EVALUATION OF THE CHANGES IN THE CLIMATIC PARAMETERS AFFECTING WATER RESOURCES IN THE KELANI RIVER BASIN, SRI LANKA

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Thesis submitted in partial fulfilment of the requirements for the
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DECLARATION

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Name of the Supervisor: Prof. R. L. H. L. Rajapakse

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Signature of the supervisor: Date: 05th August, 2021

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ABSTRACT

Evaluation of the Changes in the Climatic Parameters Affecting Water Resources in the Kelani River Basin, Sri Lanka

The impact of climate change on the freshwater resources of Sri Lanka is most likely to affect the Sri Lankan economy since most sectors are vulnerable to climate change. There is limited research on Climate Change in Sri Lanka and the studies related to climate change impacts on water resources are not definite on their rates and impacts. Most of them have pointed out the need for further investigation and strengthening of the methodologies. The impacts of global-scale climate change on local climate is ambiguous and there is a disparity between global climate models or large climate models and the climate at catchment scale. It is thus necessary to carry out investigations of climate change on the catchment scale. The main objective of this study is the investigation of climate change impacts on water resources in relation to two sub watersheds in the Kelani river basin using parameters such as rainfall, and temperature that are major drivers of water availability at a monthly resolution and evaluating the significance of these changes to global changes while assessing their spatial and temporal variation and influence on water resources.

Present work evaluated the climate of the Kelani river basin with monthly rainfall, temperature, and streamflow data. The trends in the climate parameters were studied using Linear Regression models, Mann-Kendall's trend test and Sen's Slope method to compare and determine whether the impacts associated with the study area are consistent with global and regional climate changes which were obtained from the literature review. The trends in intra-annual, seasonal, annual, and decadal scales were computed for the measured values as point climate information. The recent IPCC base period (1961 to 1990) was also used for comparing changes relative to that period. The Streamflow variation and trends were compared with the contributing rainfall computed using Thiessen weights. Observed variations and shifts in the rainfall patterns were compared with the long-term averages and associated magnitudes were further scrutinized with the prevailing hydrological characteristics of the catchment in order to ascertain the consistency of gauged and spatially averaged data.

The Linear Regression and Mann-Kendall tests revealed similar results. An increase in temperature in the Kelani basin was observed with a decreasing trend in rainfall and streamflow. These trends were however relatively small with minor increases/decreases. Increase in mean temperature was about 0.018 °C over the 60-year period and the decrease in rainfall and streamflow amounted to values less than 40 mm over the 60-year period. These trends although negligible at present would ultimately distress the catchment moisture condition. Considering the increasing minimum temperature and the decrease in rainfall in both sub-catchments and resulting precipitation elasticity of runoff, the cumulative effects of such events were studied and the behaviour of the parameters and their effect on the watershed wetness was measured. The net loss of water is attributed to the increasing evaporative demand in the sub-catchments due to an increase in the temperature. These results when further examined with composite evaluations of each climate parameter revealed a collective increase in the losses in the recent decades. The cumulative decrease in the rainfall and streamflow in the basin when compared with the long term averages showed escalations in the deficit wet periods of almost 10% higher in the recent decades (1983/84-2013/14). This reveals a rather distressing situation for the available water in the two sub-catchments of the Kelani basin. The loss of water through replenishment of the catchment water storage needs to be measured and monitored for proper water resources management since data on soil moisture within the country are limited. The method adopted in this study was helpful to capture the current situation of water resources in the basin and the moisture status within the sub-catchments. It can be used in other catchments of the country to check the status of available water resources and especially the watershed wetness so that it can be monitored for water security.

Keywords: Climate Change, Mann-Kendall Trend Test, Precipitation Elasticity of Runoff

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1 INTRODUCTION

1.1 General

The Intergovernmental Panel on Climate Change (IPCC) defines climate as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period ranging from months to thousands or millions of years (IPCC, 2001). The conventional period is thirty years, as indicated by the World Meteorological Organization (WMO). The IPCC has stated that the scientific evidence of climate change is unambiguous and that climate change consequences such as increasing temperature, shifting precipitation patterns, snow cover changes, and increasing frequency of floods and droughts are the major factors affecting water resources (IPCC, 2008). As per the Third Assessment Report (TAR) published in 2001 by the IPCC, the global average surface temperature has risen by about 0.6°C during the 20th century and the sea level has risen by about 10 to 20 cm during the last century with increases being more dominant in the minimum temperature leading to a reduction in the diurnal temperature. As per the World Meteorological Organization (WMO), the warmest decade recorded was 2001-2010 and highest warming has been observed in the recent decades (WMO, 2016). The rainfall on the other hand shows more variability spatially and temporally with an increase in frequency and intensity of extreme events. Greater increases in extreme precipitation are anticipated, as compared to the mean. Climate warming has been closely associated with the changing precipitation patterns, increase in evaporation, melting of snow and ice, and variations in soil moisture and runoff (IPCC, 2008). Studies have shown a strong correlation between temperature and rainfall supporting the fact that the hydrological cycle and the temperature are closely linked together. Most authors have correlated higher warming with low precipitation (Nicholls, 2004; Rusticucci and Penalba, 2000; Trenberth and Shea, 2005)

An increase in water demand and lack of proper management of water resources are expected to cause water scarcity issues. Climate change causes intensification of the hydrological cycle increasing the intensity and frequency of extreme events and thereby the availability of water (Cap-net, 2011).

Projections of precipitation show an increase over the tropical oceans and the South Asian monsoon in summer from June to August. Runoff is projected to increase in high latitudes and Southeast Asia and decrease in central Asia. Projections for average annual runoff for the year 2050, relative to the average runoff for the years 1961 to 1990, are expected to mostly follow projected changes in precipitation (Cruz et al., 2007). Higher warming is predicted for the South Asian region compared to the global mean (Hijioka et al., 2014)

1.2 Climate of Sri Lanka

Sri Lanka has a tropical climate consisting of distinct wet and dry seasons, located between 5° 55’ to 9° 51’ North latitude and between 79° 42’ to 81° 53’ East longitude within the tropics. Physical geography differs across the country, from mountainous terrain in the central region to a flat terrain in the north. On the basis of rainfall, the climate is divided into two distinct monsoon rainfall seasons (Domroes, 1974); the Southwest Monsoon (SWM) starts from May and lasts till September, the Northeast Monsoon (NEM) starts from December and lasts till February. There are two inter monsoon rainfall; the First Inter Monsoon (FIM) is from March to April and the Second Inter Monsoon is from October to November. The main cultivation season known as the Maha season starts in October and ends in March and the secondary cultivation season known as the Yala season starts in April and ends in September (Zubair, 2002). The Yala monsoon brings profuse rainfall to the western and southern regions of the Country. The area experiences its dry season during December through March. The Southwest receives around 4000 mm of rainfall each year. The Maha monsoon lasts from October to January and affects northern and eastern Sri Lanka and the dry season usually lasts from May to September. This region receives approximately 1000 mm of precipitation annually, significantly less than the other half of the country. The average temperature of Sri Lanka usually ranges from 28 °C – 32 °C. The temperature varies from 16 °C in the central highlands and to as high as 32 °C along the Eastern coast of the island (CCS, 2016).

1.3 Water Resources and Climate Change in Sri Lanka

Sri Lanka has 103 distinct river basins; most of the main rivers originate from the central highlands and eventually flow into the sea, passing through the lowlands. Surface water is the primary source of water for Sri Lanka (National Science Foundation, 2000). The changing climate would alter water resources and the hydrological cycle as their fundamental drivers such as precipitation; temperature and evaporation are affected by climate change. These in turn impact the variability and magnitude of the streamflow, thereby affecting water availability and security.

Regional climate and its changes have been rigorously studied in the past years with different methods and models. Studies have shown that temperature has clearly been increasing in all the stations of Sri Lanka and increasing rainfall variability has resulted in an increase in water insufficiencies in the dry zone of Sri Lanka (Chandrapala, 2007b; Erigama, Smakhtin, Chandrapala and Fernando, 2010; Jayatilake, Chandrapala, Basanayake and Dharmaratne, 2005, Marambe et al., 2015). Variations in annual temperature in Sri Lanka are lesser due to its latitude but substantial regional variations in temperature have been observed due to the altitude differences within the country (Abhayasinghe, 2007; Basnayake, 2007; Chandrapala, 2007b).

The increasing population and economic development of the country challenge meeting of freshwater demands thus raising issues on water security. Other factors such as seawater intrusion, over extraction of water from wells and overuse of surface water will further intensify the susceptibility of water resources to climate change.

Kelani Ganga is an important source of freshwater for Colombo, the capital of Sri Lanka. The average annual rainfall in the basin is about 2400 mm and the peak flow during the monsoon season is about 800-1500 m^3/s. The upper catchment of the basin is mountainous, and the lower catchment is plain with the entire catchment being situated in the wet zone receiving high intense rainfalls. The steep rise in Kelani streamflow due to heavy rains and the risk of constant flood hazards is a major problem for Colombo. The river currently faces problems with increasing pollution as a result of industrial discharges, poor environmental management and governance (CEA, 2014). Moreover with climate change, water availability and its quality will be highly affected.

In Sri Lanka, major gaps have been identified in the existing system of climate information and the credibility of the existing information has been challenged on many occasions (IPS CLIMATEnet, 2014). Review on surface water and climate change publications in Sri Lanka by (Wijesekera, 2010) pointed out the limitations in terms of quantification, temporal and spatial variations and methods of analysis. Most authors have pointed out the need for further investigation and strengthening of the methods used for evaluation. Moreover, the studies carried out in relation to climate change and surface water were not conclusive on their rates and impacts on water. The IPCC has also stated the need for improvement of modelling of climate change and their impacts on the hydrological cycle at catchment scale for proper decision making.

There are limited studies on climate change impacts on water resources. Although numerous authors have tried to associate changes in rainfall patterns and temperature changes with the available water resources, there seem to be major gaps in terms of quantification of these impacts. Some of the studies have elaborated on rainfall changes and shifts across the country but have not looked into the variability and impacts on the available water and have provided very restricted information on the same. Some have examined the probable impacts of climate change on soil moisture deficit and have anticipated such effects to have a serious impact on the available water resources. Some have not specified the data period or the data source for their study or the selection for their method of analysis. There is a lack of research on the spatial and temporal impacts of climate change on water resources at finer scales, which would help determine impacts at local scales. Most studies have worked with monthly data while analyzing climate change impacts. The studies also lacked in terms of outputs related to water resources and their justification on the choice of the climate parameter selection. Most studies have worked with monthly data while analyzing climate change impacts.

1.4 Problem Statement

There is a lack of research on the spatial and temporal impacts of climate change on water resources at catchment scales in Sri Lanka. Although numerous authors have tried to associate changes in rainfall patterns and temperature changes with the available water resources, there seem to be major gaps in terms of quantification of these impacts. This necessitates carrying out investigations on a catchment scale while comparing historical observations with the global predictions. Available literature suggests further strengthening of evaluations with detailed analysis on climate change and its impacts on water resources.

1.5 Overall Objective

Identification of important climate parameters to evaluate the impacts on water resources and comparison with global indications to assess the changes in climate and their impacts on water in relation to two sub watersheds in Kelani river basin Sri Lanka.

1.6 Specific Objectives

- Identification and evaluation of climatic parameters and their impacts on water resources
- Investigating the significance of climate change in the river basin with regional and global climate changes
- Recommendation on water resources management in the catchments

2 LITERATURE REVIEW

2.1 Observed and Predicted Changes in Climate (Global)

Climate change has been related to human activities resulting in a change in the atmospheric composition, and climate variability has been attributed to natural causes (IPCC, 2007). Climate change is the variability that continues over a longer period which is statistically significant. Climate variability is the changeability in the mean state and other statistics of climate elements on all spatial and temporal scales beyond those of individual weather events (IPCC, 2001). Many studies reveal that the atmospheric carbon dioxide (CO_2) levels may affect water availability through its influence on vegetation. Rosenberg, Kimball, Martin and Cooper (1990) in their study suggest that by doubling Carbon dioxide, stomata resistance would increase which will reduce transpiration on average by about 50%. Min, Zhang, Zweirs and Hegerl (2011) observed intensification of heavy precipitation events due to human-induced increases in greenhouse gases.

