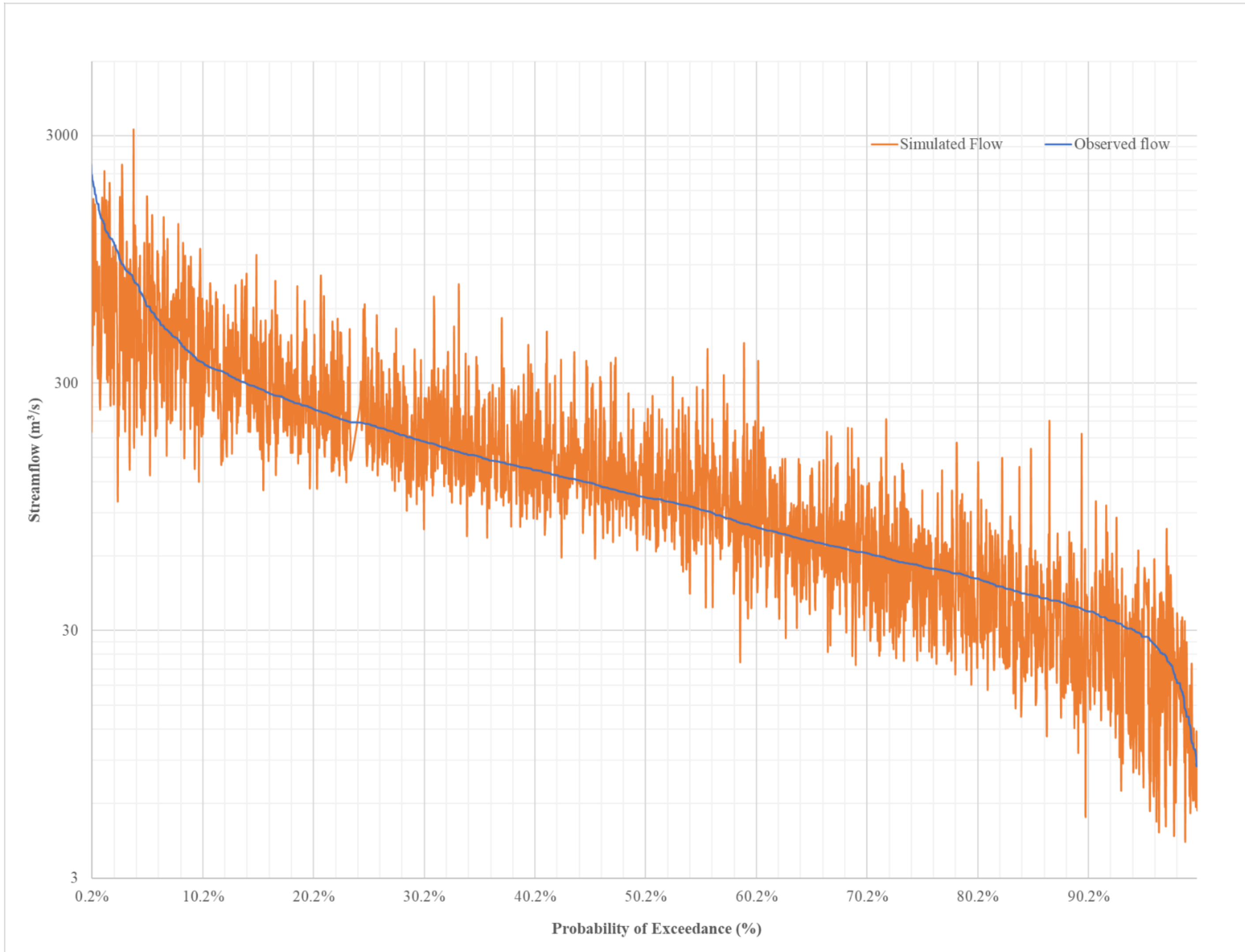


Figure 4-20: Flow Duration Curve (FDC) for the unsorted simulated flow vs sorted observed flow for the calibration period of 1980 to 1986 (top) and for validation period of 1973 to 1980 (bottom) for Hanwella Gauging station

4.6.4 Calibration and validation Results for Kitulgala Catchment

The optimised values for objectives functions during calibration and validation are given in Table 4-17.

Table 4-17: The optimised values for objectives functions during calibration and validation for Kitulgala gauging station

Objective functions	Calibration period of 1990 to 1996	Validation period of 1981 to 1987
Mass balance performance Error (*E*r)	18.8 %	29.7 %
Coefficient of determination (R^2)	0.36	0.345
Nash–Sutcliffe efficiency (*NSE)*	-1.9	-1.3

4.7 Future Climate Scenarios

4.7.1 LTA variation for both rainfall over runoff

LTA variation of streamflow over Rainfall for both Baseline Climate scenario and Pessimistic Future Climatic scenarios for Glencourse hydrometric station for 2040 are given in Figure 4-21 and Table 4-18.

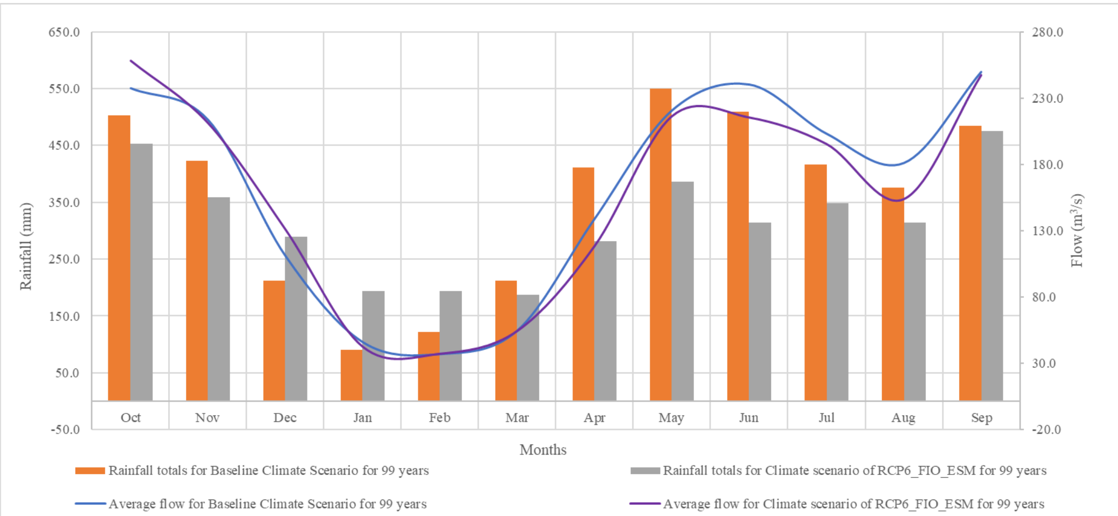


Figure 4-21: LTA variation of streamflow over Rainfall for both Baseline and Pessimistic Future Climatic Scenarios without Landuse change

4.7.2 LTA variation for Temperature

LTA variation of Temperature for both Baseline and Pessimistic Future Climatic scenarios for Glencourse hydrometric station with and without landuse for 2040 are given in Table 4-19 and Figure 4-22.

Table 4-18: LTA variation of streamflow and Rainfall for both Baseline and Pessimistic Future Climatic scenarios

Parameter Type	**Scenario**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Rainfall totals/ Average Flow**
Rainfall (mm)	Rainfall totals for Baseline Climate Scenario for 99 years	503	422	212	91	121	212	411	550	510	417	375	484	**4308**
	Rainfall totals for Climate scenario of RCP6_FIO_ESM for 99 years	453	358	290	193	194	188	282	386	314	348	314	476	**3795**
Streamflow (m^3/s)	Average flow for Baseline Climate Scenario for 99 years without projected landuse for 2040	237	213	111	46	37	55	139	220	240	203	181	250	**161**
	Average flow for Climate scenario of RCP6_FIO_ESM for 99 years without projected landuse for 2040	258	211	131	42	37	54	118	216	215	195	154	247	**157**
	Average flow for Baseline Climate Scenario for 99 years with projected landuse for 2040	236	212	110	45	36	55	141	221	240	202	179	228	**159**
	Average flow for Climate scenario of RCP6_FIO_ESM for 99 years with projected landuse for 2040	258	211	130	42	37	55	119	217	216	196	153	250	**157**

Table 4-19: LTA variation of Temperature for both Baseline and Pessimistic Future Climatic scenarios for Glencourse hydrometric station

Scenario for Temperature	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average (ºC)
Average for Baseline Climate Scenario for 99 years	25.4	25.0	24.7	24.9	25.5	26.3	26.7	26.5	25.8	25.7	25.8	25.5	25.7
Annual Average for Climate scenario of RCP8.5_FIO_ESM for 99 years	26.3	26.1	25.7	25.5	26.2	26.6	26.9	27.0	26.8	26.6	26.7	26.6	26.4

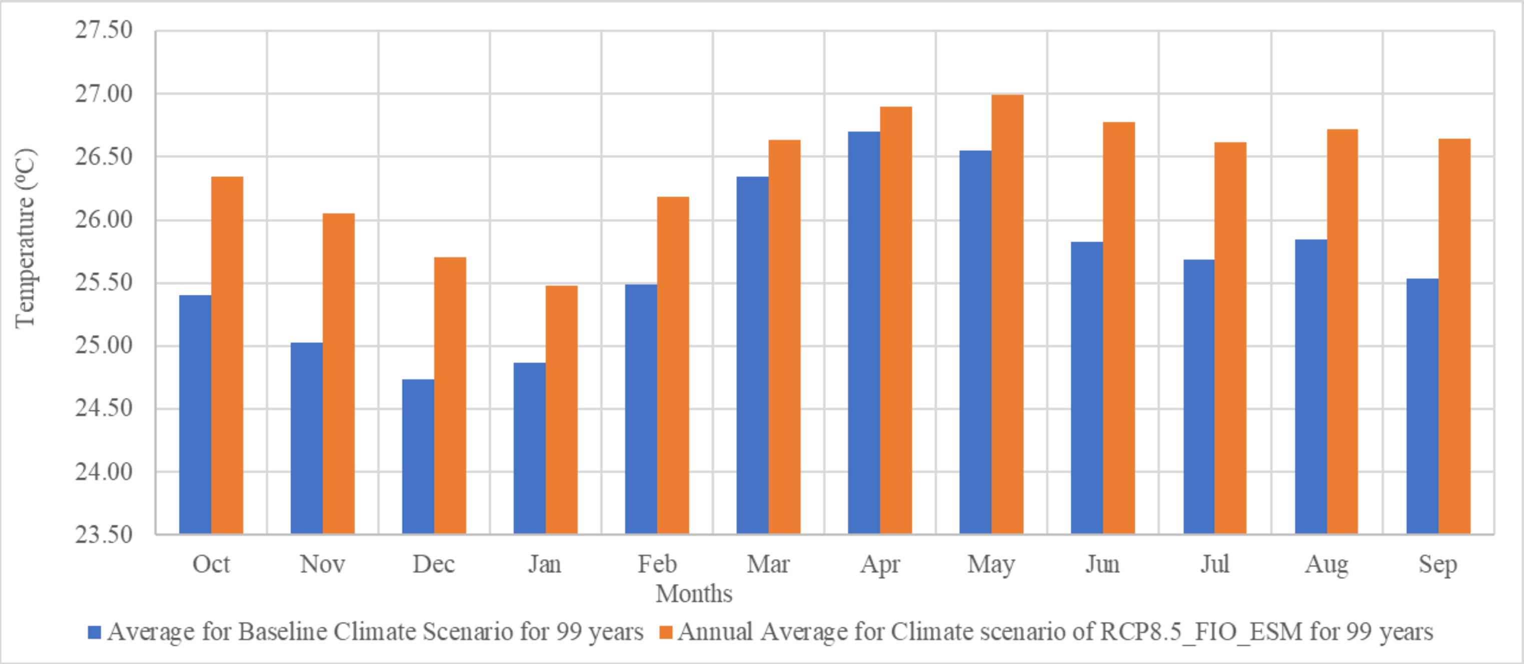


Figure 4-22: LTA variation of Temperature for both Baseline and Pessimistic Future Climatic scenarios for Glencourse hydrometric station

5 DISCUSSION

5.1 Data and data Period

Rainfall, temperature, streamflow and evaporation data was used for analysis in daily time-step, as it is the best time step to be used for both hydrological and climate change analysis for a long period (Jeffrey et al., 2001). Though gap filling was carried out for the period of 1960 to 2016, statistical tests were carried out for the period of 1980 to 2016, as the baseline period is taken from 1980/81 to 2009/10 as the WMO guideline for Climate Change (WMO, 2017). Among the eight (8) Agroecological zones, the WL1a (18%) is the dominant agro-ecological zone in the selected Kelani Ganga basin.

5.1.1 Rainfall stations

Among the selected 41 rainfall stations, 17 rainfall stations are located within the Kelani Ganga basin, while the 24 rainfall stations are located near to the Kelani Ganga basin, which were used for gap filling process using Inverse Distance Weighting (IDW).

As Bandarawela, Badulla, Dyrabba Estate, Welimada Group, Negombo, Hakgala Botanical Gardens, Katugasthota and Nuwara Eliya are far away to Kelani ganga basin, they were not used to calculate the rainfall variability in the basin as well as for SWAT modelling. Those stations were used only for gap-filling of other nearby stations using IDW, as it is a spatial averaging method. Therefore, average annual rainfall variation in the basin are given in Table 5-1 without considering the aforementioned 5 stations. The annual average rainfall is varied from 1750 mm to 5680 mm, while rainfall totals varied from 760 mm to 1850 mm and from 920 mm to 3920 mm in the basin for Maha and Yala seasons respectively.

Table 5-1: Average annual rainfall variation in the basin

Description	LTA or Standard Deviation (SD)	Maximum	Minimum
For annual average Year	LTA from 1960 to 2016 (mm)	5436	1966
	LTA from 1980 to 2016 (mm)	5681	1756
	SD from 1980 to 2016 (mm)	1246	368
For Maha season	LTA from 1960 to 2016 (mm)	1914	830
	LTA from 1980 to 2016 (mm)	1853	760

Description	LTA or Standard Deviation (SD)	Maximum	Minimum
	SD from 1980 to 2016 (mm)	557	245
For Yala season	LTA from 1960 to 2016 (mm)	3783	952
	LTA from 1980 to 2016 (mm)	3916	923
	SD from 1980 to 2016 (mm)	964	218

It is observed that the maximum LTA of rainfall is increased by 245 mm (5 %), while the minimum value is being decreased by 210 mm (11 %) for the annual averages from the duration of 1960 to 2016 to the duration of 1980 -2016 for the Kelani Ganga basin.

It is also noted that the maximum LTA value is decreased by 61 mm (3 %), while the minimum value is being decreased by 70 mm (8 %) for the annual averages for Maha season from the duration of 1960 to 2016 to the duration of 1980 -2016 for the Kelani Ganga basin.

It is also noted that the maximum LTA value is increased by 133 mm (4 %), while the minimum value is being decreased by 29 mm (3 %) for the annual averages for Yala season from the duration of 1960 to 2016 to the duration of 1980 to 2016 for the Kelani Ganga basin, hence the change of the LTA of the rainfall from the duration of 1960 to 2016 to the duration of 1980 to 2016 is not significant.

5.1.2 Temperature stations

Though none of the stations is in the basin, 10 temperature gauging stations are located around the basin are taken into the analysis of the study. Annual average temperature (T_{avg}) is varied from 16.1 ^{0}C to 28.1 ^{0}C, while average (T_{avg}) for Maha season is varied from 15.7 ^{0}C to 27.6 ^{0}C and average (T_{avg}) for Yala season is varied from 16.5 ^{0}C to 28.5 ^{0}C in the basin. The highest temperature shows at the lower reaches in the basin, while the lowest temperature shows in the most upper reaches in the basin (Table 5-2).

Table 5-2: Average annual temperature variation in the basin

Description	for annual average (^{0}C)		for Maha season (^{0}C)		for Yala season (^{0}C)	
	LTA from 1980 to 2016	SD from 1980 to 2016	LTA from 1980 to 2016	SD from 1980 to 2016	LTA from 1980 to 2016	SD from 1980 to 2016
Maximum Temperature variation	28.11	0.54	27.63	0.65	28.54	0.55

Description	for annual average (°C)		for Maha season (°C)		for Yala season (°C)	
	LTA from 1980 to 2016	SD from 1980 to 2016	LTA from 1980 to 2016	SD from 1980 to 2016	LTA from 1980 to 2016	SD from 1980 to 2016
Minimum Temperature variation	16.10	0.29	15.70	0.36	16.48	0.29
Difference	12.00	0.25	11.93	0.28	12.06	0.27

5.1.3 Streamflow stations

Annual average flow is varied from 3,815 MCM to 3,273 MCM for the period of 1960 - 2016 to for the period of 1980 - 2016 by reduction of flow about 542 MCM (14 %) at Glencourse (Table 5-3). Kitulgala hydrometric station also shows the 3 % of reduction of flow for the aforementioned both durations. As Hanwella gauging station was started in 1973, the comparison was unable to do for the same duration as given in Table 5-3.

Table 5-3: Comparison of flow reduction between two durations (from the period of 1960 - 2016 to the period of 1980 - 2016)

Description	for annual		for Maha		for Yala	
	LTA (m^3/s)	LTA (MCM)	LTA (m^3/s)	LTA (MCM)	LTA (m^3/s)	LTA (MCM)
Difference at Glencourse for the durations of 1960 to 2016 and 1980 to 2016	17.18	541.85 (14 %)	13.82	224.67	20.55	324.89
Difference at Kitulgala for the durations of 1960 to 2016 and 1980 to 2016	1.04	32.75 (3 %)	0.14	4.87	1.94	30.62

The runoff to rainfall ratio 52.8 %, 55.4 % and 79 % for Glencourse, Hanwella and Kitulgala hydrometric stations, respectively for the period of 1980 to 2016 and runoff variation over catchment average rainfall for the selected gauging stations are given in Figure 5-1.

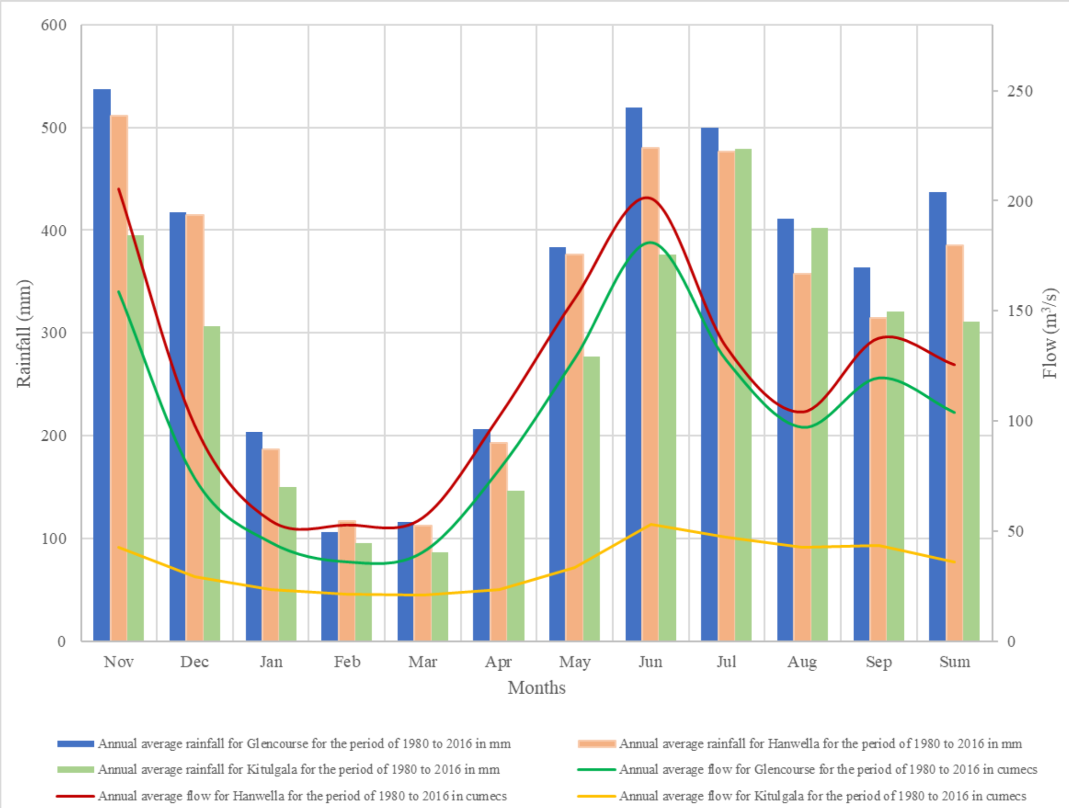


Figure 5-1: Annual average rainfall over runoff variation for the selected gauging stations for the period of 1980 to 2016

5.2 Statistical test results analysis

5.2.1 Overview

The several tests were completed to check the Stationarity, Relative Consistency and homogeneity of the rainfall and temperature data series. Inconsistency and non-homogeneity properties of the time series of hydrological data may be exhibited by trends and jumps (Yevjevich & Jeng, 1969). The stability of variance is tested during the basic data-screening process and it is an additional advantage, indicating any data improvements that might have influenced the variance. A linear relation between time series of hydrological data is assumed by Double-mass analysis (Subramanya, 2013). It is also used to verify the relative consistency of a time series.

Investigating persistent trends away from the average slope, the linear relationship deviates between the means of two parts of the time series and that one is considered as break points between two periods with seemingly different slopes. This is a break that, if significant, indicates a real change.

In summary, correlation coefficients were used to assess the strength and direction of the linear relationships between pairs of variables. Spearman's correlation coefficient is more robust to outliers than the other correlation techniques (Mukaka, 2012).

5.2.2 Rainfall stations

Among the selected rainfall stations, Angoda mental hospital, Campion Estate, Digalla estate, Dyabra Estate, Galatura Estate, Holomwood Estate, Negombo and Welimada Group shows the non-normality, while Angoda mental hospital, Chesterford, Laxapana, Negombo, Wagolla, Welimada Group shows the trends for the period of 1980 to 2016 for both Spearman Rank correlation test and t-test. Pasyala shows the trends for only Spearman Rank correlation test. Digalla Estate, Holomwood Estate, Katugasthota and Katunayaka rain gauges show the instability of variance, while Castlereigh rain gauge only shows the serial correlation.

Holomwood Estate, Nuwara Eliya and Bopaththalawa show break points respective to Ambewela, while Digalla Estate, Labugama Tank, Hanwella Group, Kalatuwawa and Avissawella Hospital show the two break points respective to Avissawella estate in the double mass curve as given in Figure 5-2.

Cumulative rainfall variation in the middle and upper reaches of the basin shows the larger range comparatively to the lower basin and it varies from 60,000 to 175,000 mm in the upper reaches, and from 7,000 to 12,000 mm in the lower reaches of the basin from Colombo to Hanwella group as given in Figure 5-2.

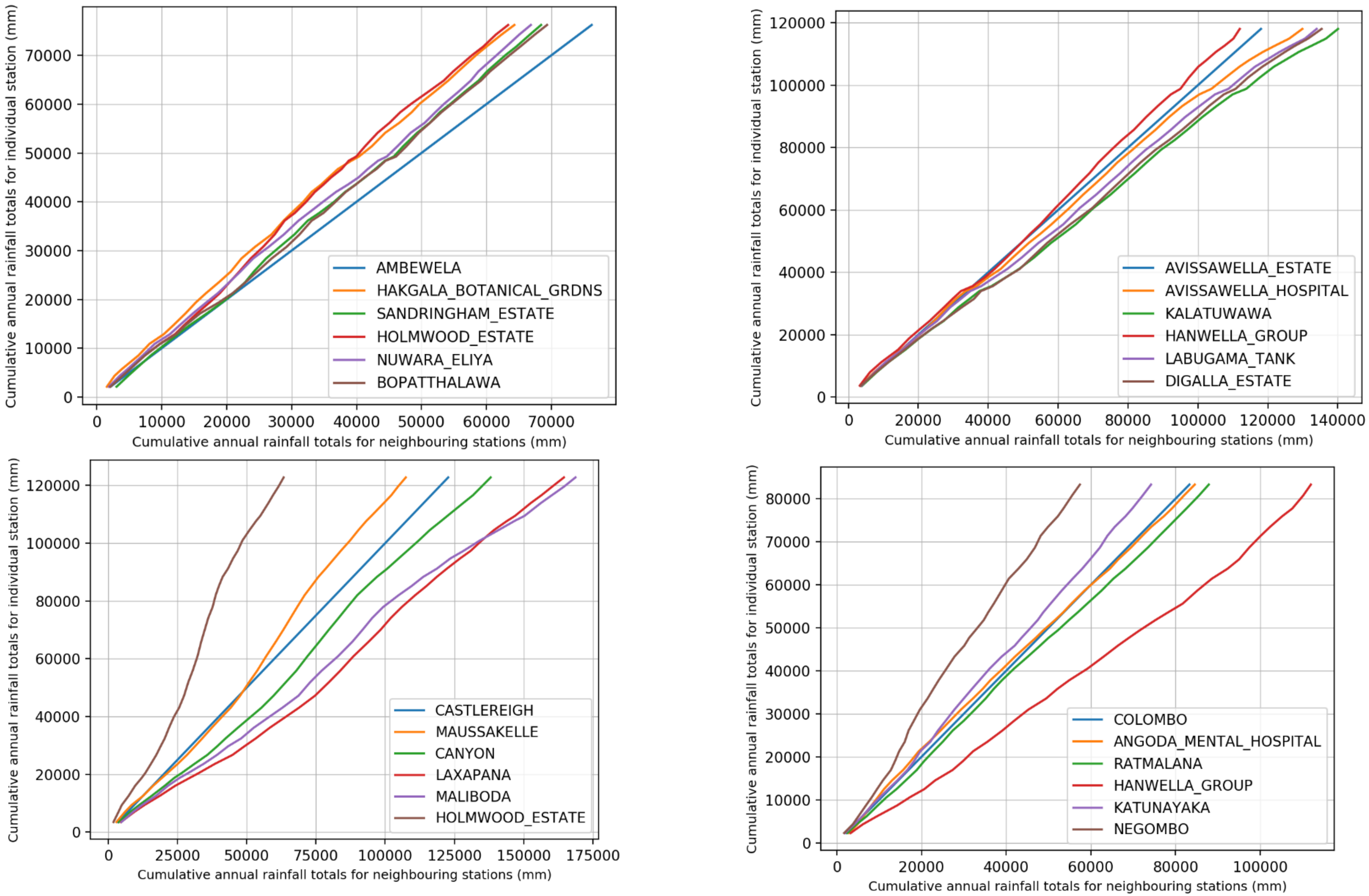


Figure 5-2: Double Mass Analysis carried out for Ambewela(top left), Avissawella etate (top right), Castlereigh (bottom left) and Hanwella Group (bottom right)

5.2.3 Temperature stations

Katunayaka and Nuwara Eliya show the non-normality for T_{max} time series, while Bandarawela and Seetha Eliya show the non-normality for T_{min} times series. Katunayaka shows a trend for T_{max}, while Bandarawela, Colombo, Katugasthota, Katunayaka, Kurunegala, Nuwara Eliya, Ratmalana and Seetha Eliya show the trends for T_{min} for both Spearman rank correlation test and t test.

Badulla, Rathmalana and Seetha Eliya show the the serial correlation for T_{max}, while Bandarawela, Colombo, Katunayaka, Kurunegala, Nuwara Eliya, Ratmalana and Seetha Eliya show the serial correlation for T_{min}.

5.2.4 Streamflow stations

As uncertainties associated with record length, observed water level data and the rating equations for all hydrometric stations, due to lots of reasons such as rating equations were not updated properly by considering bed lowering effect in the river as a result of sand mining in Kelani Ganga (Wijesinghe, 2010), the overall uncertainty is associated with observed flow records in the Kelani Ganga basin.

Single mass curve shows the same differences in both Hanwella and Glencourse hydrometric stations upto 1996/97. Hanwella shows the upward trend, while Glencourse shows the downwards trend from 1998 onwards.

Double mass curve of Hanwella shows the upward trend from its average slope upto 1996/97, then it shows downward trend from 2003/04 upto 2016. It is clearly identified that the trend of the flow mainly changed from 1994/95 onwards for both Hanwella and Glencourse gauging stations, as the overall uncertainty associated with observed flow records. Double mass curve of Glencouse shows the downward trend from its average slope from 1994/95, then it shows more downward trend from 2007/08 onwards and both Hanwella and Glencourse show the divergence trends from 2007/08 onwards. Though Hanwella and Glencourse show the two break points, Kitulgala station shows only one break point from 1996/97 with apparently different slopes in double mass analysis.

5.3 Other Tests

5.3.1 Decadal averages and Deviation from mean

The behaviour of the time series was analysed by plotting decadal averages and deviation from Mean of each rainfall gauging station by plotting Decadal averages with LTA and SD. The plots of the decadal averages were analyzed to identify trends visually and to check whether the Standard Deviation (SD) are significant in the time series. Summary of the positive and negative trends for annual rainfall totals, for Maha rainfall totals and for Yala rainfall totals and shown in Appendix C.

5.3.2 Innovative Trend Analysis (ITA), Mann-Kendall (MK) test and Sen's Slope estimator

Though one of the commonly used non-parametric trend test is Mann-Kendall trend test, the main drawback of the test is that the auto-correlation and non-normality of time series are ignored. This can be eliminated by using the Modified Mann-Kendal test (Hamed & Ramachandra Rao, 1998). Innovative trend analysis (ITA) provides visual inspection and identification of categorical trends, which doesn't show by other two tests such as Mann-Kendall and Sen's slope test.

As MK test results, all selected three streamflow gauging stations exhibit significant downward trends for the period of 1980 to 2016. Streamflow is decreased significantly at 1 % for annual averages, SWM II and Yala season and at 5 % confidence levels for SWM III and Maha season for Glencourse, while it was decreased significantly at 10 % confidence level for annual averages and SWM II and at 5 % confidence level for Yala season for Kitulgala. Hanwella shows 0.1 %, 1 %, 5 % and 10 % significant decreasing trends for all four rainfall seasons, Maha and Yala seasons.

5.3.2.1 Trends analysis based on annual, Maha and Yala seasons

5.3.2.1.1 Rainfall stations

The significant increasing trends are exhibited in MK test for annual rainfall totals by Colombo, Negombo and Walpita rainfall stations at 10 % confidence level and by Angoda mental hospital and Pasyala rainfall stations at 5 % confidence level, while significant decreasing trends are exhibited for annual rainfall totals by Hanwella group and Sandringham Estate at 10 % confidence level and by Laxapana and Maussakele at 5 % confidence level (Table 4-6).

The Sen’s Slope trend magnitude varies between -30.2 to 30.0 for annual rainfall totals for the period of 1980-2016. The Chesterford exhibits the highest upward trend, while Laxapana shows the highest downward trend annually.

Only Dunedin Estate, Dyrabba Estate and Wewelthalawa Estate show different upward and downward trends in aforementioned tests and the values for both ITA and MK tests are varied in between -0.75 to 0.50. Nevertheless, Castlereigh station shows the serial-correlation, it shows the positive trends even in MK test.

The significant increasing trends are exhibited in MK test for the rainfall totals for Maha season by Holmwood Estate and Kalatuwawa rainfall stations at 10 % confidence level and by Ambewela, Angoda mental hospital, Campion Estate, Negombo, Welimada Group and Pasyala rainfall stations at 5 % confidence level, while none of significant negative trends is exhibited in MK test for the rainfall totals for Maha season (Table 4-6).

The Sen’s Slope trend magnitude varies between -12.0 to 16.5 for Maha rainfall totals for the period of 1980 to 2016. Negombo exhibits the highest upward trend, while Hanwella Group shows the highest downward trend for Maha season.

Undugoda, Maussakelle, Maliboda, Hapugasthenna Estate and Avissawella Estate show the different upward and downward trends in aforementioned three tests and the values for both ITA and MK tests are varied in between -0.85 to 0.75.

The significant increasing trends are exhibited in MK test for the rainfall totals for Yala season by Avissawella estate, Colombo and Walpita rainfall stations at 10 % confidence level and by Chesterford rainfall station at 5 % confidence level, while significant negative trends are exhibited by Maussakele and Wagolla in MK test for the rainfall totals for Yala season (Table 4-6).

The Sen’s Slope trend magnitude varies between -45.6 to 28.8 for Yala rainfall totals for the period of 1980 to 2016. Chesterford exhibits the highest upward trend, while Laxapana shows the highest downward trend for Yala season.

Undugoda, Maussakelle, Maliboda, Hapugasthenna Estate and Avissawella Estate show the different upward and downward trends in aforementioned tests and the values for both ITA and MK tests are varied in between -1.3 to 1.75.

Significant trends were analysed for rainfall stations for the annual, Maha and Yala seasons during ITA test above and below the ±10 % error, by identifying the regions as High, Medium and Low (Şen, 2012, 2014) and it is given in

Figure 5-3, Table 5-4 and Table 5-5.

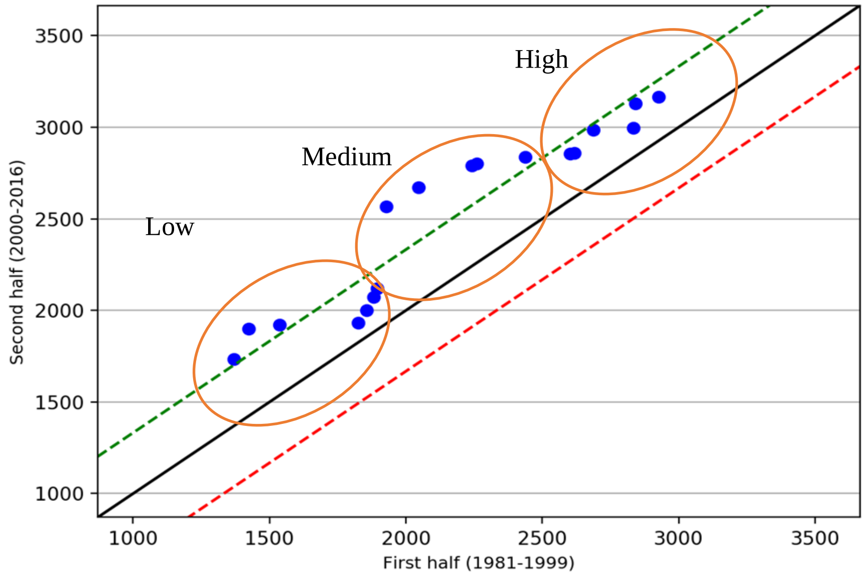


Figure 5-3: ITA analysis was completed by dividing the total region into three as High, Medium and Low

The rainfall stations were divided into 5 regions for easy analysis of ITA and the classification regions are given below.

- ✓ Lower Basin upto Hanwella
- ✓ Middle Basin from Hanwella to Kitulgala
- ✓ Intermediate basin from Kitulgala to Maussakele
- ✓ Upper Basin upstream to Maussakele
- ✓ Around the Basin

Colombo and Rathmalana stations show significant increasing trends for high annual rainfall totals, while Angoda Mental Hospital shows significant increasing trend for medium and low rainfall totals in the lower basin. Pasyala shows significant decreasing trend for low rainfall totals and Hanwella group shows decreasing trend for medium and high rainfall totals for the period of 1980 to 2016 as ITA analysis. The results of the ITA analysis for 41 stations are given in Appendix D.

Rainfall stations in the upper basin and lower basin show increasing trends for annual and Maha totals of rainfall for high and medium region. The most of the rain gauges in the middle and upper basins in the Kelani Ganga basin, show significant decreasing trends for high to low rainfall totals for Yala season as ITA analysis for the period of 1980 to 2016.

Table 5-4: The trend analysis of rainfall stations in and around Kelani ganga basin based on ITA, MK and Sen's Slope estimates on annual, Maha season and Yala seasons

Name of the Rainfall Station	for Annual			for Maha			for Yala		
	ITA D value	Z value in MK test	Q_{med} in Sen's Slope Estimates	ITA D value	Z value in MK test	Q_{med} in Sen's Slope Estimates	ITA D value	Z value in MK test	Q_{med} in Sen's Slope Estimates
Alupolla Group	0.66	0.99	12.90	1.21	1.05	7.17	0.25	0.89	11.81
Ambewela	-0.93	-0.29	-2.54	1.53	2.06	11.90	-2.70	-0.50	-6.23
Angoda mental hospital	1.56	2.38	19.65	2.89	2.00	12.39	0.57	3.01	20.83
Avissawella Estate	-0.52	-1.27	-18.68	0.20	-0.75	-7.79	-1.06	-0.56	-8.82
Avissawella Hospital	0.55	1.21	13.57	1.41	0.96	12.58	-0.12	1.74	19.95
Balangoda Post Office	0.00	0.18	1.27	1.09	0.94	6.40	-1.34	0.15	1.08
Bandarawela	0.43	0.91	4.08	0.71	1.11	6.81	0.02	0.17	1.64
Bopatthalawa	-1.13	-1.57	-10.11	0.68	1.02	4.42	-2.33	-1.46	-9.58
Campion Estate	0.14	0.80	7.02	1.73	2.30	12.91	-1.19	1.19	8.72
Canyon	-0.79	-1.51	-17.46	0.63	0.67	2.53	-1.32	-1.10	-14.14
Castlereigh	0.19	0.26	2.91	2.48	0.99	8.97	-0.70	-1.29	-20.92
Chesterford	1.49	2.68	30.01	1.79	0.88	10.01	1.25	2.04	28.78
Colombo	0.57	1.73	11.25	1.77	1.38	7.38	-0.39	1.87	10.60
Digalla Estate	-0.60	-0.86	-8.21	0.40	0.01	0.35	-1.23	-0.37	-4.57
Dunedin_Estate	-0.29	0.00	-0.21	0.62	1.41	12.91	-0.94	1.26	17.99
Dyrabba_Estate	-0.75	0.15	0.91	0.35	1.07	6.17	-2.34	-0.21	-2.71
Galatura_Estate	-0.23	-0.23	-2.66	0.40	0.32	3.10	-0.63	-0.36	-5.17
Hakgala Botanical Gdns	0.24	1.35	11.90	1.38	1.56	14.14	-1.26	0.99	12.63
Hanwella Group	-1.09	-1.92	-22.88	-0.60	-1.41	-12.04	-1.49	-2.68	-32.61
Hapugastenna Estate	-0.52	-1.02	-14.17	0.52	-0.84	-10.47	-1.14	-1.63	-29.84
Holmwood Estate	-0.34	-0.12	-1.16	0.89	1.89	12.17	-1.19	0.99	5.63

Name of the Rainfall Station	for Annual			for Maha			for Yala		
	ITA D value	Z value in MK test	Q_{med} in Sen's Slope Estimates	ITA D value	Z value in MK test	Q_{med} in Sen's Slope Estimates	ITA D value	Z value in MK test	Q_{med} in Sen's Slope Estimates
Kalatuwawa	-0.02	0.04	0.73	0.62	0.66	6.42	-0.51	0.36	3.99
Katugastota	0.62	1.10	8.24	2.20	1.71	14.55	-1.13	0.96	6.51
Katunayaka	0.57	0.31	1.81	1.84	0.77	6.56	-0.57	0.32	3.38
Kenilworth Strathellie	0.37	0.64	14.03	1.73	1.43	14.87	-0.19	0.42	9.86
Labugama Tank	0.25	0.69	5.97	1.03	1.18	10.79	-0.36	0.47	3.68
Labukelle	-1.18	-0.89	-13.63	0.59	0.39	4.47	-2.25	-0.96	-18.37
Laxapana	-1.40	-2.11	-30.16	-0.23	-0.43	-4.10	-1.91	-2.79	-45.59
Maliboda	0.35	1.05	14.40	0.72	-0.21	-3.53	0.15	-0.02	-1.91
Maussakelle	-1.14	-2.03	-19.10	-0.12	0.24	2.48	-1.61	-2.38	-30.43
Negombo	2.17	1.92	12.01	3.65	2.23	16.51	0.81	2.61	17.79
Nuwara Eliya	-0.80	-0.86	-6.41	1.09	1.26	8.23	-2.30	-1.26	-8.92
Pasyala	1.15	2.30	16.34	1.73	2.08	15.89	0.65	1.48	13.00
Rathmalana	0.99	1.29	8.66	2.35	0.99	7.68	-0.08	1.18	9.73
Rathnapura	-0.08	-0.01	-0.23	0.52	0.47	5.04	-0.49	-0.24	-3.94
Sandringham Estate	-1.27	-1.65	-9.72	0.17	0.66	3.68	-2.25	-0.96	-10.90
Undugoda	-1.26	-0.91	-10.57	-0.55	0.32	6.16	-1.78	-0.51	-8.97
Wagolla	-1.63	-2.22	-15.72	-0.39	-1.26	-8.25	-2.78	-2.42	-16.83
Walpita	1.27	1.89	13.44	1.64	0.92	6.62	0.95	1.93	12.75
Welimada Group	1.60	2.66	9.39	1.87	2.19	11.45	1.15	1.48	7.60
Weweltalawa Estate	-0.31	0.50	8.58	0.83	0.77	12.13	-0.93	0.69	17.11

trend at 0.001 significant level		trend at 0.05 significant level	
trend at 0.01 significant level		trend at 0.1 significant level	

Table 5-5: Identified significant trends for annual, Maha and Yala seasons during ITA test above and below the ±10 % error, by identifying the regions as High, Medium and Low

Basin Area	Name	For annual		For Maha		For Yala	
		Increasing trends as ITA	**Decreasing trends as ITA**	**Increasing trends as ITA**	**Decreasing trends as ITA**	**Increasing trends as ITA**	**Decreasing trends as ITA**
Lower Basin upto Hanwella	Colombo	High		High			
	Ratmalana	High		Low to High			
	Angoda mental hospital	Medium and low		High and Medium		Low and Medium	
	Pasyala		Low		Medium and High	Low	
	Hanwella group		High and medium		High		Medium and High
Middle Basin from Hanwella to Kitulgala	Avissawella estate		High	Low			High
	Avissawella hospital	Low		Low and Medium			
	Kalatuwawa			Low			High
	Labugama tank				Medium		High
	Chesterford	Medium		Medium and High		Medium	
	Digalla estate	Low	Medium and low	-			High
	Dunedin estate	-	Low				Medium
Intermediate basin from Kitulgala to Maussakele	Alupolla group			High and Medium			
	Hapugastenna estate		High		Low and High		High
	Kenilworth strathellie	Low			Low to High		
	Maliboda	High			Middle and High	High	
	Weweltalawa estate		High				High
	Canyon	High	Low and Medium	High	Low		Medium and High
	Castlereigh			Low to High			Medium
	Laxapana		Medium				Low to High
	Maussakelle		Medium				Low to High
	Wagolla		Low and High				

Basin Area	Name	For annual		For Maha		For Yala	
		Increasing trends as ITA	**Decreasing trends as ITA**	**Increasing trends as ITA**	**Decreasing trends as ITA**	**Increasing trends as ITA**	**Decreasing trends as ITA**
	Undugoda		Low and Medium				Low to High
Upper Basin upstream to Maussakele	Bopaththalawa		Middle	High			Low to high
	Campion estate	Medium		Medium and High			Medium
	Holmwood estate	High	Low	High			Medium
Around the Basin	Ambewela	High	Low	Medium and High			Low to High
	Balangoda post office	Low		Low and Medium			Medium
	Bandarawela						
	Dyrabba estate		High				Medium and High
	Galatura estate						Medium and Low
	Hakgala botanical grdns			Low and Medium			Medium
	Katugastota	High		Medium and High			Medium
	Labukelle		Medium		High		Low to High
	Negombo	Medium and High		Medium and High			
	Nuwara Eliya	High	Low	Medium and High			Low to High
	Katunayaka	High			Medium and High	High	
	Ratnapura						
	Sandringham estate		Medium		High		Low to High
	Walpita	Low and Medium			Low to High	Low	
	Welimada group	Medium and High			Medium and High	High	

5.3.2.1.2 Temperature stations

5.3.2.1.2.1 Maximum temperature (T_{max})

Katunayaka station exhibits significant decreasing trend in MK test for annual averages and averages of Yala season at 10 % confidence level, while it shows significant decreasing trend for Maha season at 5 % confidence level (Table 4-7) for the period of 1980 to 2016.

The Sen's Slope trend magnitude varies between -0.2 to 0.1 for annual, Maha and Yala averages for the period of 1980-2016. Badulla exhibits the highest downward trend for Maha and Yala seasons (Table 5-6).

5.3.2.1.2.2 Minimum temperature (T_{min})

Katunayaka station exhibits significant increasing trend in MK test for annual averages at 10 % confidence level, while it shows significant increasing trend for Maha season at 5 % confidence level for the period of 1980 to 2016 (Table 5-7).

The Sen's Slope trend magnitude varies between 0.0 to 0.3 for all annual, Maha and Yala averages for the period of 1980-2016. Katunayaka exhibits the highest upward trend for annual, Maha and Yala seasons (Table 5-7).

Table 5-6: The trend analysis of Temperature stations in and around Kelani ganga basin on T_{max} averages for annual, Maha season and Yala seasons based on ITA, MK and Sen's Slope estimates

Name of the Temperature Station	For annual averages			for averages for Maha season			for averages for Yala season		
	ITA D value	Z value in MK test	Q_{med} in Sen's Slope Estimates	ITA D value	Z value in MK test	Q_{med} in Sen's Slope Estimates	ITA D value	Z value in MK test	Q_{med} in Sen's Slope Estimates
Badulla	-0.11	-0.78	-0.01	-0.14	-1.48	-0.02	-0.04	-0.78	-0.02
Bandarawela	0.07	1.24	0.01	0.01	-0.26	0.00	0.12	1.24	0.01
Colombo	-0.03	0.07	0.00	-0.05	-0.07	0.00	0.00	0.07	0.00
Katugastota	0.01	1.02	0.01	-0.03	-0.31	0.00	0.07	1.02	0.01
Katunayaka	-0.10	-1.87	-0.01	-0.15	-2.49	-0.02	-0.05	-1.87	-0.01
Kurunegala	0.00	0.61	0.00	-0.05	-0.31	0.00	0.03	0.61	0.01
Nuwara Eliya	-0.06	0.72	0.00	-0.09	-0.53	0.00	0.01	0.72	0.01
Ratmalana	0.00	1.19	0.01	-0.02	0.59	0.00	0.05	1.19	0.01
Ratnapura	-0.02	0.31	0.00	-0.04	0.04	0.00	0.00	0.31	0.00
Seetha Eliya	0.00	0.72	0.01	0.01	0.31	0.00	0.03	0.72	0.01

Table 5-7: The trend analysis of Temperature stations in and around Kelani ganga basin on T_{min} averages for annual, Maha season and Yala seasons based on ITA, MK and Sen's Slope estimates

Name of the Temperature Station	for annual averages			for Maha averages			for Yala averages		
	ITA D value	Z value in MK test	Q_{med} in Sen's Slope Estimates	ITA D value	Z value in MK test	Q_{med} in Sen's Slope Estimates	ITA D value	Z value in MK test	Q_{med} in Sen's Slope Estimates
Badulla	-0.01	0.07	0.00	-0.14	0.00	0.00	-0.01	-0.45	0.00
Bandarawela	0.49	1.24	0.01	0.01	-0.26	0.00	0.49	0.91	0.01
Colombo	0.18	0.07	0.00	-0.05	-0.07	0.00	0.18	0.23	0.00
Katugastota	0.13	1.02	0.01	-0.03	-0.31	0.00	0.13	1.24	0.01
Katunayaka	0.18	5.54	0.03	-0.15	4.45	0.03	0.18	4.75	0.02
Kurunegala	0.15	0.61	0.00	-0.05	-0.31	0.00	0.15	1.02	0.01
Nuwara Eliya	0.27	0.72	0.00	-0.09	-0.53	0.00	0.27	0.78	0.01
Ratmalana	0.18	5.71	0.03	-0.02	5.03	0.03	0.18	4.97	0.03
Ratnapura	-0.06	0.31	0.00	-0.04	0.04	0.00	-0.06	0.48	0.00
Seetha Eliya	0.49	0.72	0.01	0.01	0.31	0.00	0.49	0.61	0.01

5.3.2.1.3 Streamflow stations

Glencourse hydrometric station exhibits significant decreasing trend in MK test for Maha averages at 5 % confidence level, while it shows significant decreasing trend for annual averages and for Yala season at 1 % confidence level. Kitulgala station exhibits significant decreasing trend in MK test for annual averages at 10 % confidence level, while it shows significant decreasing trend for Yala season at 5 % confidence level (Table 5-8) for the period of 1980 to 2016.