The observed warming for the period 1850-1900 to 1986-2005 is 0.61°C. Under every emission scenario, the surface temperature is projected to rise during the 21st century with recurrent and lengthier heat waves in many regions (IPCC, 2014). Figure 2-1 shows the observed and predicted changes in temperature for RCP2.6 and RCP8.5 based on Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations. Temperature estimates of three datasets is shown by the black lines, while the blue and red lines show the projections under RC2.6 and RCP 8.5 respectively. The ensemble mean ±1.64 is shown by the shading.

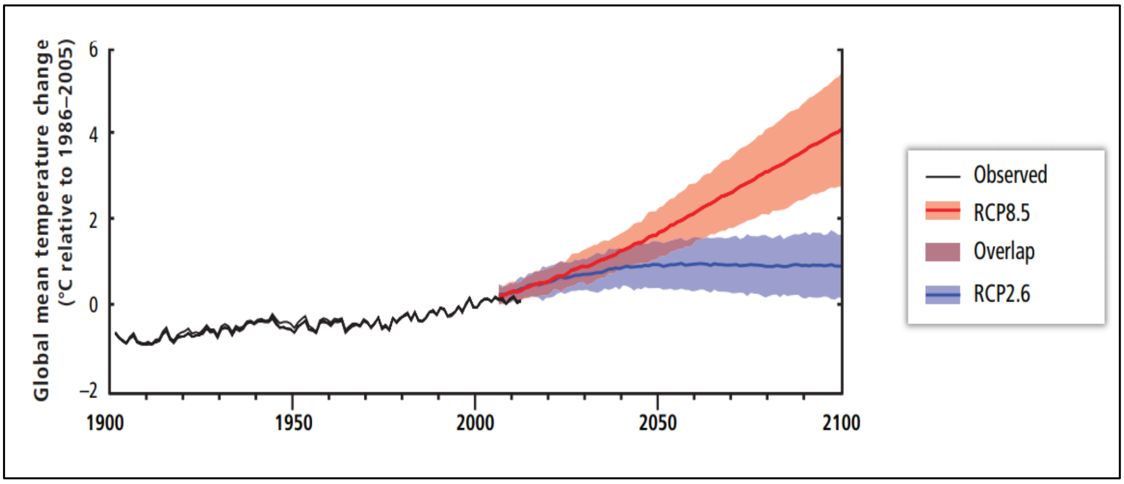

Figure 2-1 Observed and Predicted Changes in Temperature (Source: IPCC, 2014)

Observed changes in precipitation reveal an increase in the number of extreme precipitation events since 1950 (IPCC, 2014). Figures Figure 2-2 and Figure 2-3 show the observed and predicted changes in precipitation. It is predicted that the changes in precipitation will be non-uniform. The sub-tropical dry regions are expected to go drier with reduced precipitation, while mid-latitude areas will experience increased precipitation and an increase in extreme precipitation events under RCP 8.5.

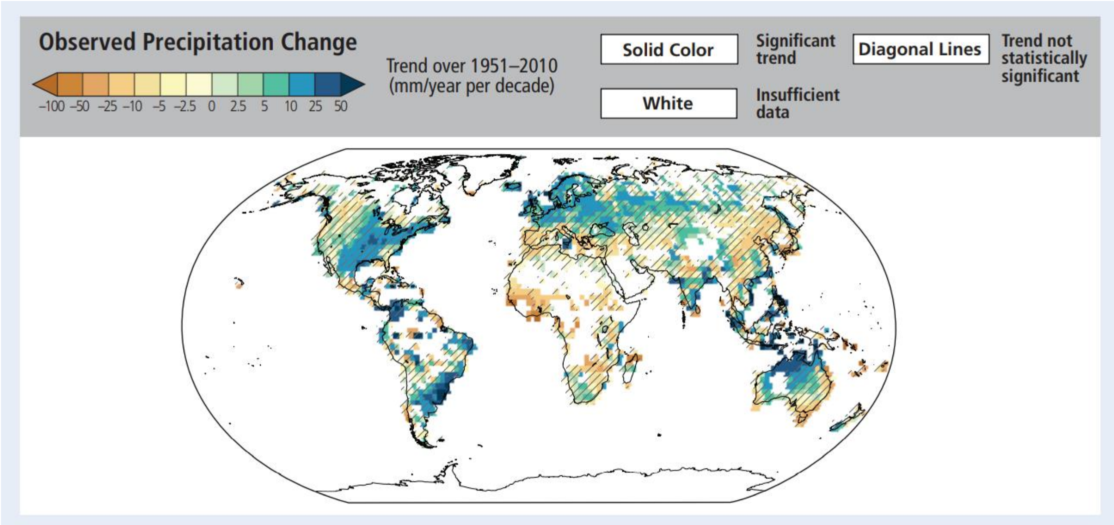

Figure 2-2 Observed Precipitation Changes (Source: IPCC, 2014)

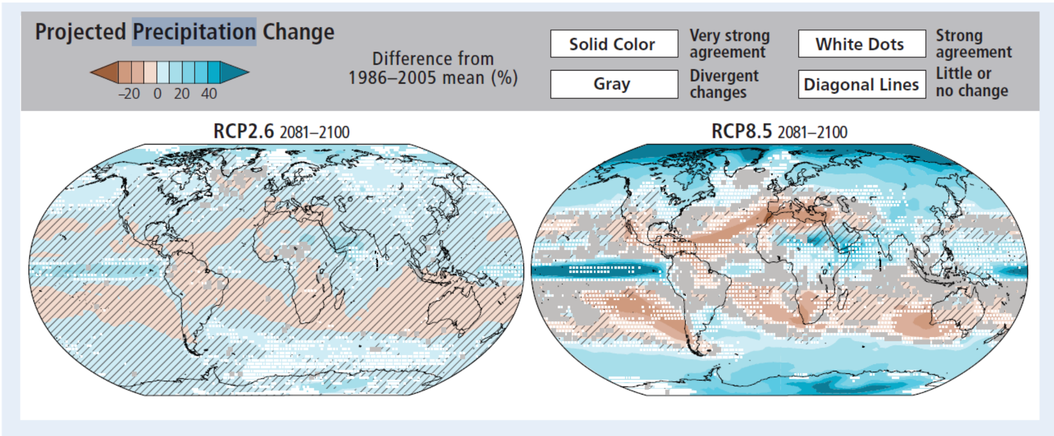

Figure 2-3 Predicted Precipitation Changes (Source: IPCC, 2014)

As per the fifth assessment report, the global average annual precipitation is expected to increase in the 21st century with both increases and decreases of 5% to 20% projected at a regional scale. Global average mean precipitation and evaporation is expected to increase as a direct consequence of warmer temperatures, these increases in global average precipitation are not similar for every location and each season but the model simulations show an increase in some regions while a decrease can be observed in other regions and similarly for different seasons (IPCC, 2008). Evaporation is projected to increase following similar patterns of spatial variation to surface warming. Southern Canada recorded an increase in evaporation without changes in precipitation for the period 1847–1996 (IPCC, 2007a). Earlier models have predicted an increase in the probability of extremely warm days and a reduced probability of cold extremes. Gregory and Mitchell (1995); Hennesy, Gregory and Mitchell (1997), have projected a decrease in the cold extremes in northern temperate mid continental regions. A review of the evidence of the impacts of climate warming on the water by the IPCC suggests that there will be shifts in precipitation timing and change in the regional pattern of precipitation events, with a likely increase in intense precipitation events. An increase in global mean temperature of about 1.5 °C to 4.5 °C would result in an increase in global mean precipitation by about 3% to 15% (IPCC, 1995). Shiklomanov (1991) found significant changes in seasonal runoff compared to the annual runoff due to sudden increases in winter runoff and reduction in spring snowmelt runoff, due to more intense snowmelt in winter. Similar conclusions have been drawn for regions with comparable physiographic conditions (Belgium, Canada, Poland, Scandinavia, Scotland, etc.). The IPCC projects widespread increase in seasonal temperatures and an increase in extreme temperatures in the second half of the 21st century. The long-term global mean temperature records show that the global mean temperature changes are non-homogenous across the globe and not linear as accepted by the scientific community. Global surface temperature increased by 0.74 °C (0.56 °C to 0.92 °C) from 1906 to 2005 with a higher warming trend in the past 50 years (Bates et al., 2008). Vehvilâinen and Lohvansuu (1991) studying the impacts of climate change on discharges and snow cover in Finland under hypothetical scenario (doubling CO_2 concentration) found an increase in mean discharge by 20% to 50% and vanishing of winter snow cover in Southern Finland.

Model predictions for precipitation showed increases in precipitation intensity with spatial variations for an increase in greenhouse gases and these results were consistent with improved, more detailed models (Hennesy et al., 1997; Kothavala and Henderson-Sellers, 1997). Helfer, Lemckert and Zhang (2012) while studying the impacts of climate change on a large reservoir in Australia using nine Global Climate Models predicted an increase in annual evaporation of about 8% due to a temperature increase of 0.9 °C during the period 2030-2050. For the period 2070-2090, the annual evaporation was estimated to be approximately 15% higher than the annual evaporation estimated for the present climate due to a temperature increase of 1.7 °C.

Climate warming in the South Asian region is projected to be greater than the global mean with higher warming in the NEM than the SWM. The RCM projections show widespread warming for areas including Sri Lanka at the end of the 21st century. The IPCC envisage an increase in extreme events for South Asia with an increase in heatwaves and extreme precipitation events (Cruz et al., 2007).

2.2 Climate Change in Sri Lanka

Eriyagama and Smakhtin (2010) have reviewed climate change studies in Sri Lanka and have identified knowledge gaps in relation to the identification of direct impacts of climate change and their quantification in relation to water and agriculture. In their review, the authors summarized the predictions from various papers, Basnayake and Vithanage (2004) predicts 2 °C to 3 °C increase in mean temperature under scenario A1F1, 0.9 °C to 1.4 °C under B1 and 1.7 °C to 2.5 °C under B2. A 2.9 °C increase during the NEM season and a 2.5 °C increase in SWM season was predicted by Basnayake (2008). De Silva (2006b) envisages an increase in mean temperature mainly in the dry zones of the country with increases ranging from 1.6 °C under A2 and 1.2 °C under B2 by 2050. Jayatillake and Droogers (2004) predict an increase in temperature of about 0.5 °C during 2010-2039 and an increase ranging from 2 °C to 3 °C in 2070-2099 in the Walawe Basin with an increase in rainfall. Authors have stated that the rainfall predictions for Sri Lanka are uncertain and inconsistent, with major projecting increases and others projecting decreases in mean annual rainfall. A decrease in NEM rainfall ranging from 26% to 34% and an increase in SWM rainfall ranging from 16% to 38% for the B2-A2 scenarios is projected by De Silva (2006b).

Sri Lanka is expected to become warmer with higher warming in the NEM than the SWM (Cruz et al., 2007). As per the Sri Lankan Centre for Climate Change Studies, climate change in Sri Lanka largely adheres to the regional projections. The temperature projections for Sri Lanka shows an increase of 2.5 ºC and 2.9 ºC by 2100 for the SWM and NEM respectively. Rainfall is anticipated to increase in both seasons with a larger increase during the SWM than the NEM but with spatial variations in these increases and larger increases on the windward side of the central hills. These changes are assumed under ‘medium’ levels of greenhouse emissions (CCS, 2016).

Panabokke and Punyawardena (2009) in their study on rainfall variability in the dry zone of Sri Lanka found an increase in extreme events. Herath and Ratnayake (2004) found a decrease in the mean annual rainfall with the first Inter monsoon showing the highest decrease while analyzing inter-annual and intra-annual rainfall from 1964 to 1993 using daily rainfall in the central region of the country. They also found a considerable decline in the number of rainy days and an increase in their intensities. Punyawardena et al. (2013) have stated that heavy rainfall events have become more common in central highlands in recent years. They also predict drier and wetter dry and wet zones in the future respectively.

Wickramagamage (2015) while examining 30-year daily rainfall data of 48 stations distributed over the island (1981 to 2010) observed spatially variable increasing and decreasing trends in annual and seasonal rainfall. Higher decrease in annual rainfall was observed in the last three-decades. The Southwest Monsoon (SWM) season trends were seen to be primarily negative throughout the country.

Shantha and Jayasundara (2004) have also found a significant decrease in rainfall in the upper Mahaweli watershed area of about 39.12% and have predicted a further 16.6% reduction in the next 21 years using data from 1888 till 1974.

Manawadu and Fernando (2008) studied the spatio-temporal trends of rainfall from 1961-2002 during the four seasons using daily rainfall data from 22 stations and their implications on climate variability and change in recent decades. The authors noted an increase in annual rainfall for Jaffna, Pothvil and Mulativue though with a few missing data and a decrease in the mean annual rainfall for the wet zone and intermediate zones of the country. The authors also found a significant decrease in the number of rainy days in all stations with the exception of the station at Nuwara Eliya but no changes in the total annual rainfall. The authors have attributed this to the increasing intensity of rainfall events together with the increased duration of dry spells. Trends in water volume by watersheds show a decrease in water volumes in the wet zones of the country while a slight increase in the dry zone. The change in the rainfall patterns has affected the paddy farmers since paddy is highly sensitive to changes in temperature, rainfall, and soil moisture. The paddy farmers have changed their plantation and harvesting timing over the past 20 years due to the changes in precipitation timing.

De Silva and Sonnadara (2009) in their study, analyzing monthly data of rainfall and temperature for five stations namely Badulla, Ratnapura, Diyatalawa, Kandy and Nuwara Eliya for a period of 1896 to 2006 saw a significant reduction in the annual rainfall particularly in Nuwara Eliya and positive trend for temperature change in all stations except Diyatalawa. South-West monsoon rainfall showed decreasing trends and increasing temperature trends in all stations except Diyatalawa. The SWM rainfall reduced by 385 mm over the last 100 years and North Western monsoon of about 47 mm and stated that the reduction in annual rainfall is mainly due to SWM. The temperature trends show an increase in both seasons with a mean annual temperature increase of more than 1 ºC in Nuwara Eliya from 1901 to 2001 and a higher contribution to annual changes from NEM. Since the stations were not affected at the same level, the authors have stated that changes due to El Nino Southern Oscillation do not account for in their study as the local effects are altering the monsoon rainfall.

Piyasiri, Peiris and Samita (2004) in their study on climate variability in Agro-ecological regions in low country wet intermediate (IL1) in Sri Lanka examined monthly rainfall and temperature data from 1932 to 2001 on a seasonal and annual basis. A decrease in annual rainfall of 9.0% and 1.4% increase in maximum temperature and significant changes in minimum temperature was observed 10 years prior to changes in the annual rainfall and maximum temperature. The reduction in rainfall was mainly in the First Inter monsoon (25.75%) and Northeast monsoon (15.98%) with a significant change from 1990. Maximum temperature only showed significant changes on the Second Inter Monsoon from 1983 and significant changes in minimum temperature were observed in all four seasons with significant changes in NEM starting from 1998, FIM from 1965, SIM and SWM 1996 and diurnal temperature only showed similarity to the annual changing pattern in FIM. The mean values obtained from their test indicated a decrease in the annual rainfall period from 1992 to 2001 compared to 1932 to 1971 and an increase in maximum and minimum temperature. High variability within a year than between years was also noted. The test also indicated a disturbance to increasing minimum temperature for the period of 1982 to 1991, which they have associated with an unusual weather pattern that had occurred in 1985 in Sri Lanka. Bartlett's test for variance also indicated a significant change for minimum temperature during the 1982-1991 periods with no significant changes in rainfall, maximum temperature and the temperature difference but these changes did not increase or decrease after or before that period. ANOVA and Bartlett test showed that changes in climate were with respect to annual rainfall, maximum, minimum and diurnal temperature and with Man-Kendall non-parametric statistic, the starting points of significant climate change with respect to the above four climate variables were found to be from 1986, 1983, 1970 and 1988, respectively. Piyasiri, Peiris, and Samita (2004) have correlated diurnal temperature with the cloud cover thereby confirming a reduction in rainfall. Linear trend analysis further showed that the rate of decrease in rainfall is higher than the diurnal temperature and higher increases in maximum temperature than that of minimum temperature.

De Silva, Weatherhead, Knox and Roriguez (2007) studied the impacts of climate change on paddy irrigation water requirements in Sri Lanka using climate projections for Sri Lanka which were derived from the outputs of the UK Hadley Centre for Climate Prediction and Research model, HadCM3 (Gordon et al., 2000) for the Scenarios A2 and B2. Their results suggest a 17% decline in average rainfall in the wet season under the A2 scenario, and a 9% decline under the B2 scenario, with shorter rainfall periods. They also saw an increase in potential evapotranspiration of about 3.5% under the A2 scenario and 3% under B2. As a result, the average paddy irrigation water requirement increased by 23% under A2 scenario and 13% under B2. Further the authors highlighted considering spatial variability after finding variations in impact of climate change across the country. Higher increases in wet season (Maha season) paddy irrigation requirements were noticed in both the scenarios but a positive impact was found for the extreme south part of the country.

Wijesuriya, Sepalika and Amarasekera (2005) studied the changes in dry spells in several rubber growing zones of Sri Lanka. Daily data were observed on yearly, monthly and standard weekly basis for 14 stations for two-time scenario's: viz. 1941-1970 and 1971-2000. Days with rainfall < 0.5 mm per day were considered as dry days and weeks receiving less than 10mm as dry weeks. The probability of receiving rainfall less than 10 mm in different standards of the weeks of different locations was higher during the 1971 to 2000 period compared to 1941 to 1970. Thus, an increase in dry spells over the recent years compared to the previous years had been observed.

Ampitiyawatta and Guo (2009) found decreasing trends of annual precipitation while investigating the annual and monthly precipitation trends in the Kalu Ganga basin using Mann-Kendall statistical test. The decreasing trends of annual precipitation were attributed to climatic changes within the basin that affected the magnitude and timing of the precipitation within the study area. A trend of -0.98 was identified with an annual rainfall reduction of 12.03 mm/year.

Wickramagamage (2010) examined the temporal and spatial pattern of rainfall in Sri Lanka using monthly rainfall data covering over 646 rainfall stations in Sri Lanka. A significant correlation was observed between most of the stations. Months within the same season were found to show the best correlations except for October. The spatial pattern of these months was similar for the strongly correlated months.

Malmgren, Hulugalla, Hayashi and Mikami (2003) studied the rainfall trends in Sri Lanka at 15 climate stations from 1870 and their connection with the El Nino Southern Oscillation (ENSO). A statistically significant trend in SWM rainfall was seen at five rainfall stations, with three stations showing an increase of 100mm/month and two stations showing a decrease in rainfall amounting to 150 mm/month. Stations located at higher elevations were noted to show a loss of rainfall while those showing heightened rainfall were found to be located in the lowlands in the Southwest. The NEM did not show any significant changes over time.

De Silva (2006a) found a small increase in annual average rainfall while using climate datasets for Sri Lanka from the UK Hadley Centre for Climate Prediction and Research model (HadCM3) for selected IPCC SRES scenarios for the 2050s. An increase in the southwest monsoon rainfall and a decline in the northeast monsoon rains along with an increase in annual average temperature was observed at the stations. The baseline period (1961-1990) showed the highest PSMDmax in the northern and eastern parts of the country. An increase of about 12% PSMDmax as compared to the baseline under the A2 2050 scenario was observed for the northern regions of the country.

De Costa (2008) while analyzing long-term monthly data from 1869 to 2007 at seven selected stations representative of the climatic zones of the country found a warming climate and declining rainfall in the stations but with significant variations between the stations and their rates. The majority of the locations were found to have exceeded the global average warming rate of 0.074 °C per decade from 1906 to 2005, thus revealing the impact of global scale climate change on the climate of Sri Lanka. The study did not assess the relationship or subtleties of variation of the variables. The paper stipulates the urgent need for investigations on such connections and their spatial and temporal variations to increase the knowledge of climate change impacts in Sri Lanka.

2.3 Data Requirements and Climate Change Detection Methods

Hegrel et al. (2004) have stated that observations for the climate change detection approach should cover a longer time period to distinguish an emerging anthropogenic signal, typically 20 years to 50 years. These changes in climate can be detected by analyzing fundamental statistics such as mean, standard deviation, coefficient of variation. Most studies have worked with monthly data while analyzing climate change impacts. Since the seasonal patterns and inter-annual fluctuations of precipitation significantly alter the availability of surface water resources, most studies recommend working with monthly data for planning and management of water resources while finer resolution data (Daily data) are mostly used for flood analysis.

While most studies have used linear regression to identify trends in the climate parameters, the intrinsic variability of the hydrological time series often conceals the trends. Hence smoothing techniques is often suggested to decrease the effect of random variations and cyclic patterns. Moving averages are the most simple and common method for smoothing long term fluctuations (Nandargi and Mulye, 2014). The most common moving average period adopted by most studies is five- to ten-year moving averages. Nandargi and Mulye (2014) have used seven-year moving averages while testing moving average periods of three, five, seven, and nine-year moving averages because of the disappearance of shorter oscillatory components.

Nonparametric tests have been widely preferred over the years for trend analysis. These tests are not sensitive to anomalies and comparatively robust against missing values (Ahmadi et al., 2017). The Mann-Kendall (MK) test, by Mann 1945 and Kendall, 1975 is a progressively well-known trend test and widely used method, proposed by the World Meteorological Organization (WMO) for examining trends in hydrological and meteorological data (Kumar et al., 2009). Numerous investigations have been done to detect trends in hydrometeorological variables utilizing non-parametric tests such as Mann-Kendall. The test has been found to be an effective tool for identifying trends in hydrometeorological variables (Ampitiyawatta and Guo, 2009b; Elnesr et al., 2010; Mondal et al., 2012; Xu et al., 2003; Zeng et al., 2001).

2.3.1 Linking climate change and water resources

The following sections present a review of the inputs and output required for the evaluation of climate change impacts on water resources.

2.3.1.1 Global climate changes and impacts on water resources

A review of climate change impact studies highlights the susceptibility of water resources to climate change. The findings reveal largescale changes in the overall system with small changes in climate variables (IPCC, 1995). The effect of elevated (Carbon dioxide) CO_2 levels on transpiration has been observed in many studies. Rosenberg et al. (1990) suggest a reduction in transpiration by about 50% with a doubling of CO_2. Nan, Hui, and Chunkun (2011) in their comprehensive review on water resources and climate change studies elucidate the impacts of climate change on hydrology and water resources through basin temperature; precipitation and evaporation, which may tend to increase or decrease the runoff and its watershed water supply. Observed and projected increases in temperature, evaporation, and sea level and the varying precipitation patterns impact the overall management of freshwater systems (Parry, Canziani, Palutikof, van der Linden and Hanson, 2007). Globally, most studies have been carried out for trend analysis of climate variables such as rainfall, temperature and evapotranspiration for identifying changes in climate (Dore, 2005; Kruger and Shongwe, 2004; New et al., 2006; Warburton and Schulze, 2005). Others have related increases in the occurrence and intensity of extreme events such as floods and droughts as evidence of a changing climate.

The IPCC (2008) has stated that the most important climate drivers of water availability are temperature, rainfall and evaporation. Studies from across the globe have looked into the potential impacts of climate change on hydrology and possible changes in water balance, such as changes in streamflow over the year. Most climate change studies have used precipitation, temperature and evaporation as climate variables to quantify impacts on streamflow. An increase in temperature enhances rates of evapotranspiration and precipitation, which in turn intensifies the hydrological cycle and affects water resources. The interaction between rainfall, catchment physiography and land use is an important aspect of understanding catchment hydrology. The increases and losses must be quantified so that the net water available can then be redistributed taking stakeholders needs into account. These impacts of climate change are expected to vary spatially and temporally due to different catchment physiographic, antecedent conditions, rainfall quantity, intensity and distribution that affects the runoff, soil moisture, evaporation and drainage and eventually surface and groundwater resources.