The Sen's Slope trend magnitude varies between -2.2 to -0.3 for annual, Maha and Yala averages for the period of 1980-2016. The Hanwella exhibits the highest downward trend for annual, Maha and Yala seasons among three selected stations, while it shows significant downward trends for annual, four rainfall seasons, Maha and Yala seasons for only MK test.

Table 5-8: The trend analysis of flow at hydrometric stations in and around Kelani Ganga basin on averages for annual, Maha season and Yala seasons based on ITA, MK and Sen's Slope estimates

Name of the hydrometric station	for annual averages			for Maha averages			for Yala averages		
	ITA D value	Z value in MK test	Q_{med} in Sen's Slope Estimates	ITA D value	Z value in MK test	Q_{med} in Sen's Slope Estimates	ITA D value	Z value in MK test	Q_{med} in Sen's Slope Estimates
Kitulgala	-2.43	-1.65	-0.27	-2.09	-0.97	-0.13	-2.67	-2.17	-0.31
Glencourse	-3.60	-3.04	-1.77	-3.18	-2.19	-1.12	-4.06	-2.93	-1.83
Hanwella	-3.04	-3.39	-2.01	-2.74	-2.66	-1.67	-2.75	-3.28	-2.15

5.3.2.2 Trends analysis of rainfall for rainfall seasons

Angoda Mental hospital, Avissawella Hospital, Bandarawela, Bopatthalawa, Kenilworth Strathellie, Labugama Tank, Maliboda, Negombo and Welimada Group stations exhibit significant increasing trends at 10 % confidence level, while Chesterford, Colombo, Kalatuwawa, Pasyala, Rathnapura and Walpita show significant increasing trends at 5 % confidence level for FIM in MK test (Table 5-9). Digalla Estate, Dunedin Estat, Galatura Estate, Katunayaka, Labukelle, Rathmalana and Weweltalawa Estate show none of significant trends for any seasons. Some stations show both increasing and decreasing trends for ITA, MK and Sen's Slope estimates. The Sen's Slope trend magnitude varies between -4.0 to 7.9 for FIM, between -24.0 to 10.5 for SWM, between -5.0 to 8.6 for SIM and between -4.6 to 6.4 for NEM, respectively (Table 5-9).

Table 5-9: The trend analysis of rainfall stations in and around Kelani ganga basin based on ITA, MK and Sen's Slope estimates on four rainfall seasons

Name of the Rainfall Station	ITA Test Results				Mann-Kendal Test Results				Sen's Slope Estimates			
	D value for FIM-I	D value for SWM-II	D value for SIM-III	D value for NEM-IV	Z value for FIM-I	Z value for SWM-II	Z value for SIM-III	Z value for NEM-IV	Q_{med} for FIM-I	Q_{med} for SWM-II	Q_{med} for SIM-III	Q_{med} for NEM-IV
Alupolla Group	1.936	0.23	0.47	1.97	0.72	0.97	2.17	0.50	2.46	7.81	8.61	1.80
Ambewela	0.180	-2.99	1.55	1.54	0.97	-2.22	2.52	1.10	2.22	-13.28	7.21	3.32
Angoda mental hospital	2.800	0.31	2.27	4.98	1.83	0.91	1.24	1.78	4.94	4.15	6.81	4.75
Avissawella Estate	1.348	-0.89	-0.71	1.35	0.12	-2.06	-0.95	-0.42	0.70	-12.22	-5.10	-1.73
Avissawella Hospital	3.135	-0.27	0.23	2.55	1.73	0.01	0.56	0.75	6.14	0.23	2.09	3.18
Balangoda Post Office	0.524	-1.98	-0.33	3.83	0.94	-1.65	0.64	1.43	3.76	-6.33	2.04	4.25
Bandarawela	2.407	-0.73	0.11	1.46	1.91	-0.69	0.80	1.29	3.01	-1.79	2.33	3.36
Bopatthalawa	2.334	-3.12	-0.95	2.09	1.73	-3.50	0.12	0.72	4.72	-13.45	0.49	1.70
Campion Estate	1.419	-1.80	0.11	4.44	1.21	-0.91	1.02	2.55	3.55	-4.43	3.03	6.41
Canyon	1.878	-1.39	-0.56	4.47	1.16	-1.73	0.12	1.35	2.91	-17.66	0.25	2.38
Castlereigh	3.609	-0.29	0.38	7.23	1.32	-0.69	0.40	1.81	3.72	-8.52	1.39	3.19
Chesterford	4.389	0.99	0.44	4.40	2.41	1.78	1.05	0.78	7.84	8.40	6.97	4.13
Colombo	3.382	-0.99	0.66	4.44	2.08	-0.37	1.16	1.54	5.47	-2.03	3.30	4.14
Digalla Estate	0.674	-0.48	-0.70	2.22	-0.16	-1.02	-0.10	0.23	-0.37	-6.73	-0.51	0.60
Dunedin Estate	1.631	-1.07	-0.39	2.02	0.94	-1.21	0.07	0.37	2.81	-7.43	1.23	1.62
Dyrabba Estate	-1.569	-3.14	0.39	0.93	0.20	-2.14	1.29	0.42	0.60	-4.71	2.97	1.48
Galatura Estate	1.396	-0.57	-0.88	2.56	0.59	-0.78	-1.02	1.29	2.32	-6.04	-2.56	4.92
Hakgala Botanical Gdns	0.375	-1.77	0.44	2.24	1.29	-1.21	2.36	1.27	3.05	-3.82	6.51	6.21
Hanwella Group	1.219	-1.54	-0.71	-0.77	-0.20	-2.11	-0.80	-1.16	-0.59	-12.21	-4.60	-4.56
Hapugastenna Estate	0.956	-1.10	-0.45	2.16	0.12	-1.65	0.83	0.45	0.30	-13.78	3.26	1.60
Holmwood Estate	2.638	-1.92	-0.54	2.84	1.51	-1.32	-0.42	1.35	4.36	-6.68	-1.43	2.82

Name of the Rainfall Station	ITA Test Results				Mann-Kendal Test Results				Sen's Slope Estimates			
	D value for FIM-I	D value for SWM-II	D value for SIM-III	D value for NEM-IV	Z value for FIM-I	Z value for SWM-II	Z value for SIM-III	Z value for NEM-IV	Q_{med} for FIM-I	Q_{med} for SWM-II	Q_{med} for SIM-III	Q_{med} for NEM-IV
Kalatuwawa	2.615	-0.53	-0.19	1.22	2.00	-0.59	-0.31	0.37	7.69	-3.07	-1.19	1.23
Katugastota	2.870	-1.65	0.31	4.05	1.42	-2.44	1.78	1.32	1.92	-6.54	6.03	4.48
Katunayaka	3.485	-0.93	0.82	4.20	0.94	-0.86	0.61	0.97	1.81	-3.27	1.63	2.66
Kenilworth Strathellie	3.593	-0.11	0.65	3.46	1.65	0.50	0.89	0.86	7.27	10.52	5.27	2.97
Labugama Tank	2.742	-0.49	0.27	1.80	1.81	-0.40	0.23	0.75	7.89	-2.41	0.85	2.07
Labukelle	-1.256	-1.85	-0.98	3.33	-0.20	-1.48	0.89	1.46	-0.40	-12.82	2.27	6.01
Laxapana	0.355	-1.84	-1.18	1.73	0.00	-2.03	-0.64	0.45	0.02	-24.06	-2.61	0.79
Maliboda	2.856	0.30	-0.49	2.10	1.65	0.34	0.34	1.05	6.76	5.20	1.93	3.86
Maussakelle	0.427	-1.85	-1.01	3.21	0.29	-2.11	0.15	0.83	0.85	-19.29	0.43	2.22
Negombo	7.295	-0.60	2.07	7.45	1.65	-0.59	1.43	1.62	3.53	-2.45	5.55	4.66
Nuwara Eliya	2.194	-2.38	-0.67	2.84	1.38	-2.08	0.83	1.46	2.63	-9.52	1.72	5.00
Pasyala	3.540	0.61	0.65	2.78	2.49	0.97	1.13	0.99	6.66	3.85	4.36	2.86
Rathmalana	3.868	-0.54	1.72	3.60	1.40	-0.18	0.61	0.91	3.96	-0.63	1.75	2.64
Rathnapura	2.265	-0.62	-0.05	1.19	2.00	-0.59	0.64	0.42	4.80	-3.38	2.05	1.28
Sandringham Estate	0.319	-2.51	-0.77	1.98	0.12	-2.47	0.34	0.48	0.44	-10.86	0.57	0.84
Undugoda	-0.463	-1.50	-1.26	0.41	-1.13	-1.65	-0.20	0.20	-3.99	-12.28	-1.07	1.40
Wagolla	0.830	-2.84	-1.99	2.59	0.15	-3.72	-1.05	0.64	0.32	-13.57	-4.49	1.11
Walpita	2.522	1.09	0.52	4.21	2.00	0.72	0.83	1.87	4.45	2.74	2.77	4.30
Welimada Group	2.094	0.18	1.96	1.84	1.65	-0.94	2.60	1.38	3.01	-1.43	5.42	3.95
Weweltalawa Estate	0.860	-0.70	-0.59	4.08	0.48	-0.18	0.50	1.54	2.31	-1.59	2.32	5.83

trend at 0.001 significant level			trend at 0.05 significant level	
trend at 0.01 significant level			trend at 0.1 significant level	

5.3.2.3 Trend analysis of temperature for rainfall seasons

5.3.2.3.1 Maximum temperature (T_{max})

Significant decreasing trend is exhibited for NEM by Badulla at 10 % and by Katunayaka at 5 % confidence level in MK test. Badarawela, Katugasthota and Rathmalana stations exhibit significant increasing trends in MK test at 5 % confidence level, while Nuwara Eliya and Seetha Eliya show significant decreasing trends at 10 % confidence level for SWM (Table 4-7). Seetha Eliya shows significant increasing trend in MK test for at 10 % confidence level, while Rathmalana shows significant increasing trend at 5 % confidence level for SIM.

5.3.2.3.2 Minimum temperature (T_{min})

Only Badulla shows the significant decreasing trend for FIM at 10 % confidence level. Badarawela, Katugasthota and Rathmalana stations exhibit significant increasing trends in MK test at 5 % confidence level, while Nuwara Eliya and Seetha Eliya show the significant increasing trends at 10 % confidence level for SWM (Table 4-8).

Rathmalana and Seetha Eliya exhibit significant increasing trends in MK test for SIM at 5 % and at 10 % confidence level, respectively, while Katunayaka shows significant upward trend at 5 % confidence level for NEM.

5.3.2.4 Trends analysis of seasonal streamflow

All seasons shows the decreasing trends for the selected 3 hydrometric stations. Glencourse and Hanwella stations exhibit significant decreasing trends in MK test at 5 % confidence level for SIM and FIM, respectively, while Kitulgala and Hanwella stations exhibit significant decreasing trends in MK test at 10 % confidence level for SWM and SIM, respectively (Table 5-10).

Table 5-10: The trend analysis of selected hydrometric stations in Kelani ganga basin based on ITA, MK and Sen's Slope estimates on four rainfall seasons

Name of the selected Hydrometric Station	Innovative Trend Analysis				Mann-Kendal Test Results				Sen's Slope Estimates			
	D value for FIM-I	D value for SWM-II	D value for SIM-I	D value for NEM-IV	Z value for FIM-I	Z value for SWM-II	Z value for SIM-III	Z value for NEM-IV	Q_{med} for FIM-I	Q_{med} for SWM-II	Z value for SIM-III	Q_{med} for NEM-IV
Kitulgala	-2.75	-2.70	-2.16	-1.70	-1.29	-1.87	-0.23	-0.91	-0.16	-0.45	-0.09	-0.10
Glencourse	-0.88	-4.36	-4.35	-1.06	-0.12	-2.85	-2.30	-0.86	-0.10	-2.41	-2.69	-0.34
Hanwella	-1.96	-2.96	-2.66	-2.80	-1.98	-2.63	-1.68	-2.68	-1.09	-2.63	-2.35	-1.11

5.4 SWAT Modelling

5.4.1 Overview

The SWAT model has been broadly used globally to carry out hydrological modelling at a catchment scale under different agro-climatic conditions (Verma and Jha, 2015) and it is a powerful tool to assess the impacts of Climate Change over last decade on water resources (Jha et al., 2006).

The SWAT model can evaluate the effects of anthropogenic activities and landuse change for the management water resources sustainably as well as simulate water quantity and quality (Shi et al., 2011). Among 41 rainfall gauging stations, only 32 most neighbouring rainfall gauging stations and 10 temperature gauging stations were used for SWAT modelling as described in 5.1.1 for the duration of 1960 to 2016. Therefore, SWAT model is used to predict the flow for future scenarios for 2040 including landuse for 2040.

5.4.2 Calculation of Potential Evapotranspiration (PET)

The limited amount of recorded data and the poor spatial distribution of climate stations for the Kelani Ganga basin led to the selection of the Hargreaves method (1985) for PET calculation in SWAT.

The advantages of the Hargreaves method (1985) include the simplicity of application, reliability, minimum input data requirements and ease of computation. It is widely used in situations, where data quality is questionable or where historical data is missing. Studies have shown that the Hargreaves method (1985) has ranked highest of all methods that only require air temperature when compared against measured evapotranspiration data.

The main disadvantage of the Hargreaves method (1985) is that daily estimates are subject to error caused by the influence of the temperature range, which is caused by the movement of weather fronts and by large variations in wind speed or cloud cover. Therefore, the Hargreaves method is generally recommended to use with five-day or longer time steps.

As Colombo and Seetha Eliya only have 17 % and 20 %, respectively, a direct comparison of monthly totals could not be made, daily percentiles of the calculated and measured evaporation data were calculated instead. The comparison for each station is presented in Figure 3-12 and Figure 3-13, respectively.

It is evident that there is good agreement between the two methods between January and May at Colombo. After May, the actual evaporation data is higher than the calculated values, while the situation is reversed after mid-October. There is generally good agreement between the two methods at Seetha Eliya with values generally higher than the measured evaporation data, especially after August.

Hargreaves equation (HG), was modified, through a linear regression calibration method and LHGu (modified linear regression calibrated HG equations) is effectively a simplified method for approximating FAO-56 Penman-Monteith equation (FPM) daily reference evapotranspiration (ET_o) in tropics with the temperature data only (Kra, 2014). As the SWAT model is calibrated with best objective functions, Hargreaves equation is only used for this analysis.

5.4.3 Selection of model parameters and objective function

Glencourse gauging station is selected as the key hydrometric station in the basin, as it is located in the narrow gorge section as well as it is the best gauging station, in terms of data quality compared with the other gauging stations in the Kelani Ganga basin.

Two major reservoirs such as Castlereigh and Maussakelle are located at the upper reaches of the Kelani Ganga basin. Those two reservoirs affect the natural flow regime in the Kelani Ganga basin, therefore SWAT model was built with 2 reservoirs and 5 ponds in Kelani Ganga basin for calibration and validation purposes. The durations for calibration and validation were selected based on the best quality observed data available periods for the Kelani Ganga basin.

By visualizing the daily simulated flow vs observed flow, it is identified that peakflow and baseflow are the most sensitive parameters for optimization, hence rules for parameter regionalization were used to select the parameters (Abbaspour et al., 2015) as given in Table 2-7 and Figure 2-2. During the sensitivity anlysis about seven (7) parameters were initially chosen for optimization (Abbaspour et al., 2015) and finalized with four (4) parameters. Optimized four parameters are CN2.mgt, GWQMN.gw, SOL_AWC().sol and ESCO.bsn for the selected Hydrometric station and given in Table

4-14, which were given the highest model performance for three selected objective functions.

The Nash-Sutcliffe efficiency (*NSE*), Relative Error (*Er*) and coefficient of determination (R^2) were used to assess the SWAT model performance as suggested by lots of researchers Quinn et al. (1991), Motovilov et al. (1999) and White & Chaubey (2005).

Several sensitivities were performed to optimize the three objective functions for Glencourse hydrometric station by changing fours parameters using SUFI-2 parallel processing using SWAT-CUP. The selected three objective functions were ensured that the SWAT model performance is satisfactory for the selected key hydrometric station at Glencourse for the calibration and validation periods. Due to discrepancies of the data resolution, the actual resolution of the data series is not recorded, as the daily time step is used in observed data series. Hence one day time lag is adjusted in the observed time series to match the modelled flow series, to optimise objective functions.

Generally model performance is very good if *NSE* >= 0.75, satisfactory if 0.36 =< *NSE* < 0.75, and unsatisfactory if *NSE* < 0.36 (Nash and Sutcliffe, 1970; Krause et al., 2005; Moriasi et al., 2007), R^2 should be greater than 0.5 (Van Liew et al., 2003) and Er values are lower than 20 % (Motovilov et al., 1999). The objective functions of *NSE*, R^2 and *Er* were obtained for calibration are 0.65, 0.72 and 8.9 % and for validation are 0.69, 0.69 and 9.1 %, respectively, hence overall performance of the model in terms of R^2, *NSE* and *Er* have quite satisfactory for Glencourse hydrometric station.

Though the obtained R^2 and *Er* for Hanwella gauging station is satisfactory for calibration period and for validation period 0.6, 7.3 % and 0.5, 0.5 %, respectively, obtained NSC is very low such as 0.23 for calibration period for Hanwella gauging station. None of the objective functions were not satisfactory performed for Kitulgala station.

It was also evaluated that the same hydrological parameters, which were used for Glencourse can not be transferred for Hanwella and Kitulgala gauging station. The annual average Potential evapotranspiration (PET) variation for calibration and validation periods in each sub-basin are given in Figure 5-4.

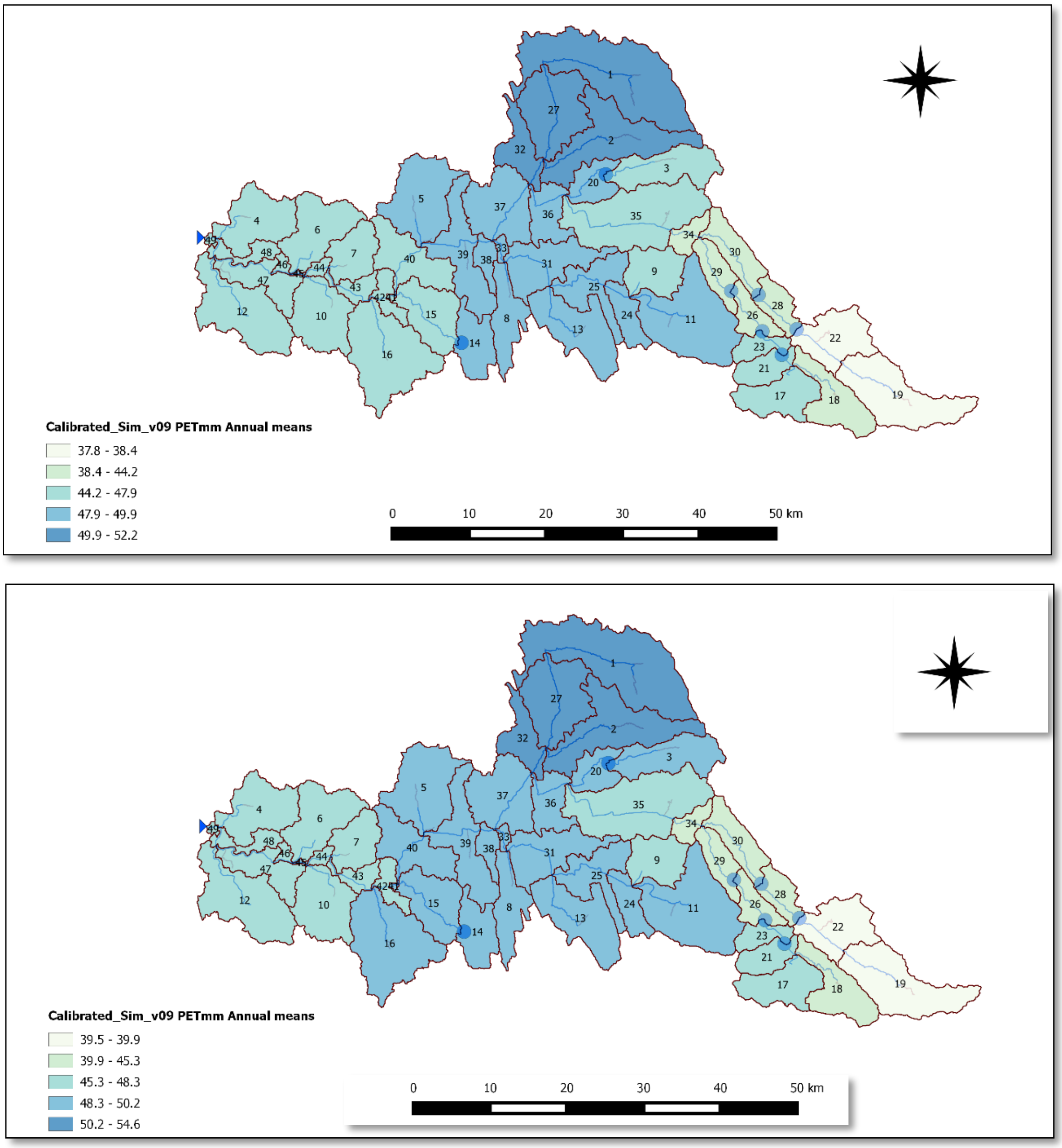


Figure 5-4: The annual average Potential evapotranspiration (PET) variation for calibration (top) and validation (bottom) periods in each sub-basin.

5.4.4 Model performance and Reliability of model results

5.4.4.1 Flow threshold selection and Model performance

5.4.4.1.1 Flow threshold selection

The threshold flows may be in the range of discharges with 70 - 90 % exceedance on FDC for hydrological drought characterisation in perennial rivers (Smakhtin, 2001) and Kelani river is a perennial river, hence the threshold for low flows was taken as 80 % for Glencourse gauging station, by visual observation of the deflection change of the FDC. As Scientific Investigations Report 2008-5126 by USGS, has considered 5th and 10th exceedance for high flows (Risley et al., 2008), hence threshold for high flows were considered as 15th exceedance probability by visual observation of the deflection change of the FDC.

5.4.4.1.2 Model performance

Model performance was checked by mainly NSC and R^2 for daily time-step. Low flow, high flow regions were identified for Glencourse as given in section 5.3.3, Figure 4-13 and Figure 4-14. The performance of objective functions for Calibration and validation period for each flow region in FDC are given in Table 5-11.

Table 5-11: The performance of objective functions for Calibration and validation period for each flow region in FDC

Flow Condition	Objective Functions for Calibration period of 1970 -1980		Objective Functions for Validation period of 1982 -1992	
	NSC	RSQ	NSC	RSQ
Overall	0.65	0.72	0.69	0.69
High	0.71	0.51	0.71	0.58
Medium	-0.63	0.46	0.00	0.57
Low	0.91	0.11	0.97	0.36

Though the satisfactory model performance is achieved for the objective functions for overall and high flow regions, the medium and low flow regions were unable to achieve the satisfactory model performance for NSC for calibration and validation periods, as given in Table 5-11. NSC was very low as -0.63 and 0.00 for validation and calibration periods, respectively for medium flow region.

Though the low flow region shows satisfactory model performance for Objective functions for validation period, it was unable to achieve satisfactory performance for calibration period for R^2 only, but NSC was good for both calibration and validation of the model for low flow region.

5.4.4.2 Reliability of model results

There is a high degree of extrapolation uncertainty associated with the existing stage-discharge relationships at Glencourse due to the absence of high flow spot flow measurements above 1,150 m^3/s as well as at low flows due to changes in cross-section at and near the gauging station; multiple ratings are required for low and medium flows due to historical changes water level data and channel geometry at least once in three years. The available data, which to develop multiple low to medium stage-discharge ratings means that there remains relatively high uncertainty in the low to medium flow record at Glencourse, after 1989. Bed lowering effects are mainly affecting the low and medium flows and the water demands has increased rapidly in the basin, hence the modelled flow results highly deviate from the observed flow measurements from 1989 up to 2016.

5.5 Runoff Elasticity

5.5.1 Overview

Climate change always links with a lot of uncertainties; hence climate change predictions are also very uncertain especially for a small island like Sri Lanka when the downscaling GCMs to small grid sizes. The uncertainty, variability and risk are probably the most important consequences of climate change.

Climate elasticity of runoff is an important indicator for evaluating the effects of climate change on runoff. Though the most common method to calculate potential evapotranspiration is Penman-Monteith, and it requires the Relative humidity, solar radiation, temperature, etc.. As the limited data availability, Hargreaves method (1985) is used to calculate potential evapo-transpiration in Kelani Ganga basin, which is incorporated in the SWAT model. Therefore, Runoff elasticity is mainly be subject to on two parameter approach and the two parameters are rainfall and temperature. Runoff estimated using the calibrated SWAT model for future scenarios with projected landuse for 2040.

The runoff elasticity (ε) is assessed by two methods based on the assessment of impacts of climate change only and impacts of climate and land surface change on the streamflow, as evaluated by Sankarasubramanian et al. (2001) and Zheng et al. (2009), respectively.

5.5.2 Current scenario

Cumulative runoff over cumulative rainfall were plotted and given in Figure 5-5, which shows the different slopes for Glencourse and Hanwella in terms of runoff/ rainfall changes in Kelani basin.

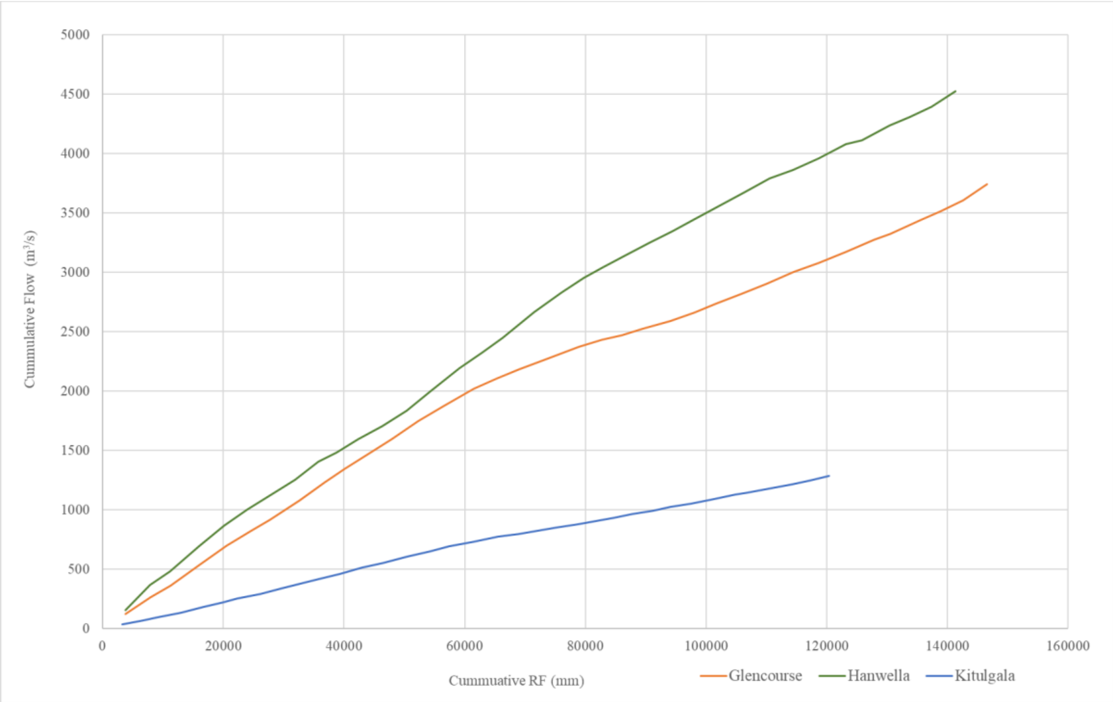


Figure 5-5: Cumulative annual average Runoff over Cumulative annual Rainfall totals for Kelani Ganga for the duration of 1980 to 2016

As uncertainties associated with streamflow, the Climate elasticity parameters can be affected not only Climate change, but also the uncertainties of streamflow records. Climate elasticity was estimated only for Glencourse hydrometric station for the period of 1980 to 2016 and given in Table 5-12, as both model was shown the poor performance for Hanwella and Kitulgala gauging stations. The Runoff change at Glencourse hydrometric station in the Kelani Ganga basin as Zheng et al. (2009) and given in the following equation (28);

$$\frac{dR}{R} = 0.002\ \frac{dP}{P} - 6.860\ dT \quad \ldots\ldots 24$$

Table 5-12: The Climate Elasticity in the Kelani Ganga basin for the period of 1980 to 2016 for Glencourse gauging station

Climate Elasticity (ε) defined as	**ε_p**	**ε_T**
As Zheng et al. (2009)	0.002	-6.860
Sankarasubramanian et al. (2001)	0.372	-7.450

Precipitation elasticity (ε_p) for 1980 to 2016 period is 0.002 and 0.375 as evaluated by Zheng et al. (2009) and Sankarasubramanian et al. (2001), respectively. A 1 ^{0}C increase will cause 7.45 % and 6.86 % runoff decrease as evaluated by Sankarasubramanian et al. (2001) and Zheng et al. (2009), respectively for Glencourse catchment. It clearly shows that 1 ^{0}C of temperature increase will cause the runoff decrease, while 1% of rainfall increase will cause runoff increase at Glencourse gauging station, hence temperature increase cause a higher impact on runoff than rainfall does for the current scenario for both methods.

5.5.3 Future climatic scenarios

Stochastic time series for both rainfall and temperature were already generated by CRIP-DBIP studies for Kelani Ganga basin for future scenarios (WS Atkins International Ltd, 2019), were taken for this analysis, as they have already analysed the Kelani Ganga in terms of Climate change. Hence Climate elasticity was estimated for Glencourse hydrometric station for the Baseline and Future Pessimistic Scenario for 99 years based on the modelled flow by SWAT model with projected landuse for 2040 (WS Atkins International Ltd, 2019) and given in Table 5-13.

It is observed that landuse change caused only 0.1 % flow increase at Glencourse, as the future landuse change is mainly dominant downstream of the Glencourse gauging station. Hence it is evaluated that the landuse change does not act as a significant impact on streamflow increase for 2040.

The Runoff change or Future Pessimistic scenario for 2040 at Glencourse hydrometric station in the Kelani Ganga basin as Zheng et al. (2009) and given in the following equation (29);

$$\frac{dR}{R} = 0.005\,\frac{dP}{P} + 0.420\,dT \quad \ldots\ldots 25$$

Table 5-13: Climate elasticity was estimated for Glencourse hydrometric station for the Baseline and Future Pessimistic Scenario

Climate Scenario	ε defined Method	ε_p	ε_T
Baseline Scenario	As Zheng et al. (2009)	0.004	0.070
	Sankarasubramanian et al. (2001)	0.400	-0.020
Future Pessimistic Scenario	As Zheng et al. (2009)	0.005	0.420
	Sankarasubramanian et al. (2001)	0.360	-1.520

Climate elasticity is widely used to assess the responses of runoff to climate change. 1 % of precipitation increases about 0.004 % and 0.400 % increase of flow, respectively as evaluated by Zheng et al. (2009) and Sankarasubramanian et al. (2001), while a 1 ºC increase causes 0.07 % increase and 0.02 % decrease of flow at Glencourse gauging station, respectively Zheng et al. (2009) and Sankarasubramanian et al. (2001) for baseline climate change scenario for 2040 with projected landuse for 2040.

A 1 ºC increase causes 0.4 % rise and 1.5 % reduction of runoff as evaluated by Zheng et al. (2009) and Sankarasubramanian et al. (2001), respectively for the Future Pessimistic Climate Change Scenario with projected landuse for 2040. 1 % of rainfall increase causes 0.005 % and 0.360 % increase of flow as evaluated by Zheng et al. (2009) and Sankarasubramanian et al. (2001), respectively for Glencourse gauging station for the aforementioned scenario. This implies a positive effect on runoff for future pessimistic scenario with projected landuse for 2040 as Zheng et al. (2009).

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Main Conclusions

1. Among 41 rainfall stations, 20 stations exhibit positive trends, while 17 stations show negative trends for annual rainfall totals for all three tests of ITA, Mann-Kendall and Sen's Slope tests. The Sen's Slope trend magnitude varies between -30.2 to 30.0 for annual rainfall totals for the period of 1980-2016.

2. More than two-thirds of the rain gauges in the middle and upper basins in the Kelani Ganga basin show significant decreasing trends for high to low rainfall totals for Yala season as ITA analysis for the period of 1980 to 2016.

3. Among 10 temperature stations, 5 stations exhibit positive trends and 2 stations show negative trends for annual averages, while 1 station exhibits positive trend and 2 stations show negative trends for averages for Maha season and 8 stations exhibit positive trends, and 2 stations show negative trends for averages for Yala season for all three tests for the period of 1980-2016 for T_{max} series.

4. Among 10 temperature stations, 8 stations exhibit positive trends for annual averages, while 1 station only exhibits positive trend for averages for Maha season and 8 stations exhibit positive trends for Yala season for all three tests for the period of 1980-2016 for T_{min} series.

5. The all selected three hydrometric gauging stations exhibit significant downward trends for the period of 1980 to 2016, while Hanwella exhibits the highest downward trend for annual, Maha and Yala seasons among three selected stations for all three tests, while it only shows significant downward trend for annual, four rainfall seasons, Maha and Yala seasons for MK test at different level of significance.

6. It clearly shows that Climate elasticity are reduced after allowing for landuse influences on Climate change for both scenarios and 1 ^{0}C of temperature causes 6.9 % and 7.4 % runoff decrease and 1% of rainfall causes 0.002 % and 0.370 % runoff increase at Glencourse gauging station for the current scenario for both methods for the duration of 1980 to 2016.

7. It is also evaluated that the same hydrological parameters, which are used for Calibration and validation of Glencourse gauging station can not be transferred for both Hanwella and Kitulgala gauging stations.

8. A 1 ºC increase causes 0.4 % rise and 1.5 % reduction of runoff as evaluated by Zheng et al. (2009) and Sankarasubramanian et al. (2001), respectively for the Future Pessimistic Climate Change Scenario with projected landuse for 2040. 1 % of rainfall increase causes 0.005 % and 0.360 % increase of flow as evaluated by Zheng et al. (2009) and Sankarasubramanian et al. (2001), respectively for Glencourse gauging station for the aforementioned scenario. This implies a positive effect on runoff for future pessimistic scenario with projected landuse for 2040 as Zheng et al. (2009).

6.2 Other Conclusions and Derivations

1. Among the selected 41 rainfall stations, 8 stations exhibit the non-normality, while only one station shows the serial correlation. Trends exhibit by 5 stations for the Spearman rank correlation test, while the same four stations show the trends except for Pasyala for t-test results. Only 4 stations show the instability in F test results.

2. Among the 10 selected temperature stations, 8 stations exhibit trends for T_{min}, while only Katunayaka station shows the trend for both t-test and Spearman rank correlation test for T_{max}. 7 stations show the serial correlation for T_{min}, while 3 stations exhibit serial correlation for T_{max}.

3. Among 41 rainfall stations, 33 stations exhibit positive trends, while 3 stations show negative trends for Maha rainfall totals for all three tests of ITA, Mann-Kendall and Sen's Slope tests. The Sen's Slope trend magnitude varies between -12.0 to 16.5 for Maha rainfall totals for the period of 1980-2016.

4. Among 41 rainfall stations, 7 stations exhibit positive trends, while 18 stations show negative trends for annual rainfall totals for all three tests of ITA, Mann-Kendall and Sen's Slope tests. The Sen's Slope trend highest magnitude varies between -45.6 to 28.8 for Yala rainfall totals for the period of 1980-2016, among Annual, Maha and Yala seasons.

5. Among 10 selected temperature gauging station, only Maximum temperature of Katunayaka shows the significant decreasing trend for annual, Maha and Yala seasons, while only Minimum temperature of Katunayaka shows significant increasing trend for both annual and Maha seasons, respectively.
6. The multi-objective functions were used to calibrate the SWAT hydrological model using 32 rainfall gauges and 10 temperature gauges in and around the Kelani Ganga basin for the period of 1960 to 2016 and the calibration and validation were completed for the key hydrometric station at Glencourse for the period of 1970 to 1980 and for the period of 1982 to 1992.
7. Mass balance performance Error (*E*r), coefficient of determination (R^2) and Nash–Sutcliffe efficiency (*NSE*) are used as multi-objective functions and 8.90 %, 0.72, 0.65 and 9.10 %, 0.69, 0.69 are obtained, respectively for the calibration and validation periods for the key hydrometric station at Glencourse.
8. 1 % of precipitation increases about 0.004 % and 0.400 % increase of flow, respectively as evaluated by Zheng et al. (2009) and Sankarasubramanian et al. (2001), while a 1 ºC increase causes 0.07 % increase and 0.02 % decrease of flow at Glencourse gauging station, respectively Zheng et al. (2009) and Sankarasubramanian et al. (2001) for baseline climate change scenario for 2040 with projected landuse for 2040.

6.3 Recommendations

As SWAT model has calibrated and validated for the duration of 1970 to 1992, the result shows the high degree of uncertainties of flow simulation for recent years. Hence it is recommended to perform Water allocation model to obtain better calibration and validation results in the Kelani Ganga basin in future with consideration of identified trend after 1995, which will reduce the degree of uncertainties on flow simulations for recent years after the 1990s as well as to increase the degree of confidence to predict runoff elasticity coefficients for future scenarios in future researches for planning and management of water resources in future.

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APPENDIX A - STATISTICAL TEST RESULTS FOR RAINFALL GAUGING STATIONS

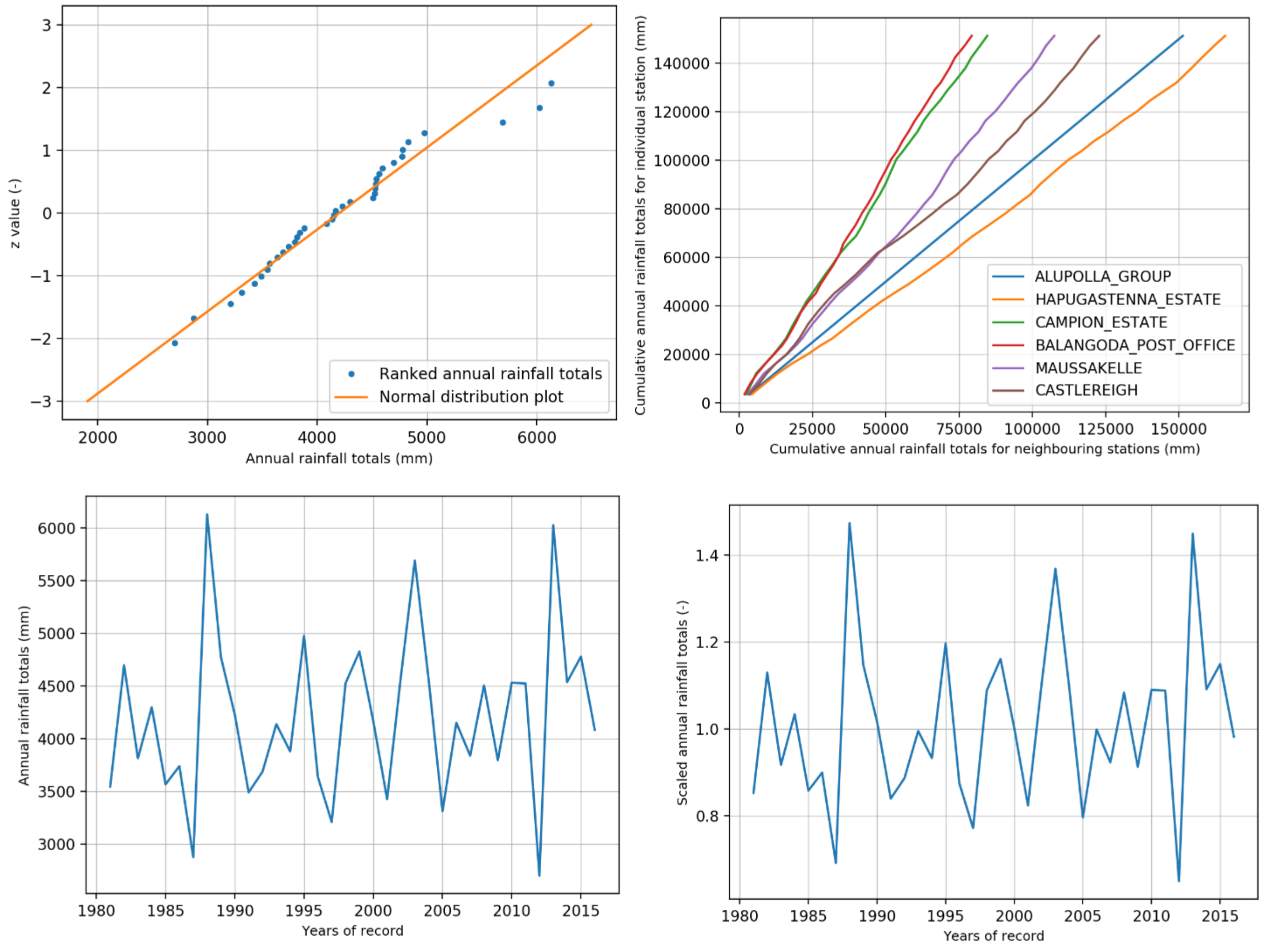

Figure A-1: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Allupola Group

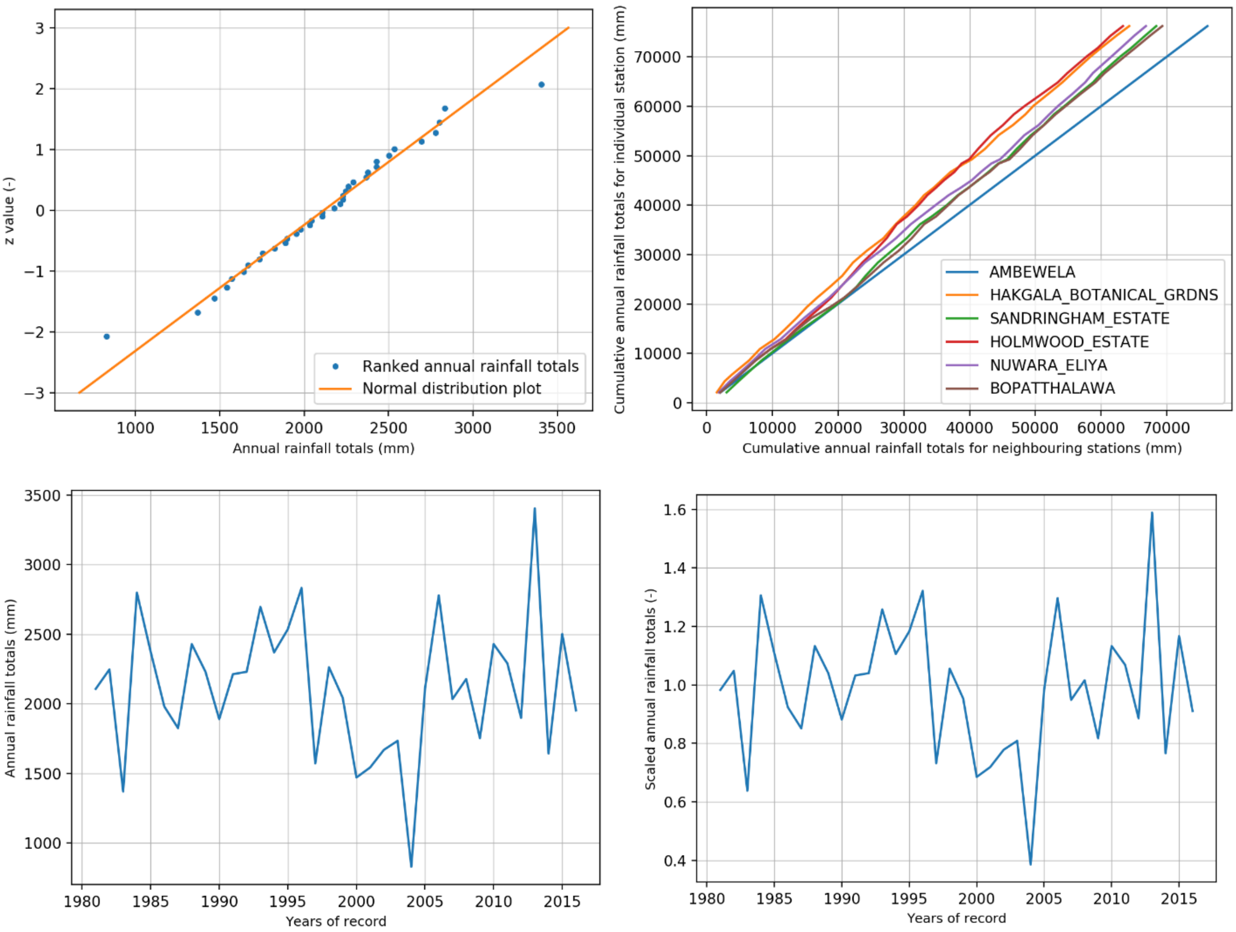

Figure A-2: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Ambewela

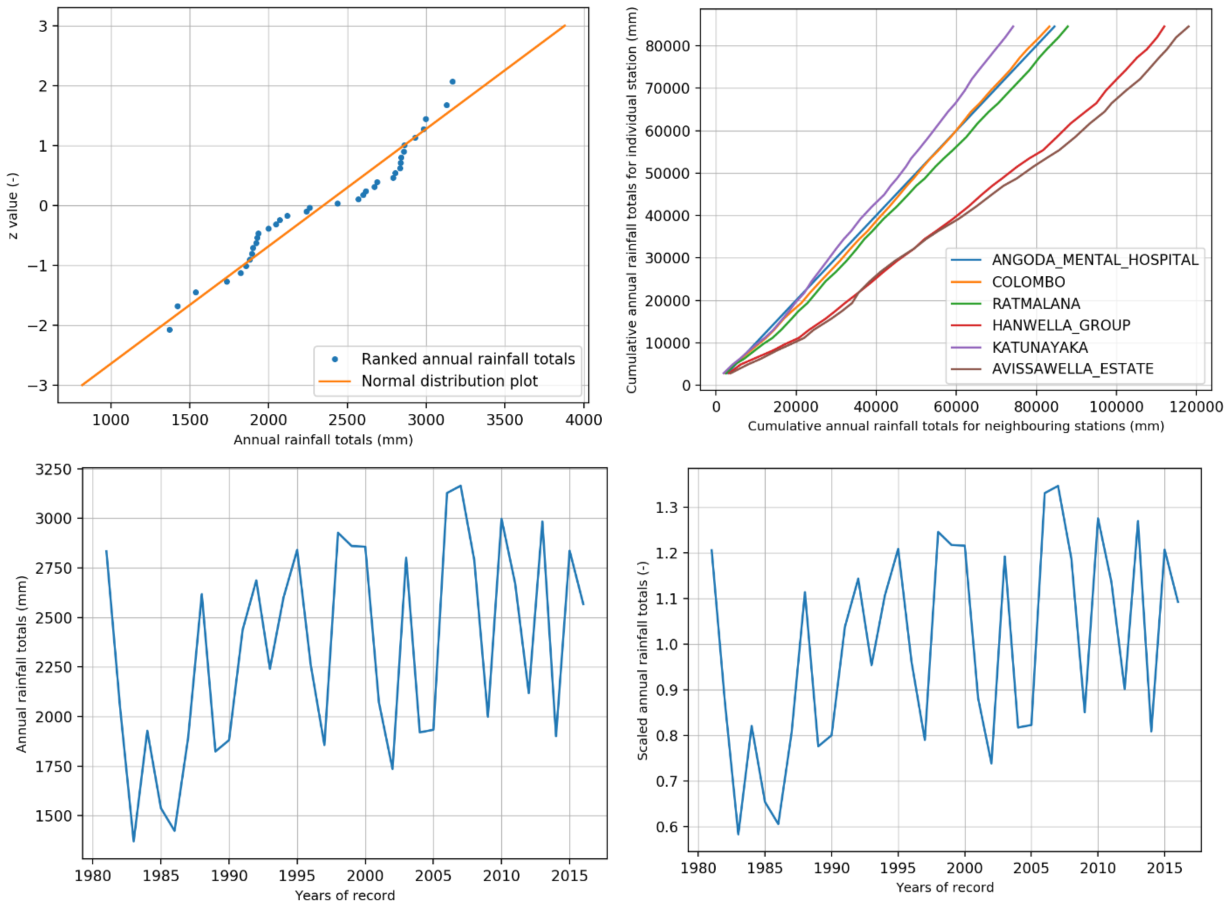

Figure A-3: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Angoda mental hospital