Studies on the impact of rainfall on runoff have shown that temporal and spatial variability in runoff is strongly influenced by the temporal and spatial variability in rainfall, which substantially affects the surface water resources and groundwater (Milly & Eagleson, 1988; Loague, 1988). In Australia, a clear shift in climate has increased the temperature and reduced rainfall since the 1970s resulting in a decline in the available water resources (Barron et al., 2011). Seasonal runoff distribution is expected to change significantly as a result of climate change with a greater impact on winter runoff as a result of reduced snow cover and an increase in frequency and intensity of storms (Arnell, 1995). In humid locations, it was found that about 93% to 96% of the variation in annual ground water recharge, streamflow and total water yield was due to seasonal precipitation amounts, summer and autumn precipitation during the previous year (Nichols and Verry, 2001). Nash and Gleick (1993) projected a decrease in runoff of 3% to 12% following a 2°C increase in temperature and a decrease of 7% to 21% with an increase in temperature of 4°C with no change in precipitation. Schaake (1990) found higher sensitivity of runoff to precipitation changes than to temperature. An increase in temperature of 1°C resulted in runoff declines of 50 %, for reduced precipitation of 10% and an increase of 50% for a 10% increase in precipitation. Labat, Godderis, Probst, and Guypt (2004) have demonstrated a relationship between global warming and its impact on the hydrological cycle. An increase in total global runoff of 4% for a 1 °C increase in temperature was observed for the 20th century, but with regional differences.

Groisman and Kovyneva (1989) studying the annual mean surface temperature averaged over the extra-tropical zone of the Northern Hemisphere as a global variable observed that an increase in the mean surface air temperature has resulted in increasing precipitation over India. They used a set of statistical estimates for the parameters describing the relationship between changes in global climatic variables and those in local climatic characteristics for different seasons of the year.

The IPCC (2007) has highlighted impacts on water resources under climate change from across the globe. In the arctic drainage basins, annual streamflow increases of 5% and an increase in winter streamflow of 25% to 90% over the period of 1935 to 1999 along with an increased winter baseflow were observed due to the increase in melting and thawing of permafrost. In Western North America, New England, Canada and Northern Eurasia, 1 to 2 weeks earlier peak streamflow was observed due to earlier snowmelt over the period of 1936 to 2000. In the Russian Arctic Rivers, heavy rainfall and earlier thawing of ice resulting in increased frequency of floods ranging from 0.5% to 1.0%

were observed in recent years. Annual streamflow decline of 29% was observed as a result of increasing temperature and evaporation without changes in precipitation in Southern Canada from 1847 to 1996. Dry and warmer summers were observed due to the warming of the pacific ocean and Indian ocean in the Western USA from 1998 to 2004. The trends in streamflow volume across the world cannot be definitely related to changes in temperature or rainfall due to a lot of other factors. However, climate change related impacts are most likely colossal changes and enhanced glacier retreat and shifts in streamflow timing (Arnell and Liu, 2001). As per observations in Lake Chad, which is one of the world's largest and oldest Lake in the Sahel region of Africa, the water levels have declined since the flows had reduced to 50% as compared to their long-term flow of over 40 km^3/annum since 1971 because of a rainfall reduction of 25%. This demonstrates the impact of small shifts and changes in rainfall on streamflow in a semi-arid region (Evans, 1996).

Shiklomanov (1991) found significant changes in seasonal runoff compared to the annual runoff due to a sudden increase in winter runoff and reduction in spring snowmelt runoff, due to more intense snowmelt in winter. Similar conclusions have been drawn for regions with comparable physiographic conditions (Belgium, Canada, Poland, Scandinavia, Scotland, etc.). Model predictions under increased greenhouse gases show an increase in precipitation intensity with regional variations (Kothavala and Henderson-Sellers, 1997; Hennesy et al., 1997). It is projected with high confidence that runoff will increase by about 10 to 40% by mid-century in the wet tropical areas of East and South-East Asia at higher latitudes and decrease by 10 to 30% in dry tropics at mid-latitudes due to decrease in rainfall and higher rates of evapotranspiration. In the South Asian region, warming is expected to be more than the global increase in temperature with higher warming in the NEM.

Milly, Dunne and Vecchia (2005) have stated that water resources will be affected because the hydrological cycle is sensitive to temperature perturbations. In their study on trends in streamflow and water availability under climate change, they have used 12 climate models and have projected an increase in runoff of 10% to 40% in eastern equatorial Africa, La Plata basin, North America and Eurasia and 10% to 30% decrease in runoff in Southern Africa, Southern Europe and the Middle East by 2050. The authors found strong global-scale relations despite the presence of large local-scale differences between the model ensembles. The uncertainties of climate change models are because of different assumptions of greenhouse gasses.

Gosain, Rao and Basuray (2006) in their study quantifying the impact of climate change on water resources in Indian river basins using a regional climate model to determine the spatio-temporal water available in the river along with a distributed hydrological model SWAT to simulate the hydrological cycle at daily time steps found a reduction in the runoff under GNG scenarios of simulated weather data overall and two basins namely Krishna and Mahanadi were predicted with severe drought and flooding, respectively. Ghosh and Mujumdar (2008) in their report stated that a decrease in monthly flows in the Mahanadi River is observed but no significant change in the median of the monsoon flows. The decreasing trend in the monthly flows was attributed to high surface warming. Murphy and Ellis (2014) in their study on the stationarity of climate and streamflow in watersheds of the Colorado River Basin analyzed temperature and rainfall. The authors found statistically significant temperature increases in all catchments with persistently non-stationary time series in the recent record relative to the earlier historical record but stationary precipitation and runoff. The authors' results were contradictory to the modelling research where non-stationary had been found.

Ahmad, Tang, Wang and Wagan (2015) studied the precipitation trends over a period of 51 years from 1961 to 2011 using Mann-Kendall and Spearman's Rho test in Swat River Basin, Pakistan. The results showed a combination of increasing and decreasing trends in precipitation on a monthly, seasonal and annual scale. Annual precipitation trends were statistically insignificant for the sub-basins.

Chiew, Peel, Mcmahon and Siriwardena (2006) assessed the sensitivity of streamflow to climate using a nonparametric estimator to estimate precipitation elasticity of streamflow (εP) defined as the proportional change in mean annual streamflow divided by the proportional change in mean annual precipitation for 500 catchments across the world which was proposed by (Sankarasubramaniam et al., 2001). The results indicated that the increases/decreases in precipitation were magnified in streamflow. Southeastern Australia and southern and western Africa showed higher εP values (greater than 2.0), while southwestern South America and mid and high latitudes in the Northern Hemisphere showed lower εP values (lower than 2.0).

Studies have shown that comparatively small changes in temperature and rainfall can have large impacts on runoff.

2.3.1.2 Climate change and its impact on water resources (Sri Lanka)

Wijesekera (2010) while reviewing a set of selected literature on climate change and surface water resources found that research related directly to the assessment of surface water resources on spatial and temporal scales were fairly limited and those that were available were not quantitative.

Zubair (2003) studied the influences of El Nino/Southern Oscillations (ENSO) on streamflow of the Kelani river basin. The El Nino conditions were found to be linked with lesser annual rainfall and La Nina with the opposite but during October to December, the opposite was true. This ambiguous result was associated with the dry soil conditions and reduced groundwater recharge during El Nino summers concealing the rainfall influences on streamflow.

Niroshinie, Babel and Herath (2016) analyzed different flooding situations due to climate change in Colombo using GCM data for extreme rainfall scenarios under future climate in the Kelani basin. The authors observed an increment of 1.5% to 2.5% in extreme rainfall events with the CSIRO Mk2 model under the A2 SRES scenario in Colombo and an increment of more than 20% in upstream. They observed variations in seasonal rainfall and an increase in flood inundation areas under climate change.

De Silva, Weerakon, Herath, Ratnayake and Mahanama (2012) in their study, found the areas vulnerable to flood in the lower Kelani river basin under future climate change scenarios by using the HEC-HMS model and Statistical Downscaling Model in A2 and B2 scenarios. The authors observed that the inundated areas generated using 2D flow modelling for 50 years rainfall return period would further expand in the 100 years return period. De Silva and Sonnadara, (2009) have also found an increase in rainfall extremes under changing climate in the future in the Kelani river basin.

2.4 Climate Change Indicators for Assessing Impacts on Water Resources

The use of indicators to assess the status and impacts of climate change on water resources is highly significant. The impact of climate change on the hydrological cycle is grounded on the changes observed on hydrological indicators such as the potential evapotranspiration, precipitation and runoff (Arnell, 1998).

2.4.1 Metrological drought indicators

Rivas and Lizama (2005) studied the impact of climate variability on water resources for the Bulgarian South Black Sea basin using rainfall data from 1952 to 2002. The long-term variability of the runoff was examined to investigate any changes occurring in its characteristics and the long-term variation of the precipitation. High temperature and low precipitation conditions in the region which are conducive to drought were found and hence Standardized Precipitation Index (SPI) was used to understand the different impacts that the precipitation deficit has on groundwater, reservoir storage, soil moisture, snowpack, and streamflow. The SPI values indicated a tendency for drought in Southeastern Bulgaria, the period from 1985 to 1994 was a drought in the study region. The runoff regime in the catchments was considerably affected by the variability caused by precipitation fluctuations and other landscape elements with a negative trend from 1952–2002 in the annual runoff. The results showed that runoff had decreased noticeably over the study area in recent years due to a considerable decrease in precipitation and an increase in temperature in the region.

Adeaga (2006) examined the probable impacts of rainfall variations on the hydrological system and water resources in the Ogun-Oshun River Basin (southwestern Nigeria) using rainfall data from 1944 to 2000. Indices of precipitation rainfall stability (RRS) was used to check the rainfall stability and the instability of the hydrological regime (IHR) was used to identify the impact of rainfall on the hydrological cycle of the Ogun-Osun River Basin. Lagos Island was found to have the lowest rainfall stability while

Osogbo station showed the lowest instability of the hydrological regime. The study found the coastal stations to have the least stability and suggested developing appropriate water resources management plans. The decadal patterns in rainfall indicated an increase in the overall mean in the 1990s. Comparatively wetter conditions were observed in the 1950s and relatively dry conditions were observed in the 1980s.

Blazejcyk, Wolowickz, Labedzki and Kunert (2005) studied the seasonal and annual variations in precipitation and their impacts on the hydrological and ecological cycle at a regional scale. They have used two indices to validate the hydrological regime: an Index of Rainfall stability (RRS) and an index of Instability of Hydrological regime (IHR) and found weak stability of precipitation at Kujawy which is one of the causes of the unstable hydrological regime of this region. They have also observed the highest IHR values at Kujawy and also found that in the dry years in the Notec valley, the effects of water scarcity are greater in dry soils (the C complex with worse retention properties) than in the periodically dry ones (the BC complex). The lowering of the groundwater table depth caused a reduction in water used for evapotranspiration and hay yield from meadows.

2.4.2 Agricultural drought indicators

De Silva (2006b) studied the potential soil moisture deficit under climate change to predict irrigation water needs in Sri Lanka. The study used a simple water balance model to assess the annual maximum deficit in soil moisture using climate datasets s from the HadCM3 and IPCC SRES scenarios: A2 and B2 for the 2050s. FAO Penman-Monteith equation was used to calculate Reference Evapotranspiration (ETo).

Maximum Potential Soil Moisture Deficit was calculated as follows:

$$PSMDi = PSMDi\text{-}1 + ETi - Pi \qquad (2\text{-}1)$$

Results showed an increase in PSMDmax (Maximum Potential Soil Moisture Deficit) in dry and intermediate zones of the country (North, Northeastern and Southeastern parts). In the dry and intermediate zones, predicted average increases in PSMDmax above the baseline were found to be in the 8%-53% range for the 2050s under the A2 scenario.

Tigkas, Vangelis and Tsakiris (2012) used Reconnaissance Drought Index (RDI) introduced by Tsakiris and Vangelis (2005) which requires two parameters, the cumulative precipitation (P) and potential evapotranspiration (PET) for forecasting the annual hydrological drought in Larissa valley, Central Greece. Precipitation and temperature data from 1955-2002 were used for the study and effective precipitation was used instead of actual precipitation. Linear regression equations linking the (RDI) reconnaissance drought index and the streamflow drought index — SDI (characteristic index of hydrological drought) was used for producing nomographs. Nomographs were devised for estimating expected streamflow reductions in case of climatic change or during drought events. The correlation coefficient (r) for the three reference periods; 12-month (October-September), 9-month (October-June) and 7-month (November-May) was used as a simple indicator of the performance of RDI and RDIe (Using effective rainfall). The results indicated that RDIe performed better for the three tested periods and showed that it could improve the link between drought severity and the reduction of agricultural production.

Schneider (2008) used a low parameterized water balance model created based on a nonlinear transfer-function approach that transforms a distributed effective water input into a characteristic regime at the outlet of the catchment to study the impacts of climate change on catchment storage, streamflow recession and summer low flow. The authors explored the sensitivity of the catchment hydrologic regime focusing on precipitation and snowmelt. The model structure was optimized to use mean precipitation and temperature data to forecast trends in mean low flows. The author observed that the fitting of summer low flows was comparatively more difficult than the snowmelt-peak and winter low flows. The results of the model indicated earlier and diluted spring peak flow according to the CGCM A2 and B1 climate scenario for the 2050s and that the significant changes during the low flow periods depend on the catchment and climatic characteristics. The authors have also found that the catchments with large unconsolidated rock aquifers and enough water available tend to be less sensitive to climate change without showing any significant changes in summer low flows.

Mimikou, Baltas, Varanou and Pantazis (2000) studied the regional impacts of climate change on the quality and quantity of water resources in the Pinios river situated in the Thessaly district in central Greece. A monthly water balance model (WBUDG) was used to check the water resources quantity with input parameters as rainfall, relative humidity, temperature, sunshine duration and wind speed, and output parameters as soil moisture, runoff and evapotranspiration. Under the climate change scenarios considered, i.e. transient (HadCM2) and equilibrium (UKHI), an increase in temperature was noted along with a drop in precipitation resulting in a considerable decrease of runoff for the majority of the months and a significant negative impact on droughts during summer.

Araújo and Brito (2011) statistically investigated the fluctuations in annual precipitation for Bahia and Sergipe states with daily precipitation data from 1947 to 1991. The sea surface temperature (SST) anomalies of the Pacific and Atlantic oceans and their relationship with the climate change indicators/indexes were assessed. A decrease of CWD (Consecutive Wet Days) was found with increases in the number of rainy days, and an increase in the amount of annual total precipitation. The authors concluded that the climate change occurring in the area surveyed, with respect to the variable weather precipitation, suggest that these are due to global climate changes. However, since many localities showed positive trends or negative for all indices examined, these were also linked to regional aspects. The daily intensity index showed a correlation between Niño 4 (Pacific) and northern (Atlantic) signifying the influence of SST in the Atlantic and Pacific Oceans on precipitation in the study highlight the role of ENSO.

2.4.3 Hydrological indicators

Yang and Liu (2011) investigated the climate change impacts on streamflow in the Yellow River basin (YRB) of China. The authors studied the temporal trends of streamflow and examined the relationship between precipitation and evapotranspiration. They used a water balance model and Budyko’s method to study the variations in streamflow. They found precipitation to be the main variable responsible for water availability and alteration of the hydrological system, while evapotranspiration had only a small impact on streamflow between climate, soil, and vegetation, in water scarce regions. The precipitation and evapotranspiration signalled a nonlinear relationship with the streamflow changes. The streamflow responses showed the intricate connections between climate, hydrology and vegetation in the catchment. The authors have quoted (Chiew, 2006; Yang et al., 2009) stating that the relationship between precipitation and streamflow exhibits a nonlinear relationship at different time scales. They have further investigated the sensitivity of streamflow to precipitation and the potential evapotranspiration and have found increasing precipitation to show more changes in the streamflow as compared to a decline in precipitation, while evapotranspiration increases/decreases were found to have an opposite impact on the streamflow.

Lee, Cho, Kang and Kim (2013) studied the effects of climate change on the Nakdong river streamflow using hydrological indicators. The Soil and Water Assessment Tool (SWAT) model was used to examine the impacts on the hydrological cycle as a result of Climate Change and change in Land use. They found land use changes at 74.5% in the 1980s to be a major cause of changes in the basin hydrology while climate change contributed only 21.3%. During the 2000s, climate change was seen to contribute more to hydrological change with about 57.7% while land use change contributed only 42.0%.

The gaps and priorities identified from the literature review are presented in Table 2-1. Table 2-2 shows the literature summary details.

Table 2-1 Gaps and Priorities

Gaps	Priority
Spatial variability of Climate variables within catchments and their relation	There is a need to study the relation between the changes in the climate parameters and the spatial and temporal variation of these variables
Cause-and-effect relationships of the Changes in climate variables and their impacts on water resources	Investigations in different catchments in the region to understand the variability and impacts associated
Significance of the climate variable trends in relation to global changes	Climate change in Sri Lanka and its consistency with regional and global studies,

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Table 2-2 Literature Summary

	Global, Regional or Local References		What has been done for Sri Lanka and in what location, spatial scale etc.		Gaps	Priority
	Reference	**Findings**	**Reference**	**Findings**		
Monthly Rainfall	Hennessy et al. (2007)	May–July rainfall in Australia has shown a substantial decline since the mid-20th century which has caused a decline of 50% in annual inflows to the reservoirs supplying water to the city of Perth	De Costa (2008)	Decrease in rainfall of 8% and 21% for April and May months respectively. The rainfall in the main harvesting season (Maha season) has also reduced due to a 19% decline in December rainfall	The study has pointed out the need to investigate the interactions of climate variables, their spatial and temporal variations and their impacts on water in Sri Lanka	There is a need to study the relation between the changes in the climate parameters and their impacts and also the spatial and temporal variation of these impacts
			Malmgren, Hulugalla, Hayashi and Mikami (2003)	Observed inconsistent trends in rainfall across Sri Lanka. Found stations showing loss of rainfall restricted to the higher elevations while those displaying increased rainfall situated in the lowlands for different periods starting from 1869 to 2000. Most stations showed a	Although the study has tried to relate changes in precipitation with ENSO impacts, the paper does not consider local impacts or influences/relation with other climate parameters	There is a need to study the impacts of precipitations variability both spatial and temporal and their relationship with other climate variables

	Global, Regional or Local References		What has been done for Sri Lanka and in what location, spatial scale etc.		Gaps	Priority
	Reference	Findings	Reference	Findings		
				substantial increase in Second Inter-monsoon precipitation during El Ni˜no years, while other stations showed enhanced SWM precipitation during La Ni˜na years		
			Wijesuriya, Sepalika and Amarasekera (2005)	Observed increase in the maximum dry run and the variability in most locations while examining daily rainfall patterns over the period of 1941-1970 and 1971-2000 over the country and an increase in dry spells in the recent decades	The study has not tried to relate the observed changes and dry spells with the increasing temperature or with other climate variables	There is a need to study the relationship amongst the climate parameters and their impacts

	Global, Regional or Local References		What has been done for Sri Lanka and in what location, spatial scale etc.		Gaps	Priority
	Reference	**Findings**	**Reference**	**Findings**		
	Cruz et al (2007)	For the South Asian region, the majority of AR4 models predict decreasing precipitation in the months of December, January and February (DJF), which are in line with earlier findings	Wickramagamage (2010)	The study found four spatiotemporal rainfall modes; the weak southwest (SW) mode from March to April, while strong SW mode was observed for May to October, strong NEM mode from December to February and mixed mode in November	The study has carried out simple correlation analysis to determine spatial modes of rainfall, the study has not considered variations or shifts in these modes across timescales	This points for a need for analyzing the variations and shifts in these spatial modes over the years
Seasonal Rainfall	Kothavala et. al. (1997)	Model simulations suggest that the increase in mean precipitation over the Midwest USA, caused by the intensification of the hydrological cycle under enhanced greenhouse gases is expected to cause a rise in the rate of recurrence of extreme events	Jayatillake et al. (2005)	No substantial changes in rainfall for the SWM and the IM2, rainfall in the NEM (Maha season) and the IM1 has reduced with the NEM showing increased variability. Shift in boundary lines of existing rainfall zones as a result of changing rainfall	The study suggests using climate and hydrological models to project Streamflow changes and limited studies have tried to estimate the streamflow	This highlights the need for coupled assessments of climate variables and hydrological parameters to determine impacts on the streamflow

	Global, Regional or Local References		What has been done for Sri Lanka and in what location, spatial scale etc.		Gaps	Priority
	Reference	Findings	Reference	Findings		
	Boko et al. (2007)	The rainfall deficit in the Sahel region as a result of a decline in the significant number of rainfall events during the peak monsoon period				
	Nichols and Verry (2001)	93% to 96% of the variation in annual groundwater recharge, streamflow and total water yield was due to seasonal precipitation amounts, summer and autumn precipitation during the previous year	De Silva (2006)	Forecasts an increase in wet zone rainfall and a decrease in the dry zone rainfall roughly 26-34% decrease in the NEM rainfall and a 16-38% increase in the SWM rainfall under B2-A2 scenario compared to 1961-1990;	The results show changes in rainfall in the future but are limited to only one future time scale. The study has also used only one GCM for the projections	There is a need to study these rainfall reductions at finer scales/catchments so as to enable proper planning and water management
	Cruz et al (2007)	Spatial irregularity in rainfall has been detected over the last decades across Asia	Malmgren, Hulugalla, Hayashi, and Mikami (2003)	All the stations did not show any major change in NEM. During the El Ni˜no years, higher SIM rainfall was noted	The study has carried out simple correlation analysis to determine spatial modes of rainfall, the study has not considered variations or shifts in	This points for a need for analyzing the variations and shifts in these spatial modes over the years

	Global, Regional or Local References		What has been done for Sri Lanka and in what location, spatial scale etc.		Gaps	Priority
	Reference	Findings	Reference	Findings		
					these modes across timescales	
	IPCC (2008)	Projections for the 21st century reveal an increase in precipitation for the high latitudes and portions of the tropics and a likely decline in some subtropical and lower mid-latitude regions	Herath and Ratnayake (2004)	Decrease in the mean annual rainfall in the central mountainous region with the first Inter monsoon showing the highest decrease while analyzing inter-annual and intra-annual rainfall from 1964 to 1993 using daily rainfall. The results show a decrease in inter-monsoon rainfall, with shorter intensities and return period of extreme events which were associated with regional climate change	The paper tries to relate the observed changes of the rainfall to impact on water resources, using only rainfall statistical analysis	The paper suggests carrying out similar studies in other locations to understand the variability and impacts of climate change and their consistency with regional and global studies, it may be necessary to relate and study changes in rainfall with other climate parameters to point out the adverse impact

	Global, Regional or Local References		What has been done for Sri Lanka and in what location, spatial scale etc.		Gaps	Priority
	Reference	Findings	Reference	Findings		
	Hoanh et al. (2004)	The results showed an increase in maximum monthly flows ranging from 35 to 41%in the basin and 16 to 19% in the delta, while the minimum monthly flows were projected to decrease by 17 to 24% for the basin and 26 to 29% for the delta.	De Silva and Sonnadara (2009)	Statistically significant reduction in annual rainfall particularly in SWM by 385mm over the last 100 years and North Western monsoon of about 47mm for a period of 1896 to 2006	The paper points out that other than ENSO impacts, there are local effects that are affecting the monsoon rainfall in the region. The paper has not investigated more on the rainfall regime and local impacts	It may be important to study the patterns and changes in rainfall at the catchment scale to understand such impacts
			De Silva, Weatherhead, Knox and Roriguez (2007)	17% decline in average rainfall in the wet season under (A2) scenario, and 9% (B2), with rains ending earlier	The study points out the need for considering spatial variation after finding spatial variations in impacts on irrigation paddy requirements	There is a need for analyzing spatial variability of impacts of changes in rainfall and other climate parameters on the available water
Annual Rainfall			Basnayake and Vithanage (2004)	Rainfall declines of 7% for the period of 1961 to 1990 compared to 1931 to 1960 while increment in rainfall was observed on the western slopes of		

	Global, Regional or Local References		What has been done for Sri Lanka and in what location, spatial scale etc.		Gaps	Priority
	Reference	Findings	Reference	Findings		
				central hills compared (windward side) to the leeward side		
			Piyasiri, Peiris and Samita (2004)	Decline in rainfall during 1986 to 2001 compared to annual rainfall 1932 to 1985 is 9%. Impact of the reduction is due to the reduction in NEM and FIM	The study has stated that the reduction could be due to enhanced GHGs and that such changes could negatively impact crop productivity. It has not tried to establish the relationship between climate warming and rainfall reductions or their impacts on the crop water	There is a need to study the rainfall changes and relate them with changes in temperature and other climate parameters so that the impact on the resulting runoff can be assessed
			Shantha and Jayasundara (2004)	Considerable amount of the rainfall in the Upper Mahaweli has been reduced by 39.12% during the past hundred years. They project a declining trend of 16.6% for 21 years	Though the study has used over 100 years of data, the study does not mention about the data quality or any checks in regard to the data,	The studies need to specify their data and data collection methods properly in order to assure the reliability of the results