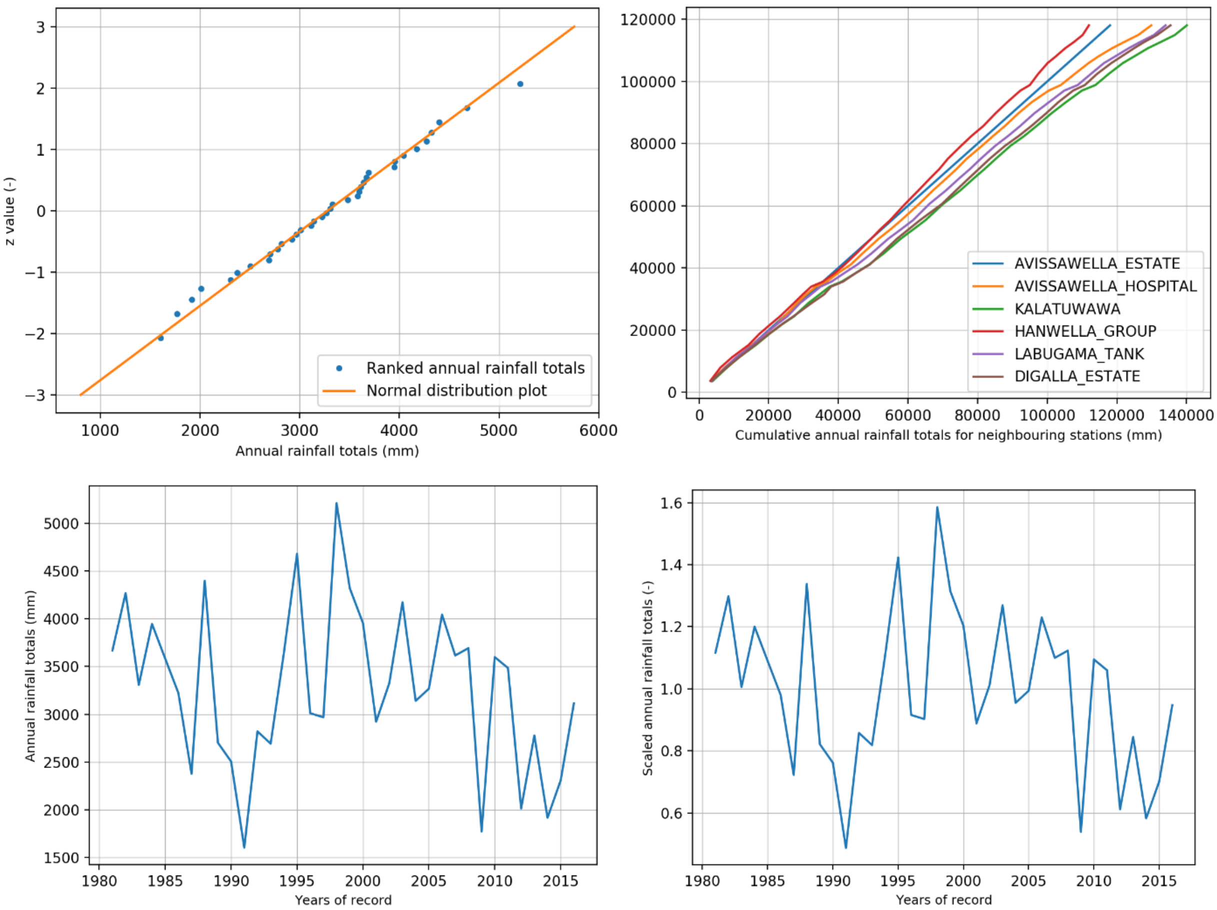

Figure A-4: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Avissawella Estate

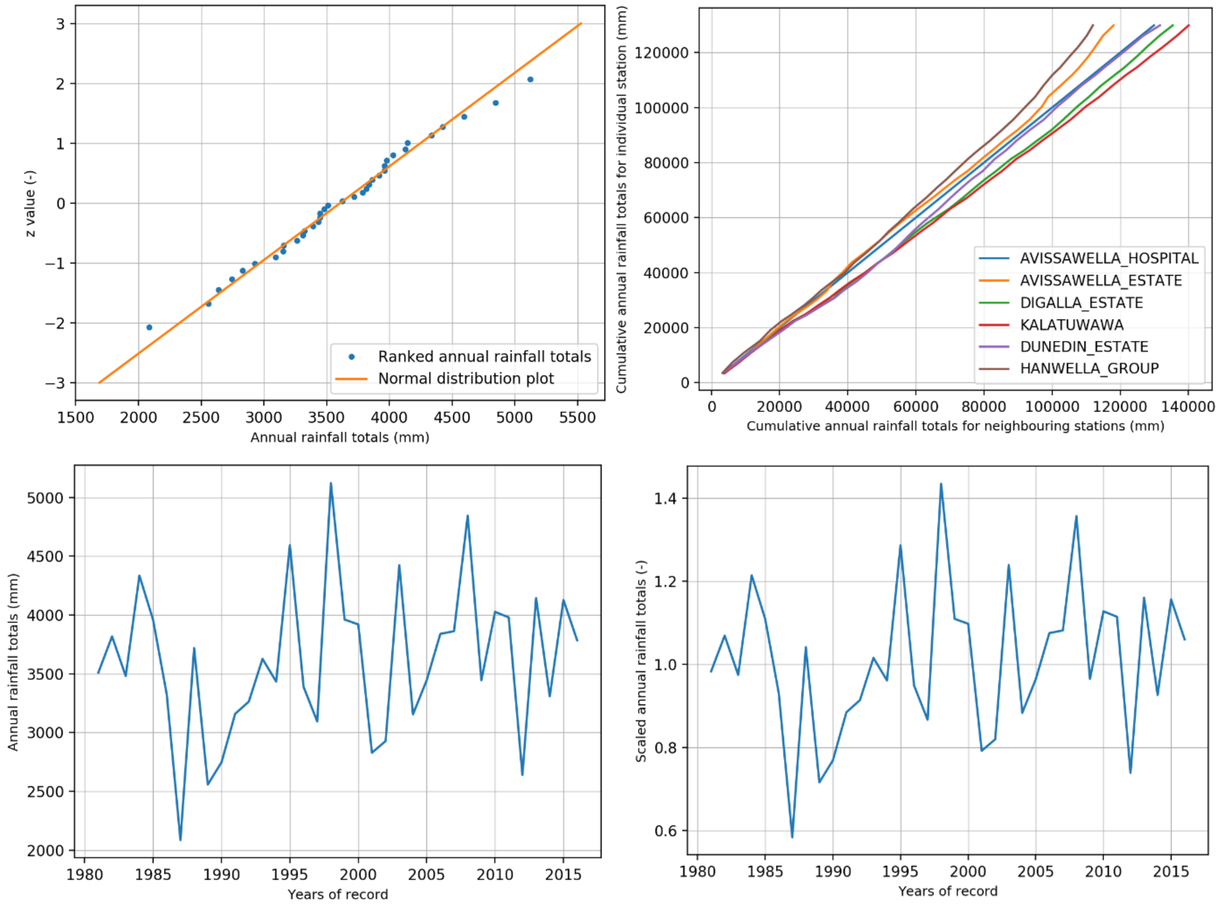

Figure A-5: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Avissawella Hospital

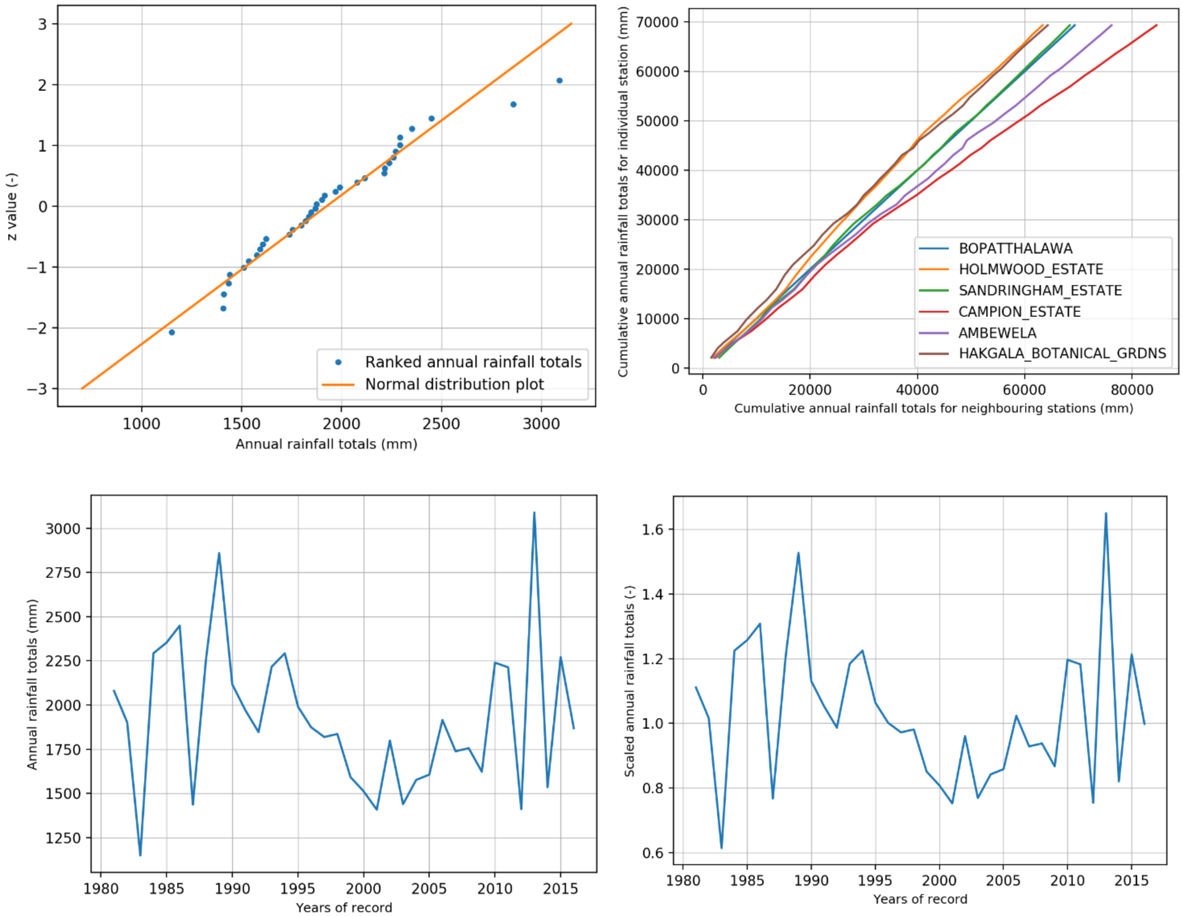

Figure A-6: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Bopaththalawa

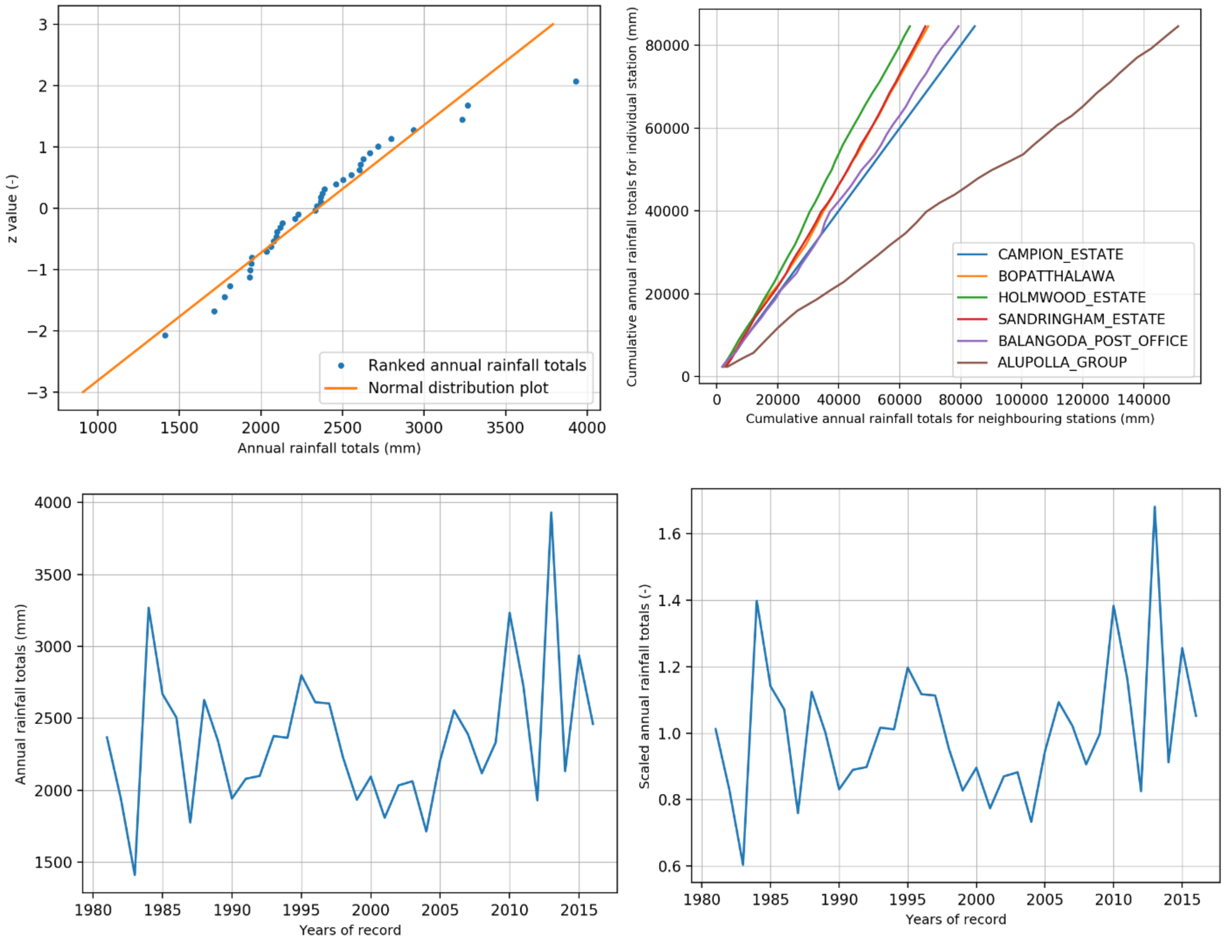

Figure A-7: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Campion Estate

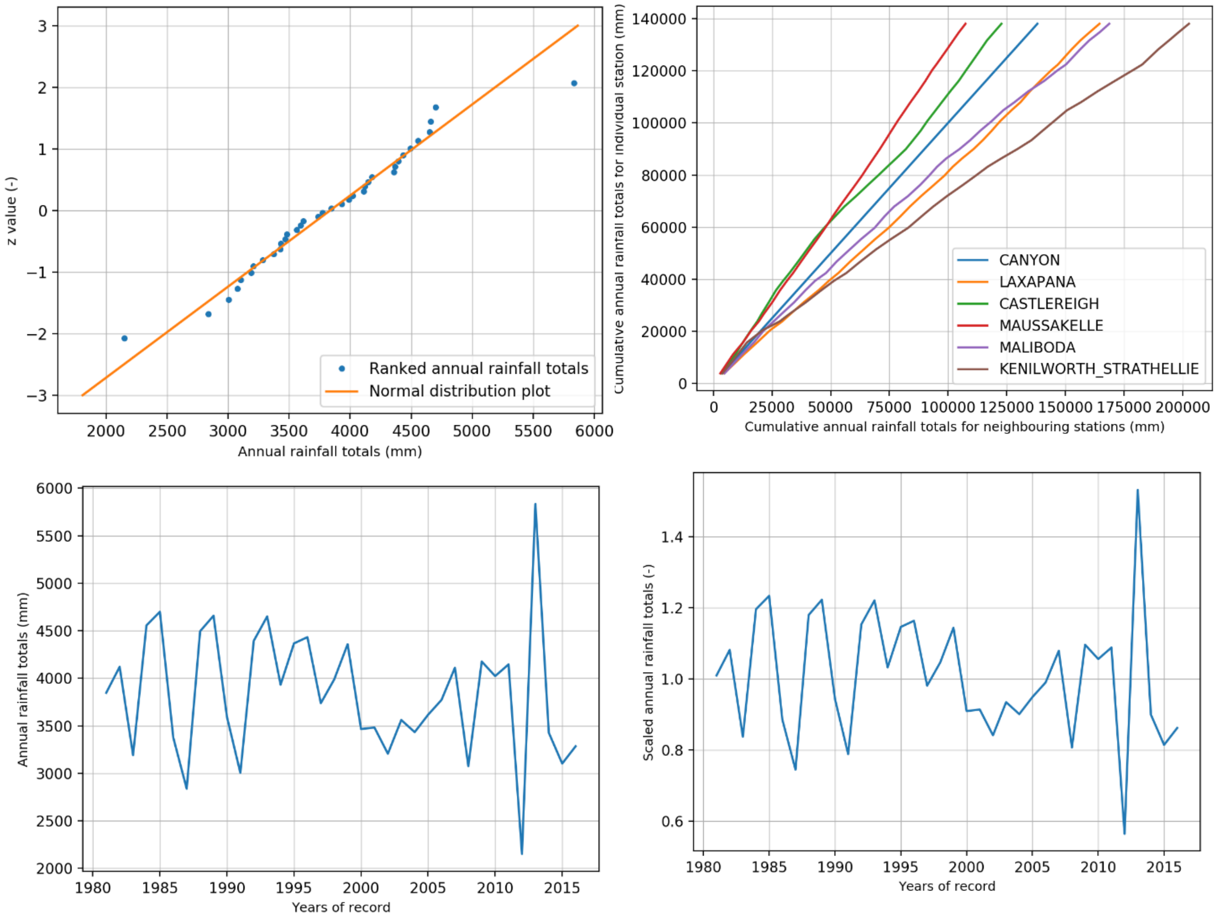

Figure A-8: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Canyon

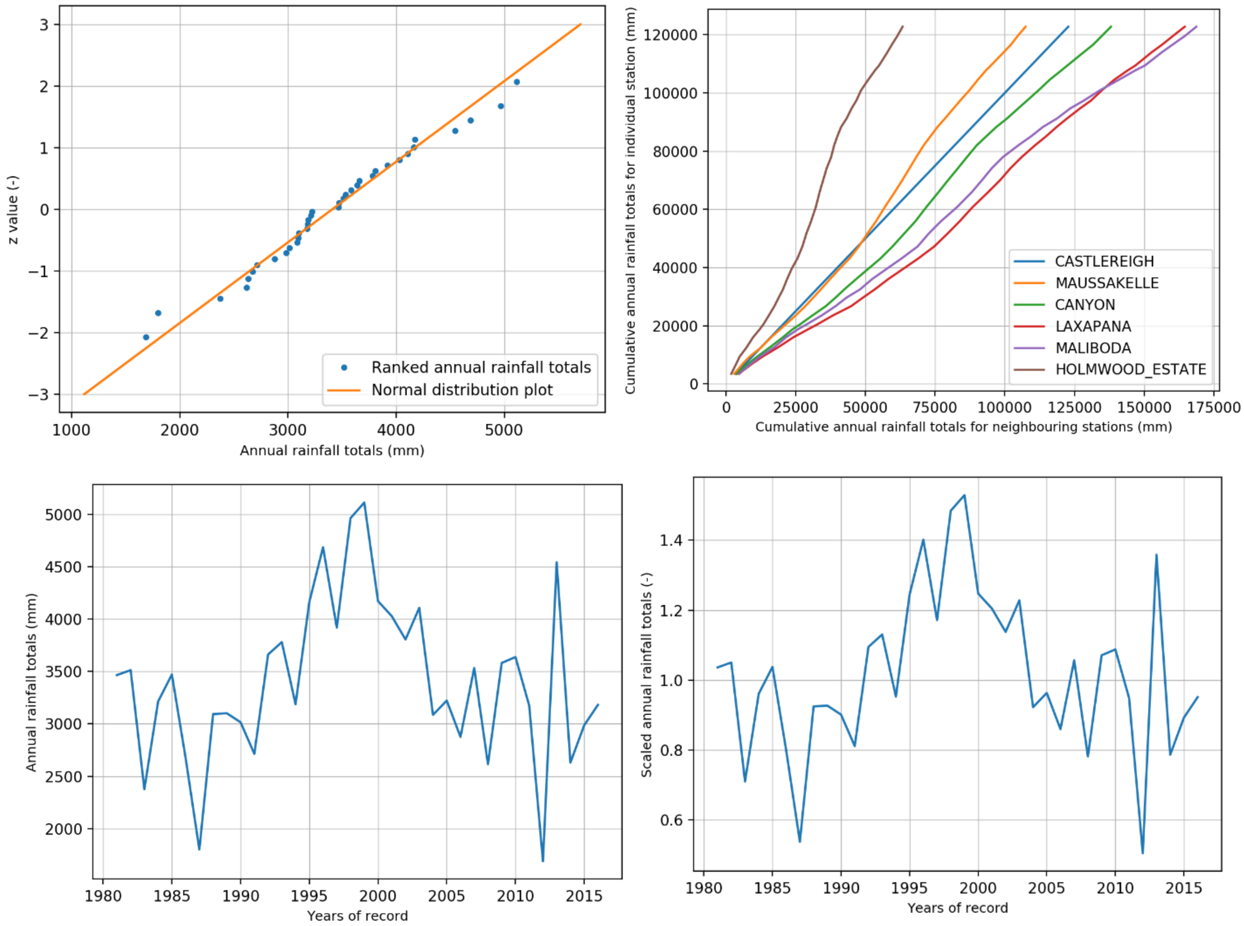

Figure A-9: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Castlereigh

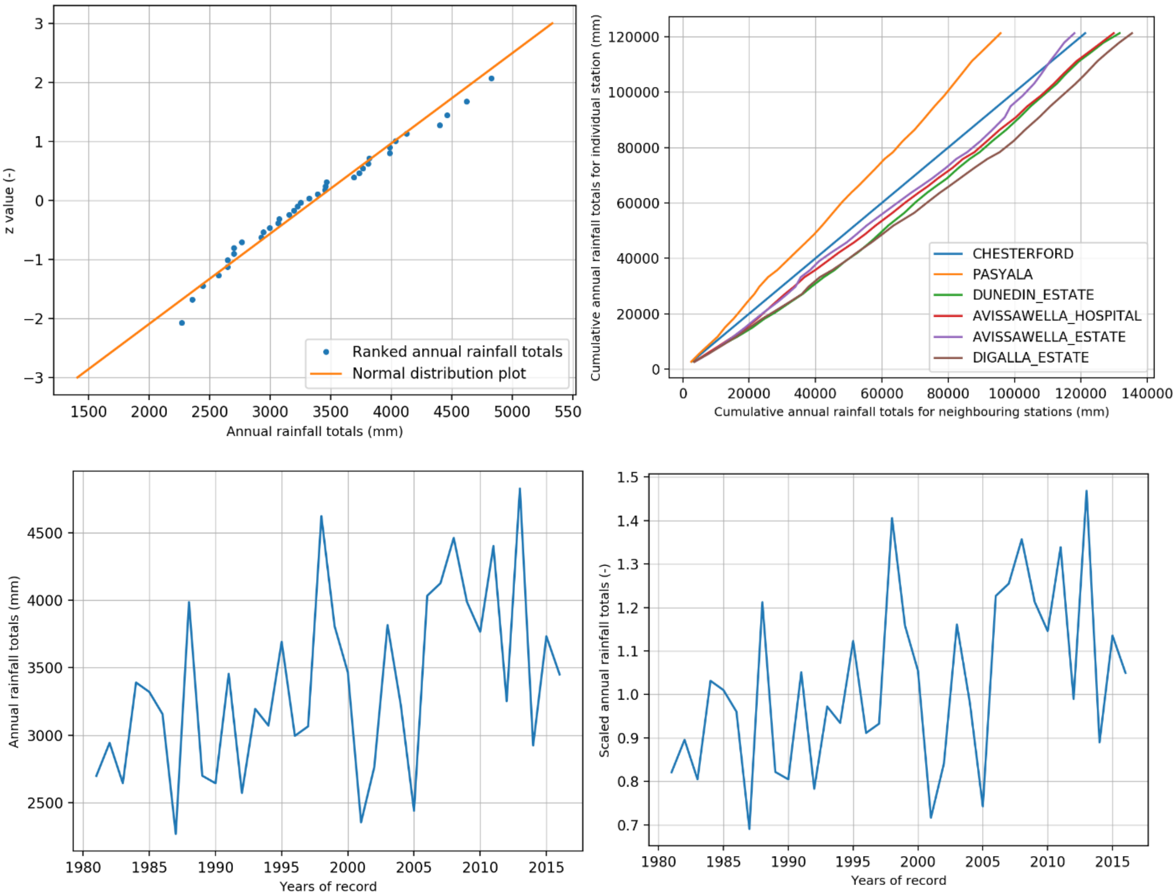

Figure A-10: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Chesterford

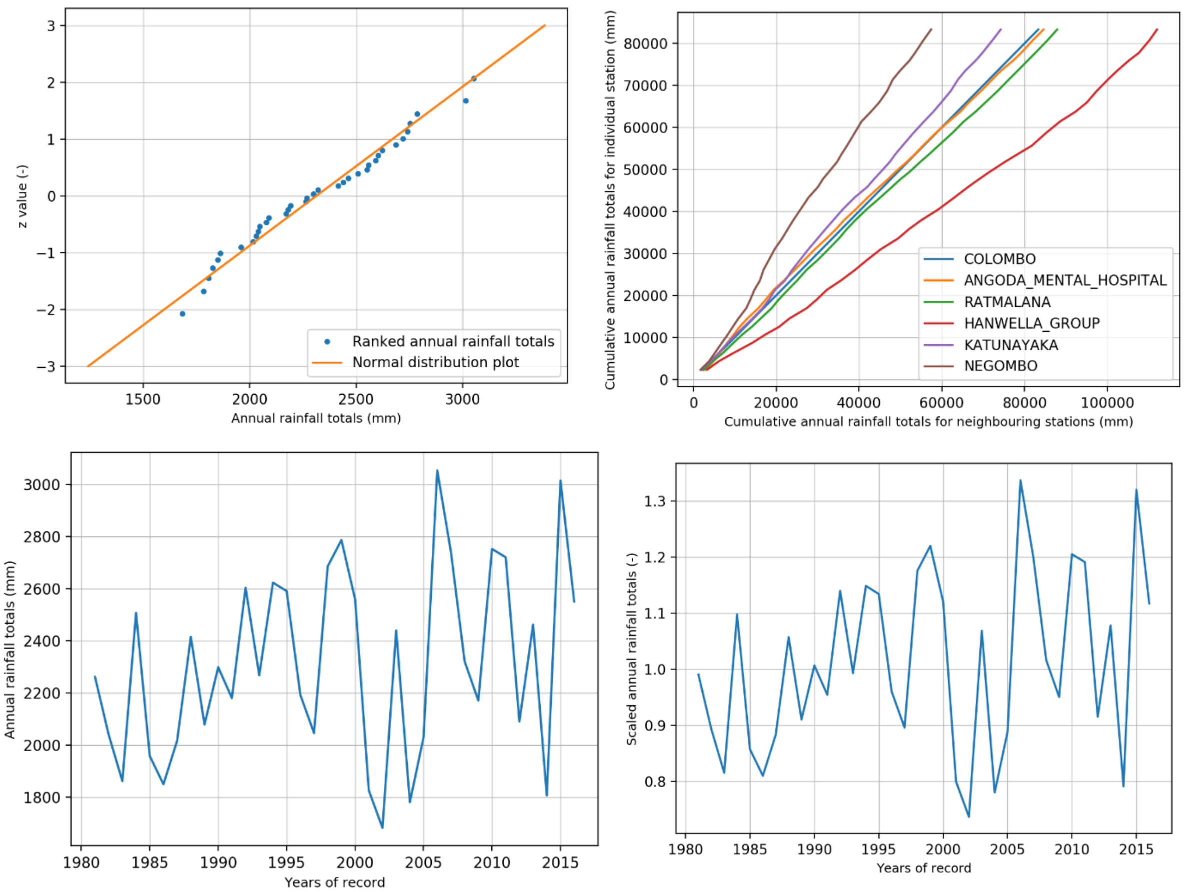

Figure A-11: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Colombo

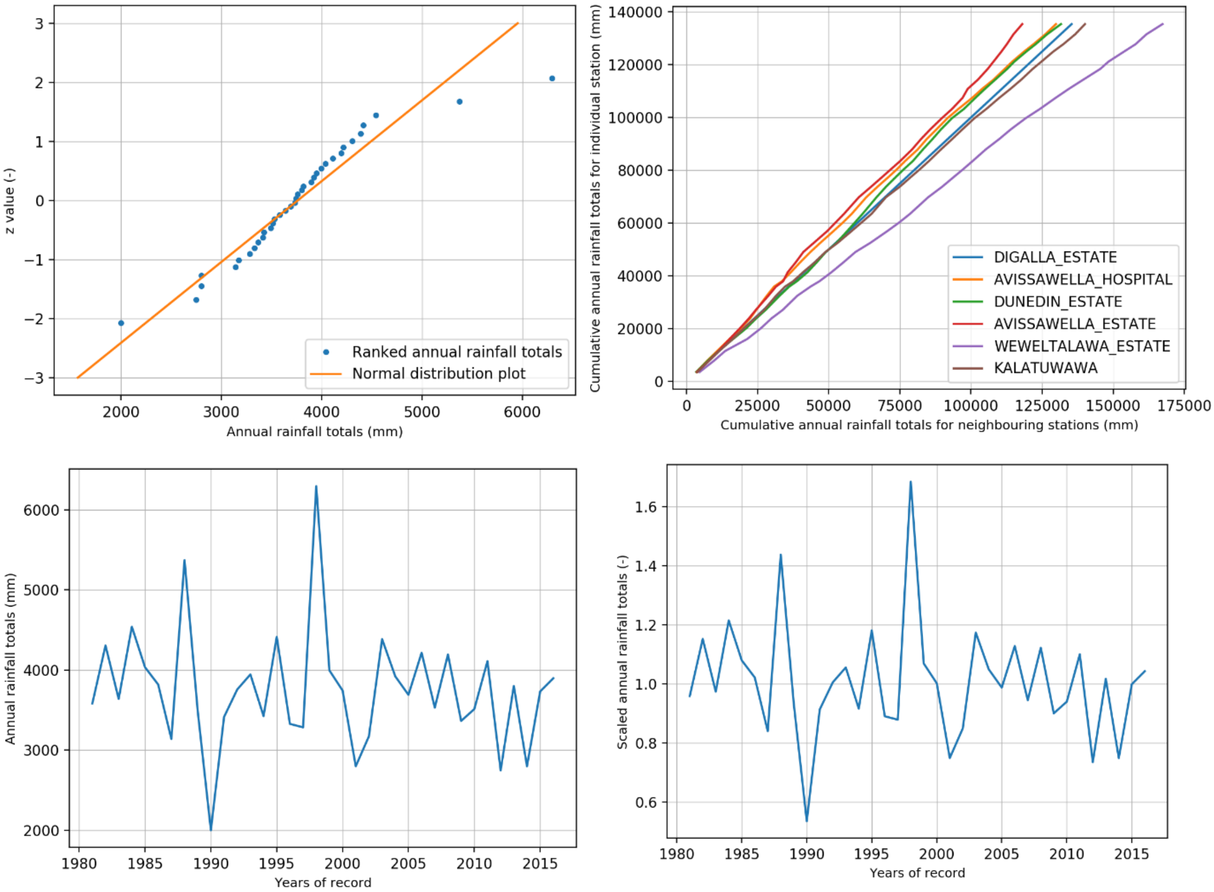

Figure A-12: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Digalla Estate

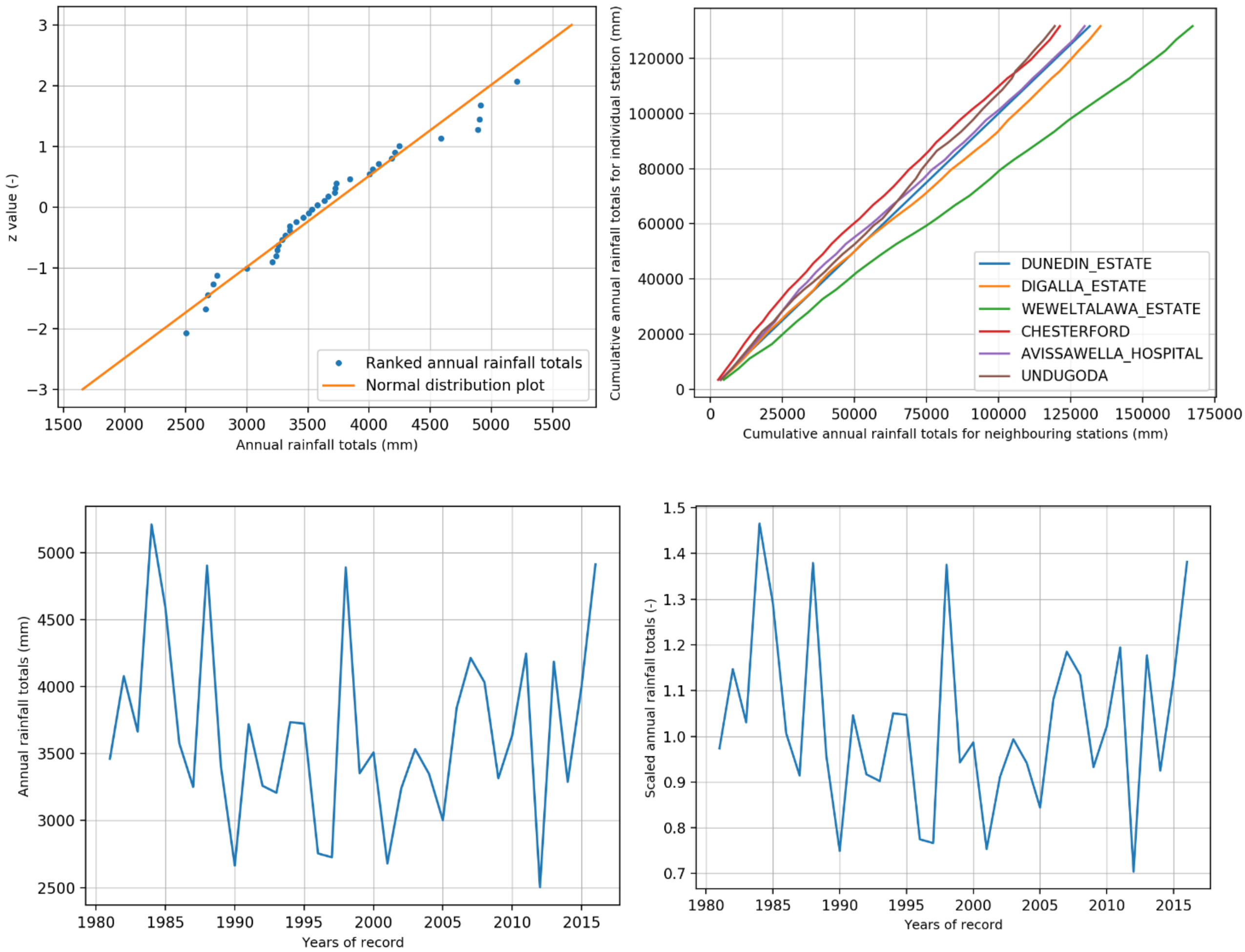

Figure A-13: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Dunedin Estate

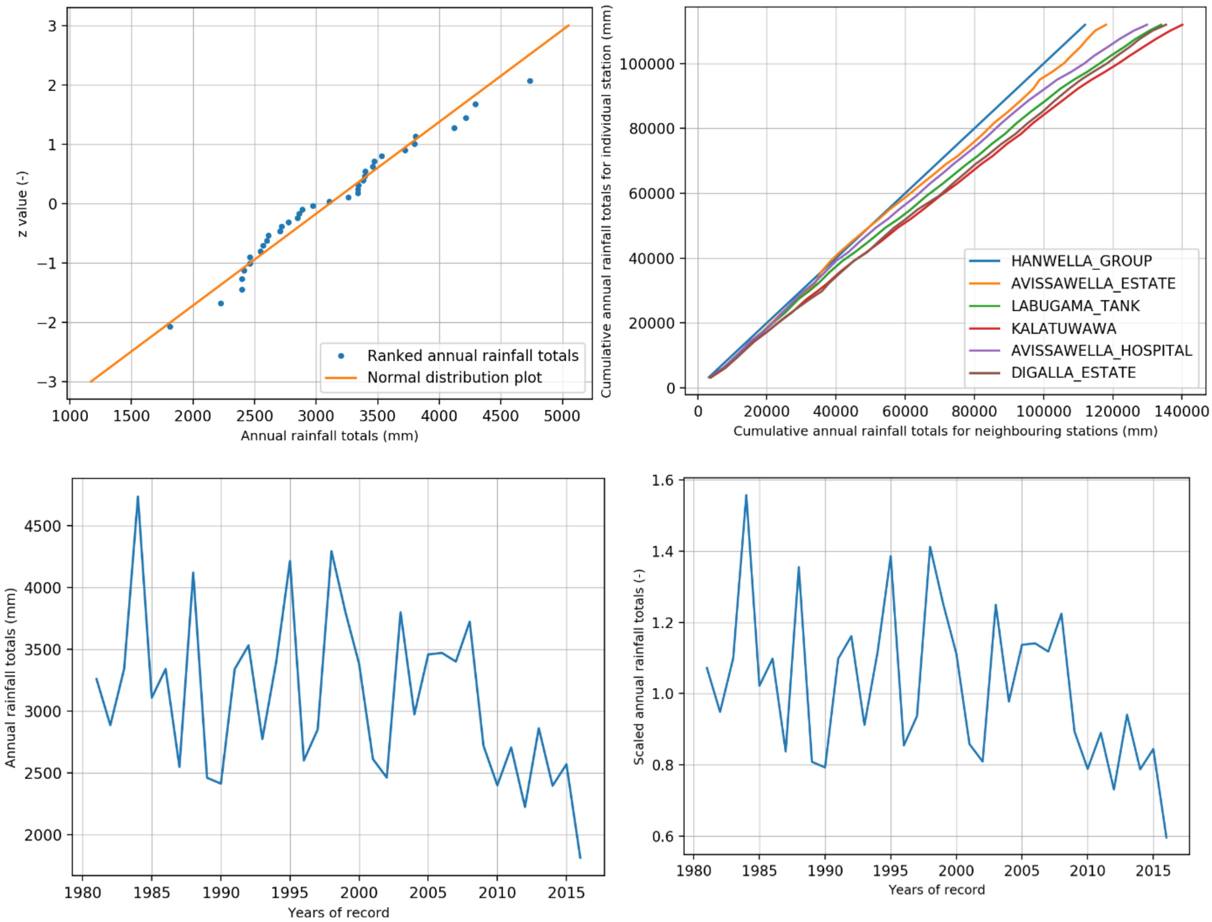

Figure A-14: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Hanwella Group

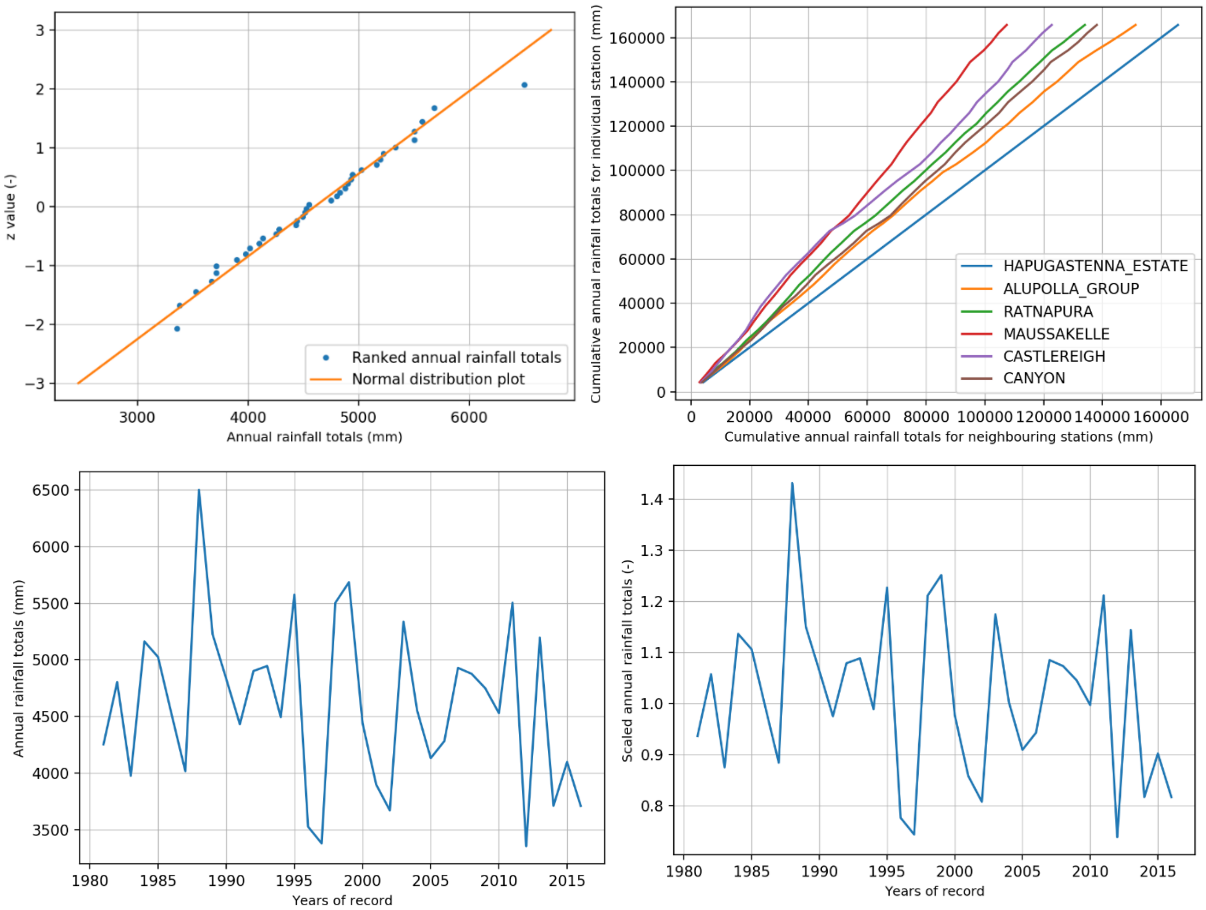

Figure A-15: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Hapugasthenna Estate