	Global, Regional or Local References		What has been done for Sri Lanka and in what location, spatial scale etc.		Gaps	Priority
	Reference	Findings	Reference	Findings		
			Marambe et. al. (2015) Punyawardena et. al. (2013)	Increasing temperature and increased rainfall variability in the country, dry zone getting drier		
			Wickramagamage (2015)	Higher and consistent decline in rainfall in the SWM across the country		
Monthly Streamflow	Milly et al. (2002)	The 100-year monthly flows at 15 out of 16 large basins worldwide are predicted to be surpassed more for a fourfold increase in CO_2. An increase in the frequency of 100-year flood is projected for some areas, however with large uncertainty				
	Zhang et al. (2005)	The snowmelt contribution to streamflow in most of the temperate regions is likely to decrease	De Silva (2006)	Found out a significant increase in the maximum annual soil moisture deficit in the dry zone as a	The study has not tried to quantify the impacts on the available water but has tried to relate the	The need for studies and assessment on variations and impact on the streamflow for catchments due to

	Global, Regional or Local References		What has been done for Sri Lanka and in what location, spatial scale etc.		Gaps	Priority
	Reference	**Findings**	**Reference**	**Findings**		
				result of decreased rainfall and increasing temperature,	increase in PSMD and water stress	changes in climate parameters
	Zhang et al. (2001)	Found a decrease in annual maximum daily streamflow of 29% due to an increase in temperature and increased evaporation without significant changes in precipitation				
	Nash and Gleick (1993)	Found decline in runoff of 3 to 12% for a 2°C rise in temperature and 7 to 21% for a rise of 4°C with no change in precipitation				
Annual Streamflow	Vehvilâinen and Lohvansuu (1991)	Under a hypothetical scenario (doubling CO_2 concentration) found an increase in mean discharge by 20–50% and vanishing of winter			There is a need to understand and quantify the impacts of climate parameters on the streamflow	The study points out the need for studying climate parameters and their relation and impacts on the streamflow in a basin

	Global, Regional or Local References		What has been done for Sri Lanka and in what location, spatial scale etc.		Gaps	Priority
	Reference	Findings	Reference	Findings		
		snow cover in Southern Finland.				
	Barron et al. (2011)	In Australia, a clear shift in climate has increased the temperature and reduced rainfall since the 1970s resulting in a decline in the available water resources	Zubair (2002)	Found El Ni˜no to be linked with reduced annual streamflow and La Ni˜na to enhanced annual flows. This relationship between the ENSO indices, rainfall and streamflow were found to be significant from January to September	The study tried to relate ENSO and rice production in Sri Lanka by studying the rainfall patterns alone	It may be important to consider other climate factors and the spatial and temporal variation of these impacts
	Labat, Godderis, Probst and Guypt (2004)	An increase in total global runoff of 4% increase for 1°C rise in temperature during the 20th century however with regional differences				

	Global, Regional or Local References		What has been done for Sri Lanka and in what location, spatial scale etc.		Gaps	Priority
	Reference	Findings	Reference	Findings		
	Chiew, Peel, Mcmahon and Siriwardena (2006)	A change of 1 to 3% in annual streamflow for every 1% change in mean annual precipitation				
	Rivas and Lizama (2005)	Runoff had decreased considerably all over the Bulgarian South Black Sea basin in recent years due to considerable decrease of precipitation and increase of temperature in the region				
	Shiklomanov (1991)	Significant changes in seasonal runoff compared to the annual runoff due to sudden increases in winter runoff and reduction in spring snowmelt runoff, due to more intense snowmelt in winter.				

	Global, Regional or Local References		What has been done for Sri Lanka and in what location, spatial scale etc.		Gaps	Priority
	Reference	**Findings**	**Reference**	**Findings**		
	Cruz et al. (2007)	Increase in recurrence of intense rainfall events casing catastrophic floods and landslides in Asia. However, the total annual precipitation has decreased with a reduced number of rainy days				
	Milly et al. (2002)	Found an increase in the frequency of floods with return period greater than 100 years across the globe				
Floods			Niroshinie, Babel and Herath (2016)	The authors observed an increment of 1.5 to 2.5% in extreme rainfall events with CSIRO Mk2 model under A2 SRES scenario in Colombo and an increment of more than 20% upstream Flood inundation	The study used coarser resolution grid of 250-500m which limited the exact hydrodynamic in the river	There is a need to study the hydrological and climatic parameters side by side to analyze the impacts and relationships between each variable and impacts on the flow

	Global, Regional or Local References		What has been done for Sri Lanka and in what location, spatial scale etc.		Gaps	Priority
	Reference	**Findings**	**Reference**	**Findings**		
				areas will increase due to climate change conditions.		
	Trenberth et al. (2003)	Found an increase in evaporation rate and the water vapour demand as a result of increasing temperature	De Silva, Weatherhead, Knox and Roriguez (2007)	Identified vulnerable areas for 50-year return period flood in Hanwella, Kaduwela, Kolonnawa, Biyagama, Kelaniya and Colombo DS divisions		
Monthly Evaporation	Milly et al. (2005)	Increased climate warming and evaporation with decreasing runoff is expected to reach 30% during the 21st century	Imbulana, Wijesekera and Neupane (2006)	Observed spatial variation in evaporation over a year ranging from 2.72 mm to 4.75 mm per day	There is a need to study the spatial variability in evaporation	The spatial variability in the evaporation trends and their impact on the runoff should be investigated for different catchments
Seasonal Evaporation	Helfer, Lemckert and Zhang (2012)	Annual evaporation is projected to be 8% higher than annual evaporation estimated for the present climate due to a temperature increase of 0.9°C				

	Global, Regional or Local References		What has been done for Sri Lanka and in what location, spatial scale etc.		Gaps	Priority
	Reference	Findings	Reference	Findings		
		during the period 2030 - 2050				
Annual Evaporation			De Silva (2007)	Projects a decline in rainfall in the wet season of about 17% under A2 and 9% under B2 with a shorter rainy season and potential evapotranspiration to increase by 3.5% under A2 and 3% under B2	The study used only one GCM and one time period for the analysis	There is a need to study different models for various future time periods and scenarios to validate the model predictions

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3 METHODS AND MATERIALS

This chapter presents the essential information on the data use, its resolution and sources, the study area and the methodology used. The data checking methods used, and the results are also presented in this chapter.

3.1 Study Area

Two sub-catchments of the Kelani River Basin were selected in this study. Glencourse has a drainage area of 1,463 km^2 and Kitulgala has a drainage area of 348 km^2, both are sub-catchments of Kelani River Basin (Figure 3-1). Out of the seven Rainfall stations selected, three rainfall stations are located in the Kitulgala sub-catchment namely Annfield, Kenilworth and Norton Bridge. Dunedin, Undugoda, Labugama tank and Wewiltalawa stations are located in Glencourse sub-catchment. The location of the river gauging stations at Kitulgala and Glencourse are given in Table 3-1 along with the rainfall station locations and the coordinates of temperature and evaporation station at Colombo. There are two reservoirs at the higher reaches of Kelani with a drainage area of 236 km^2 and a storage capacity of 169 MCM, which were operational from 1953 as storage for hydroelectricity generation stations. After 1953, two reservoirs and five power stations with a combined capacity of 335 MW were constructed to harness hydro-electricity (Ceylon Electricity Board, 1989).

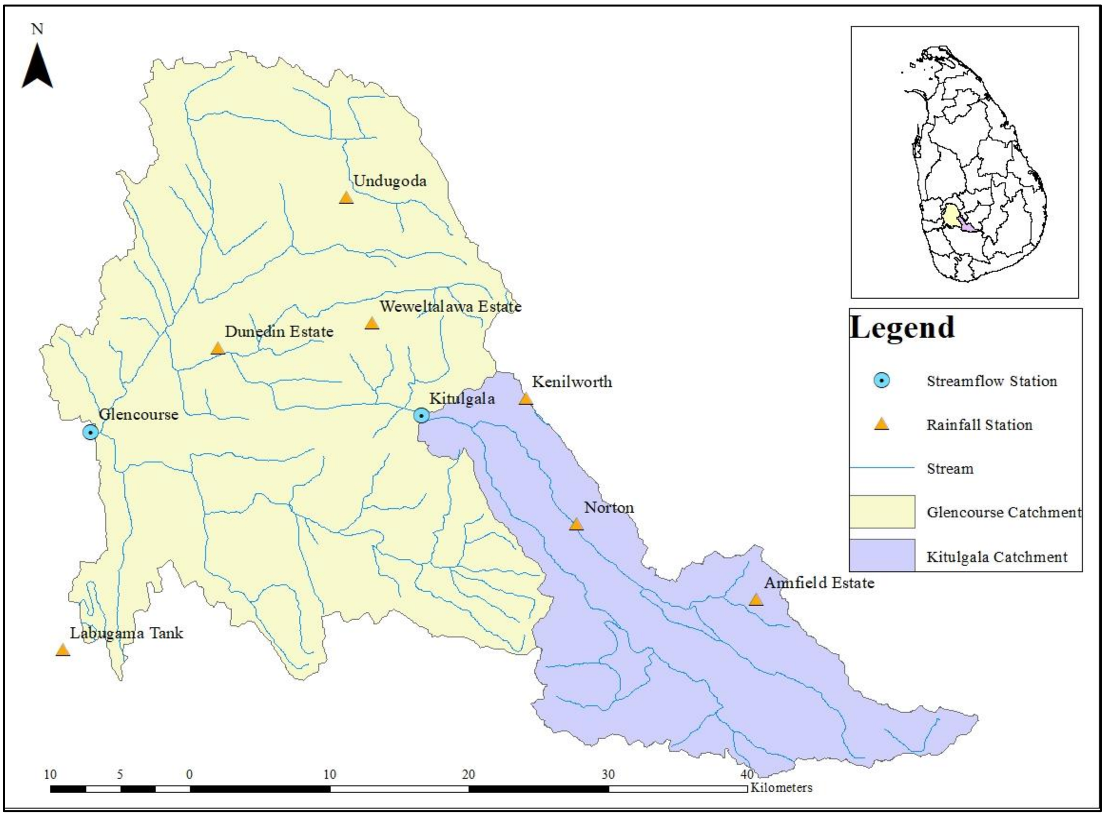

Figure 3-1 Study Area

3.2 Data and Data Checking

The data used in this study are rainfall, streamflow, evaporation and temperature of monthly resolution. The station locations and data resolutions are mentioned in Table 3-1.

Table 3-1 Data and data collection

Data type	Station name	Location	Data Period	Temporal Resolution	Data Source
Rainfall	Undogoda	6.96 °N 80.3 °E	1954-2014	Monthly	Department of Meteorology
	Dunedin	7.04 °N 80.27 °E	1954-2014	Monthly	Department of Meteorology
	Norton	6.91 °N 80.52 °E	1954-2014	Monthly	Department of Meteorology
	Kenilworth	6.99 °N 80.47 °E	1954-2014	Monthly	Department of Meteorology
	Annfield	6.8 °N 80.56 °E	1954-2014	Monthly	Department of Meteorology
	Weletalawa	6.95 °N 80.22 °E	1954-2014	Monthly	Department of Meteorology

Data type	Station name	Location	Data Period	Temporal Resolution	Data Source
	Labugama	6.88 °N 80.12 °E	1954-2014	Monthly	Department of Meteorology
Streamflow	Glencourse	6.58 °N 80.10 °E	1954-2014	Monthly	Department of Irrigation
	Kitulgala	6.59 °N 80.24 °E	1954-2014	Monthly	Department of Irrigation
Temperature	Colombo	6.56 °N79.54 °E	1954-2014	Monthly	Department of Meteorology
Evaporation	Colombo	6.54 °N 79.52 °E	1967-2014	Monthly	Department of Meteorology

3.2.1 Annual water balance

The annual water balance was carried out for Glencourse and Kitulgala sub-catchments in order to check the variation in annual rainfall, annual streamflow, and annual runoff coefficients. The runoff coefficient for Glencourse watershed was found to be 0.5 and 0.8 in the Kitulgala watershed, respectively. The water balance and the pan evaporation values were also compared to check the variations. The annual water balance for Glencourse and Kitulgala sub-catchments are attached in Appendix A.