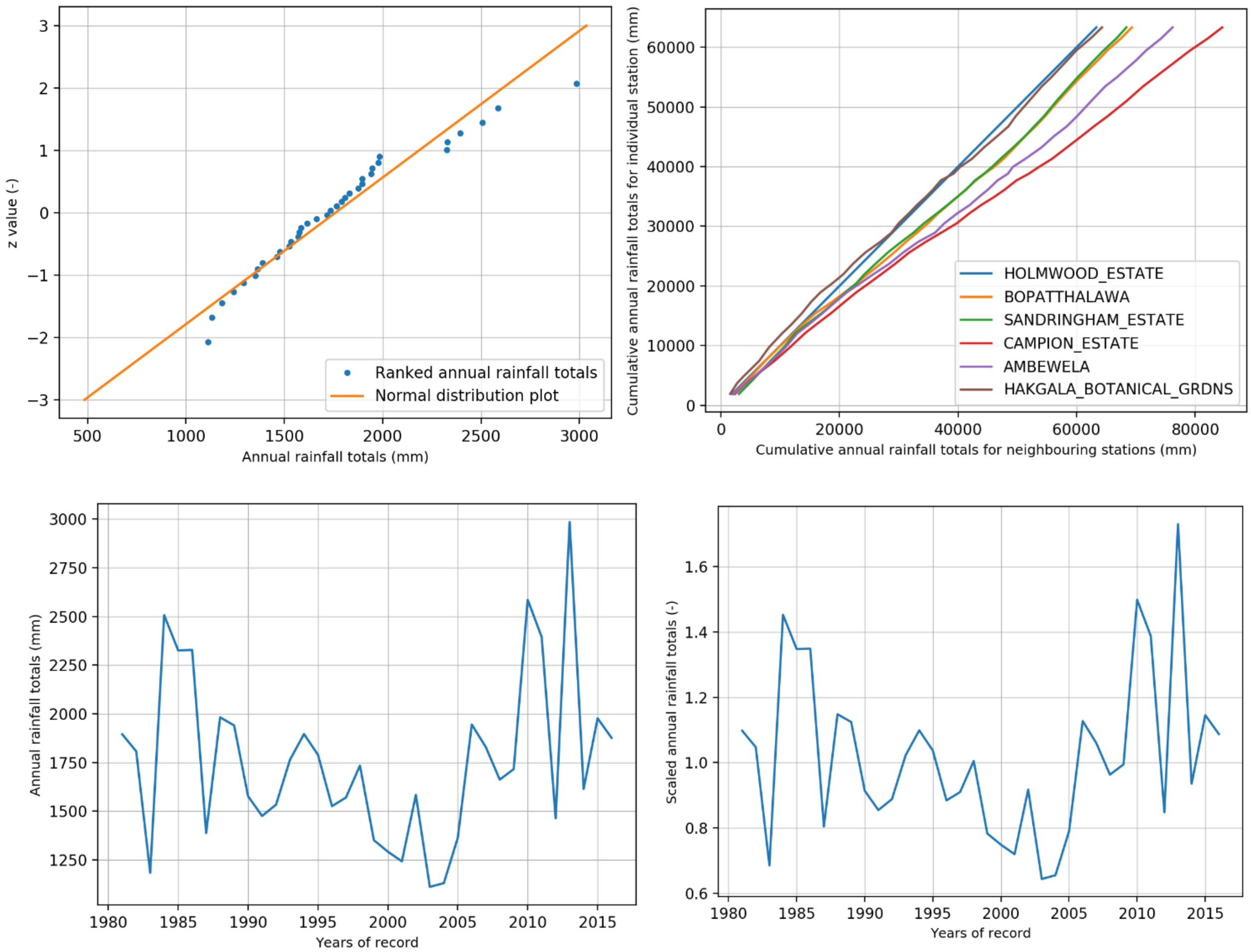

Figure A-16: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Holmwood Estate

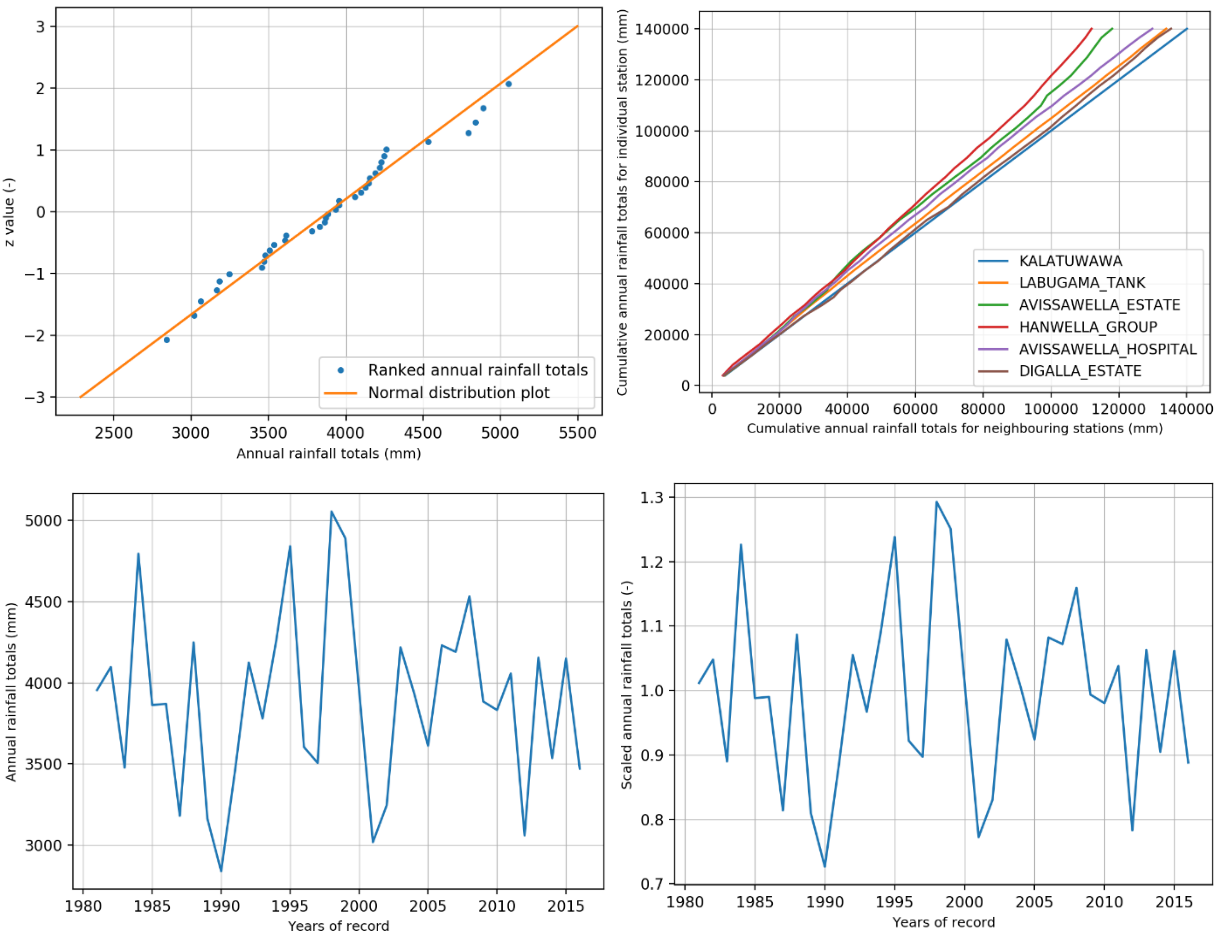

Figure A-17: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Kalatuwawa

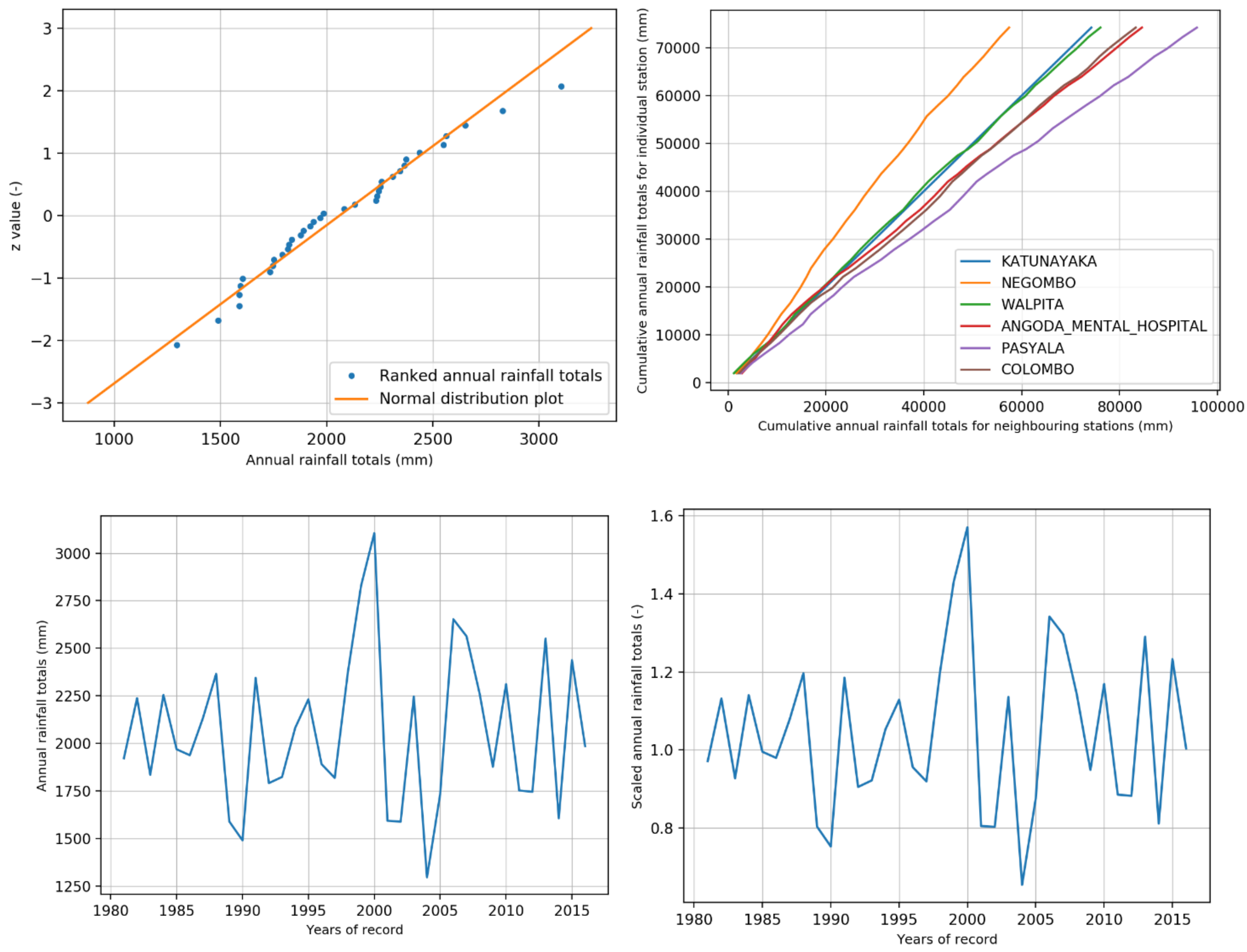

Figure A-18: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Katunayaka

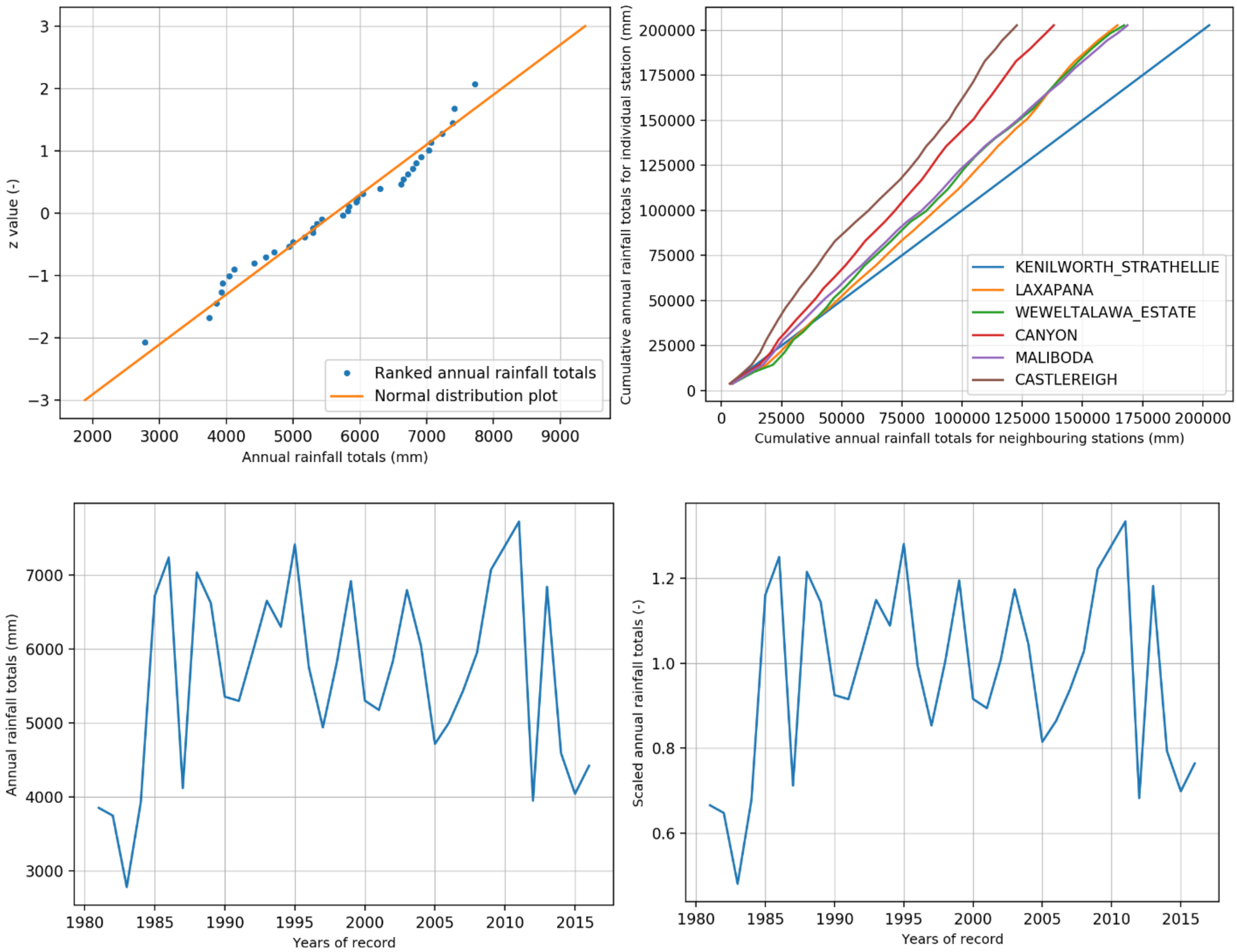

Figure A-19: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Kenilworth

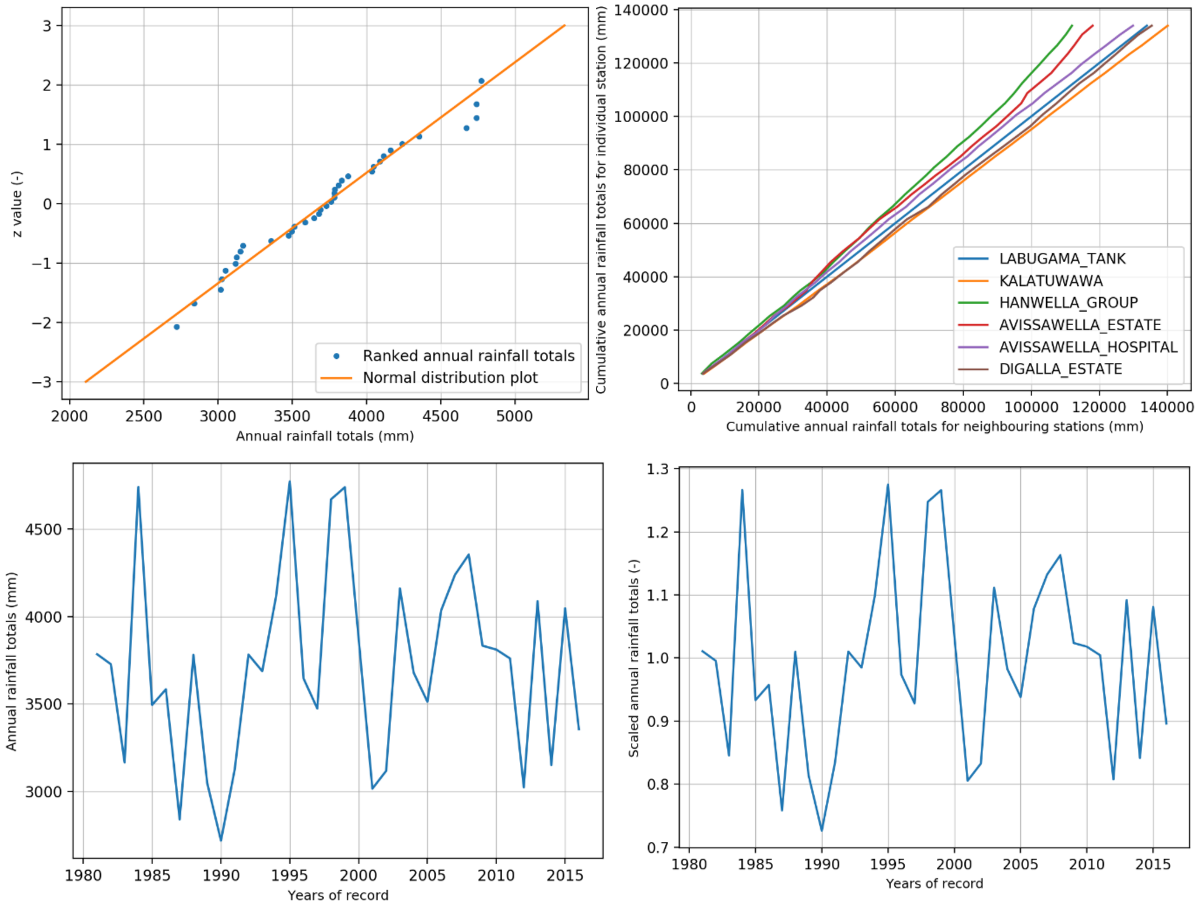

Figure A-20: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Labugama Tank

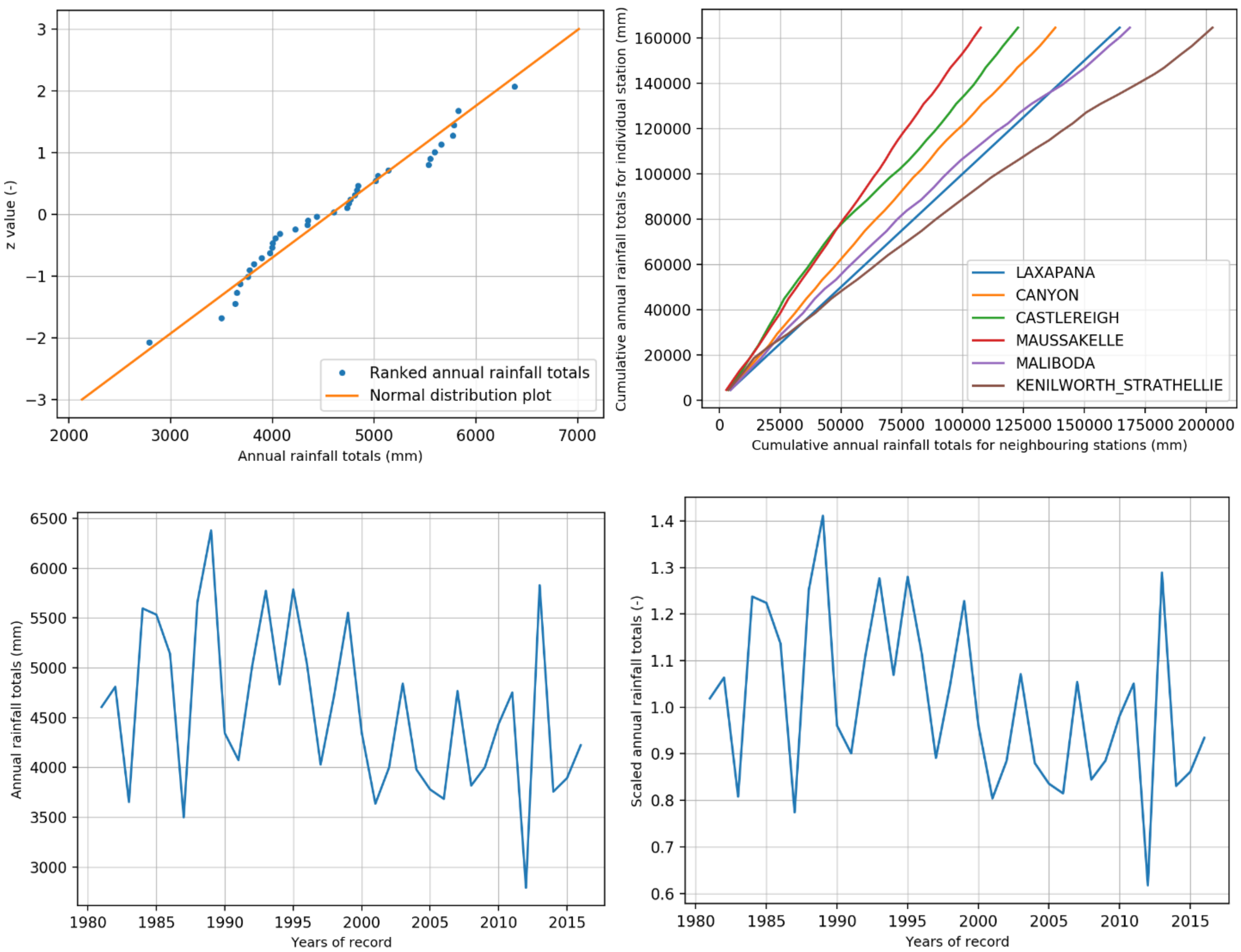

Figure A-21: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Laxapana

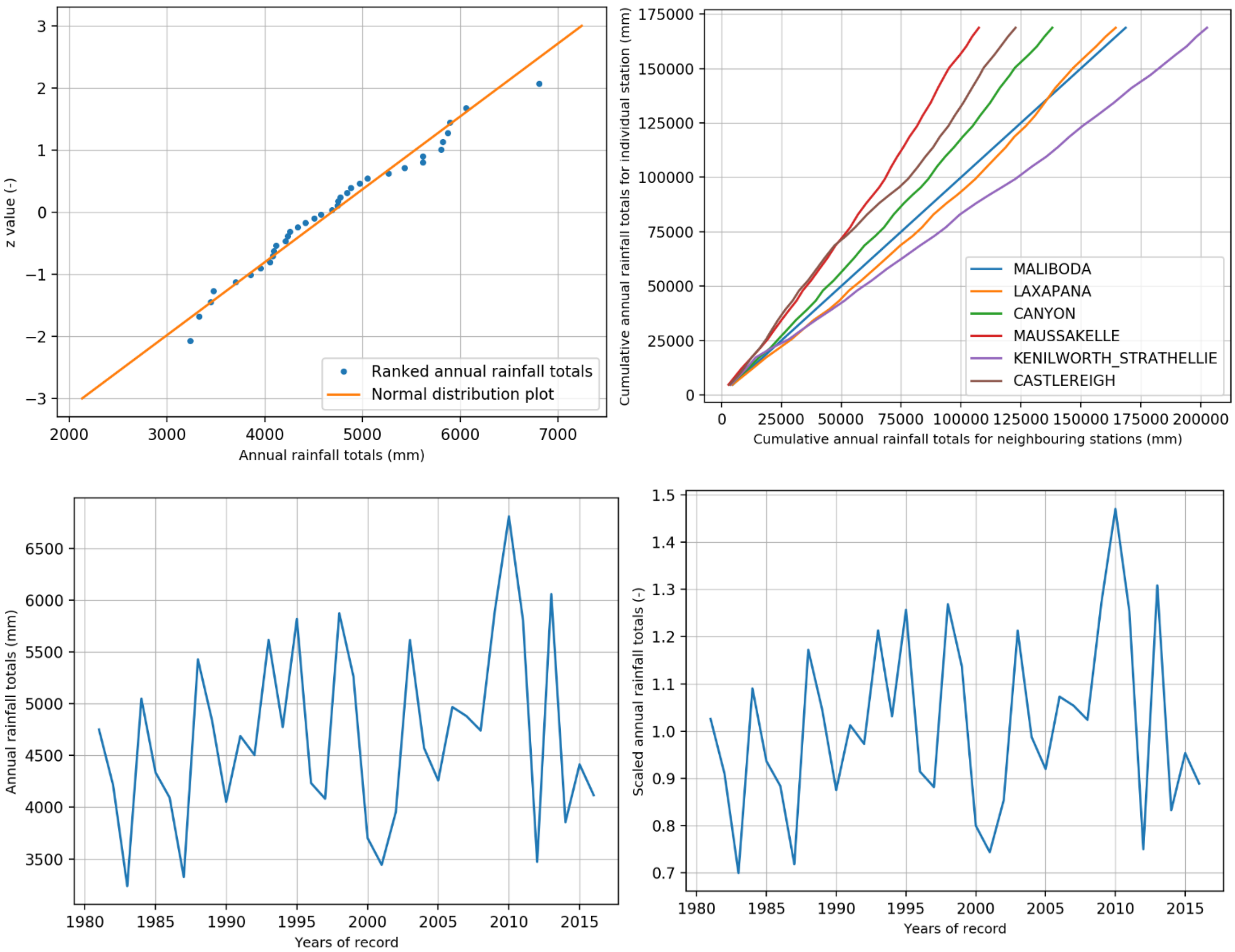

Figure A-22: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Maliboda

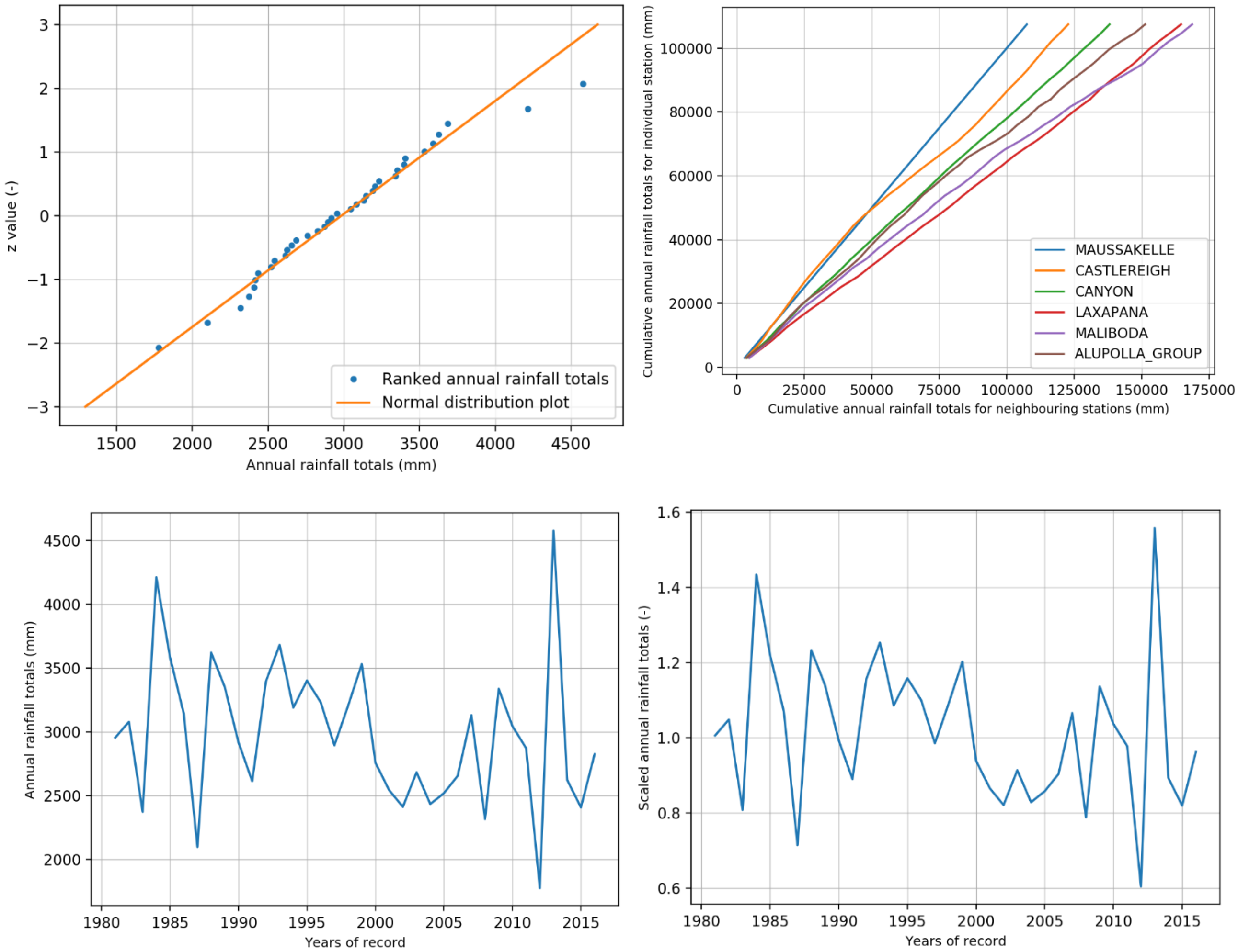

Figure A-23: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Maussakele

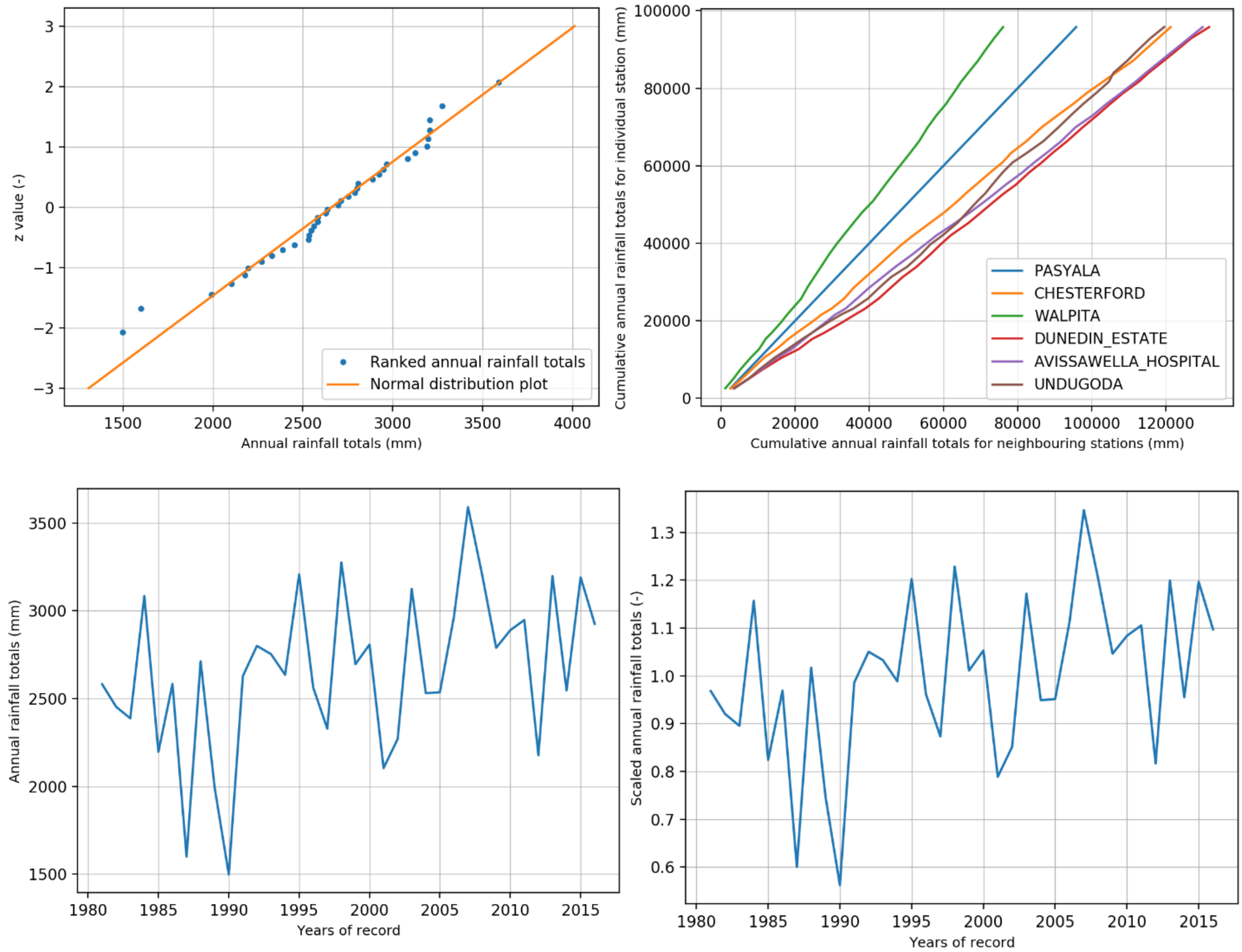

Figure A-24: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Pasyala

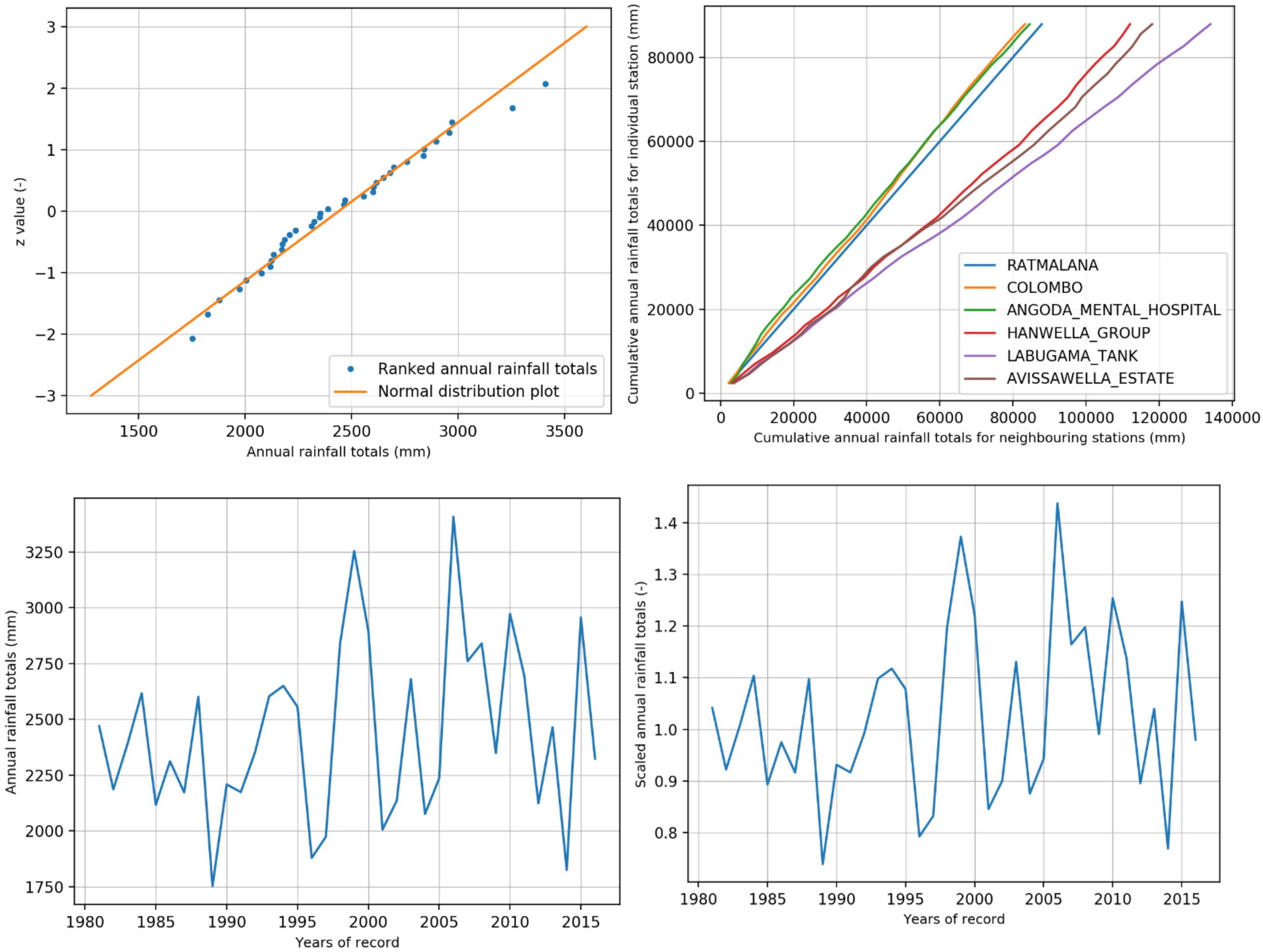

Figure A-25: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Rathmalana

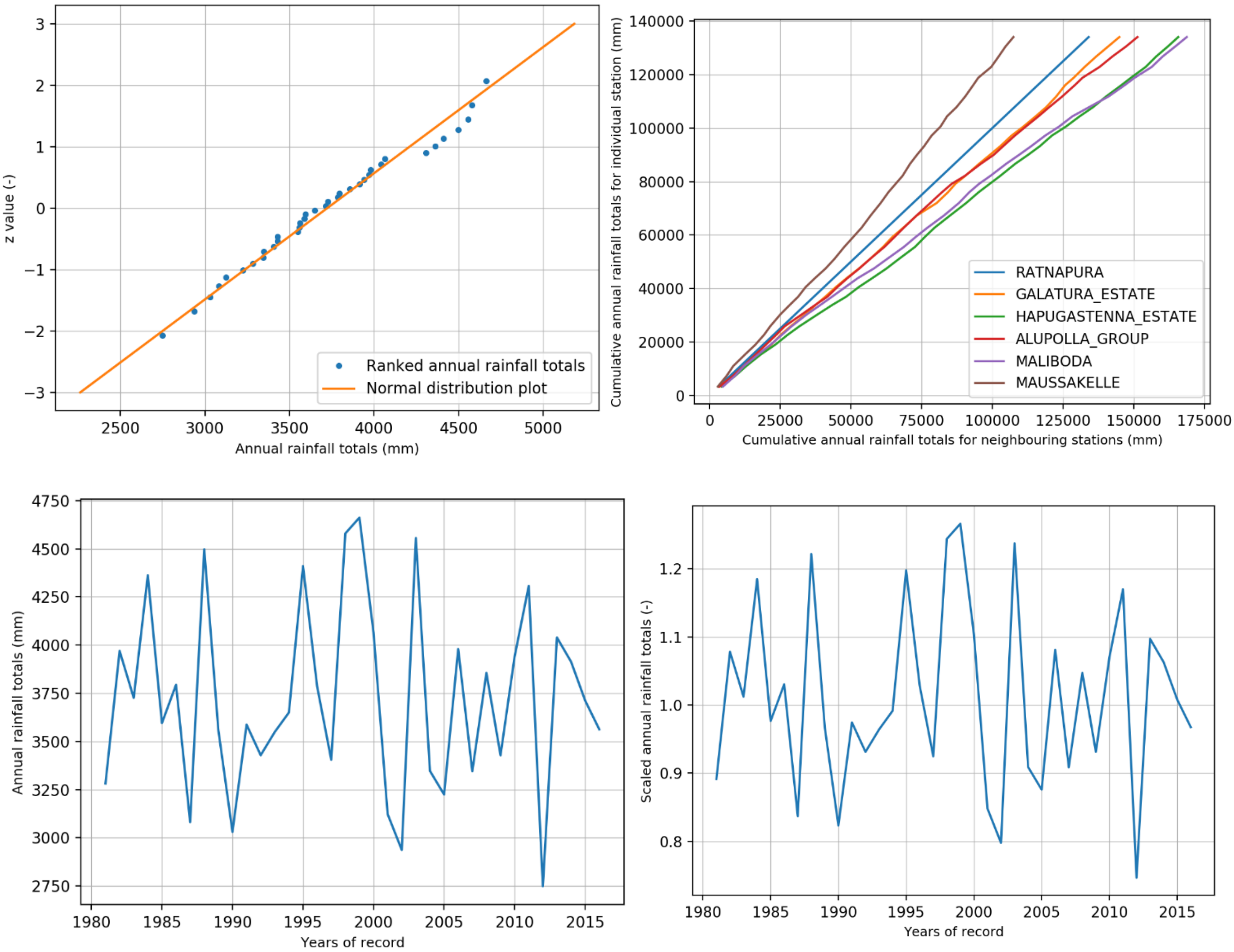

Figure A-26: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Rathnapura

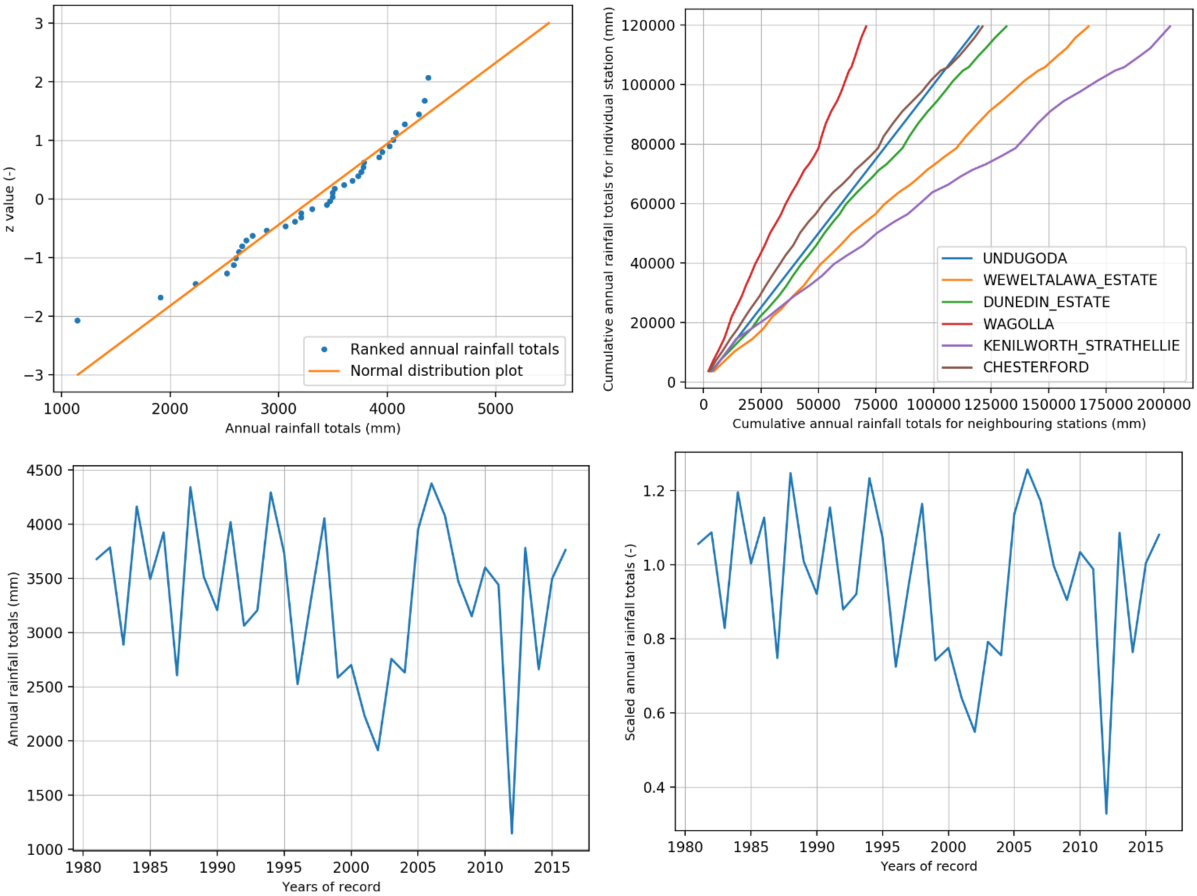

Figure A-27: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Undugoda

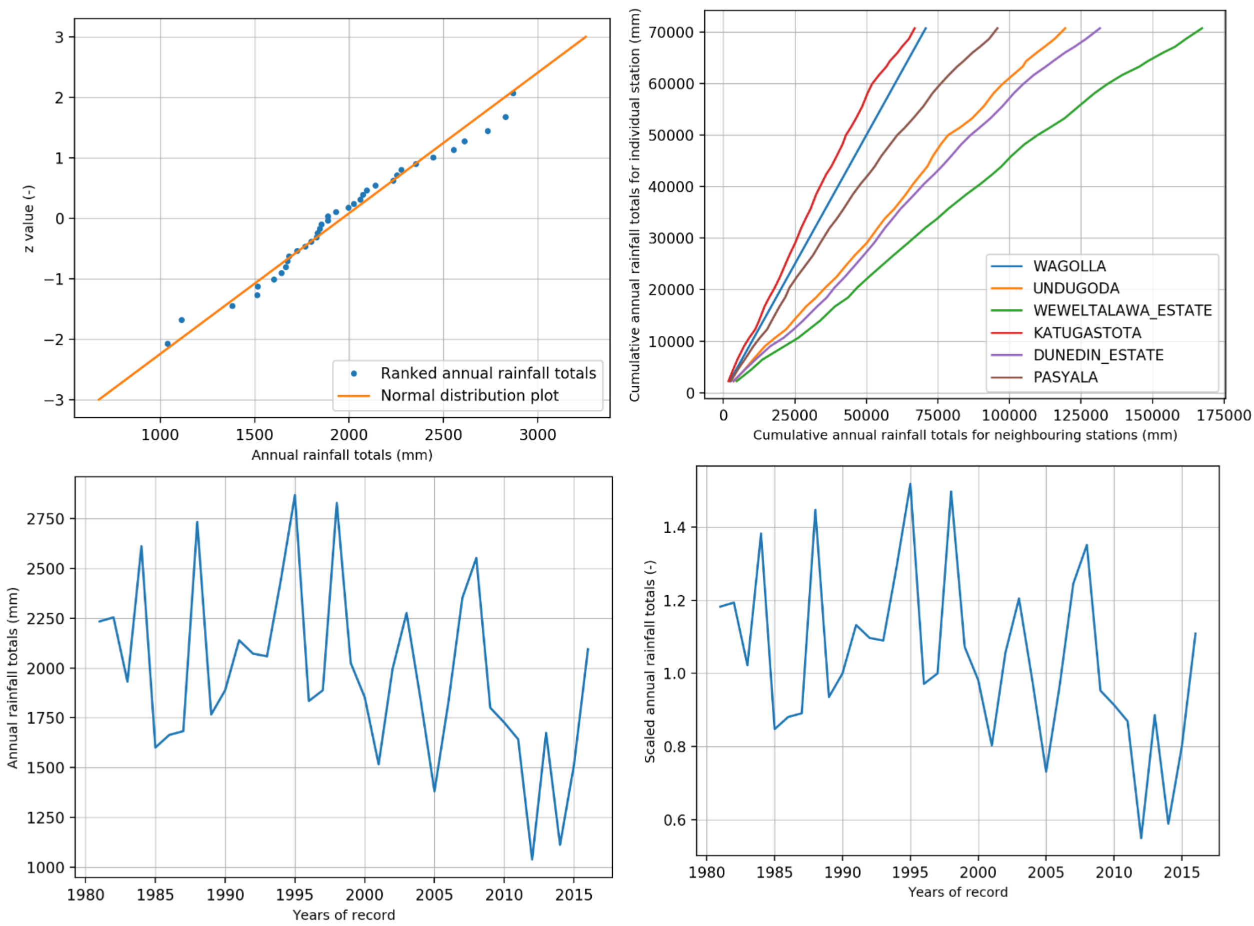

Figure A-28: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Wagolla

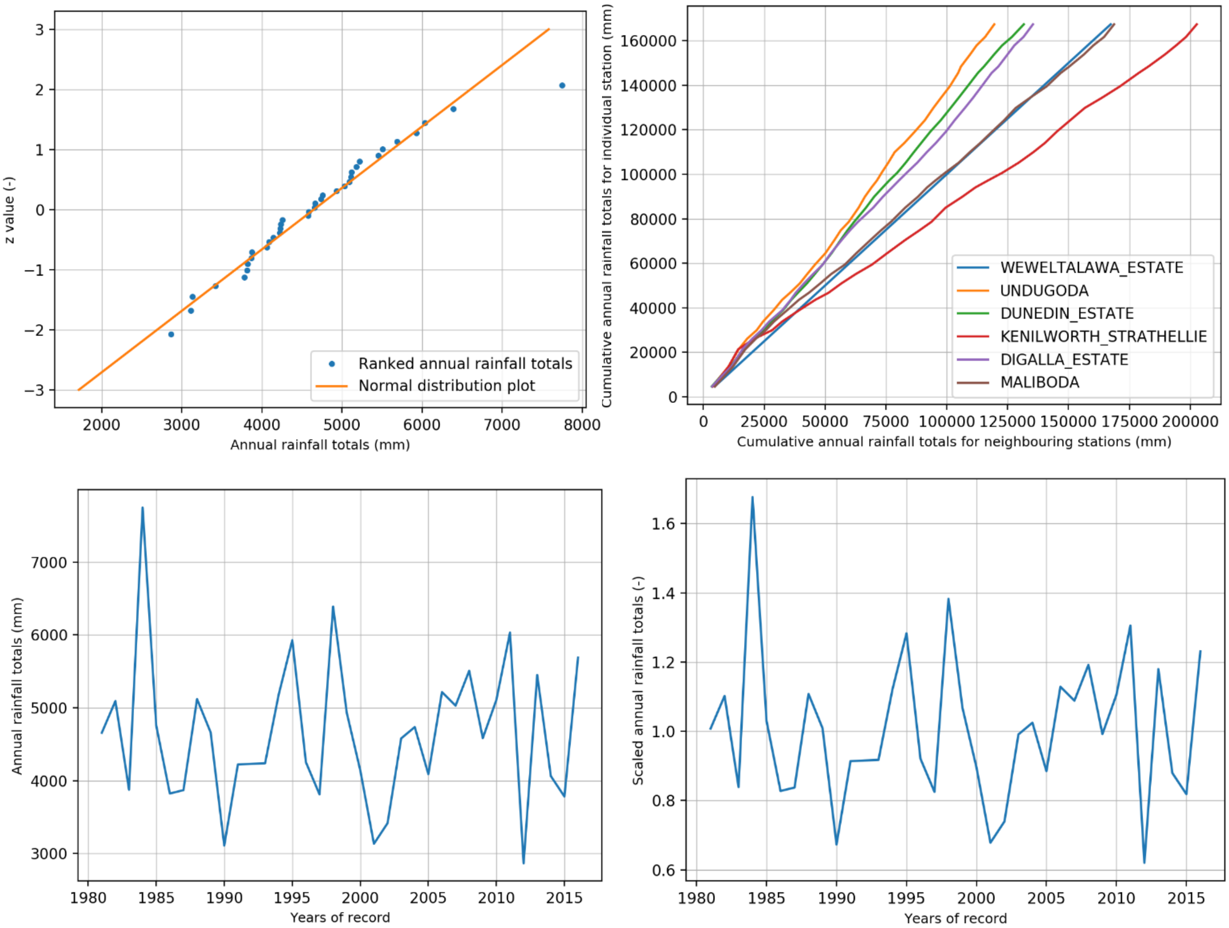

Figure A-29: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Wewelthalawa Estate

APPENDIX B - STATISTICAL TEST RESULTS FOR TEMPERATURE GAUGING STATIONS

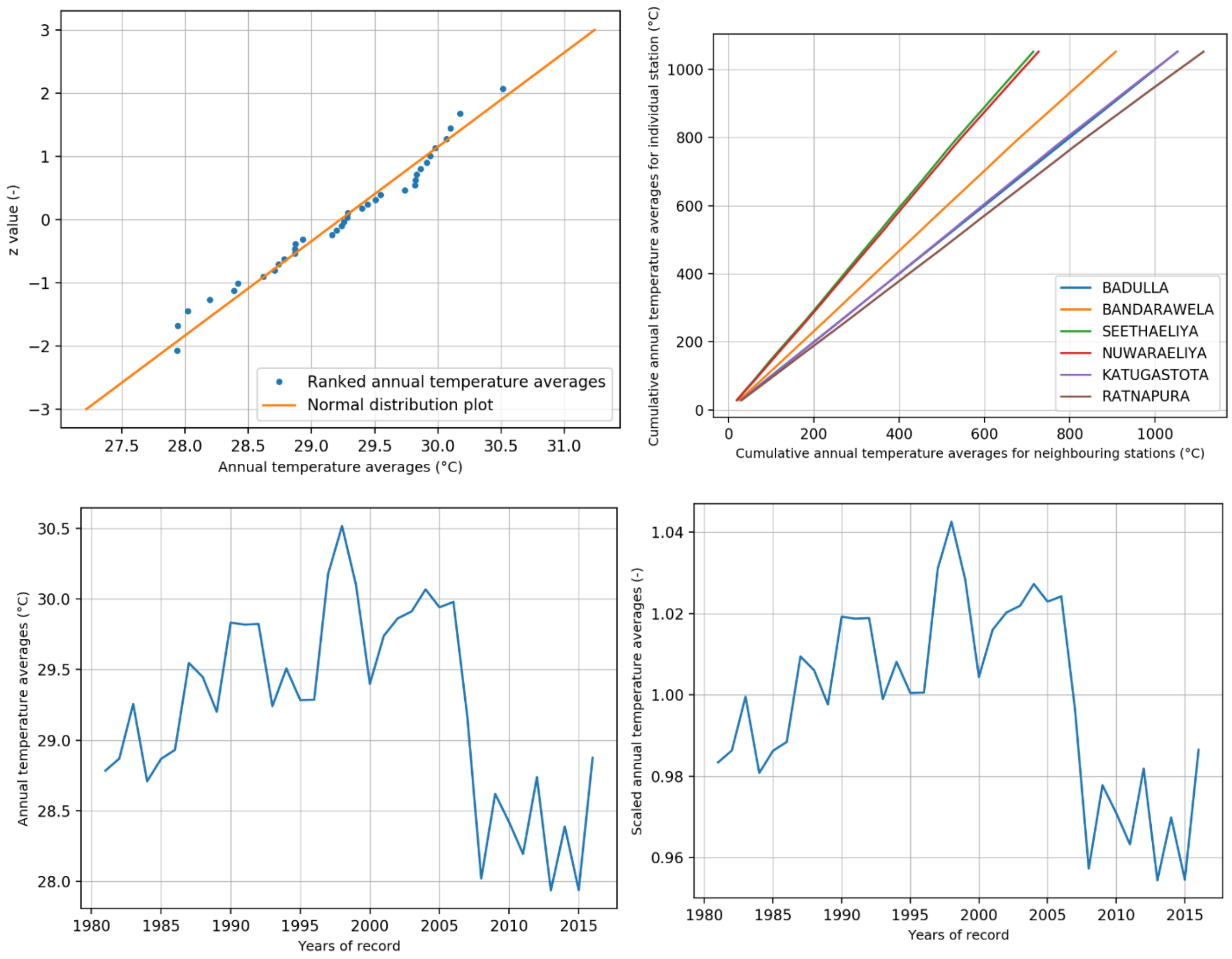

Figure B-1: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Maximum Temperature at Badulla gauging station

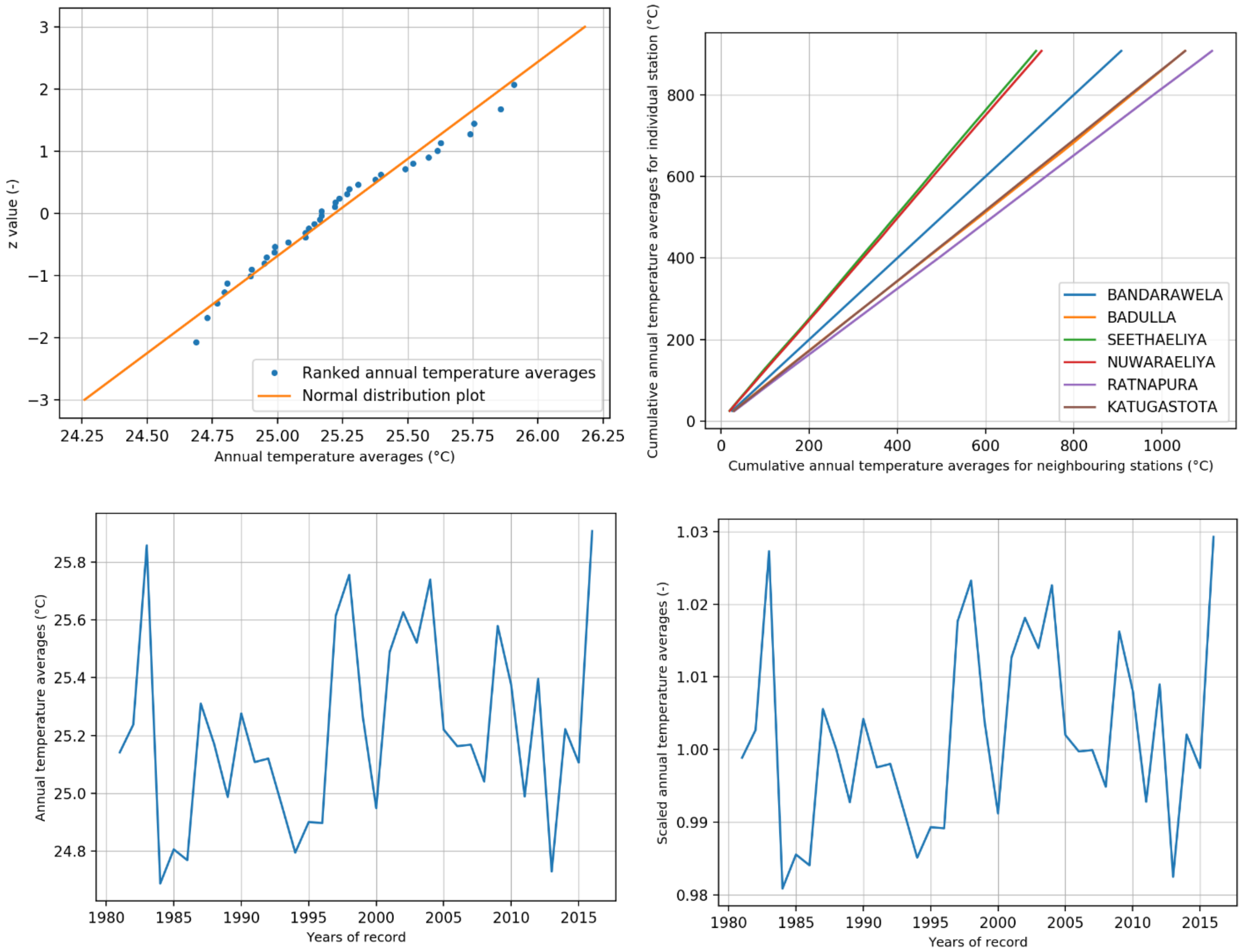

Figure B-2: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Maximum Temperature at Bandarawela gauging station

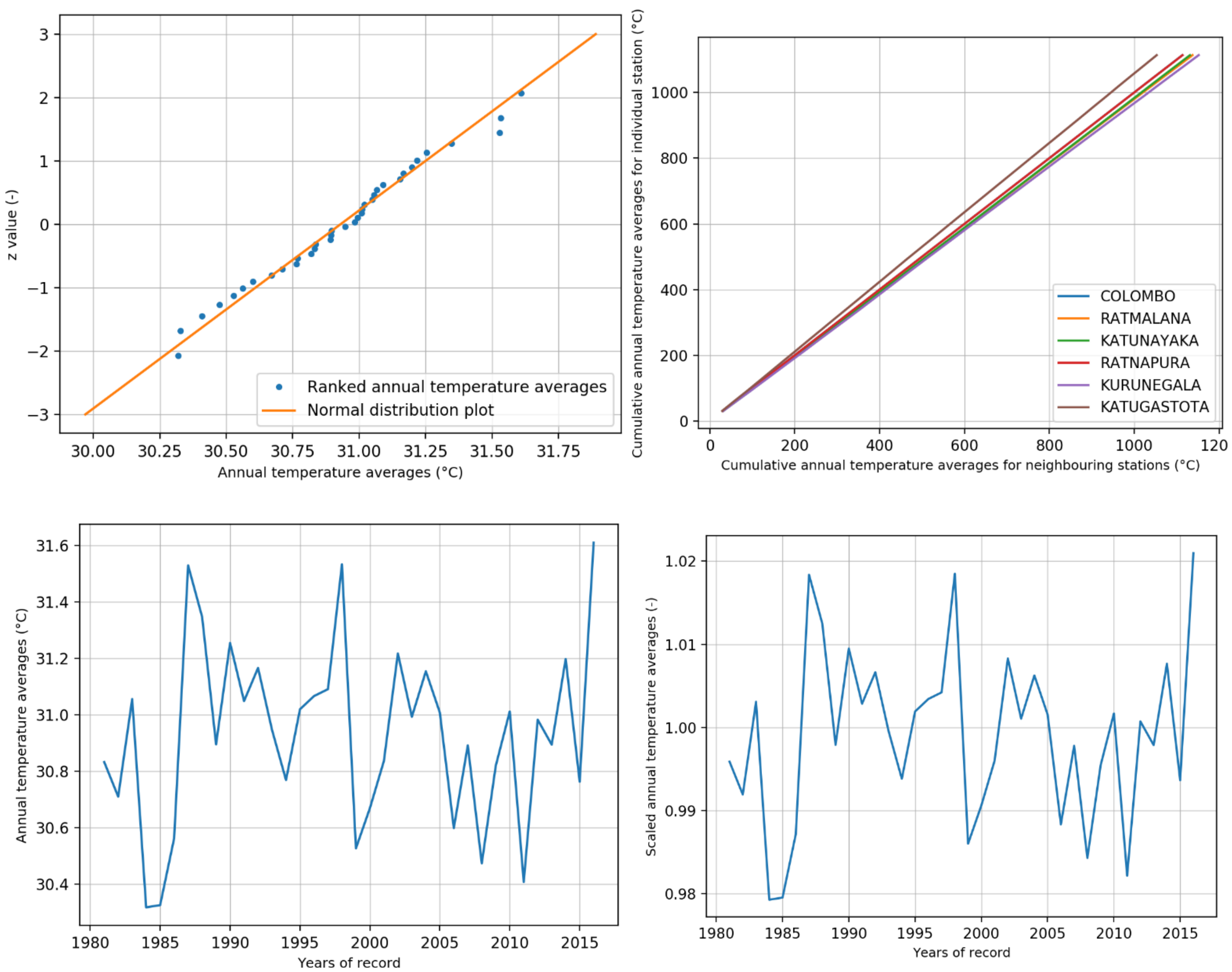

Figure B-3: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Maximum Temperature at Colombo gauging station

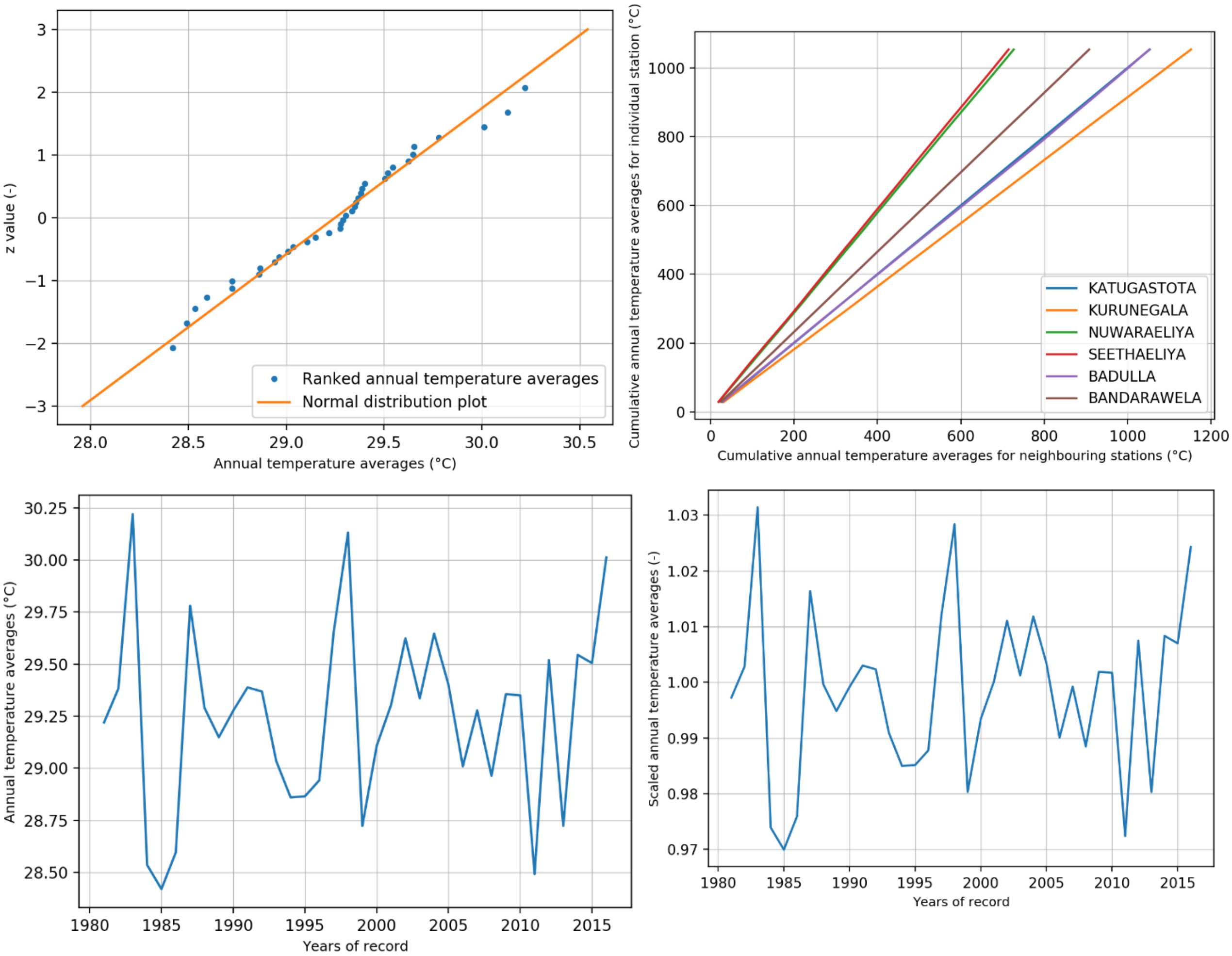

Figure B-4: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Maximum Temperature at Katugasthota gauging station

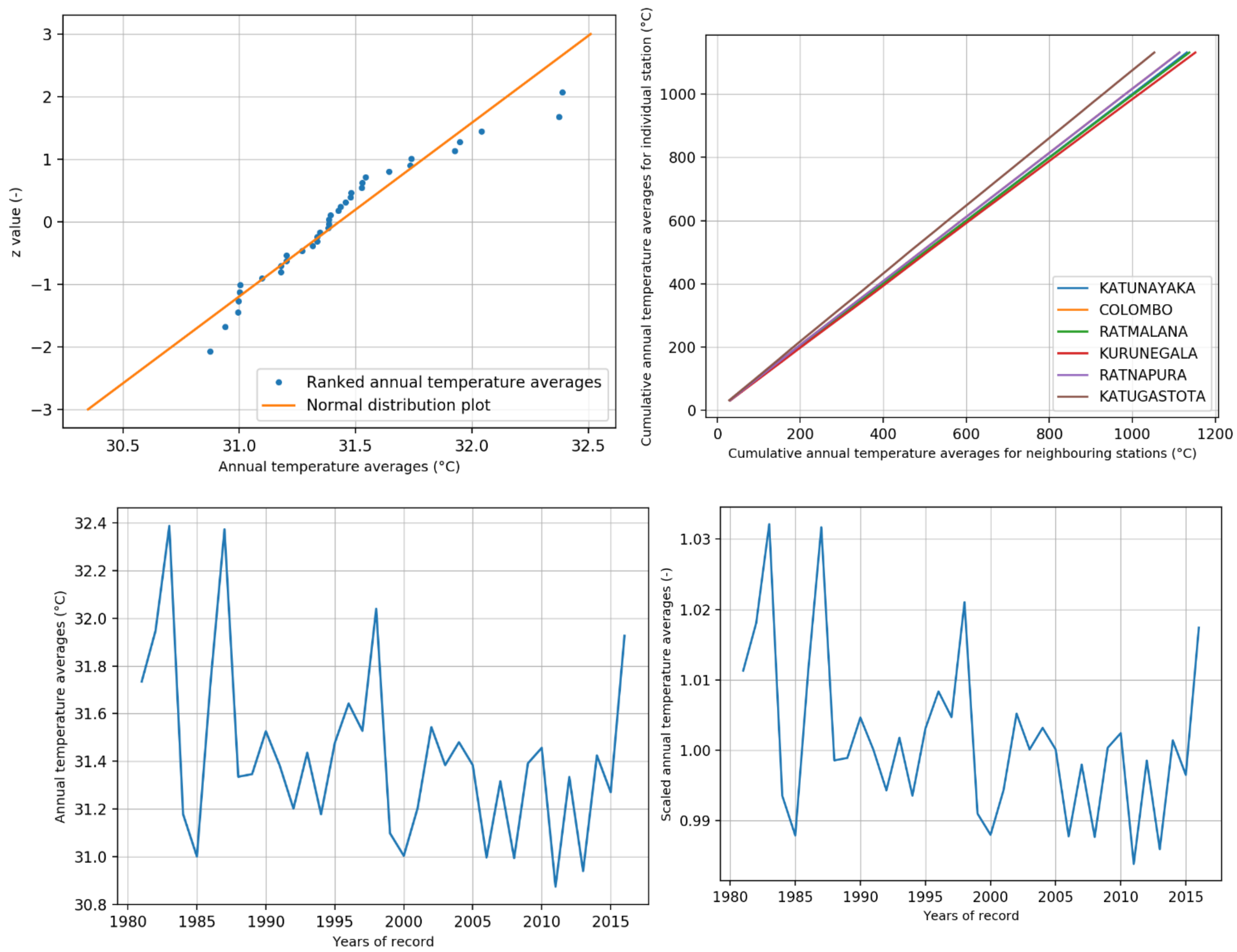

Figure B-5: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Maximum Temperature at Katunayaka gauging station

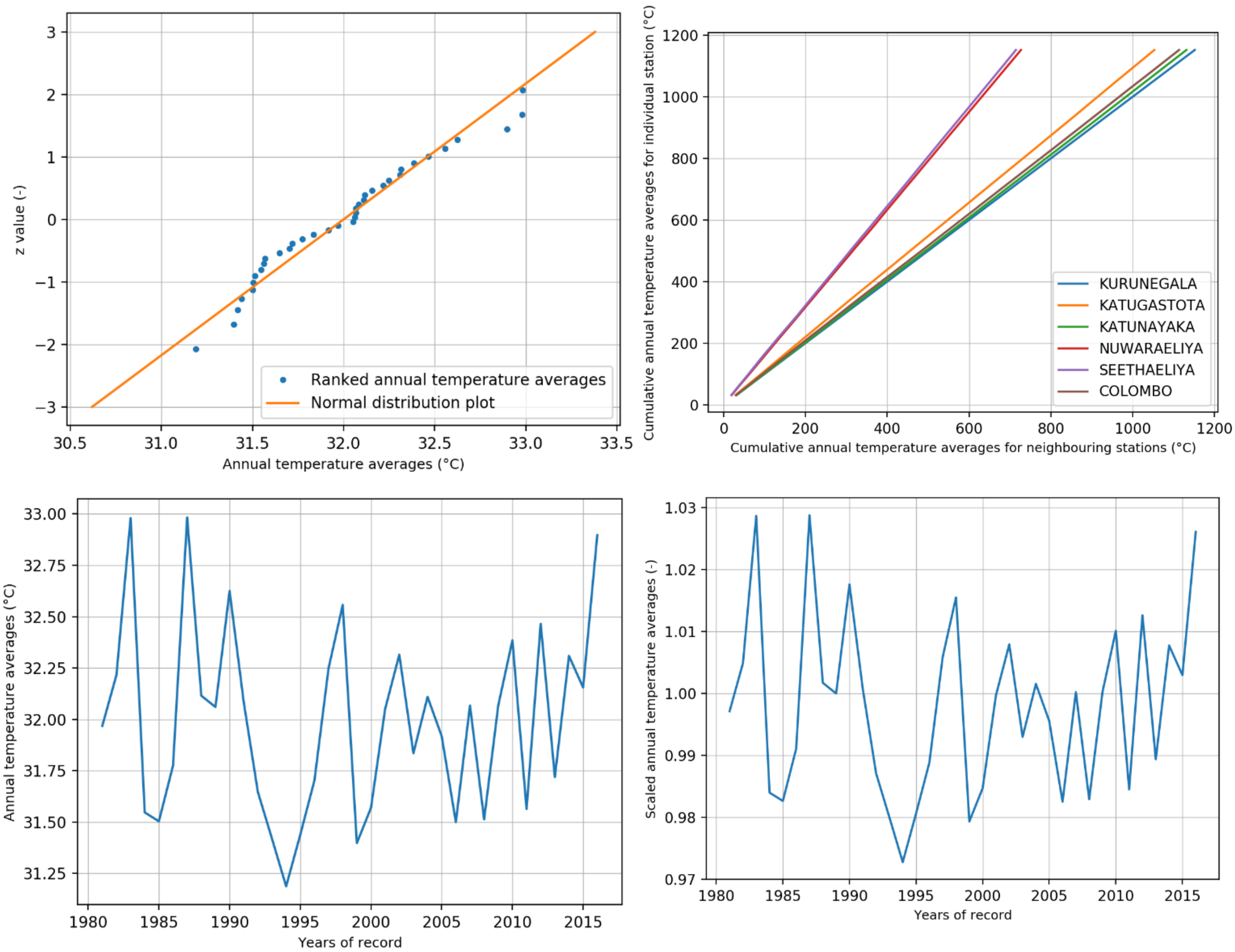

Figure B-6: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Maximum Temperature at Kurunegala gauging station

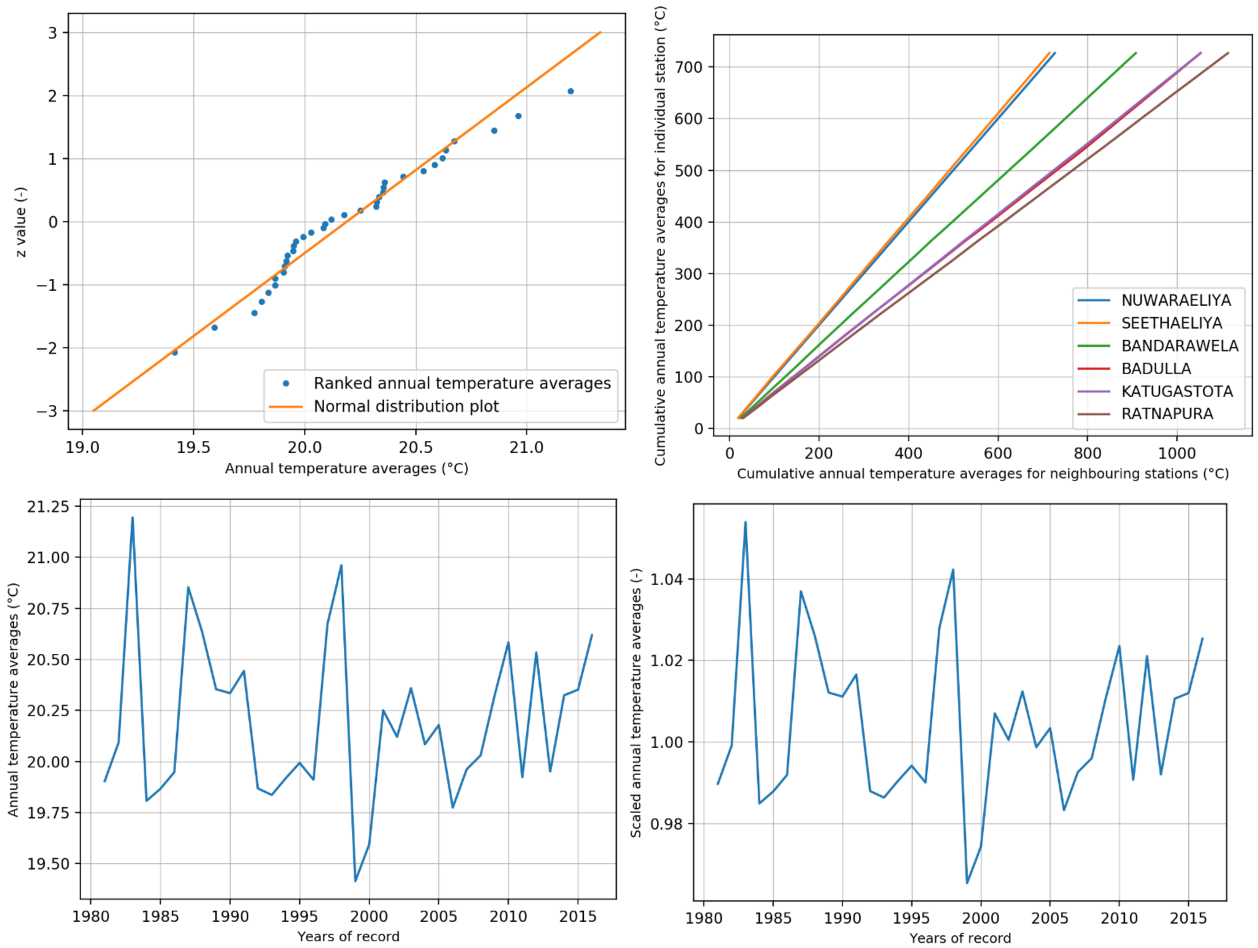

Figure B-7: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Maximum Temperature at Nuwara Eliya gauging station

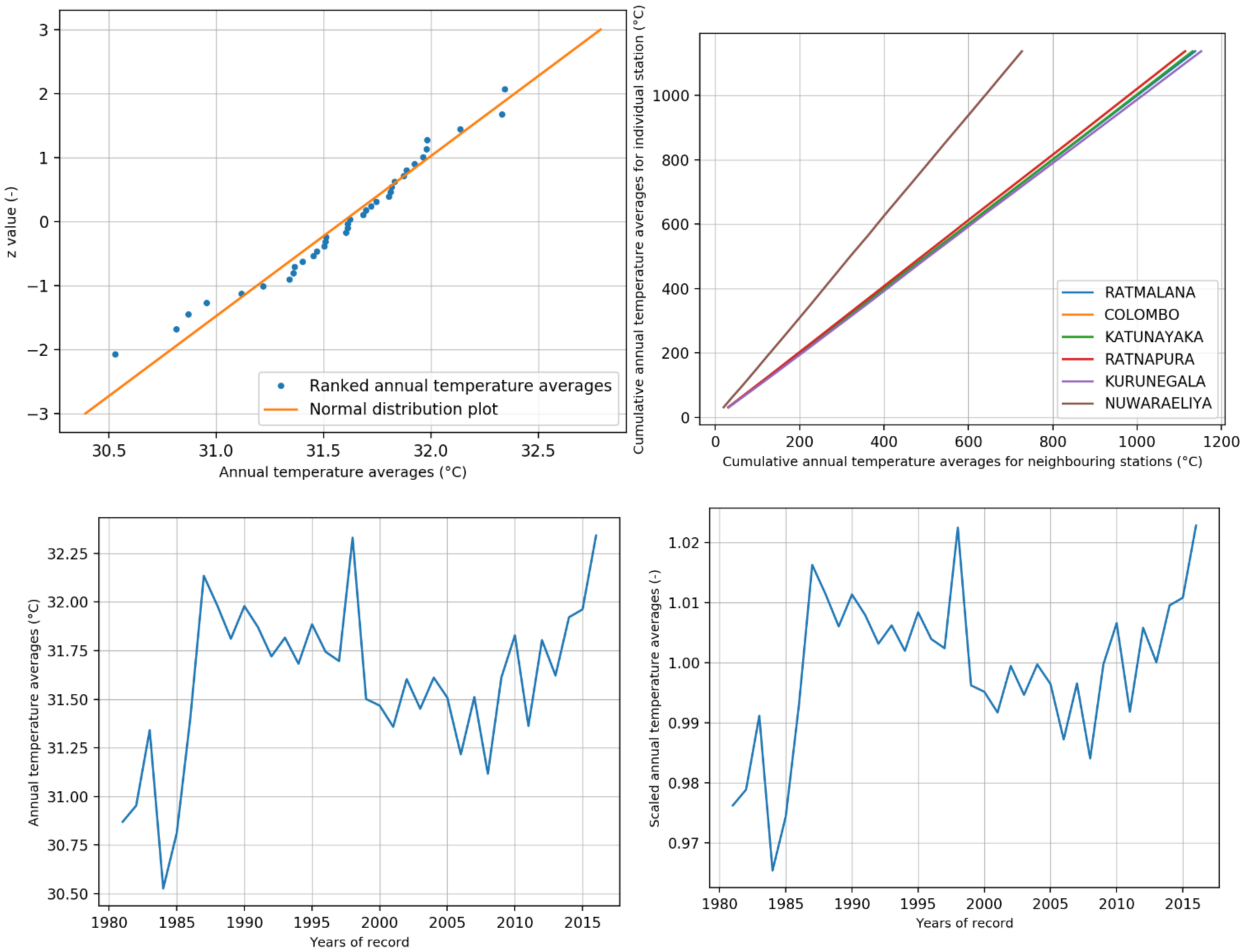

Figure B-8: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Maximum Temperature at Rathmalana gauging station

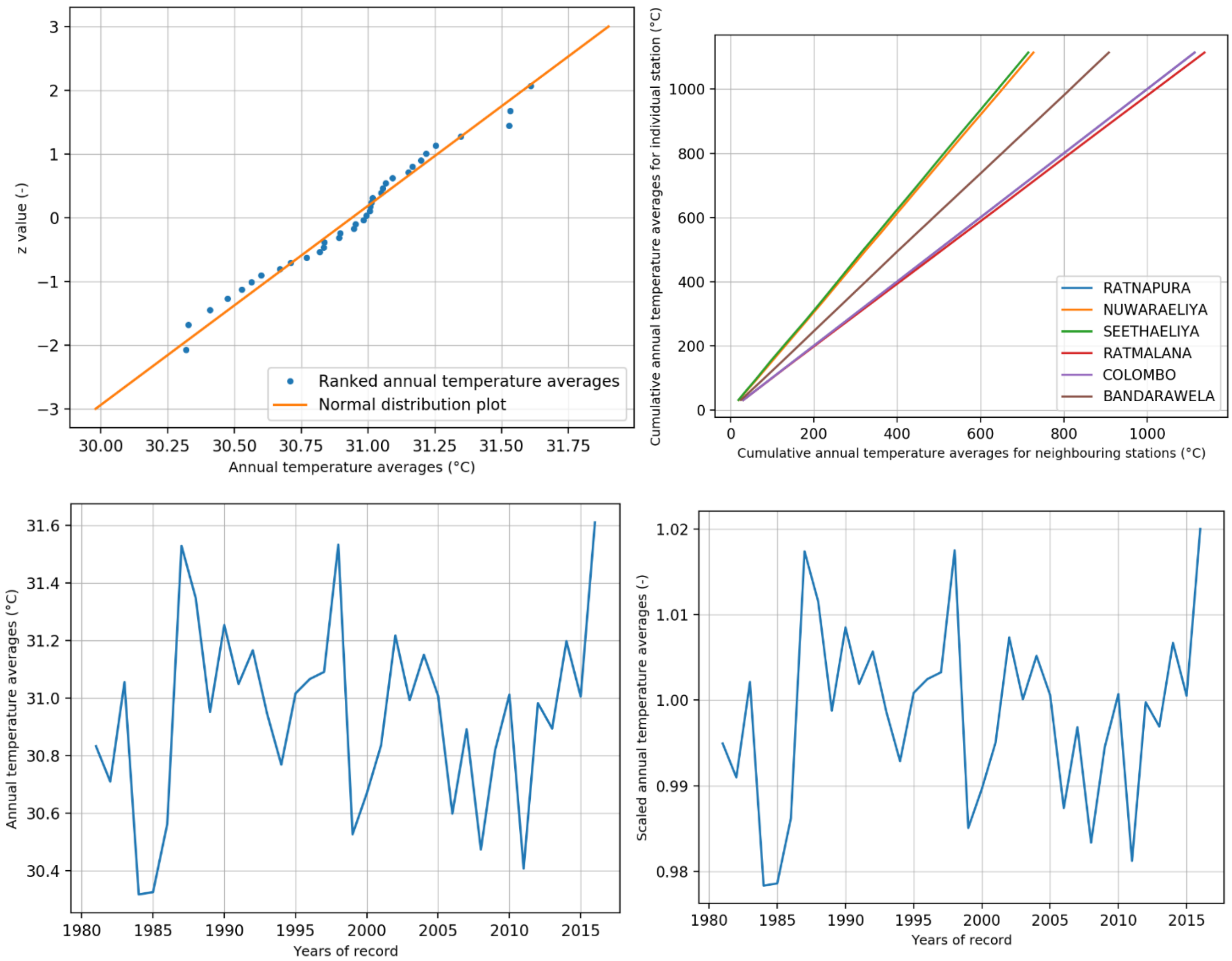

Figure B-9: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Maximum Temperature at Rathnapura gauging station

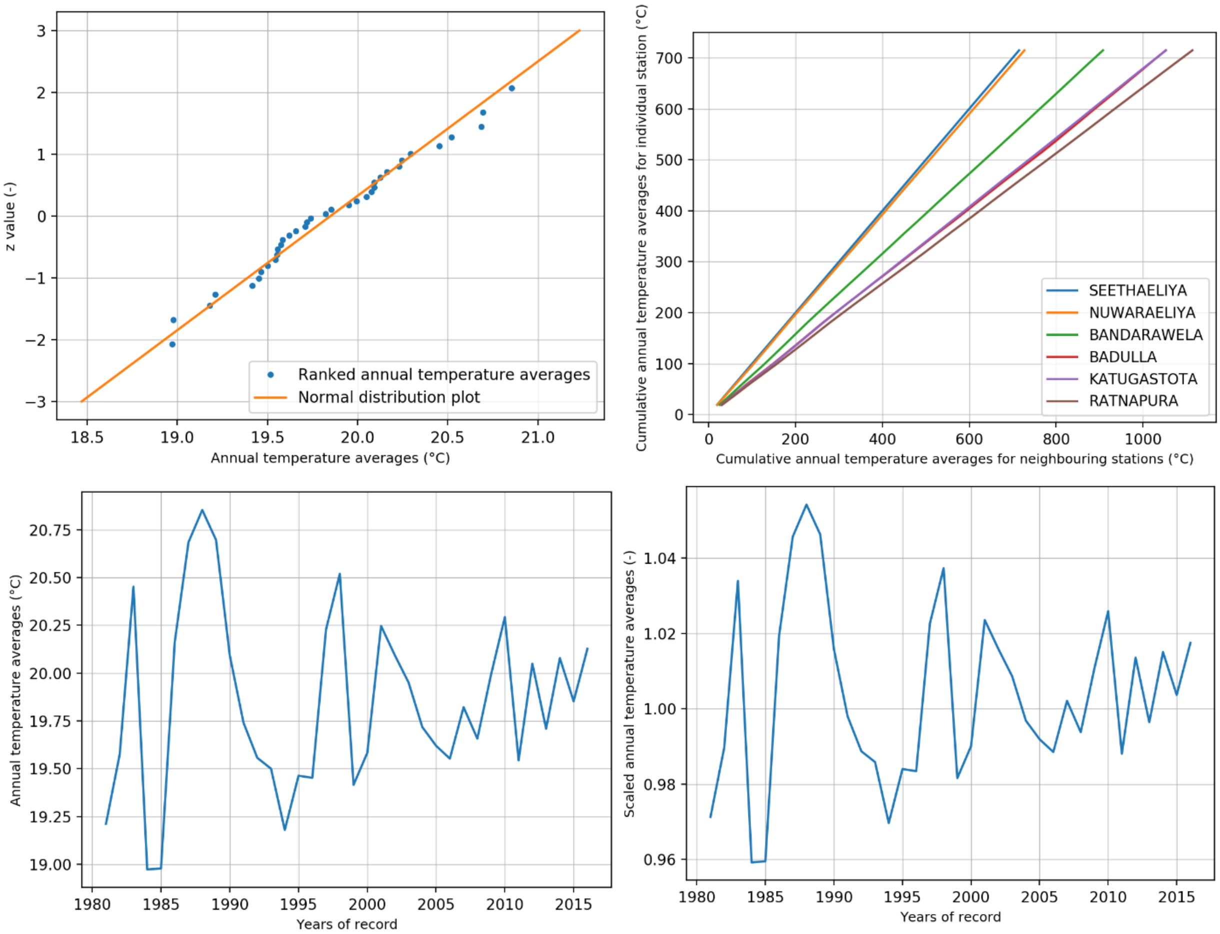

Figure B-10: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Maximum Temperature at Seetha Eliya gauging station

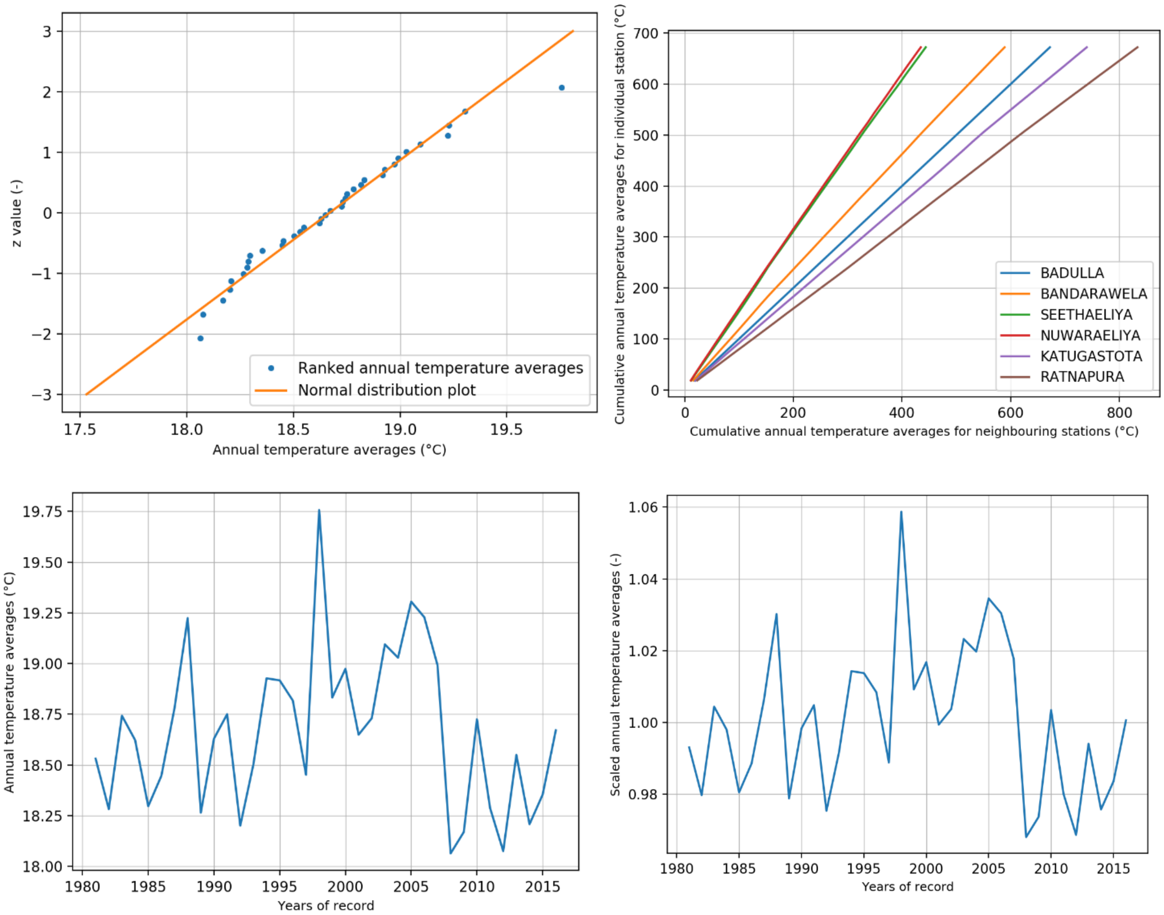

Figure B-11: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Miniimum Temperature at Badulla gauging station

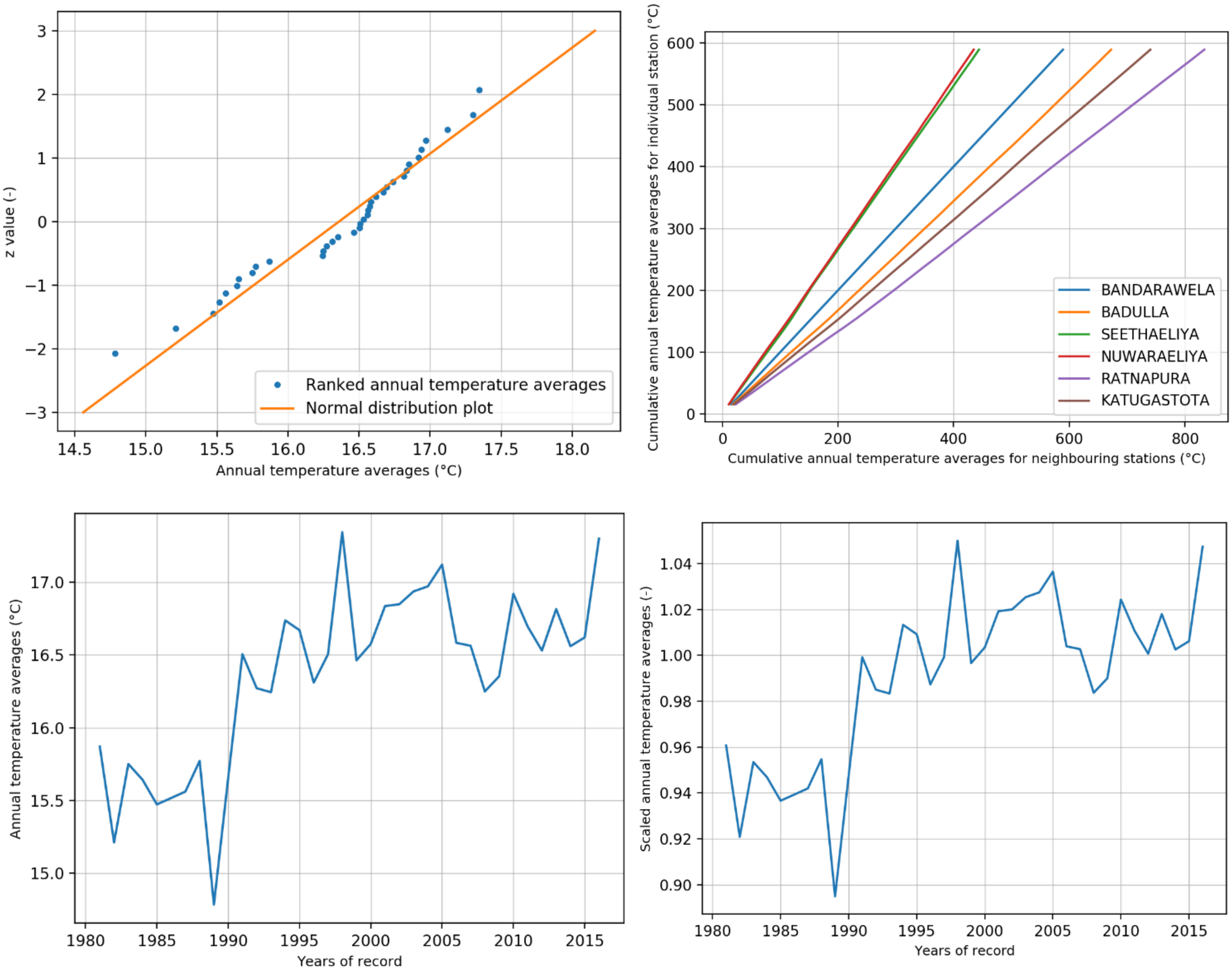

Figure B-12: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Miniimum Temperature at Bandarawela gauging station

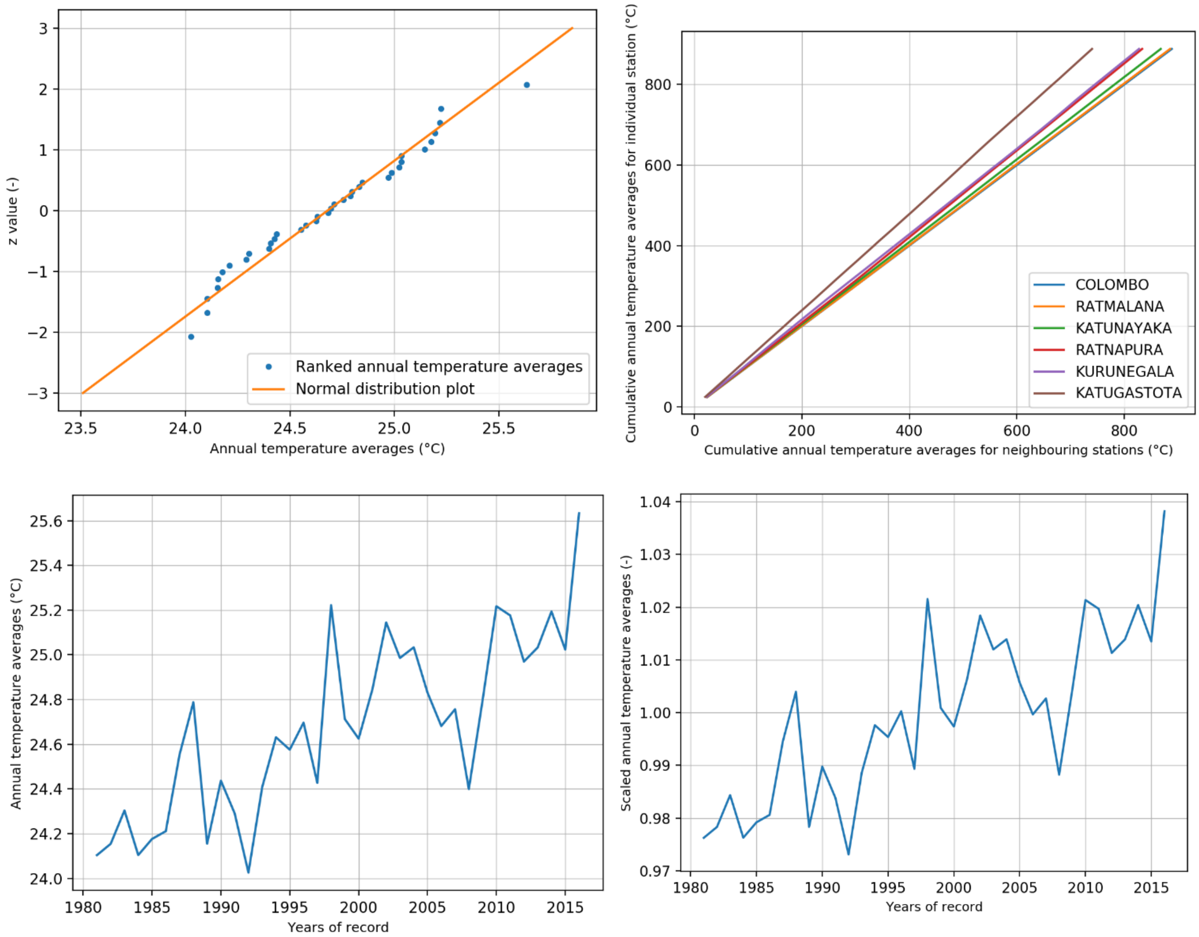

Figure B-13: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Miniimum Temperature at Colombo gauging station