3.2.2 Annual variation of rainfall and streamflow at Kitulgala

The annual streamflow response to rainfall for Kitulgala shows major data inconsistencies. This may be due to the reservoirs present in the basin. The rainfall from 1999/2000 to 2004/2005 period is very low compared to other years in the 60-year period, consecutively the streamflow for that period is also low. The streamflow for some periods does not show responses to the rainfall as in the case of 1964/65, rainfall is higher than the previous years, but the streamflow decreases in that period. Similarly, streamflow peaks are not representative of the rainfall increases in most years. The annual variation for rainfall and streamflow at Kitulgala watershed are shown in Figure 3-2. Annual evaporation, runoff coefficient and water balance checks were carried out as shown in Appendix A. The water balance for the earlier years shows a negative water balance for the basin for most years. On comparing the evaporation and water balance for these years, the water balance showed higher values than the annual evaporation values indicating inconsistent streamflow data. The streamflow is also much higher in the earlier 30-year period compared to the recent decades, thereby showing a negative water balance for most years. Hence considering these inconsistencies, data after 1984/85 was used for examining the rainfall streamflow relationship in the basin, thereby reducing the erroneous of the data.

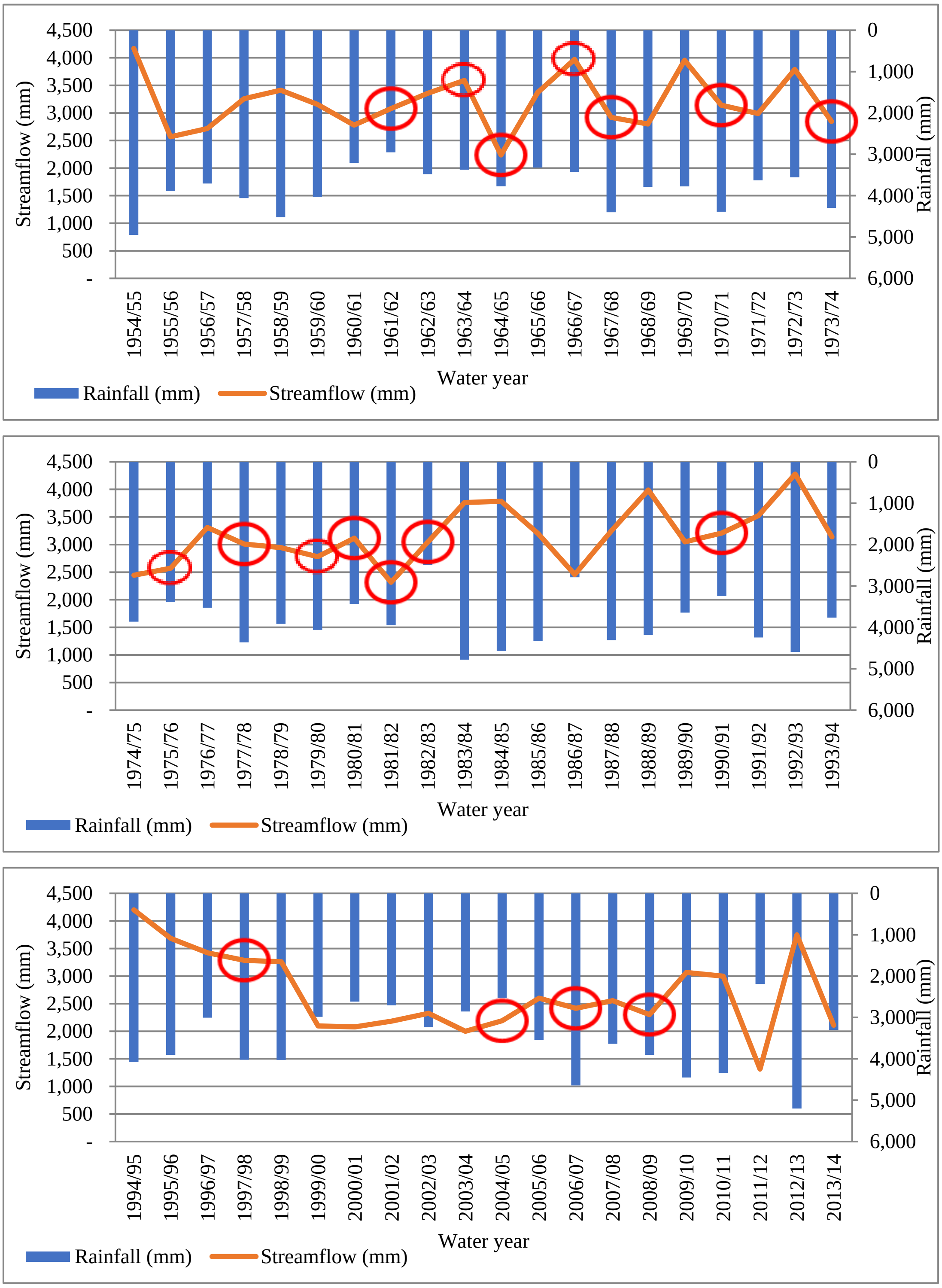

Figure 3-2 Annual variation of rainfall and streamflow at Kitulgala watershed

3.2.3 Annual rainfall and streamflow variation at Glencourse

The streamflow response of Glencourse sub-catchment to the catchment rainfall is much better as compared to Kitulgala sub-catchment. The streamflow for the earlier years is much higher compared to the recent thirty-year period resulting in lesser water balance and higher runoff coefficient of values up to 0.98. Hence data period from 1983/84 to 2013/14 was used for the analysis. The water balance and the evaporation plot for this period also showed a more or less straight-line relation between the two as shown in Appendix A. Hence the recent data period of streamflow is used for analysis. The annual variation of streamflow and rainfall for Glencourse sub-catchment are shown in Figure 3-3.

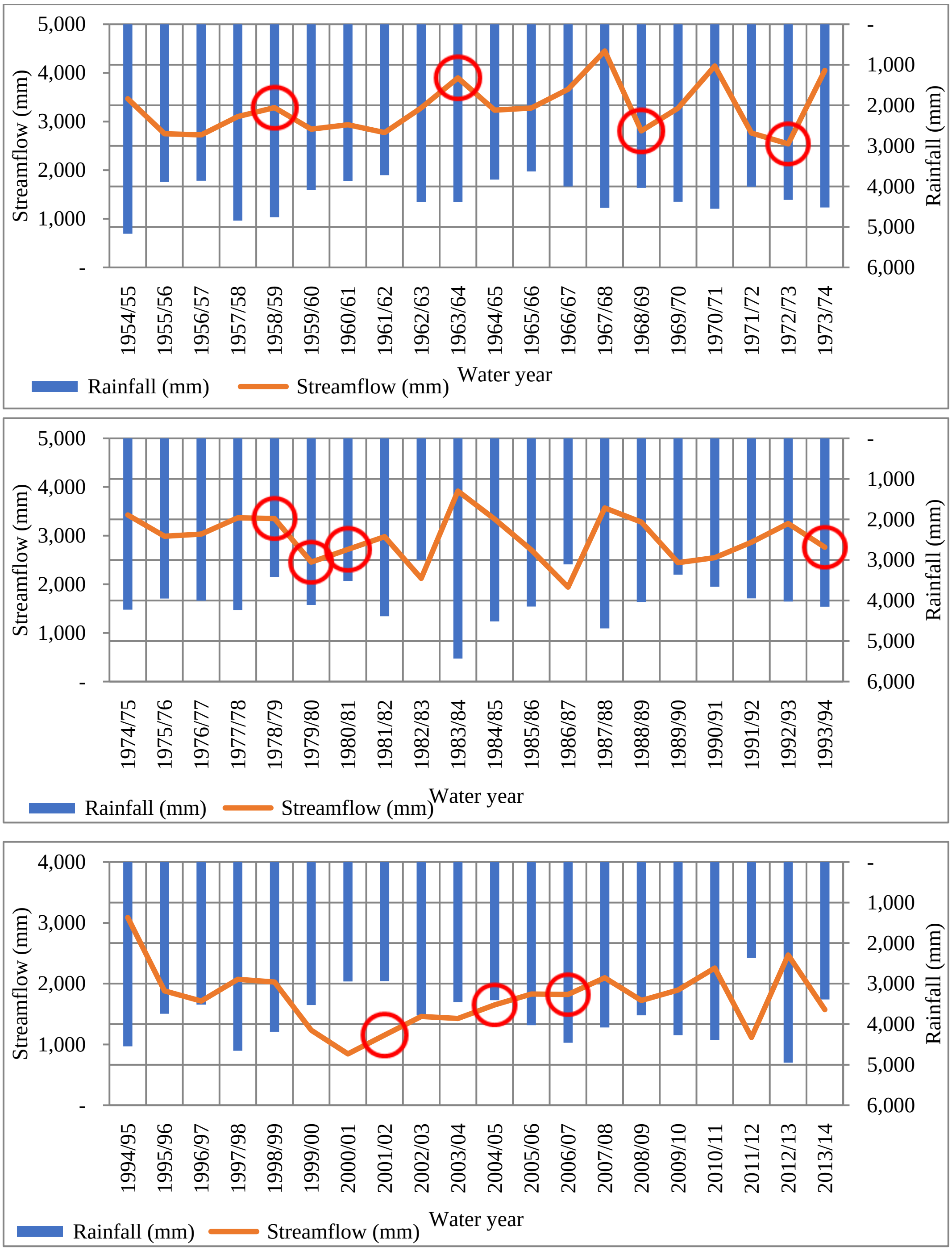

Figure 3-3 Annual variation of rainfall and streamflow of Glencourse watershed

3.2.4 Annual variation of point rainfall and streamflow

Similarly, individual rainfall stations were plotted against streamflow and the responses of the streamflow to each rainfall station were checked. This is given in Appendix A. Although adequate responses of streamflow to rainfall were observed in Glencourse sub-catchment, inconsistencies were noted for streamflow data at Kitulgala sub-catchment.

3.2.5 Seasonal streamflow responses to rainfall

On a seasonal scale, the streamflow responses are more vivid and clearer for Glencourse compared to Kitulgala with lesser inconsistencies. Maha season shows good responses of streamflow to rainfall for Glencourse sub-catchment. Kitulgala streamflow shows major discrepancies in streamflow data for Maha season. This is shown in Figure 3-4 and Figure 3-5, respectively. The Yala season streamflow response to the rainfall also shows discrepancies in streamflow data for Kitulgala (Figure 3-6), while fewer inconsistencies can be observed for Glencourse sub-catchment (Figure 3-7).