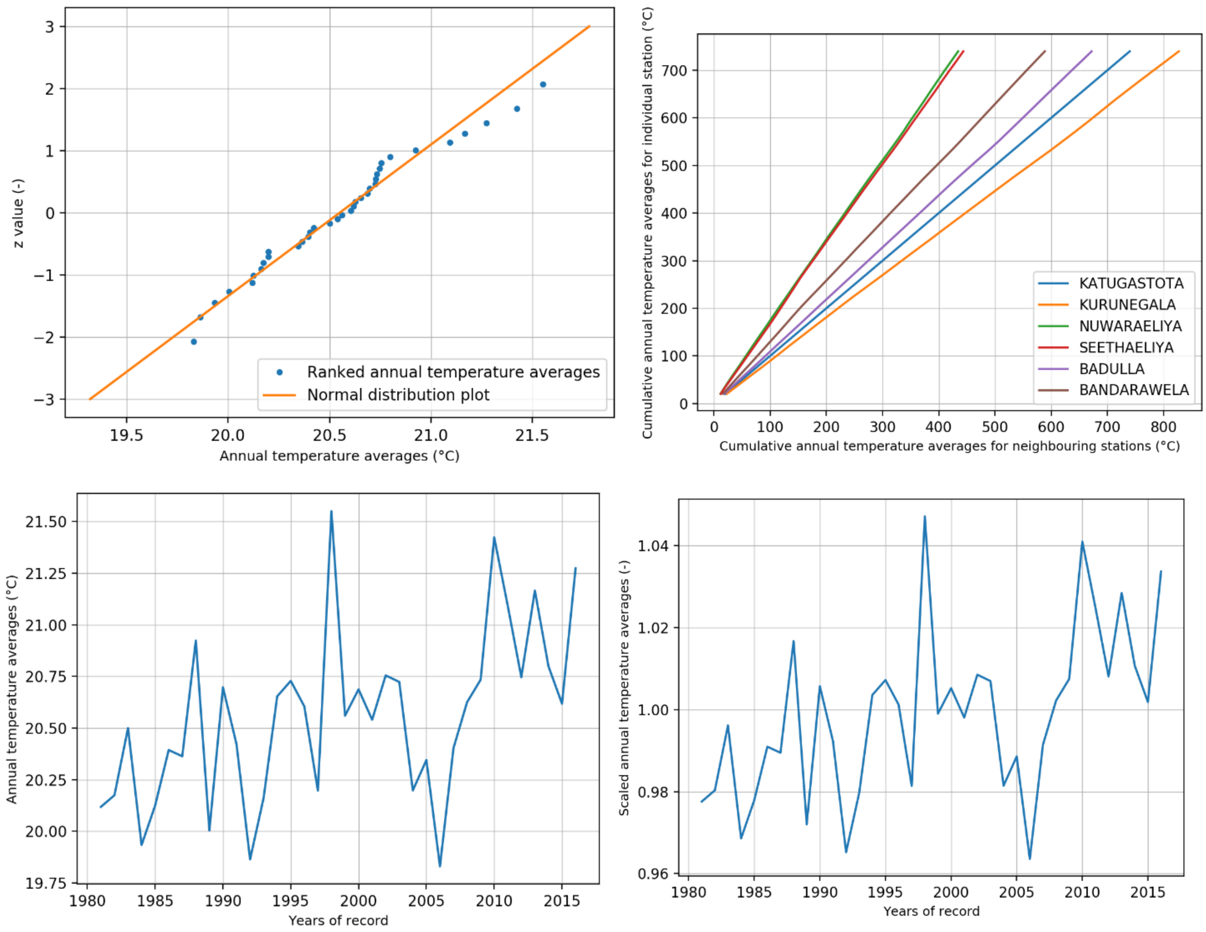

Figure B-14: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Miniimum Temperature at Katugasthota gauging station

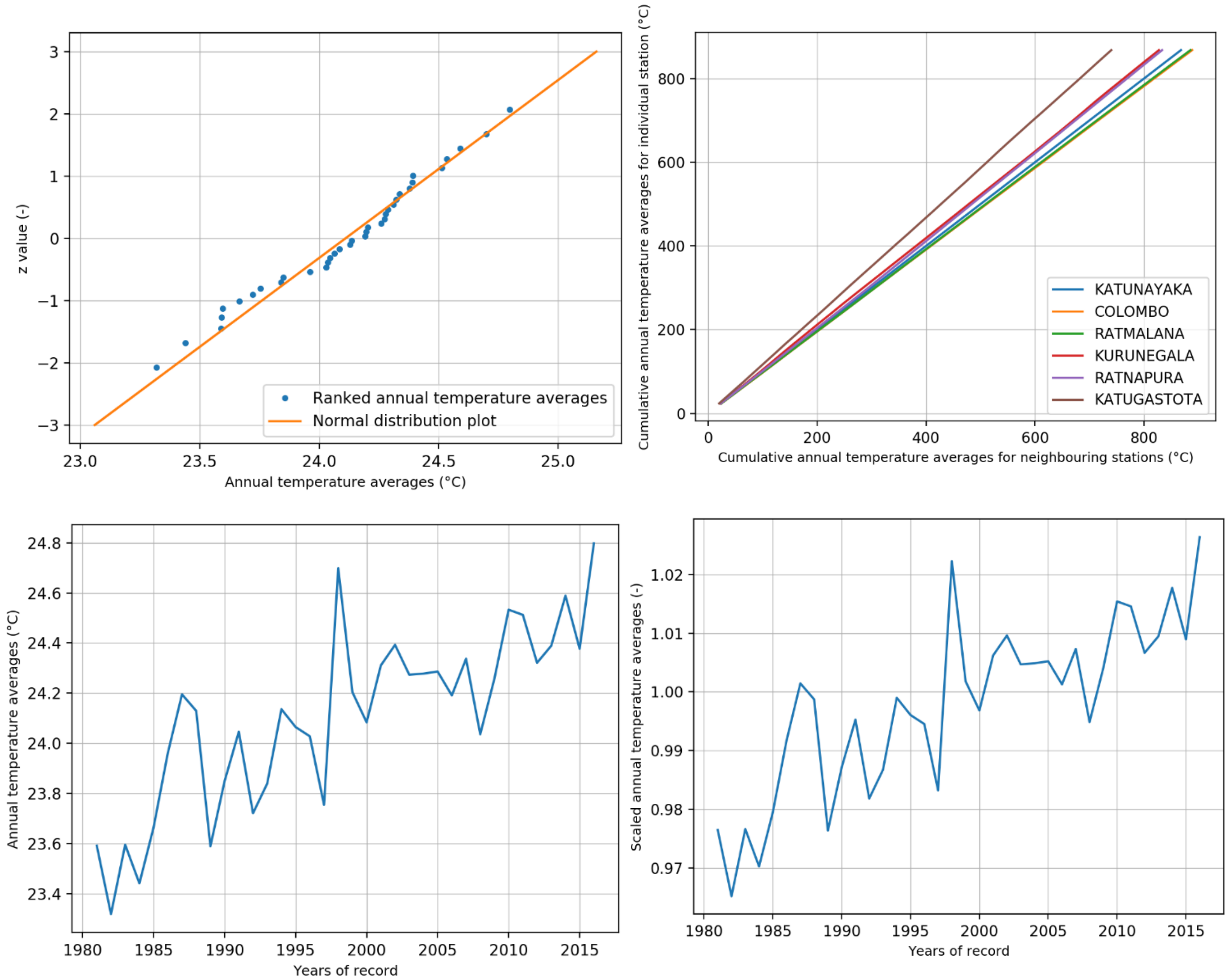

Figure B-15: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Miniimum Temperature at Katunayaka gauging station

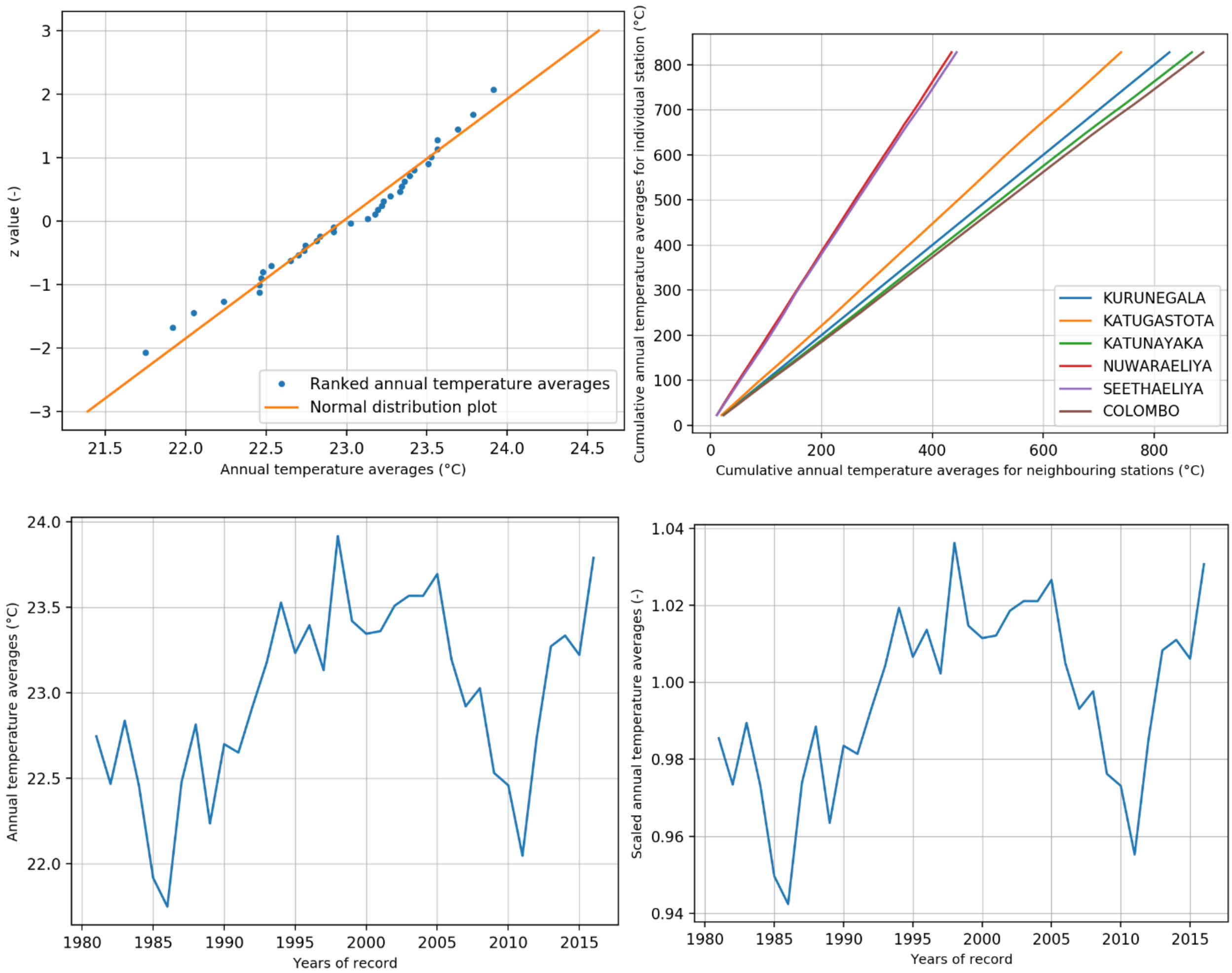

Figure B-16: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Miniimum Temperature at Kurunegala gauging station

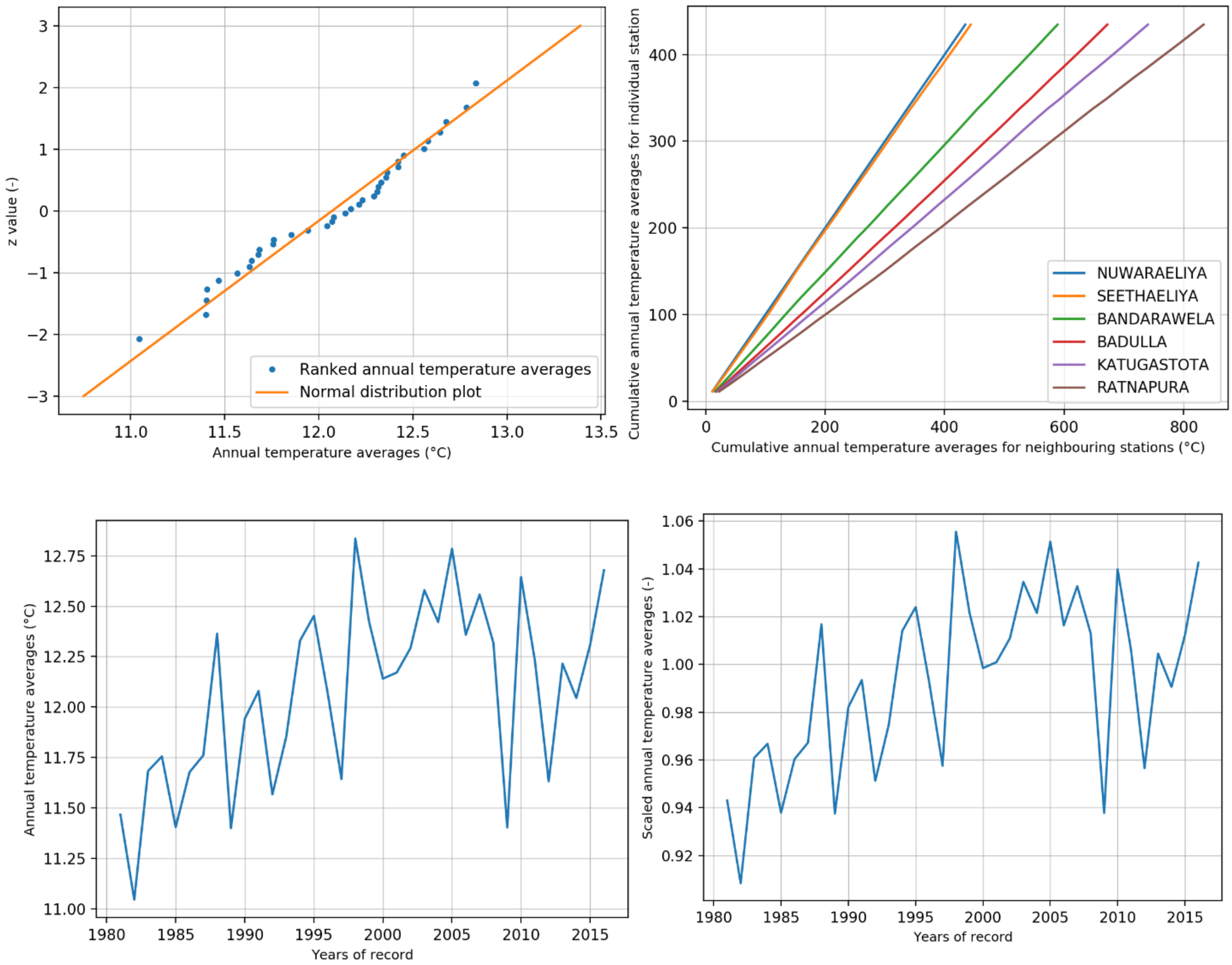

Figure B-17: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Miniimum Temperature at Nuwara Eliya gauging station

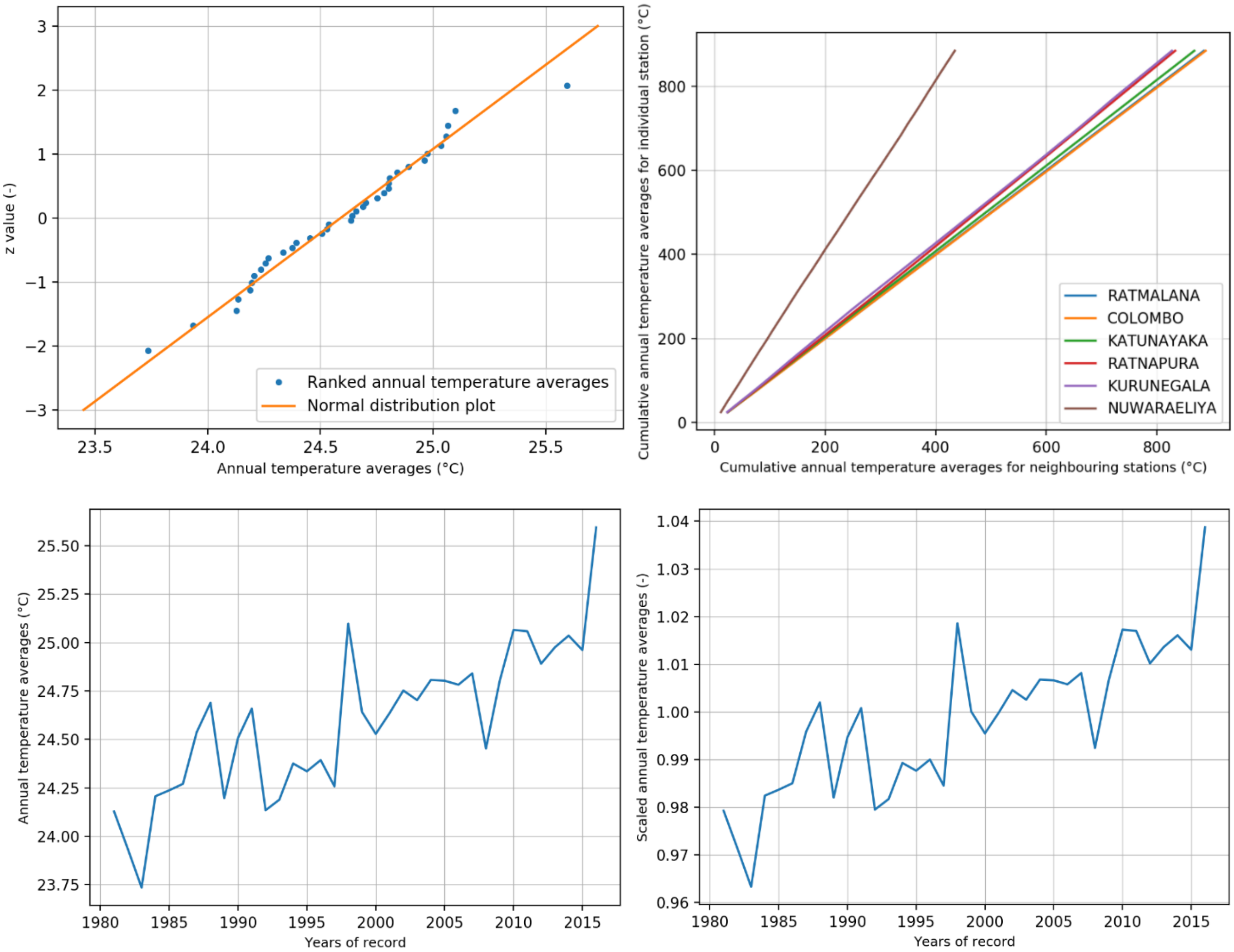

Figure B-18: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Miniimum Temperature at Rathmalana gauging station

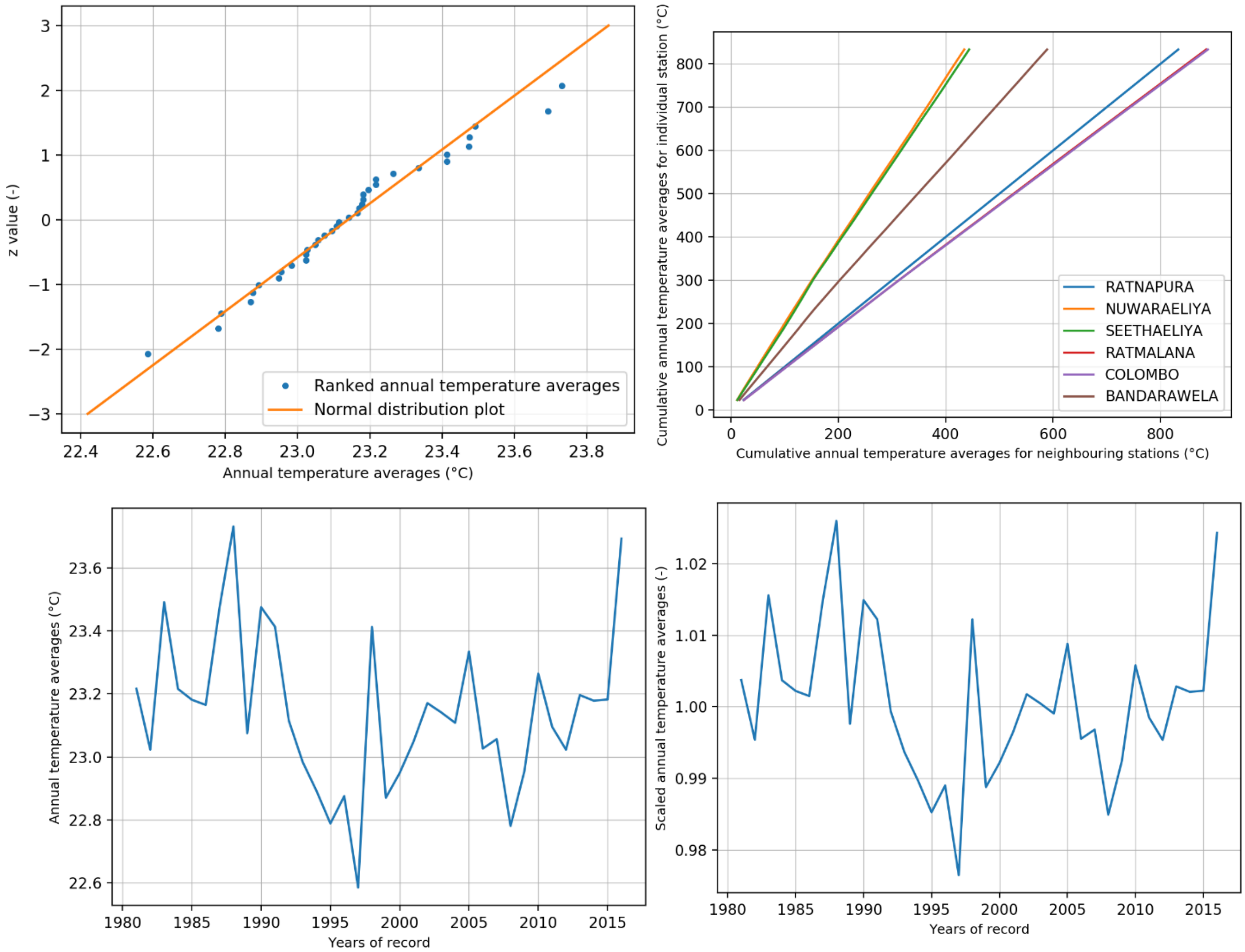

Figure B-19: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Miniimum Temperature at Rathnapura gauging station

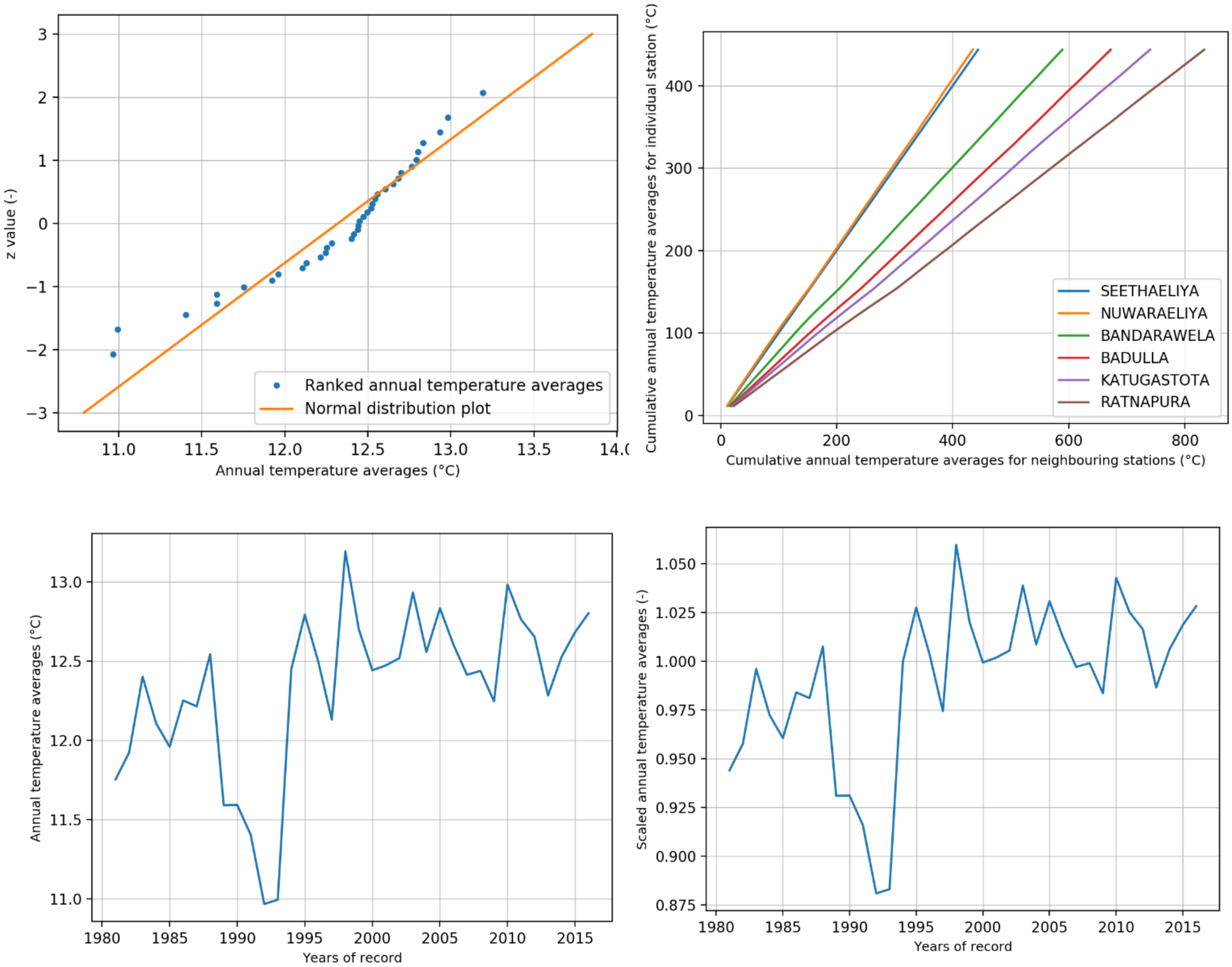

Figure B-20: Normal Distribution (top left), Double mass analysis (top right) and variation annual rainfall totals (bottom left) and variation of scaled annual rainfall totals (bottom right) for Miniimum Temperature at Seetha Eliya gauging station

APPENDIX C - DECADAL AVERAGES FOR ANNUAL RAINFALL TOTALS

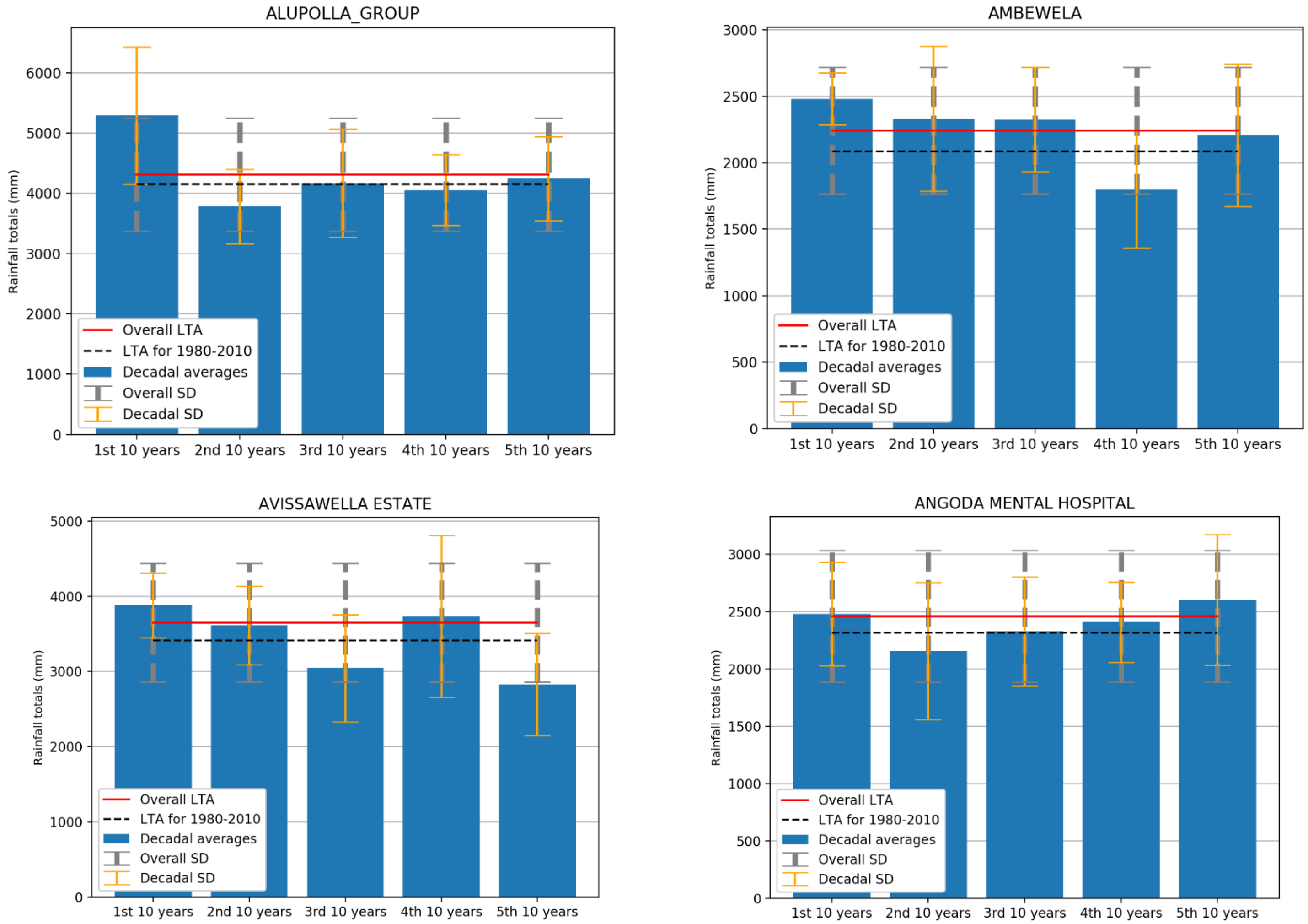

Figure C-1: Decadal averages plot for annual totals for Allupola Group, Ambewela, Avissawella estate and Angoda mental hospital

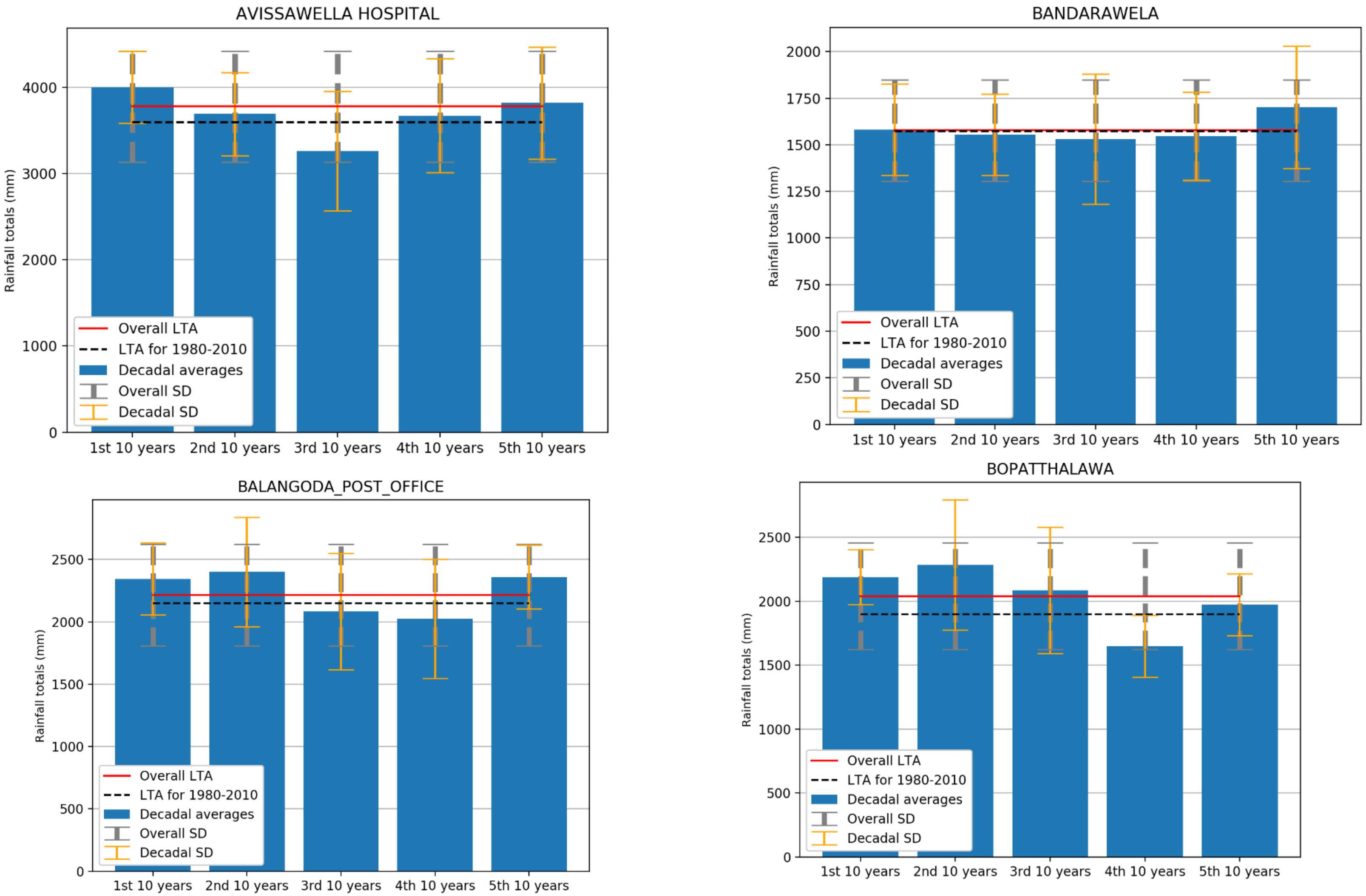

Figure C-2: Decadal averages plot for annual totals for Avissawella Group, Bandarawela, Balangoda Post Office estate and Bopaththalawa

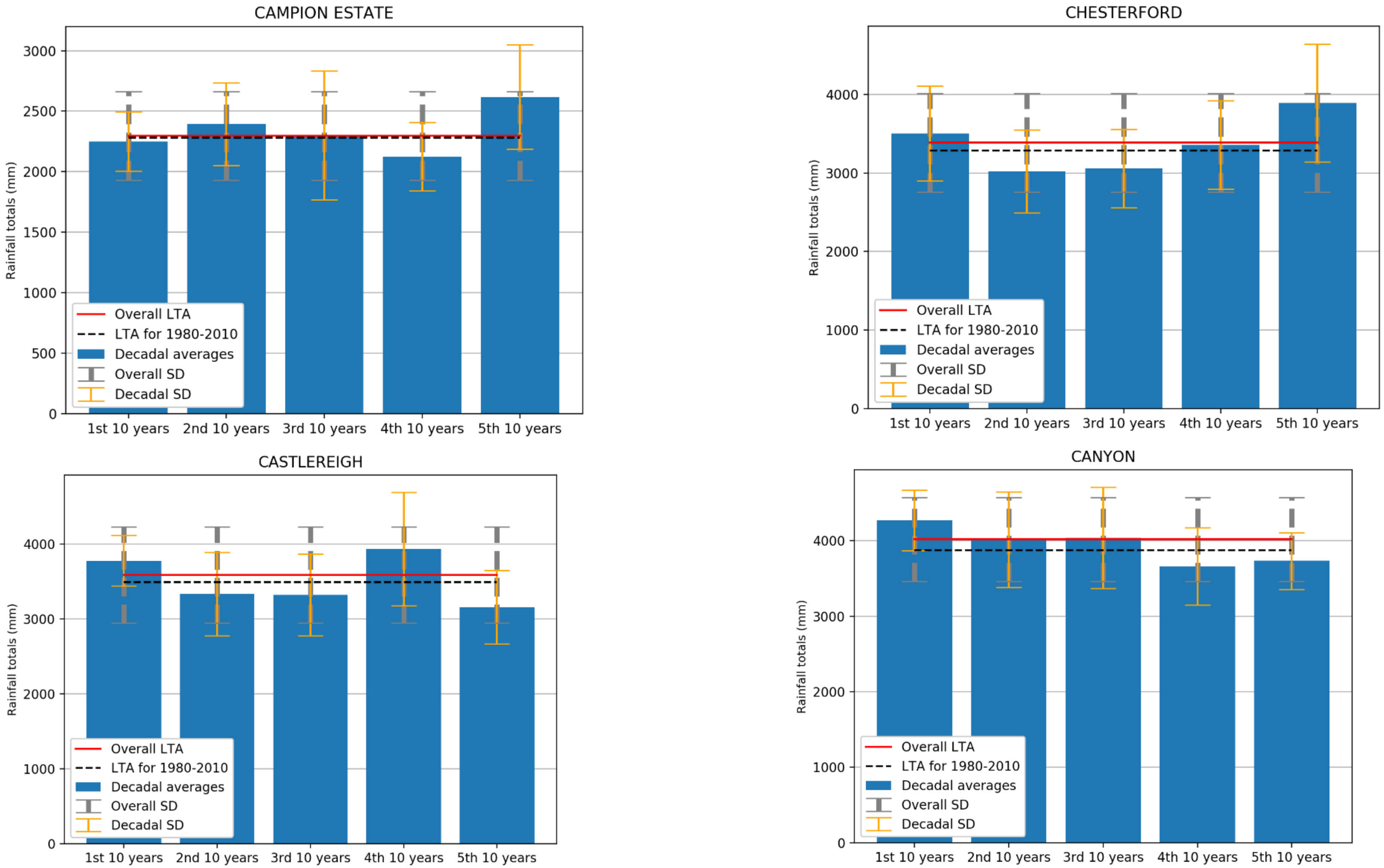

Figure C-3: Decadal averages plot for annual totals for Campion Estate, Chesterford, Castlereigh and Canyon

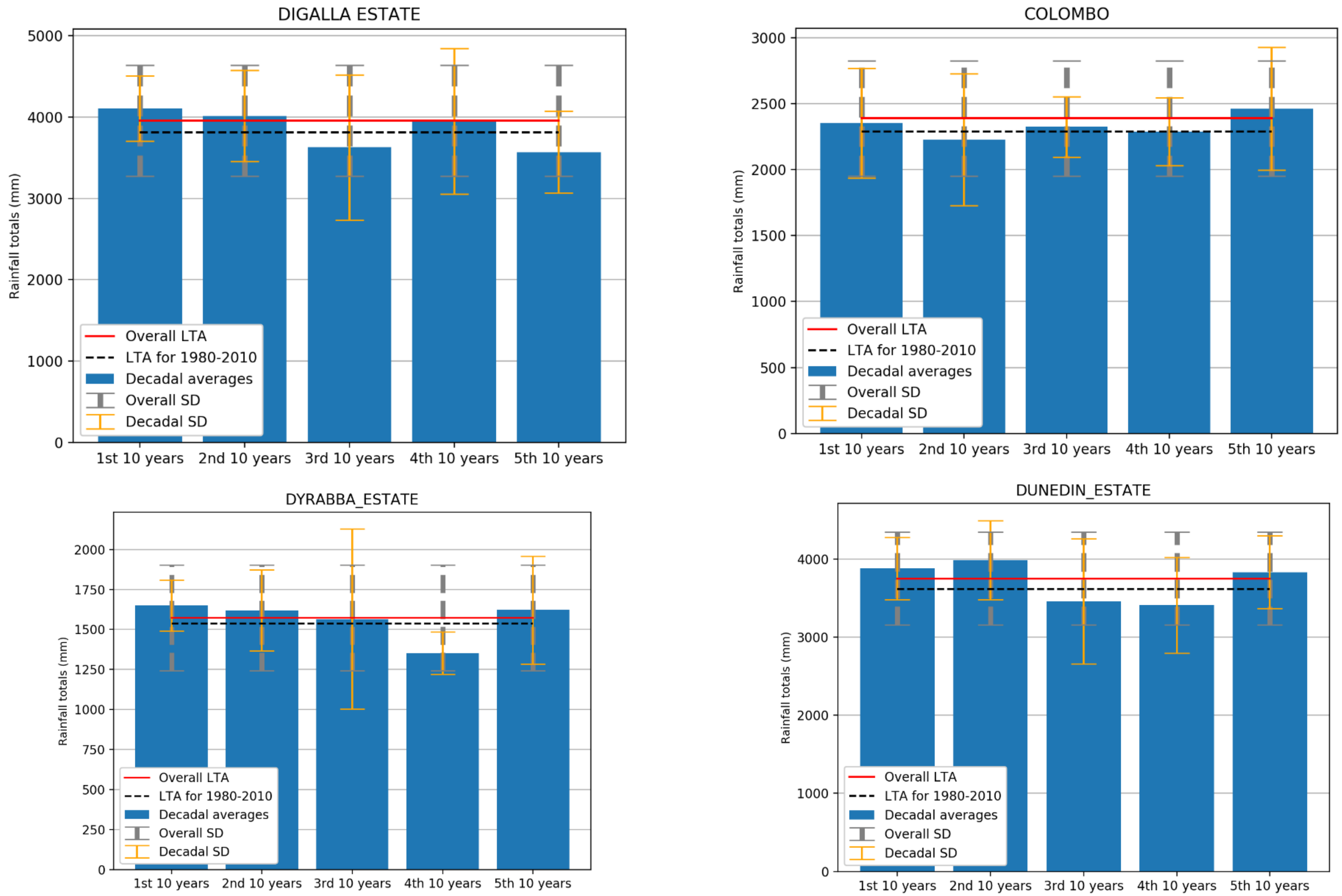

Figure C-4: Decadal averages plot for annual rainfall totals for Digalla Estate, Colombo, Dyrabba Estate and Dunedin Estate

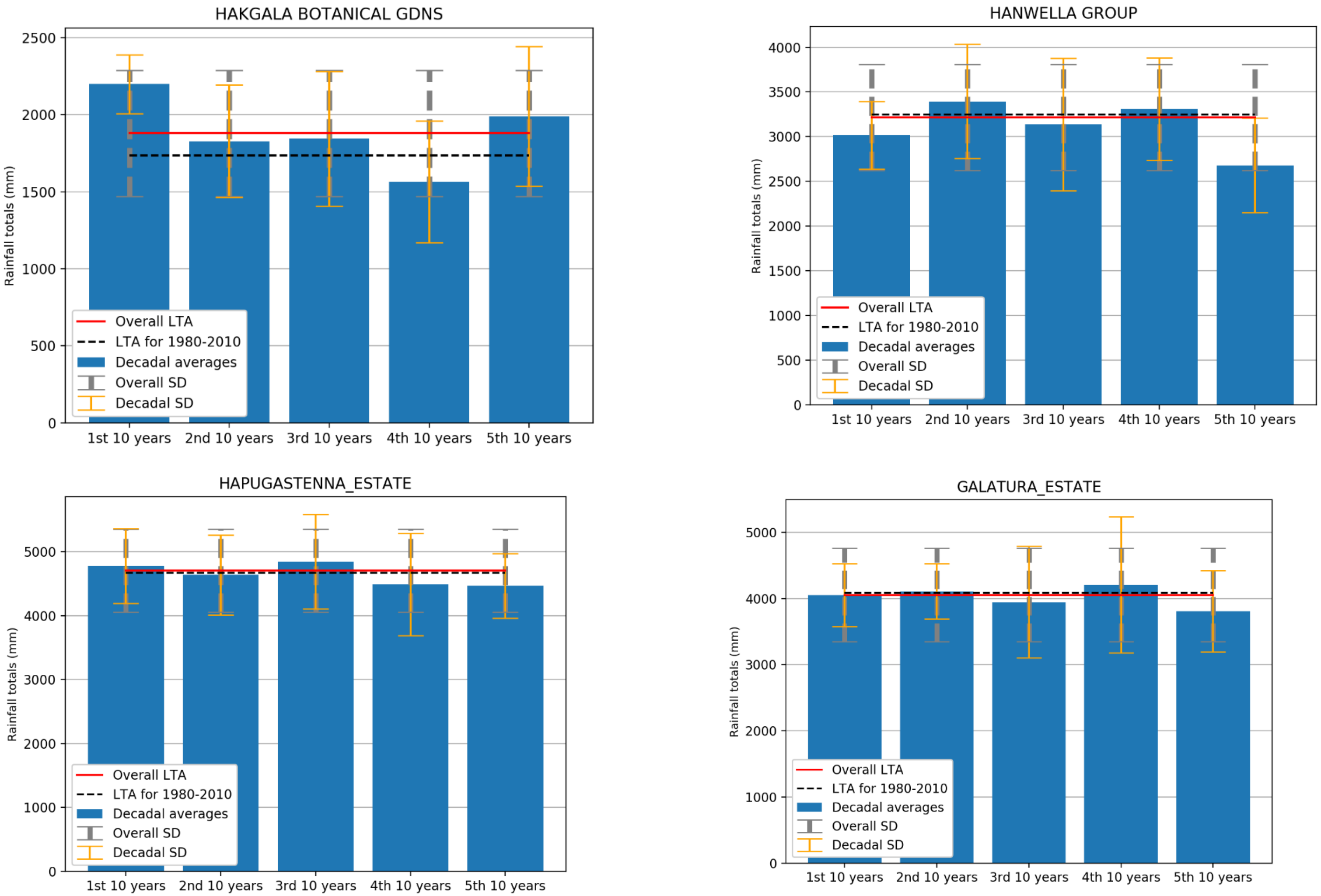

Figure C-5: Decadal averages plot for annual rainfall totals for Hakgala Boyanical Gdns, Hanwella Group, Hapugastenna Estate and Galatura Estate

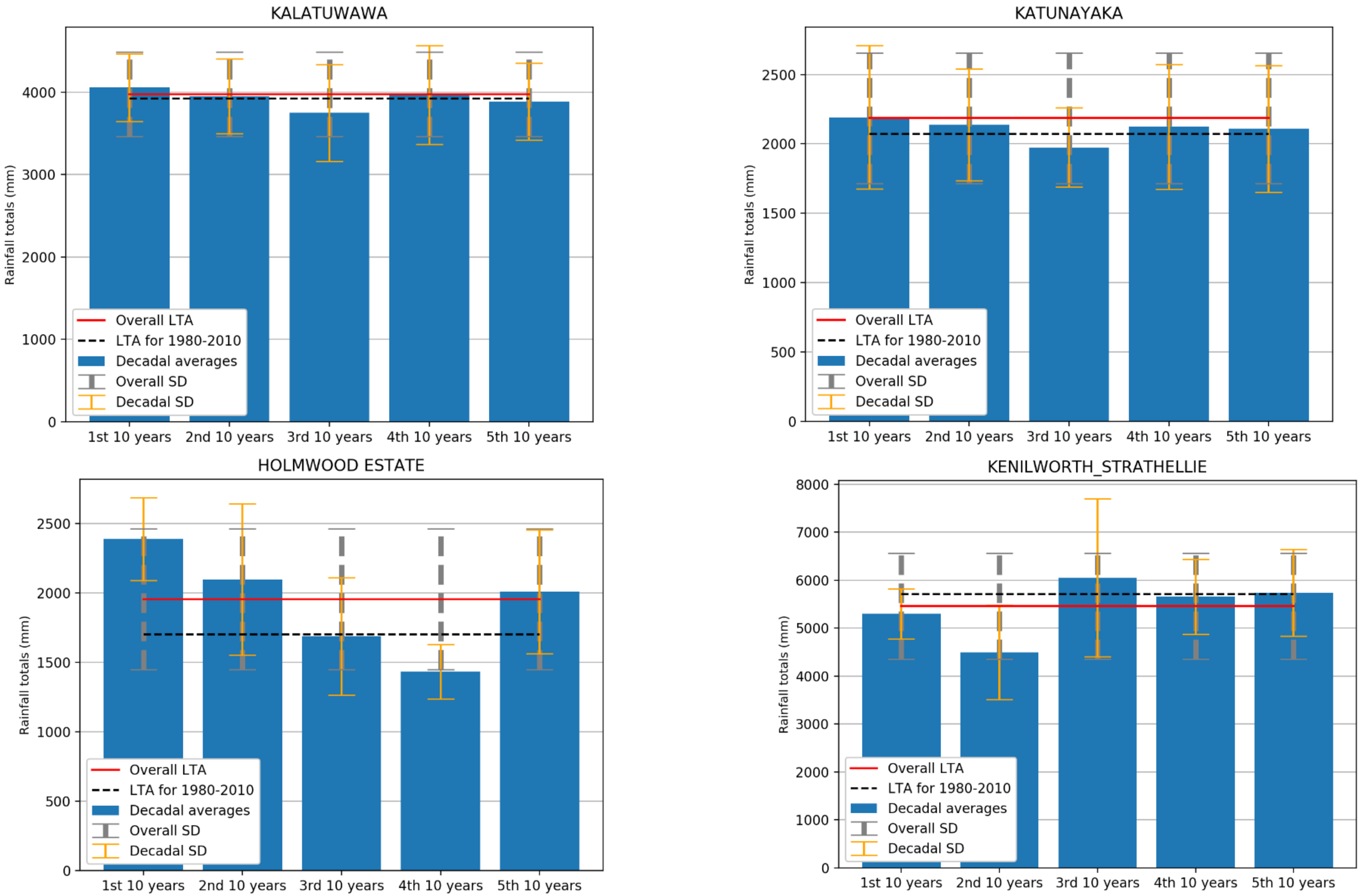

Figure C-6: Decadal averages plot for annual rainfall totals for Kalatuwawa, Katunayaka, Holomwood Estate and Kenilworth Strathellie

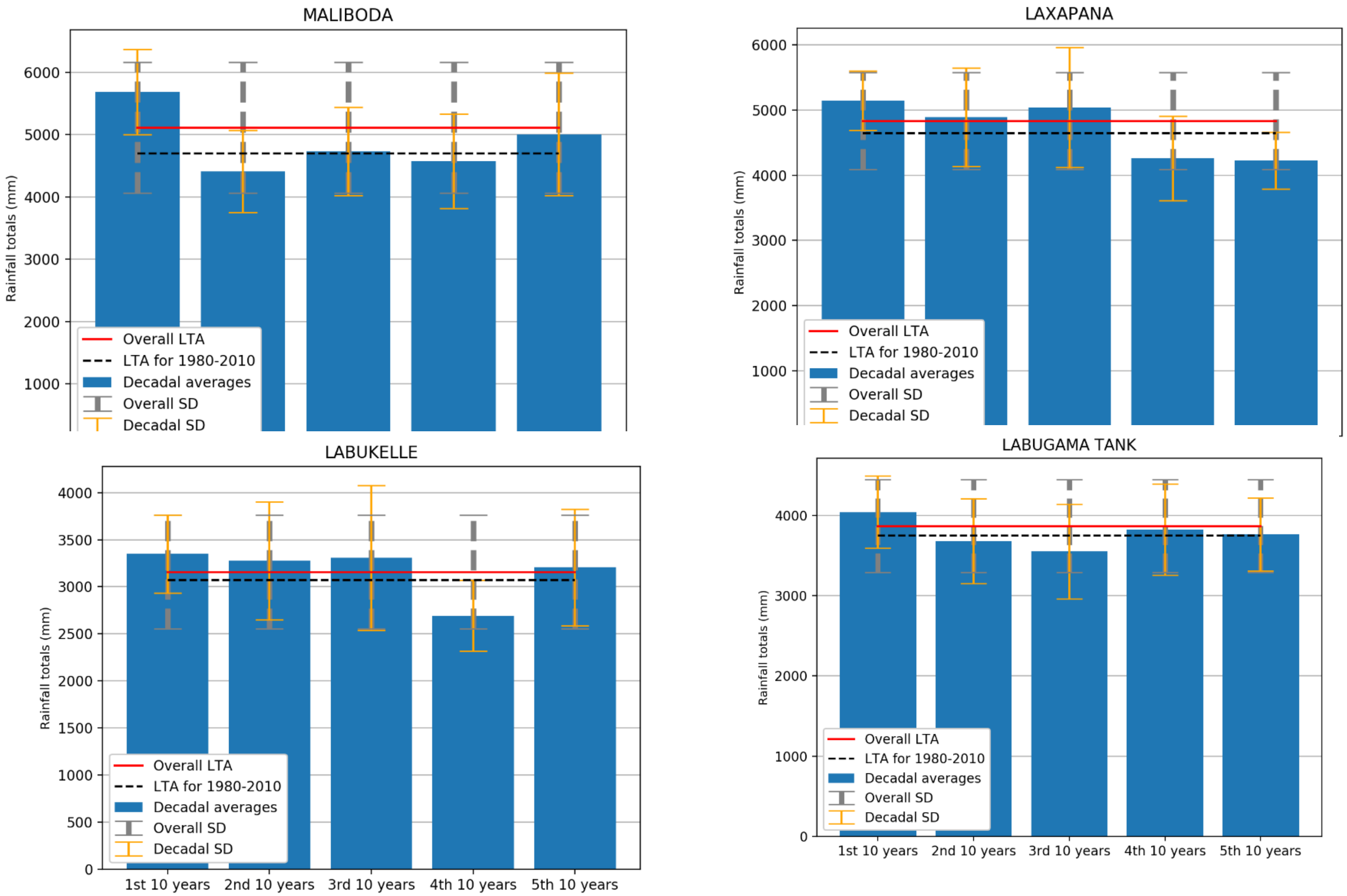

Figure C-7: Decadal averages plot for annual rainfall totals for Maliboda, Laxapana, Labukele and Labugama Tank

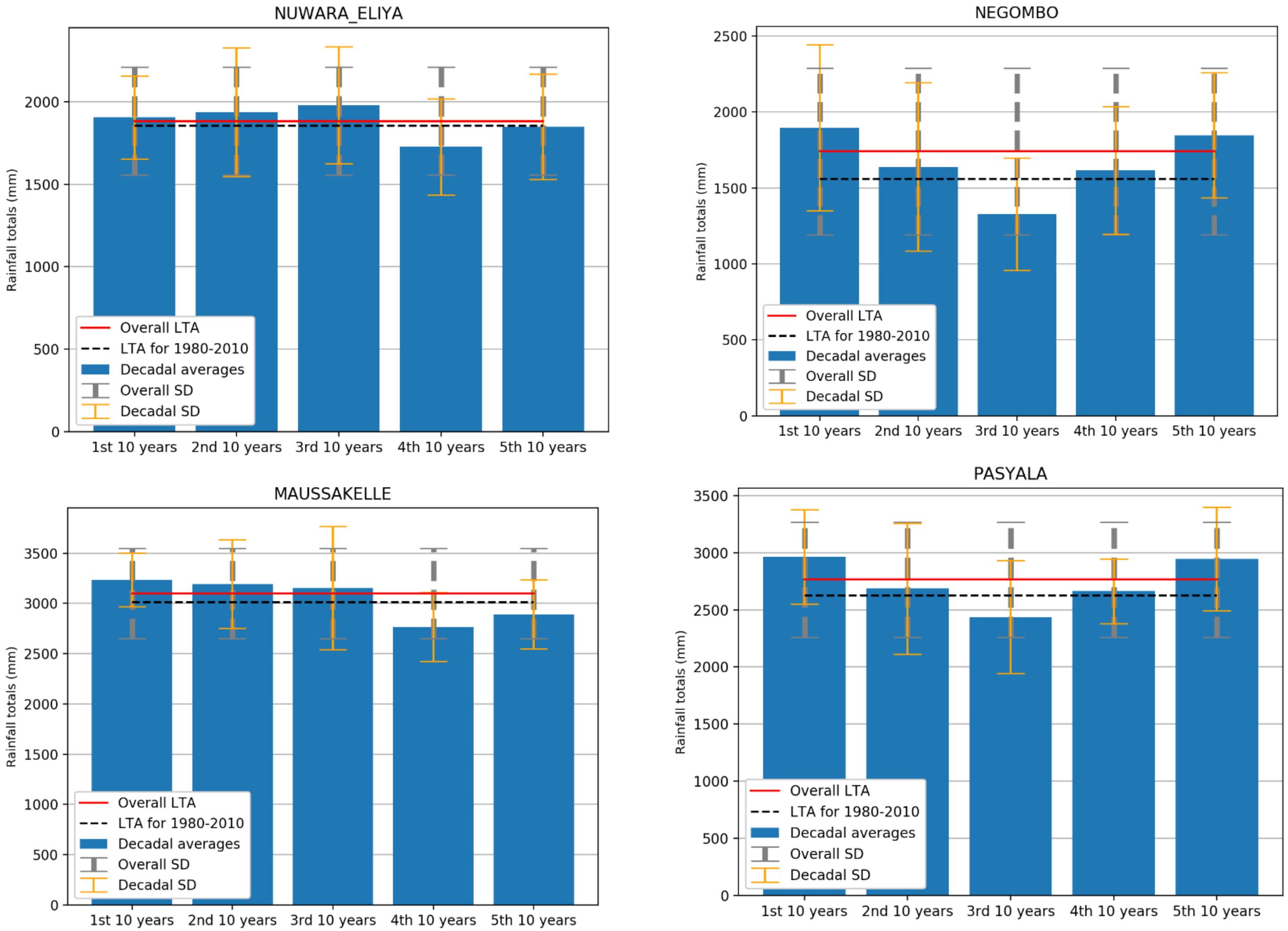

Figure C-8: Decadal averages plot for annual rainfall totals for Nuwara Eliya, Negombo, Maussakelle and Pasyala

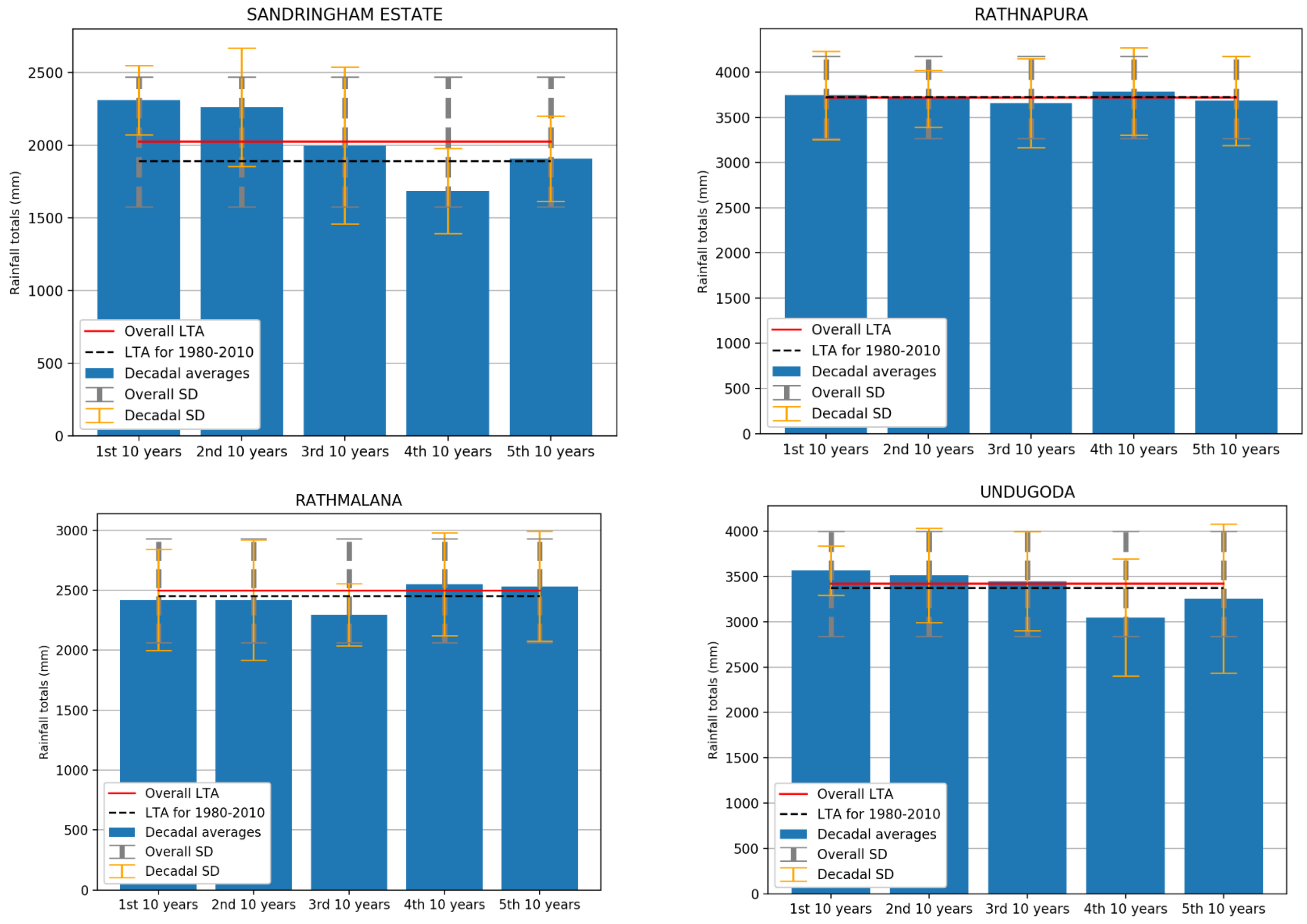

Figure C-9: Decadal averages plot for annual rainfall totals for Sandringham Estate, Rathnapura, Rathmalana and Undugoda

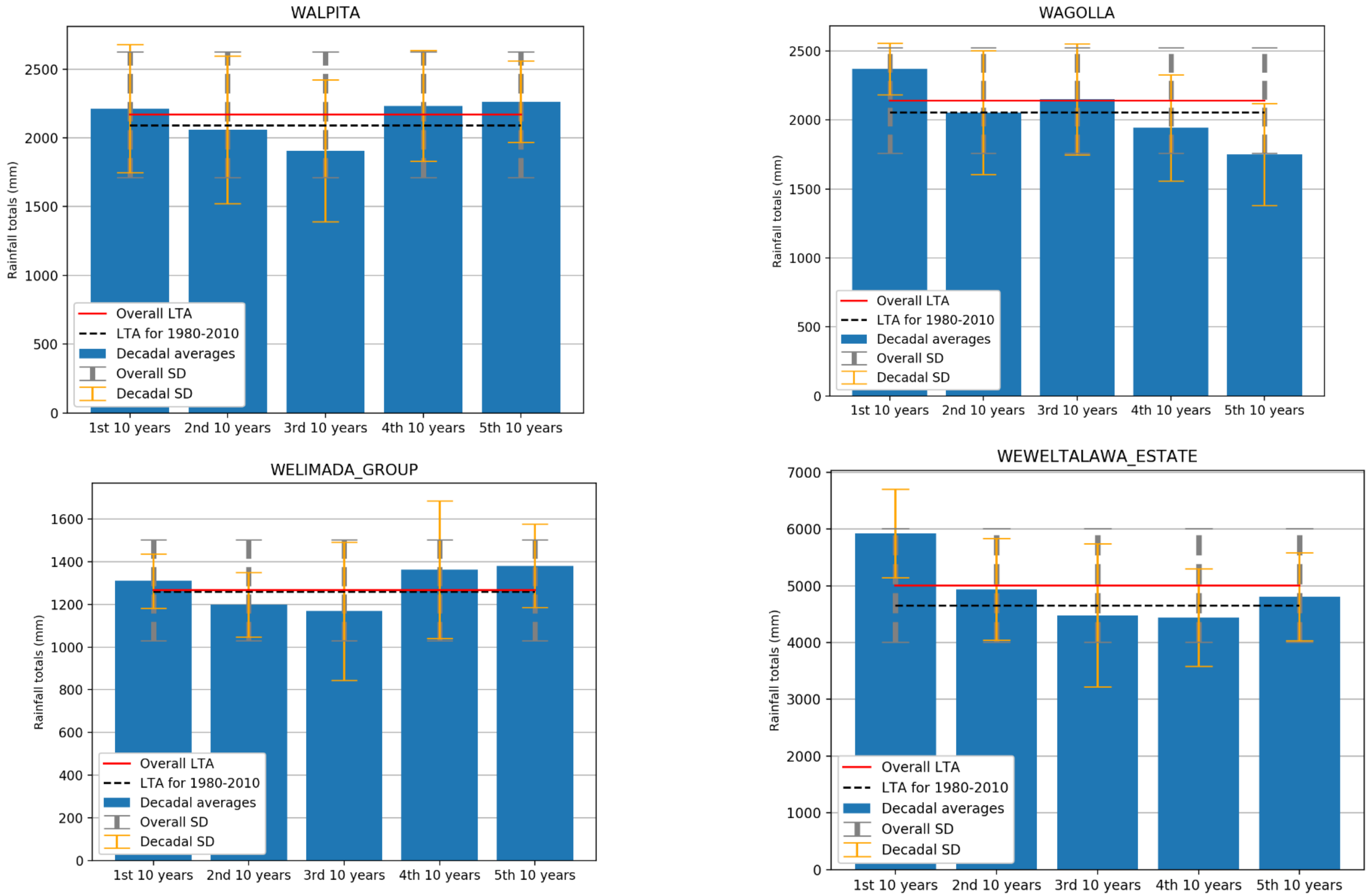

Figure C-10: Decadal averages plot for annual rainfall totals for Wewelthalawa Estate, Wagolla, Walpita and Welimada Group

APPENDIX D - INNOVATIVE TREND ANALYSIS FOR ANNUAL RAINFALL TOTALS FOR THE DURATION OF 1980 TO 2016

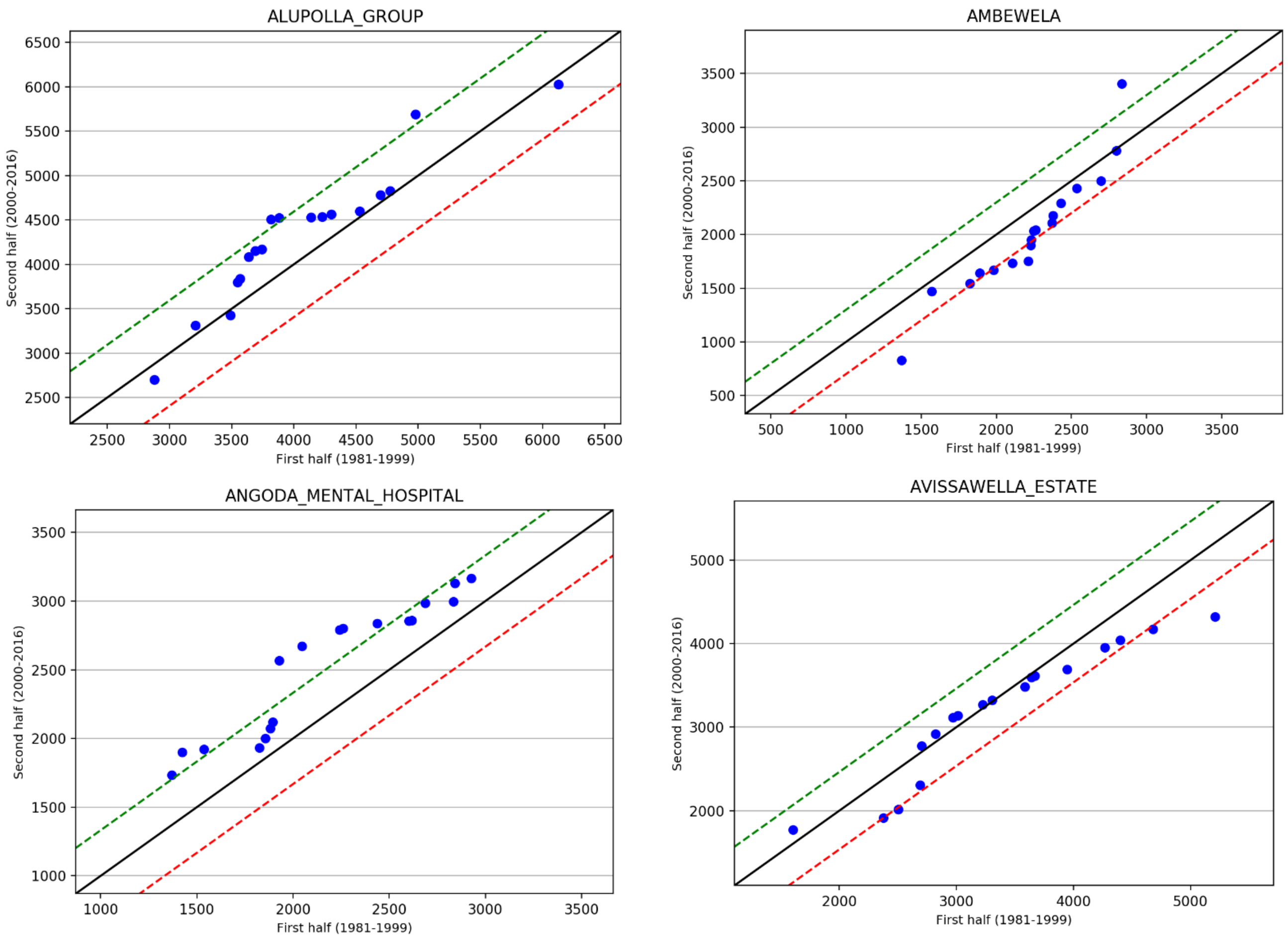

Figure D-1: Innovative trend analysis for Annual rainfall totals for Allupola Group, Ambewela, Angoda mental hospital and Avissawella Estate

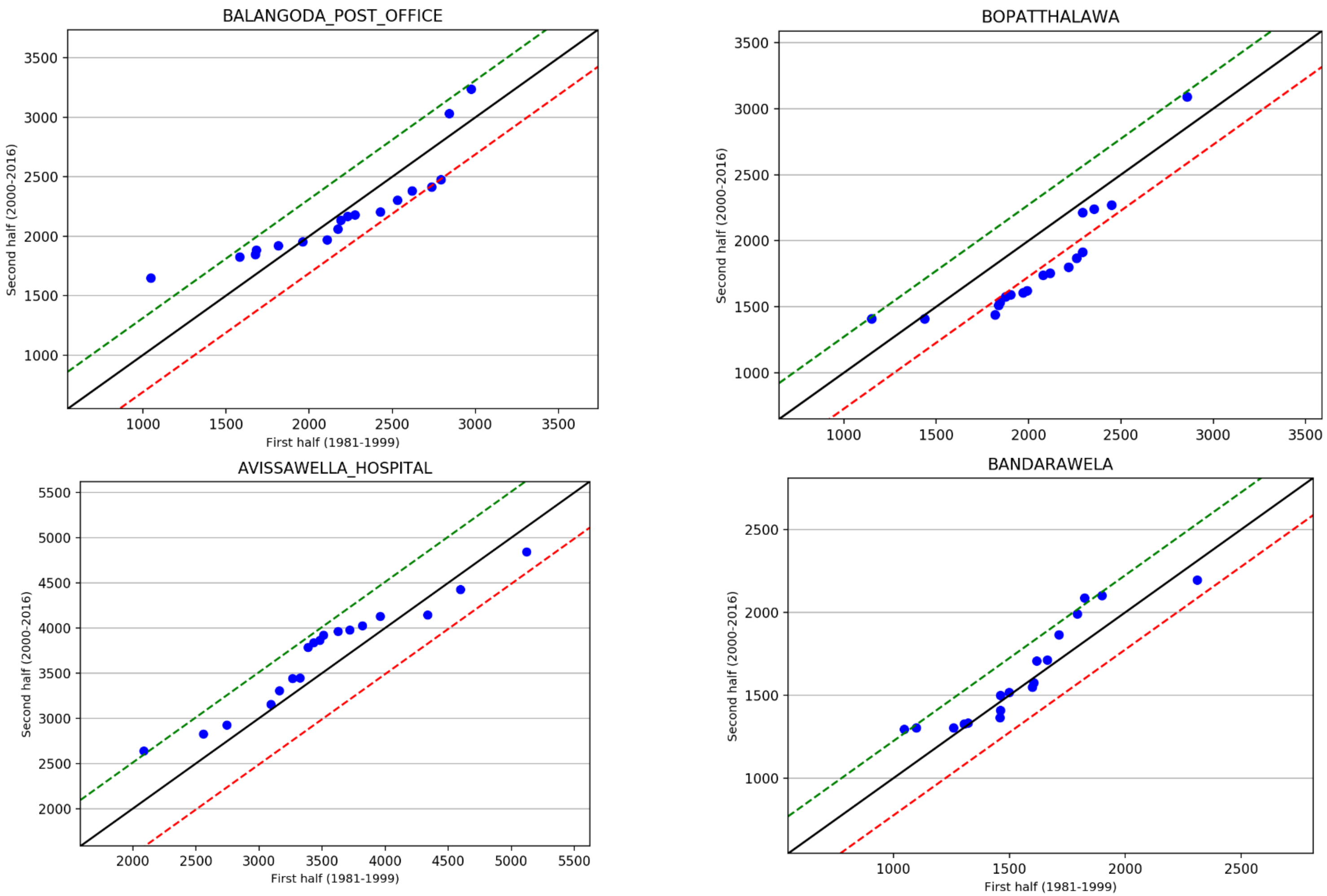

Figure D-2: Innovative trend analysis for Annual rainfall totals for Balangoda Post Office, Bopaththalawa, Bandarawela and Avissawella Hospital

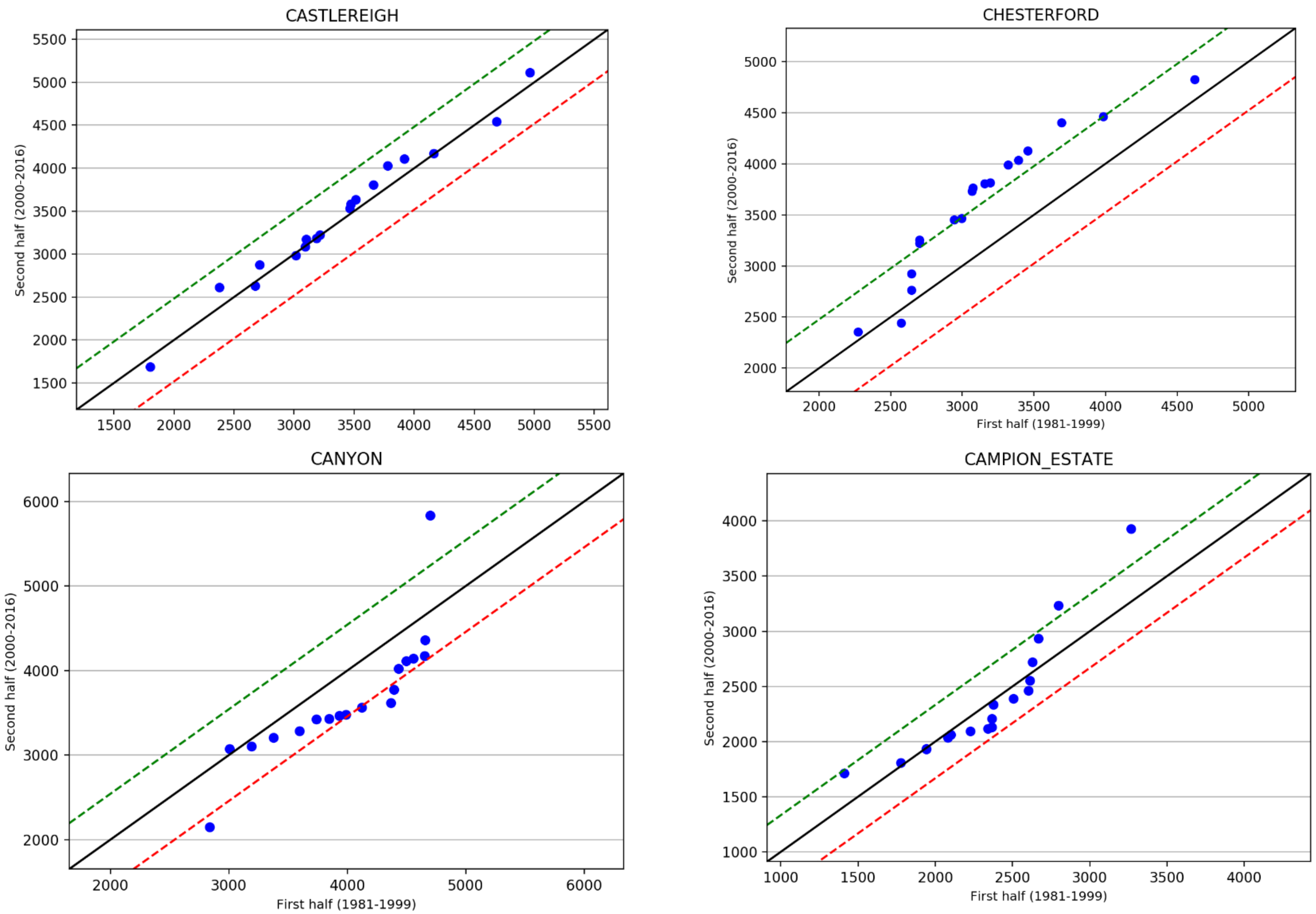

Figure D-3: Innovative trend analysis for Annual rainfall totals for Castlereigh, Chesterford, Canyon and Campion Estate

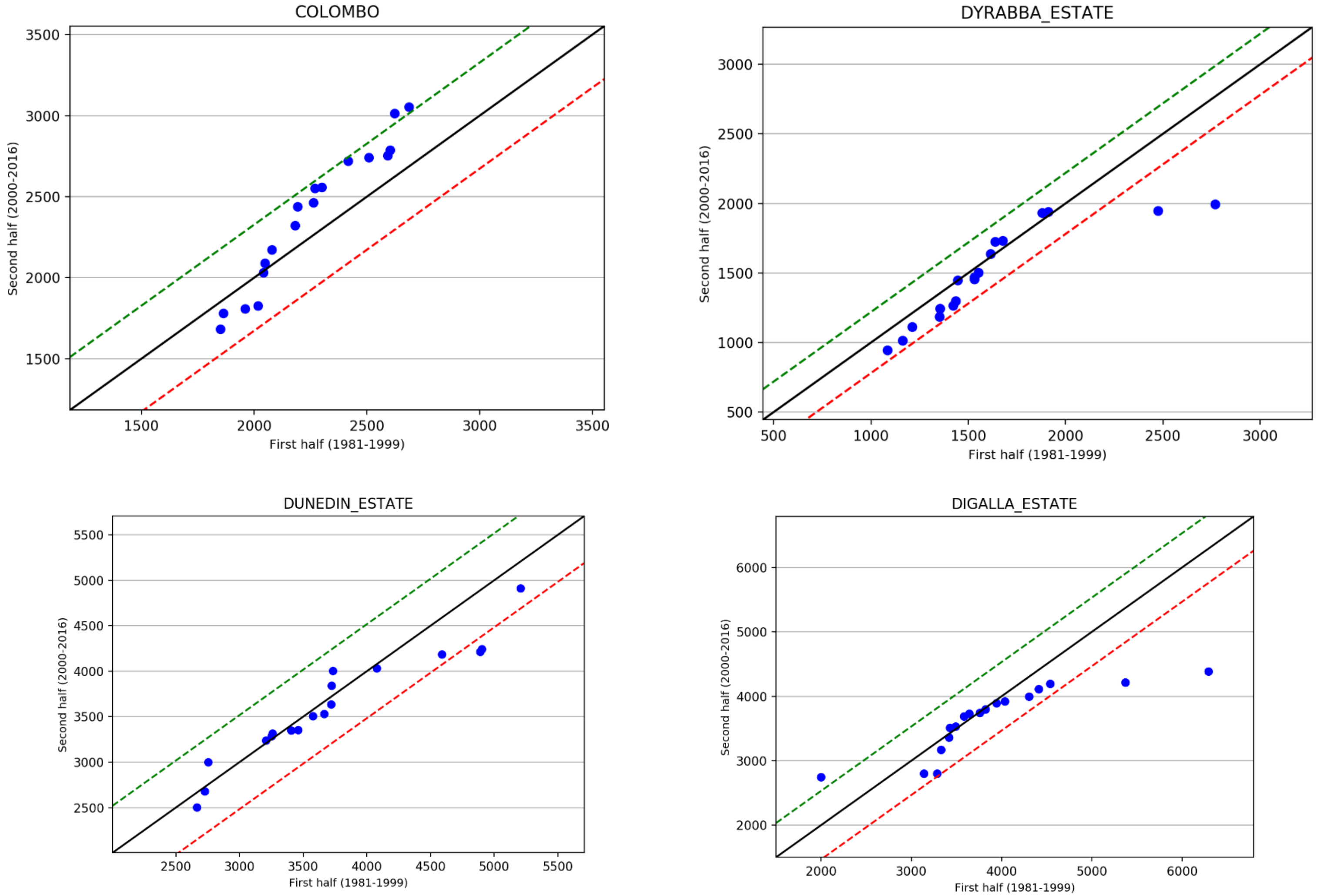

Figure D-4: Innovative trend analysis for Annual rainfall totals for Colombo, Dyrabba Estate, Dunedin Estate and Digalla Estate

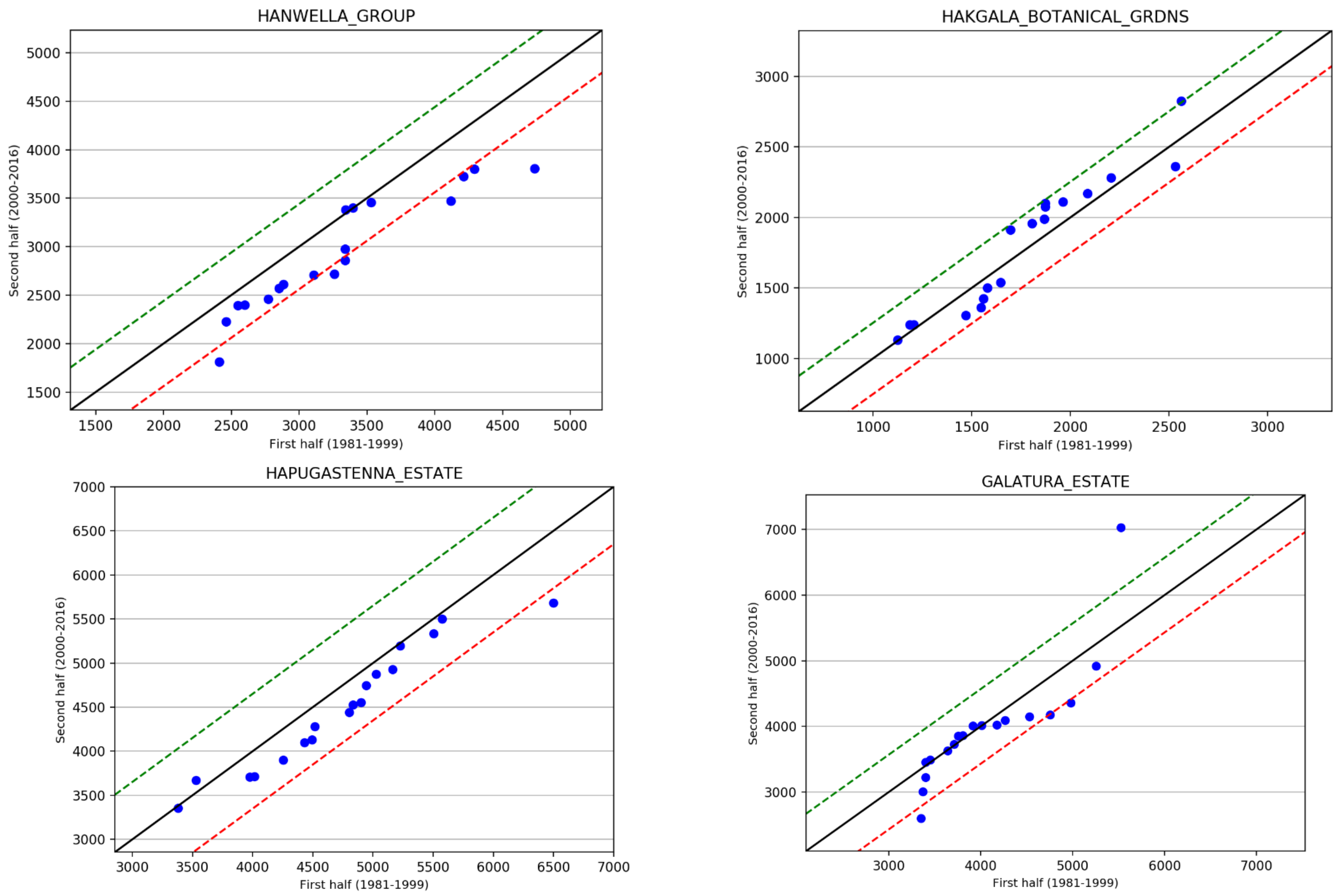

Figure D-5: Innovative trend analysis for Annual rainfall totals for Hanwella Group, Hakgala Botanical Grdns, Hapugastenna Estate and Galatura Estate

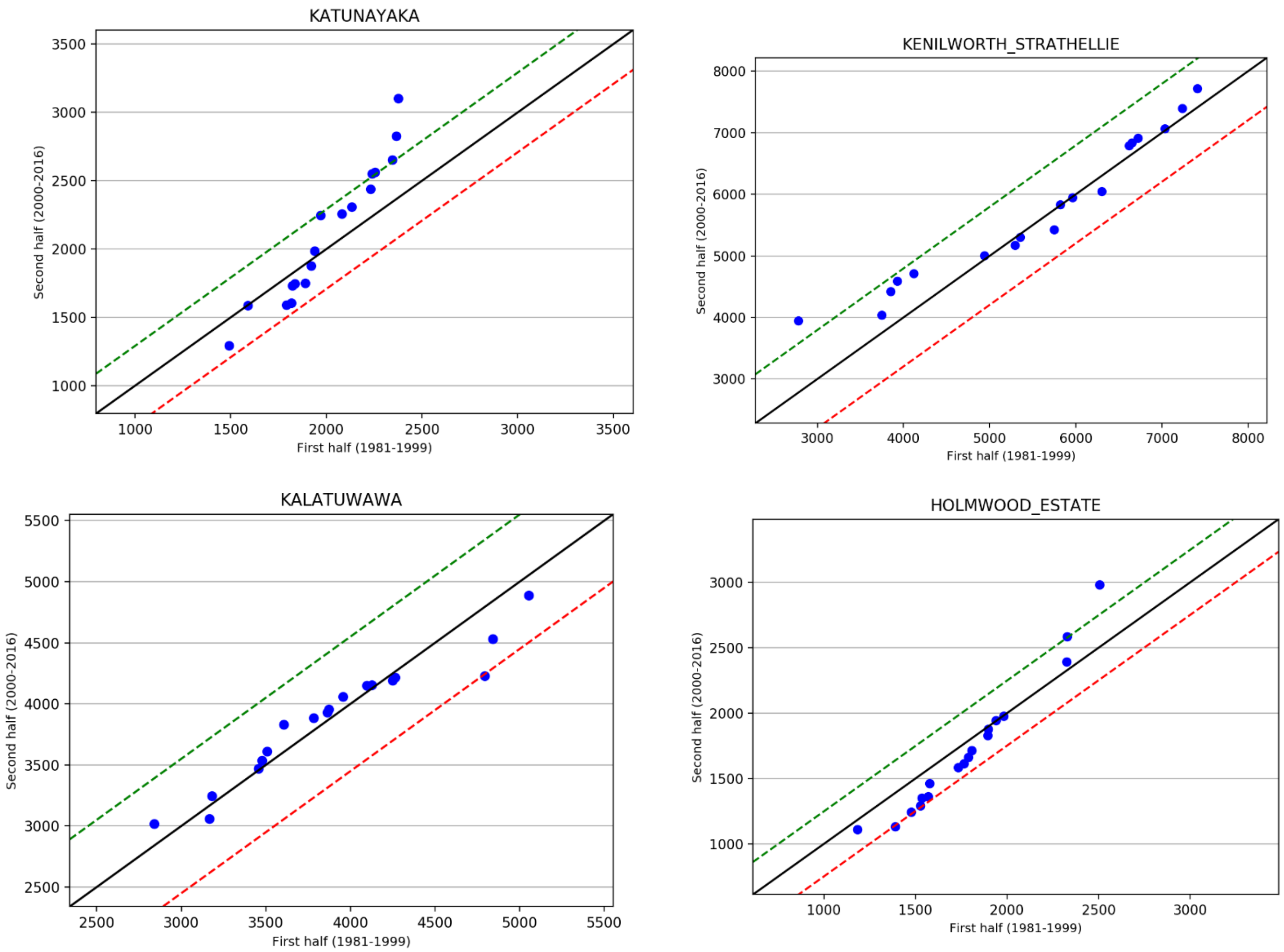

Figure D-6: Innovative trend analysis for Annual rainfall totals for Katunayaka, Kenilworth Strathelle, Kalatuwawa and Holmwood Estate

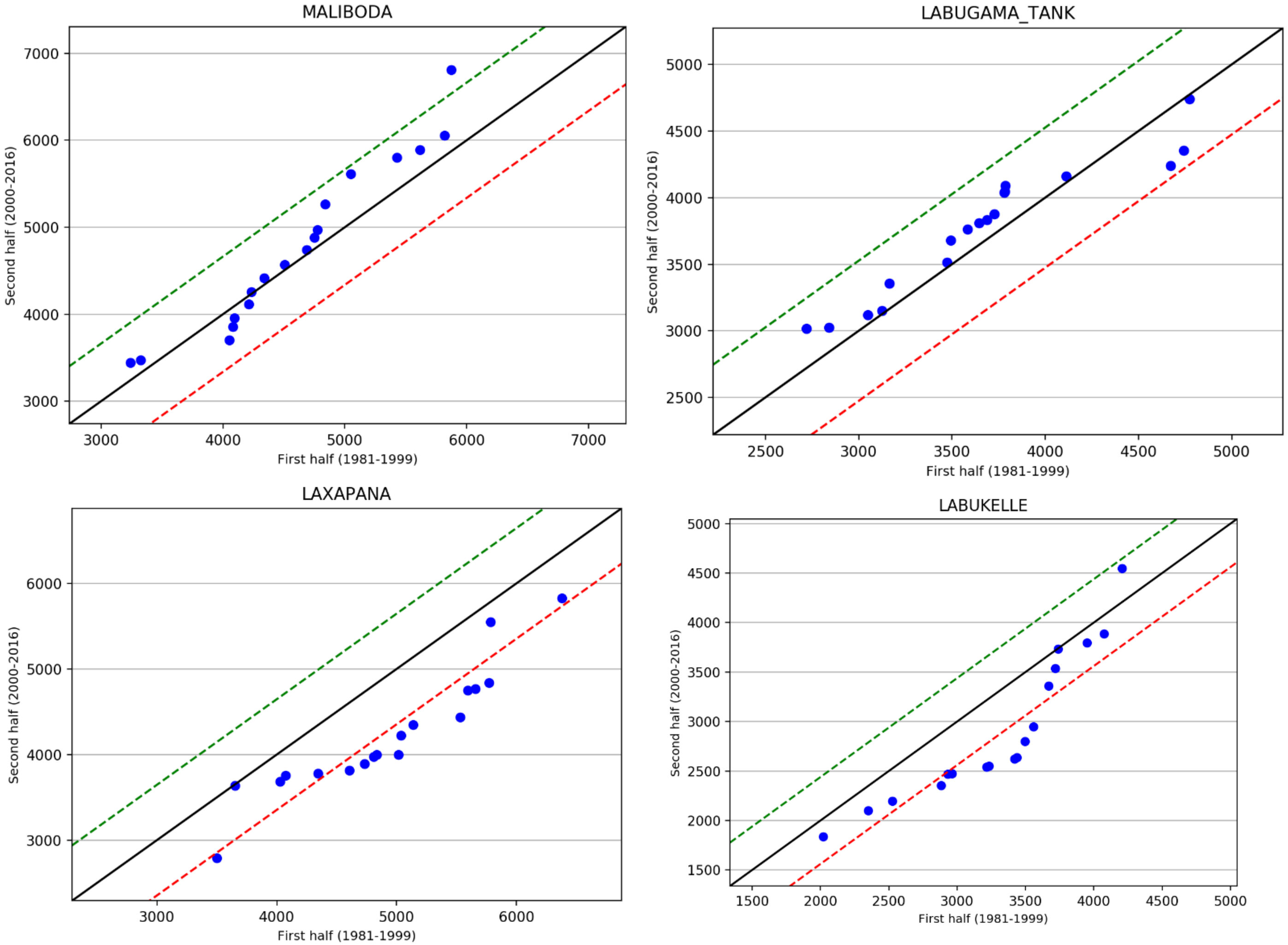

Figure D-7: Innovative trend analysis for Annual rainfall totals for Maliboda, Labugama Tank, Laxapana and Labukelle

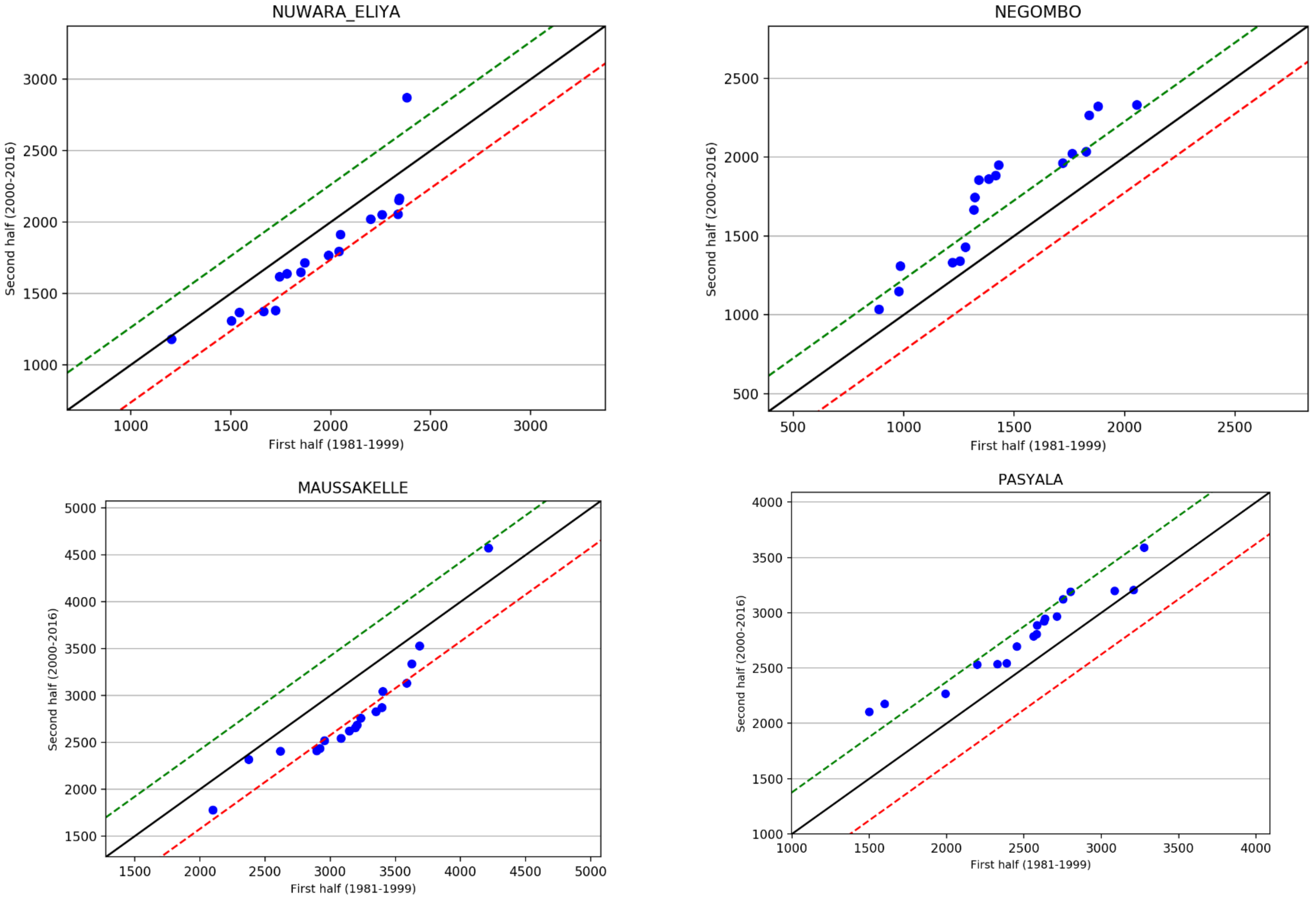

Figure D-8: Innovative trend analysis for Annual rainfall totals for Nuwara Eliya, Negombo, Maussakelle and Pasyala

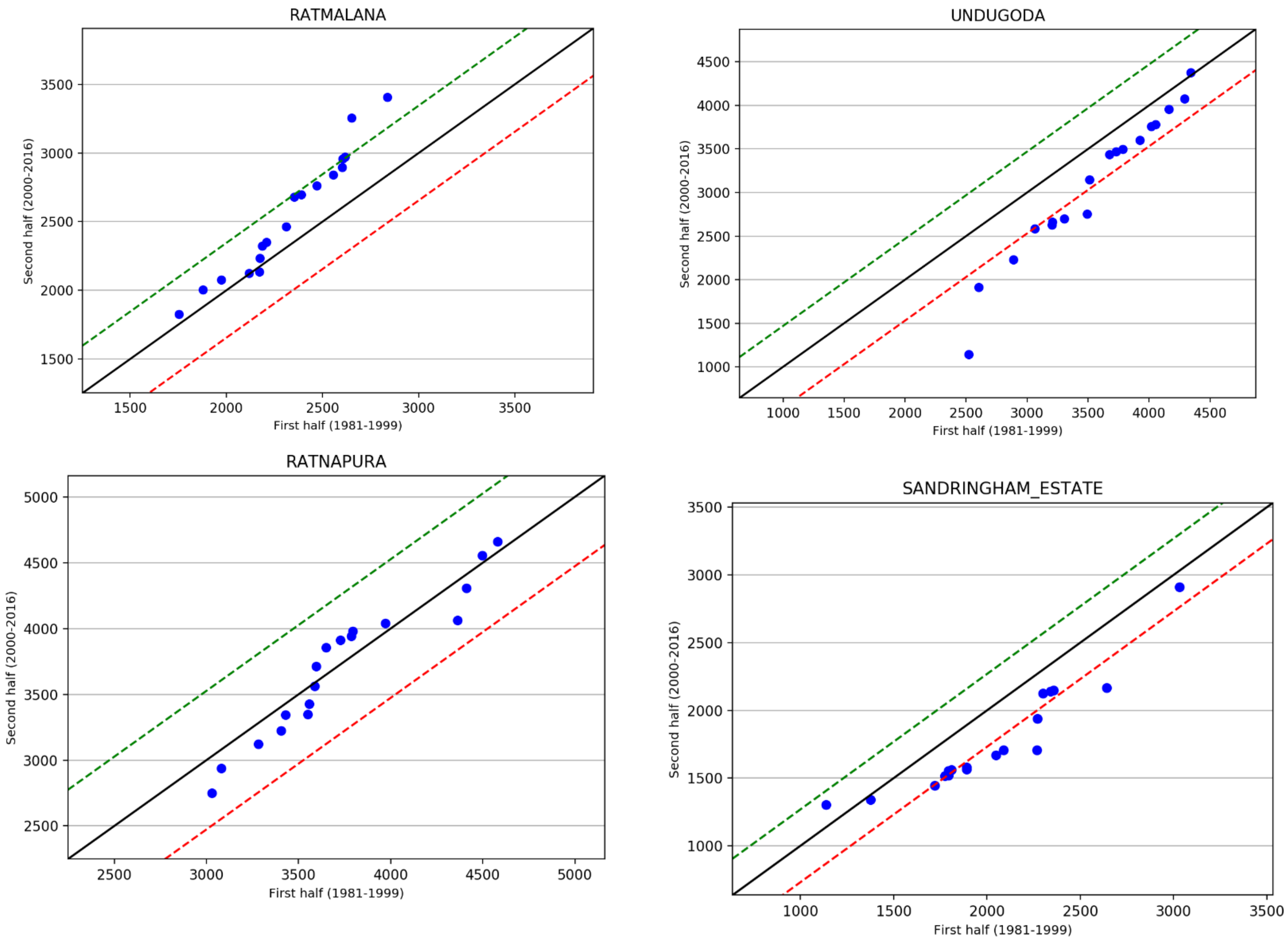

Figure D-9: Innovative trend analysis for Annual rainfall totals for Rathmalana, Undugoda, Rathnapura and Sandringham Estate

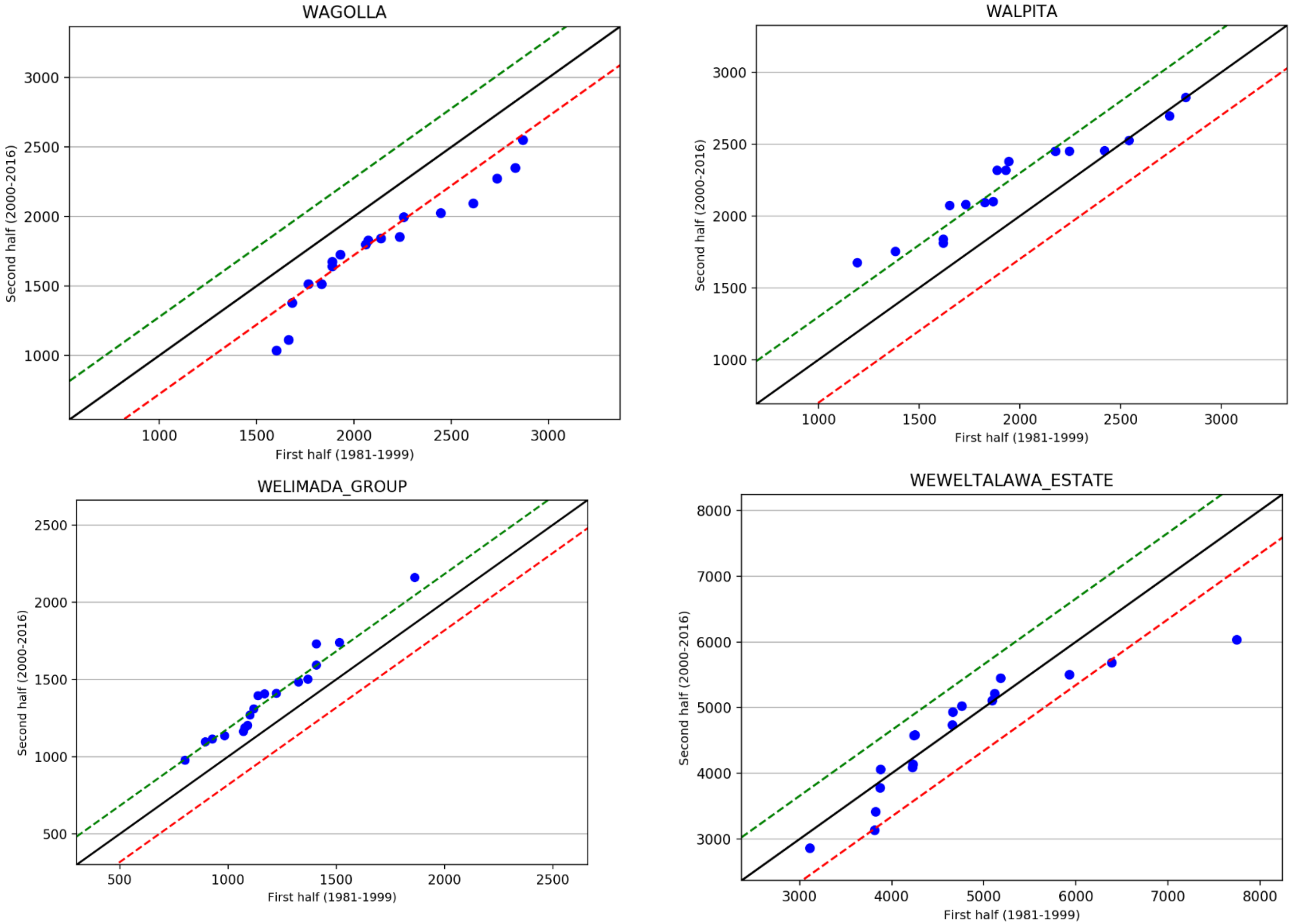

Figure D-10: Innovative trend analysis for Annual rainfall totals for Wagolla, Walpita, Welimada Group and Wewelthalawa Estat

APPENDIX E - SWAT MODELLING

New SWAT land use types were added to the SWAT reference database as URLD, URMD and URHD. Look-up tables were created by matching the local land-use types against reference SWAT land-use types, as shown in Table E-1. As required by SWAT, the re-classified polygon dataset was converted to a raster dataset at the same grid cell resolution as the underlying DEM. Summary Statistics of Processed Soil Classes are given in Table E-2.

Table E-1: Summary Statistics of Processed Land Use Types

LandUse Type	LU SWAT CODE	Area in Ha	Coverage (%)
Barren Land	BARR	52.7	0.0%
Built Up Land	URHD	4489.7	1.9%
Built Up Land_LD	URLD	8922.2	3.8%
Built Up Land_MD	URMD	14868.3	6.4%
Cemetery	UINS	22.3	0.0%
Chena	AGRL	4.0	0.0%
Coconut	COCO	5435.3	2.3%
Forest	FRST	26338.4	11.3%
Forest Plantation	FRST	2005.7	0.9%
Grass Land	RNGE	3076.2	1.3%
Home Garden	AGRL	48835.5	20.9%
Marsh	WETN	34.8	0.0%
Other	AGRL	4335.0	1.9%
Other Field Crops	AGRL	490.7	0.2%
Paddy	RICE	14098.4	6.0%
Park	RNGE	2.3	0.0%
Playground	RNGE	89.2	0.0%
Rock	BARR	520.7	0.2%
Rubber	RUBR	63412.9	27.1%
Scrub	SHRB	6568.9	2.8%
Tea	AGRR	26214.5	11.2%
Water Bodies	WATR	4199.6	1.8%

Table E-2: Summary Statistics of Processed Soil Classes

Soil association / complex	Soil – slope	Coverage (%)	SWAT soil	Soil association / complex	Soil – slope	Coverage (%)	SWAT soil
WATER	Water – flat	0.55	WATER-1972	Mattekele Series	Mattekele - flat	0.21	Ao1-3c-6343
	Water – undulating	0.20	WATER-1972		Mattekele – undulating	1.15	Ao1-3c-6343
	Water – Steep	0.04	WATER-1972		Mattekele – steep	0.57	Ao1-3c-6343
Ratupasa - Katunayake Association	Katunayake – flat	1.79	Rd11-2a-5284	Pallegoda-Dodangoda-Boralu-Gampaha Association	Gampaha – flat	0.28	Gd16-2-3a-1201
	Ratupasa – undulating	0.02	Nd17-1a-1554		Dodangoda – undulating	0.32	Af44-2b-1882
Boralu - Gampaha Association	Gampaha – flat	18.12	Gd16-2-3a-1201		Pallegoda – steep	0.13	Ap21-2b-3656
	Boralu – undulating	3.18	Af44-2b-1882	Pugoda Series	Pugoda – flat	2.33	Jd7-2a-3145
	Boralu – steep	0.23	Af44-2b-1882		Boralu – undulating	0.14	Af44-2b-1882
Galigamuwa - Homagama Complex	Homagama – flat	1.93	Bc26-2c-3660		Pugoda – steep	<0.01	Jd7-2a-3145
	Homagama – undulating	11.18	Bc26-2c-3660	Kandy - Galigamuwa - Lithosols Complex	Galigamuwa – flat	0.01	Ao42-2c-4618
	Homagama – steep	9.84	Bc26-2c-3660		Galigamuwa – undulating	0.27	Ao42-2c-4618
Boralu - Madabokka Complex	Madabokka – flat	0.08	Oe1-3a-4025		Lithosols - steep	0.39	I-Bd-2c-4352
	Boralu – undulating	<0.01	Af44-2b-1882	Palatuwa – Wagura - Madabokka Complex	Palatuwa – flat	0.97	Jt2-2a-1381
Pallegoda - Dodangoda -	Homagama – flat	2.13	Bc26-2c-3660		Boralu – undulating	0.04	Af44-2b-1882

Soil association / complex	Soil – slope	Coverage (%)	SWAT soil	Soil association / complex	Soil – slope	Coverage (%)	SWAT soil
Homagama Complex	Dodangoda – undulating	4.53	Ap19-2b-3654	Mawanella - Kandy - Kiribathkumbura Association	Kiribathkumbura – flat	0.05	Ge59-2-3a-4504
	Pallegoda – steep	1.47	Rd11-2a-5284		Kandy – undulating	0.40	Bd52-1-2c-6360
Malaboda - Lithosols Complex	Malaboda – flat	0.33	Ao1-3c-6343		Kandy – steep	0.19	Bd52-1-2c-6360
	Malaboda – undulating	3.14	Ao1-3c-6343	Negombo - Katunayake Association	Negombo – flat	0.04	Qa2-1a-5627
	Malaboda – steep	4.69	Ao1-3c-6343	Horton - Lithosol Complex	Horton – flat	0.09	Bd73-2b-6420
Galigamuwa - Pallegoda Complex	Pallegoda – flat	2.98	Ap21-2b-3656		Horton – undulating	0.89	Bd73-2b-6420
	Galigamuwa – undulating	7.56	Ao42-2c-4618		Lithosols – steep	0.81	I-Bd-2c-4352
	Galigamuwa – undulating	4.45	Ao42-2c-4618	Wagura - Palatuwa Complex	Ratupasa – flat	0.20	Nd17-1a-1554
Maskeliya-Mattekele-Lithosols Complex	Maskeliya - flat	0.64	Bd52-1-2c-6360		Boralu – undulating	<0.01	Af44-2b-1882
	Maskeliya -flat	5.74	Bd52-1-2c-6360	Erosional remnants (Inselberg)	Erosional remnants – flat	0.08	ROCK-193
	Lithosols – undulating	3.25	I-Bd-2c-4352		Erosional remnants – undulating	1.01	ROCK-193
					Erosional remnants – steep	1.38	ROCK-193

Following HRU definition, it is observed that some input land use and soil classes are not represented in the SWAT model as they provide coverage of a very small portion of the basin, as shown in Table E-3 and Table E-4 for land use and soil, respectively.

Table E-3: Land Use Class Coverage – Pre- and Post- HRU Definition

LandUse_Type	Land use SWAT code	Area (ha) prior to HRUs	Percentage (%) prior to HRUs	Area (ha) post HRUs	Percentage (%) post HRUs
Chena, other field crops, Home Garden and other	AGRL	53665	22.9%	60885.9	26.1%
Tea	AGRR	26215	11.2%	27634.4	11.8%
Coconut	COCO	5435	2.3%	2407.5	1.0%
Forest and Forest Plantation	FRST	28344	12.1%	29343.5	12.6%
Paddy	RICE	14098	6.0%	10104.2	4.3%
Grass Land, Parks and Playgrounds	RNGE	3168	1.4%	1552.2	0.7%
Rubber	RUBR	63413	27.1%	73108.8	31.3%
Scrub	SHRB	6569	2.8%	1674.6	0.7%
Built Up Land	URHD	4490	1.9%	2917.8	1.3%
Built Up Land_LD	URLD	8922	3.8%	5856.8	2.5%
Built Up Land_MD	URMD	14868	6.4%	17941.2	7.7%
Water Bodies	WATR	4200	1.8%	464.6	0.2%
Barren Land and Rock	BARR	573	0.2%	0.0	0.0%
Marsh	WETN	35	0.0%	0.0	0.0%
Cemetery	UINS	22	0.0%	0.0	0.0%

Table E-4: Soil Class Coverage – Pre- and Post- HRU Definition

Soil series	Soil SWAT code	Area (ha) prior to HRUs	Percentage (%) prior to HRUs	Area (ha) post HRUs	Percentage (%) post HRUs
Pugoda Series	Jd7-2a-3145	6066.0	2.33	4597.2	1.97
WATER	WATER-1972	1821.0	0.55	520.3	0.22
Malaboda - Lithosols Complex	Ao1-3c-6343	22628.0	0.33	24281.5	10.38
Palatuwa – Wagura - Madabokka Complex	Jt2-2a-1381	2798.0	0.97	1781.7	0.76
Boralu - Gampaha Association	Gd16-2-3a-1201	43371.0	18.12	47322.2	20.23
Boralu - Gampaha Association	Af44-2b-1882	8191.0	3.18	7543.8	3.23
Galigamuwa - Homagama Complex	Bc26-2c-3660	63447.0	1.93	64926.9	27.76
Negombo - Katunayake Association	Qa2-1a-5627	57.0	0.04	59.1	0.03
Horton - Lithosol Complex	Bd73-2b-6420	2008.0	0.09	2167.7	0.93
Boralu - Madabokka Complex	Oe1-3a-4025	194.0	0.08	43.9	0.02
Pallegoda - Dodangoda - Homagama Complex	Ap19-2b-3654	11081.0	4.53	11048.7	4.72
Erosional remnants (Inselberg)	ROCK-193	5542.0	0.08	5046.9	2.16
Galigamuwa - Pallegoda Complex	Ap21-2b-3656	7030.0	2.98	4075.6	1.74
Galigamuwa - Pallegoda Complex	Ao42-2c-4618	28908.0	7.56	31082.5	13.29
Maskeliya-Mattekele-Lithosols Complex	Bd52-1-2c-6360	16809.0	0.64	15470.2	6.61
Maskeliya-Mattekele-Lithosols Complex	I-Bd-2c-4352	9994.0	3.25	9859.5	4.22
Ratupasa - Katunayake Association	Rd11-2a-5284	3774.0	1.79	4064.0	1.74
Ratupasa - Katunayake Association	Nd17-1a-1554	34.0	0.02	<0	0.00
Mawanella - Kandy - Kiribathkumbura Association	Ge59-2-3a-4504	89.0	0.05	<0	0.00

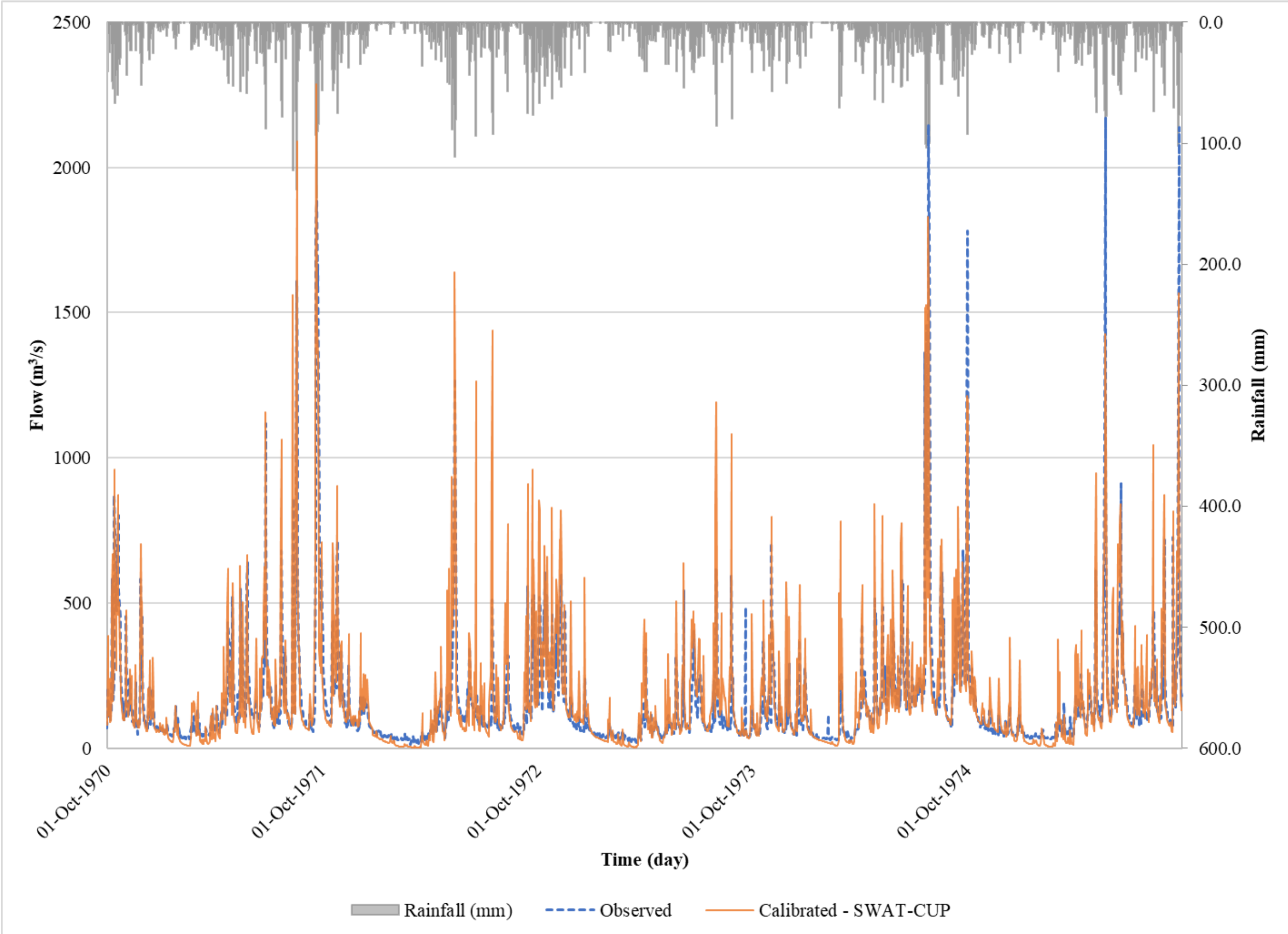

Figure E-1: Comparison of the daily observed flow and modelled flows for the first 5 years of the calibration period for the Glencourse hydrometric station in actual scale

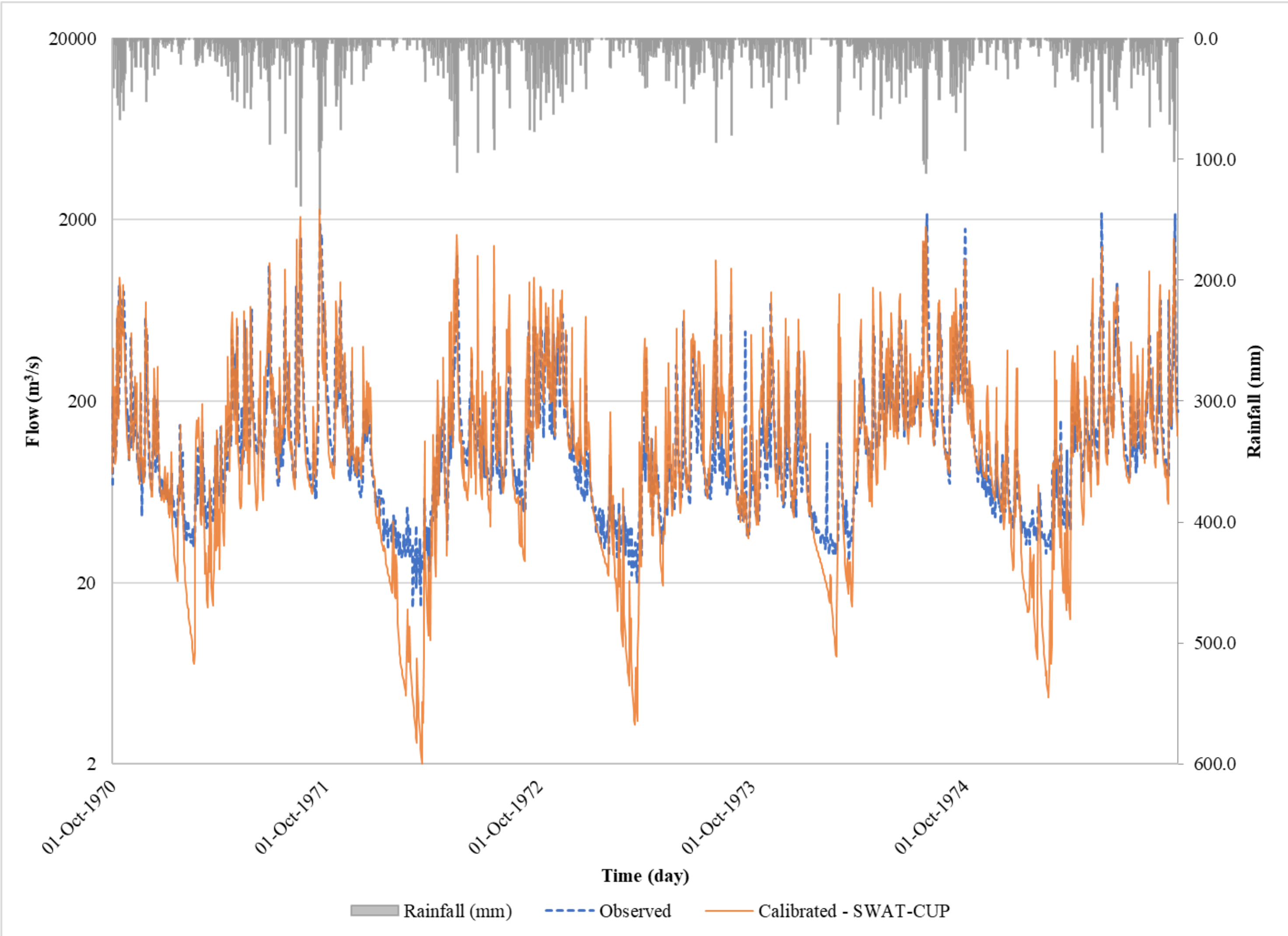

Figure E-2: Comparison of the daily observed flow and modelled flows for the first 5 years of the calibration period for the Glencourse hydrometric station in logrithmic scale

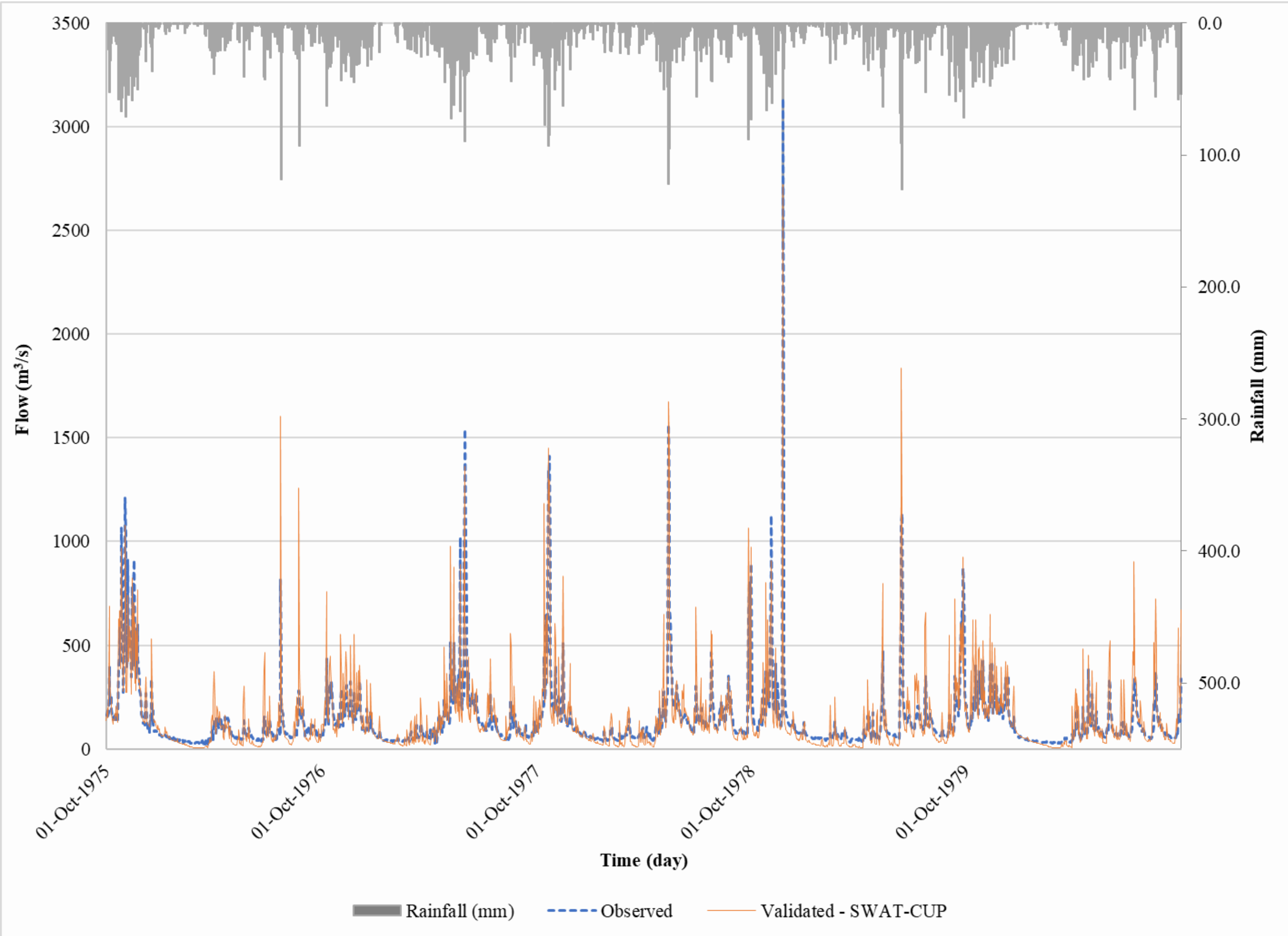

Figure E-3: Comparison of the daily observed flow and modelled flows for the last 5 years of the calibration period for the Glencourse hydrometric station in actual scale

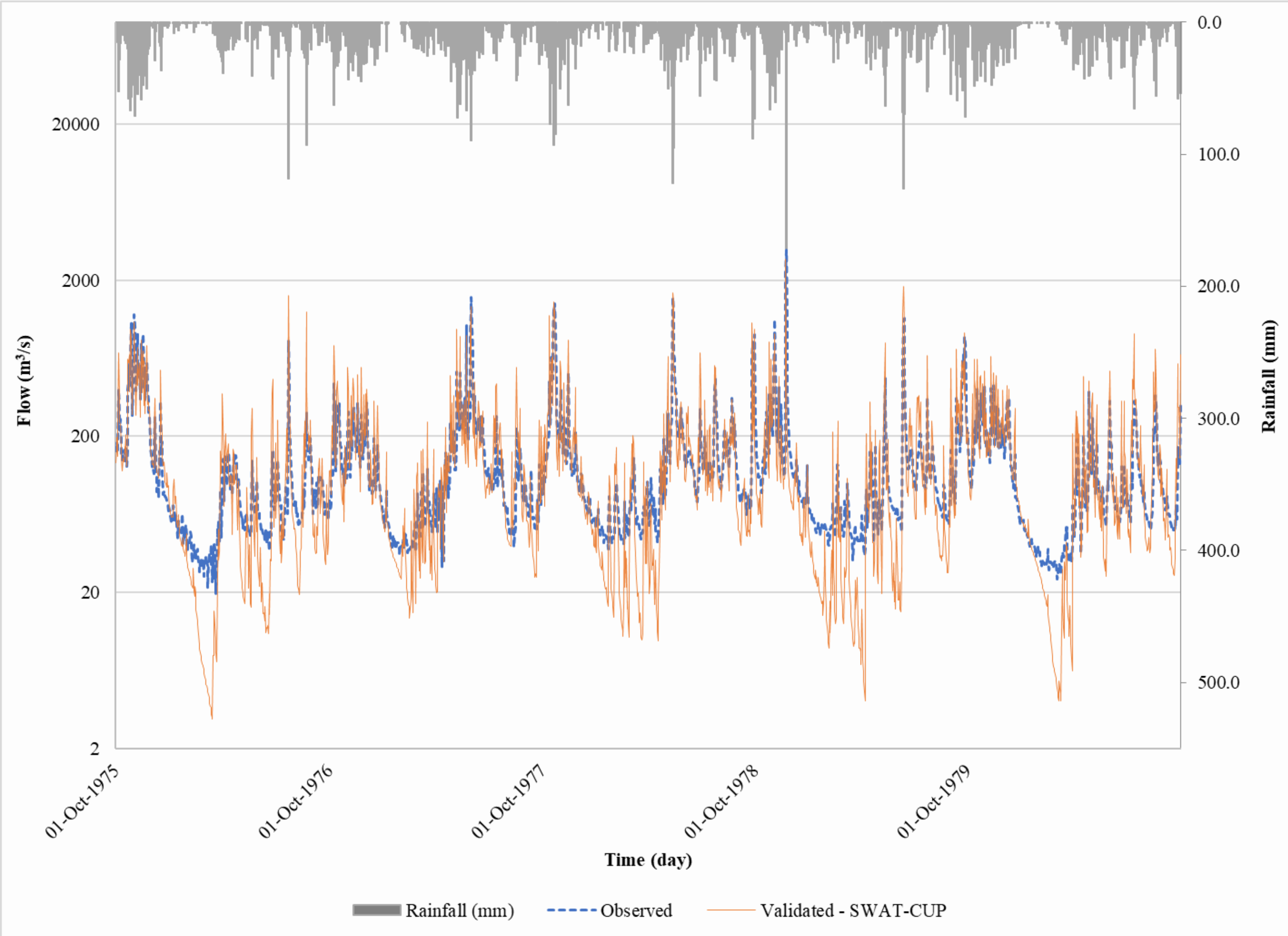

Figure E-4: Comparison of the daily observed flow and modelled flows for the last 5 years of the calibration period for the Glencourse hydrometric station in logrithmic scale

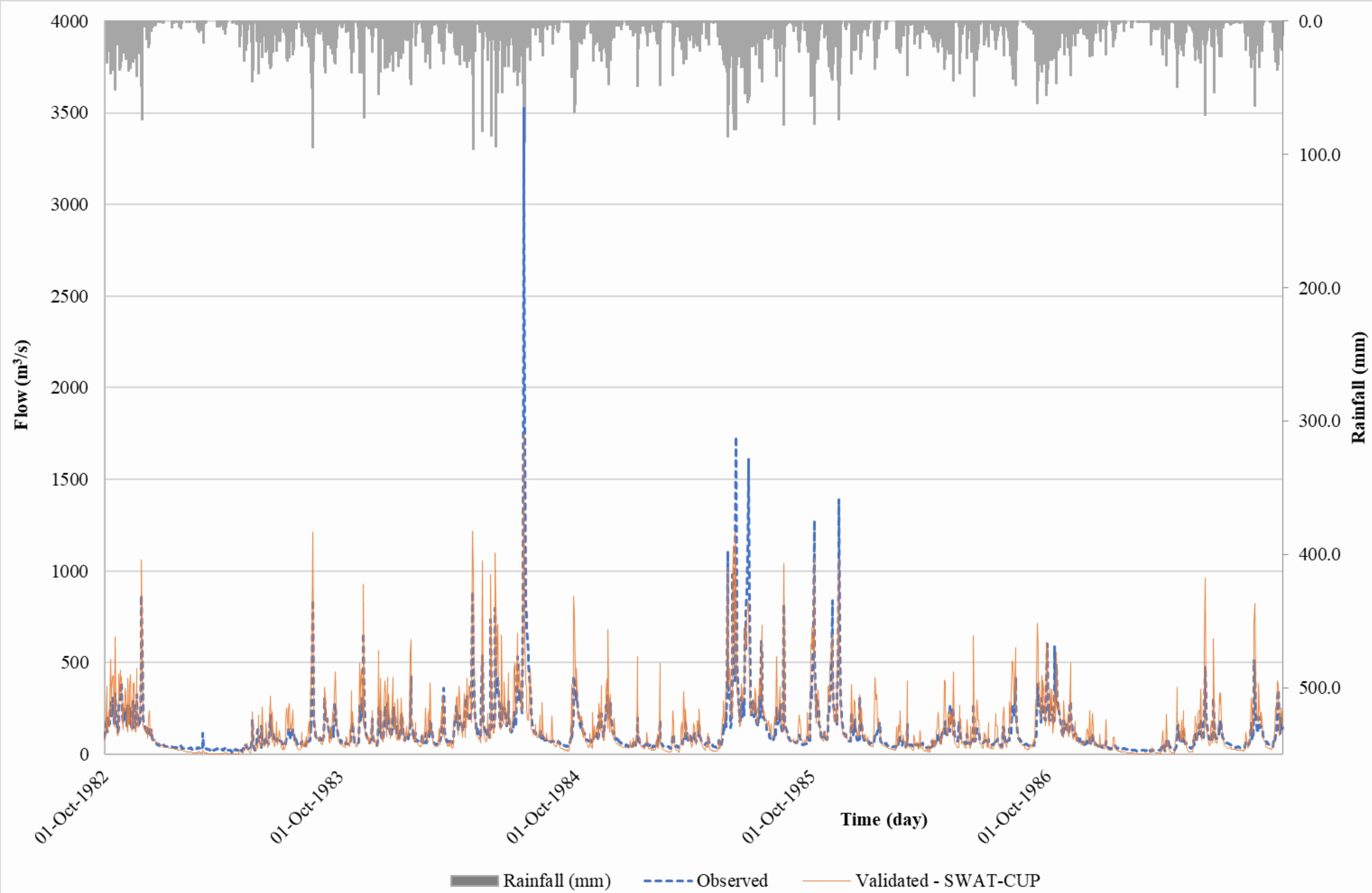

Figure E-5: Comparison of the daily observed flow and modelled flows for the first 5 years of the validation period for the Glencourse hydrometric station in actual scale

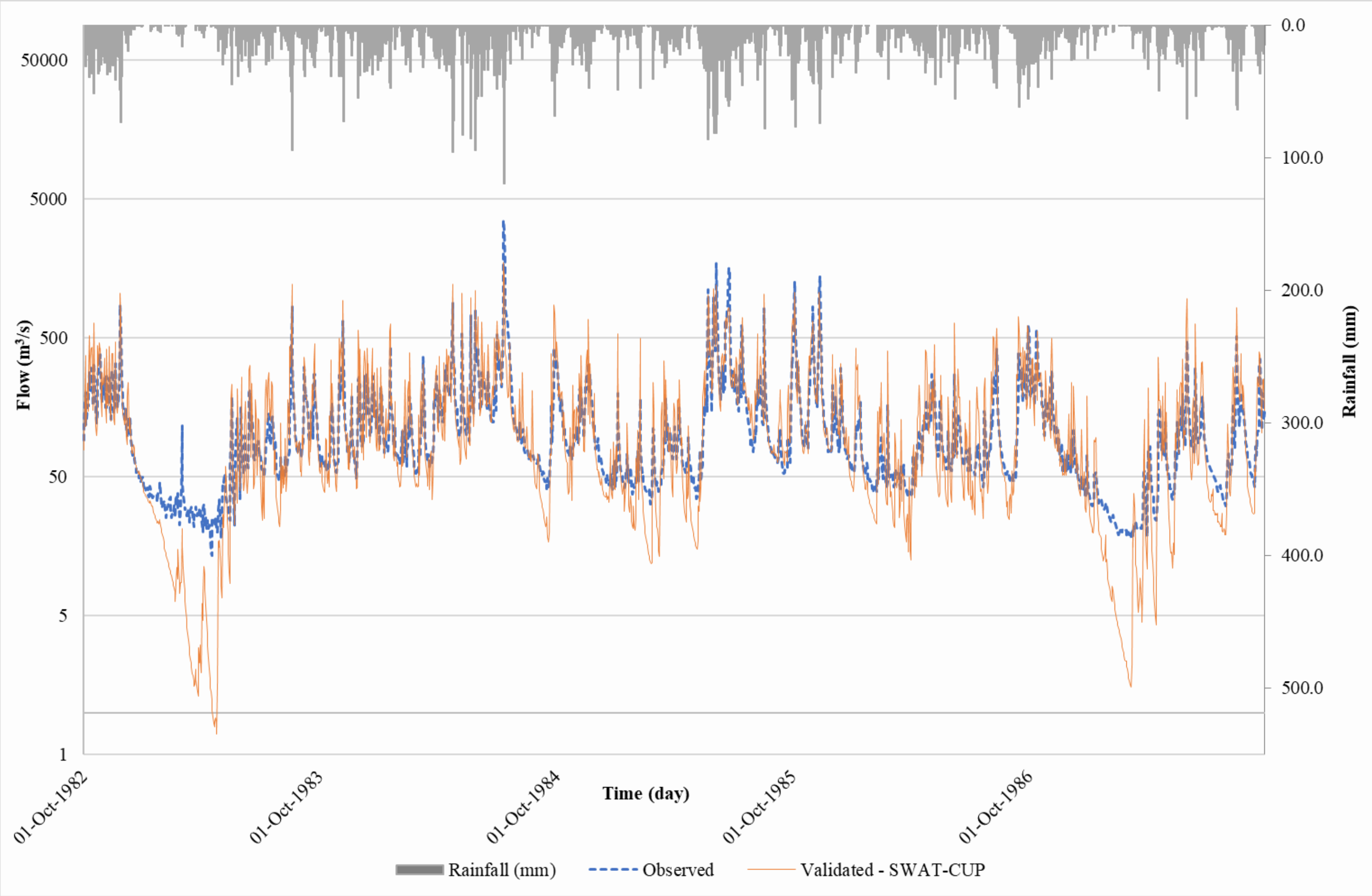

Figure E-6: Comparison of the daily observed flow and modelled flows for the first 5 years of the validation period for the Glencourse hydrometric station in logrithmic scale

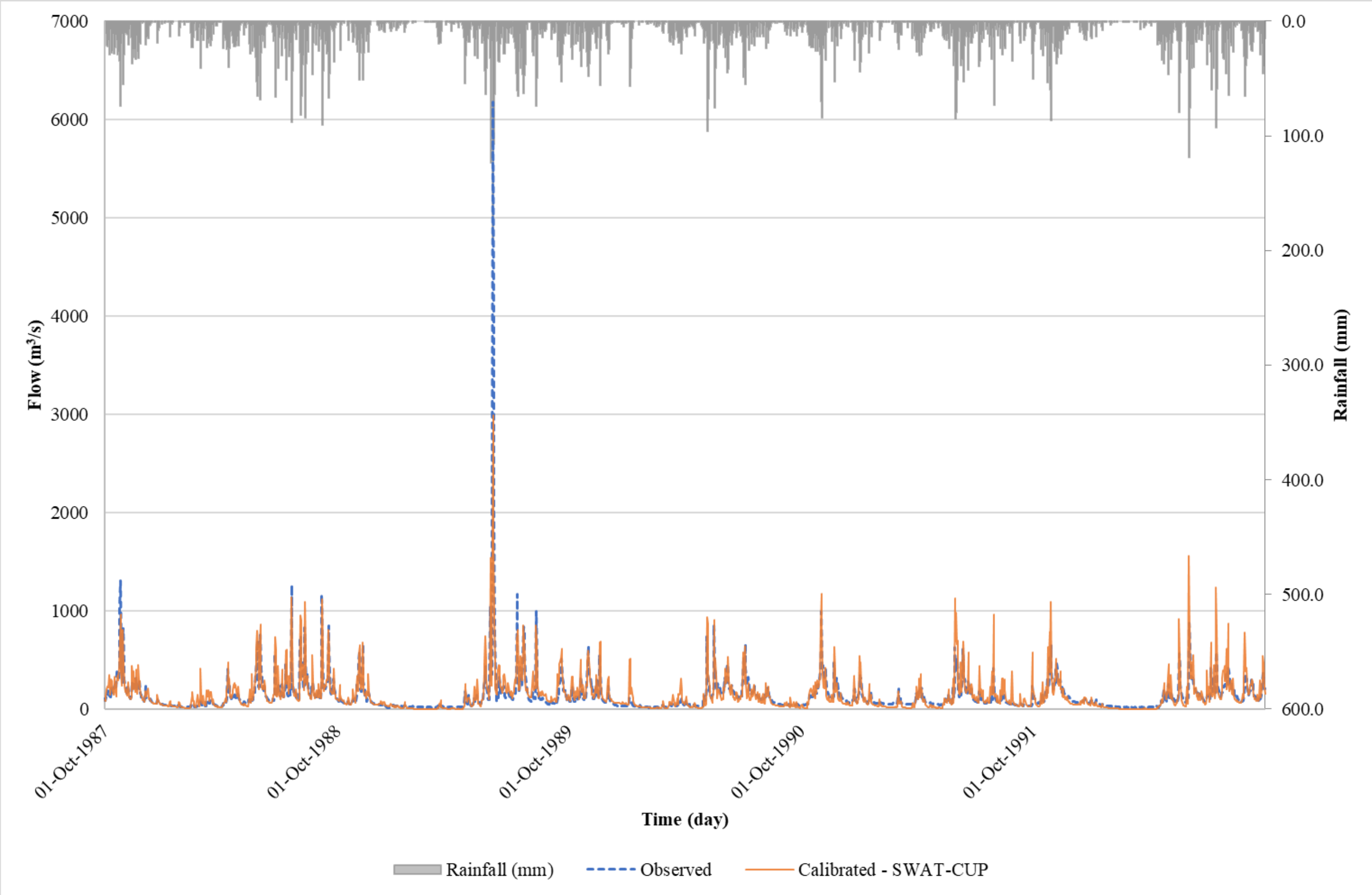

Figure E-7: Comparison of the daily observed flow and modelled flows for the last 5 years of the validation period for the Glencourse hydrometric station in actual scale

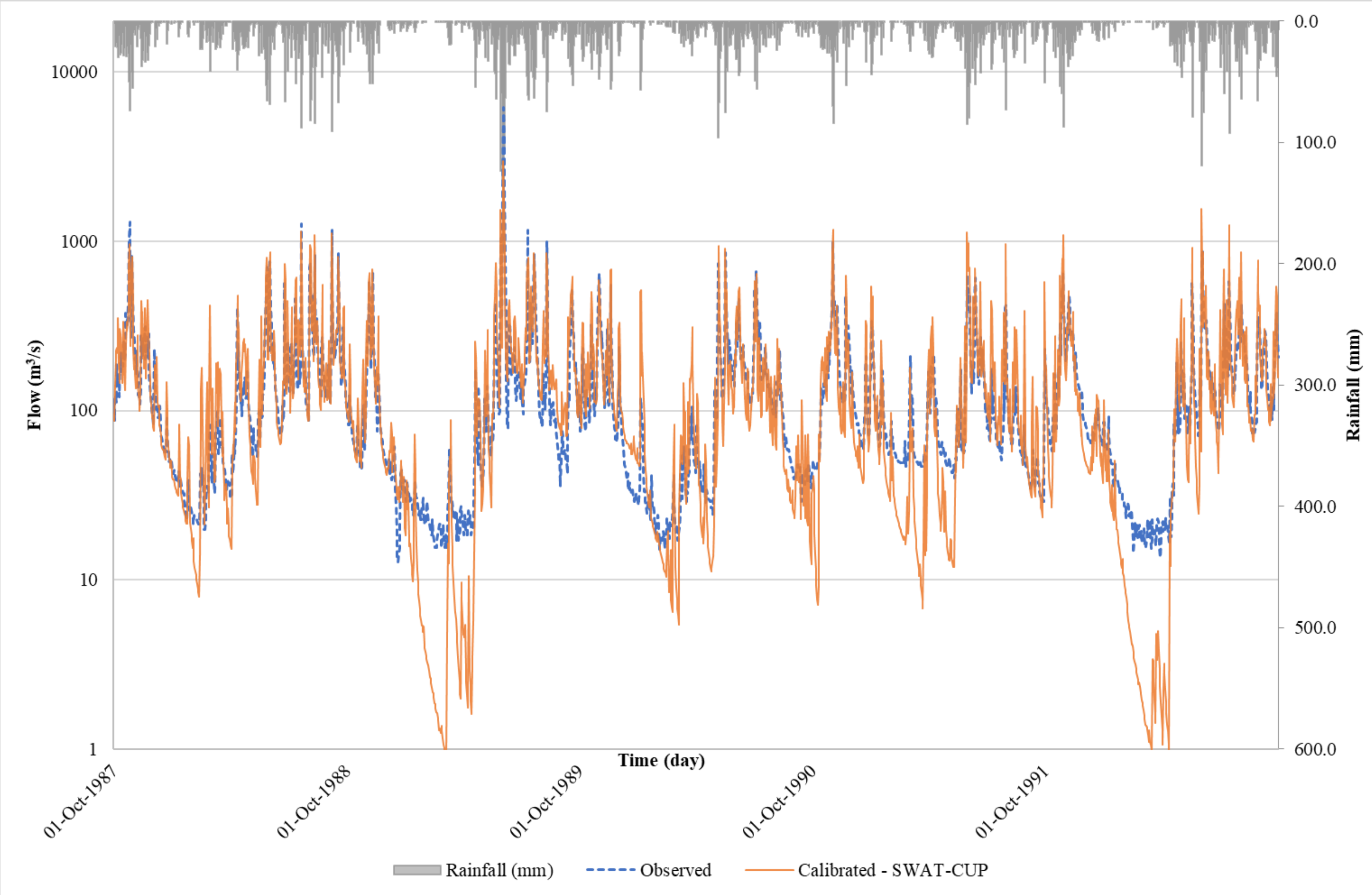

Figure E-8: Comparison of the daily observed flow and modelled flows for the last 5 years of the validation period for the Glencourse hydrometric station in logrithmic scale

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.