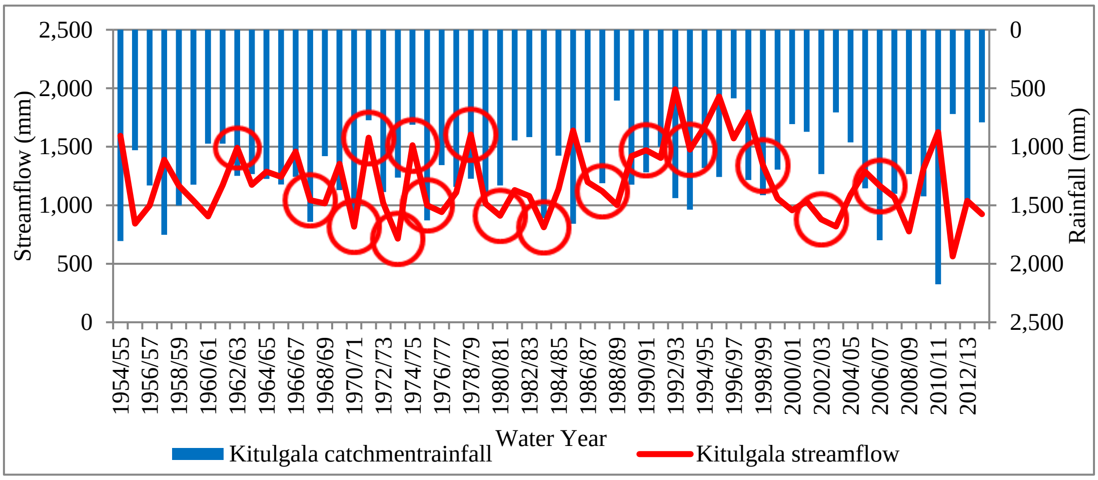

Figure 3-4 Rainfall and streamflow variation of Kitulgala watershed in Maha season

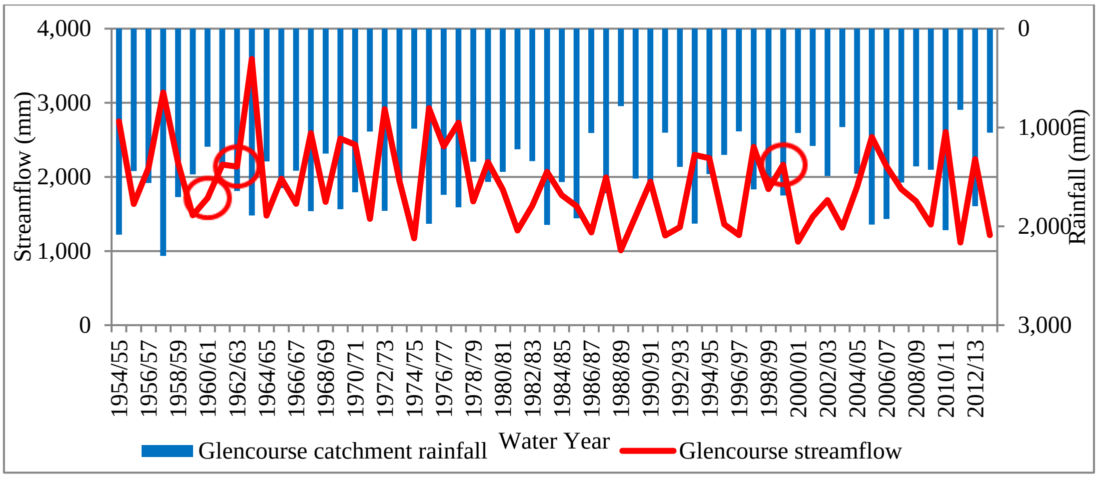

Figure 3-5 Rainfall and streamflow variation of Glencourse watershed in Maha

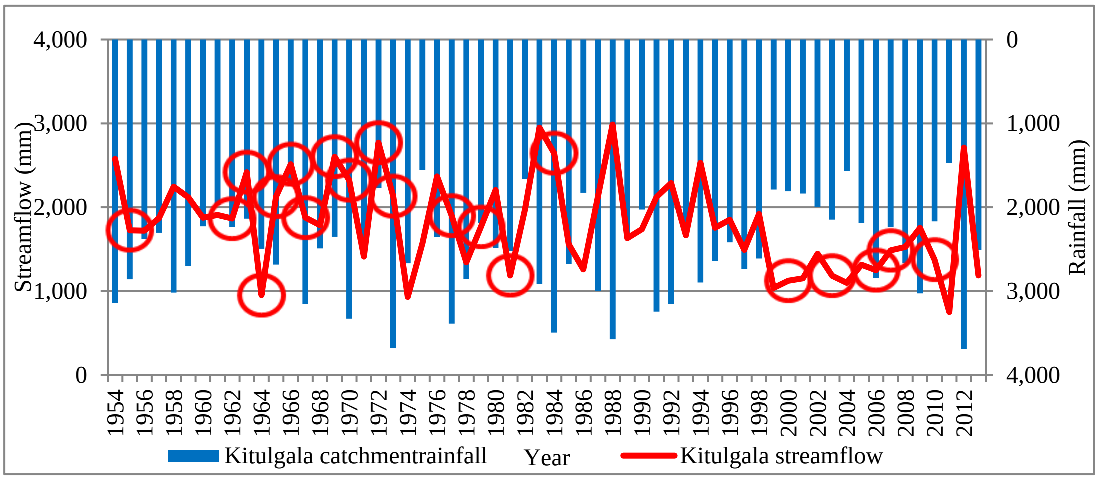

Figure 3-6 Rainfall and streamflow variation of Kitulgala watershed in Yala season

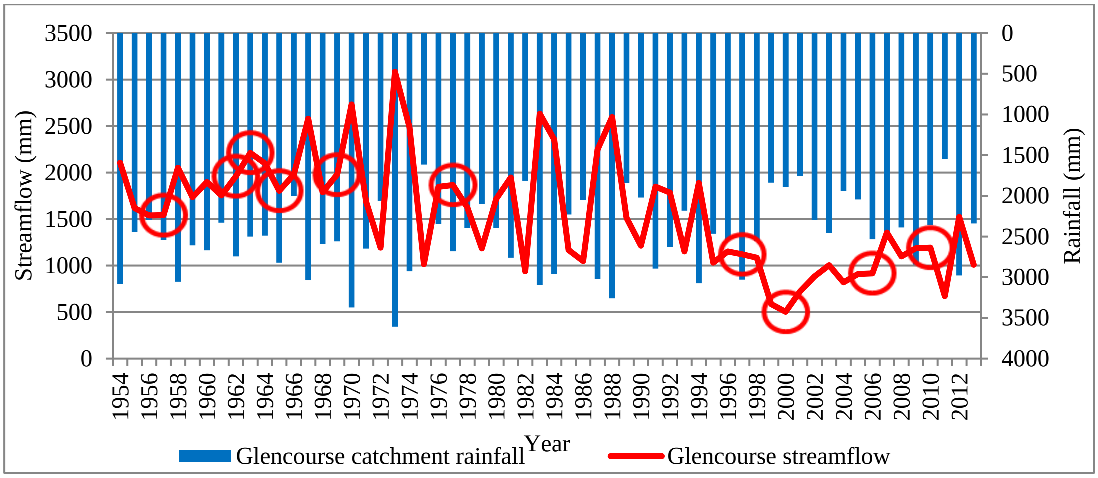

Figure 3-7 Rainfall and streamflow variation of Glencourse watershed in Yala season

3.2.6 Streamflow responses to monthly Rainfall

The response of streamflow to the monthly rainfall is shown in Appendix A. The Glencourse streamflow is much more responsive to the rainfall as compared to Kitulgala. Kitulgala sub-watershed has many reservoirs within its catchment, hence the inconsistencies in data but recent years shows comparatively lesser discrepancies with comparable evaporation and water balance data. Since Glencourse is the bigger sub-catchment, the streamflow does not get as much affected due to reservoirs as the sub-catchment has many other inflows.

The streamflow and rainfall correlation were also checked for each station and catchment rainfalls. This is shown in Appendix A. Although the linear relation between streamflow and rainfall are not significant, the two follow a similar pattern of change.

3.2.7 Annual and Seasonal rainfall

The annual rainfall for the stations for the 60-year period was plotted and checked. The annual rainfall during 2011/2012 and 1982 1983 shows a considerable drop compared to other years for every station. The rainfall plots for the 60-year period are given in Figure 3-8.

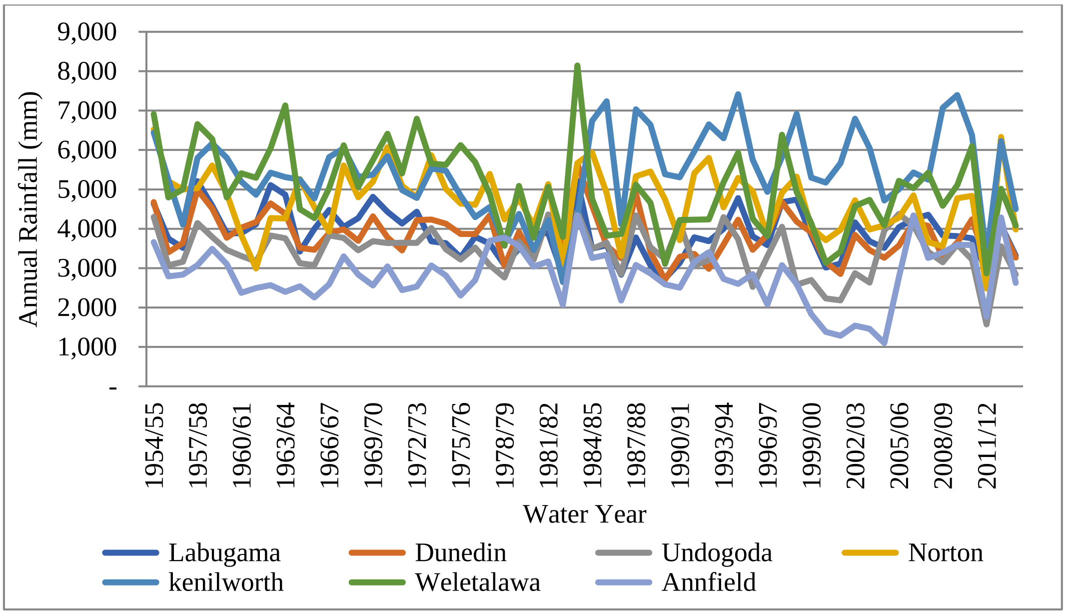

Figure 3-8 Annual rainfall variations

Monthly rainfall variations for every station are plotted for the 60-year period. These variations follow the seasonal pattern namely North-East Monsoon and South-West Monsoon (Figure 3-9). The monthly rainfall of Annfield was found to be quite low compared to the other stations.

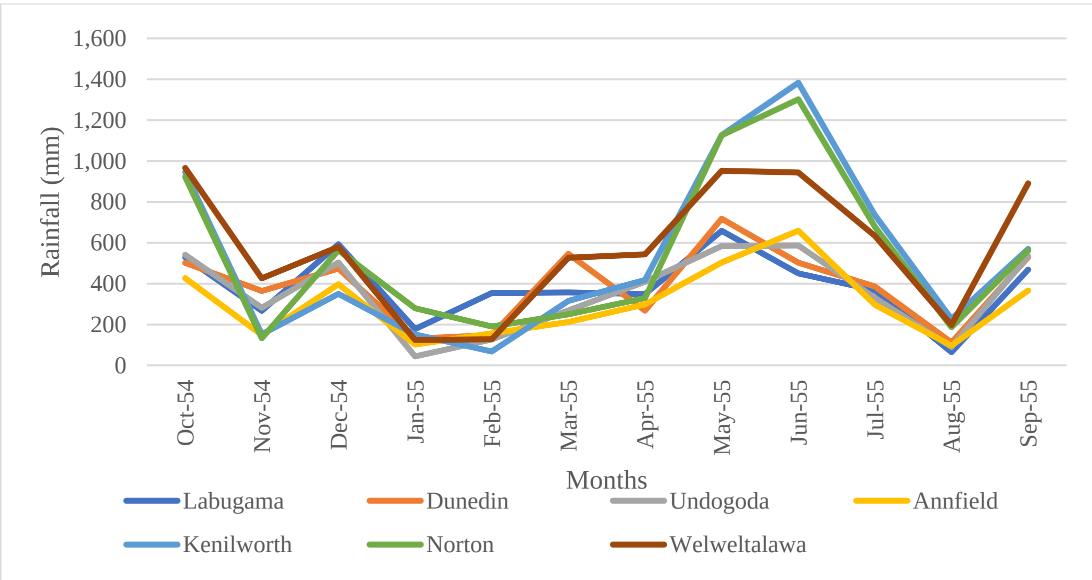

Figure 3-9 Monthly Variation of rainfall

3.2.8 Spatial average rainfall

The catchment average rainfall was calculated using the Thiessen polygon method. The Thiessen polygons for the watersheds are shown in Figure 3-10 and Figure 3-11 for Kitulgala and Glencourse, respectively and their corresponding Thiessen weights are mentioned in Table 3-2 and Table 3-3. The catchment average rainfall was plotted against the streamflow for each year. The Thiessen areas were checked against WMO standards and verified.

Table 3-2 Thiessen weights for rainfall stations at Kitulgala watershed

Rainfall station	Area (km^2)	Thiessen weight
Kenilworth	51	0.12
Norton	138	0.33
Annfield	231	0.55

`

Table 3-3 Thiessen weights for rainfall stations at Glencourse watershed

Rainfall station	Area (km²)	Thiessen weight
Kenilworth	102	0.07
Norton	259	0.17
Weletalawa	116	0.12
Labugama	186	0.08
Dunedin	360	0.24
Annfield	231	0.15
Undogoda	253	0.17

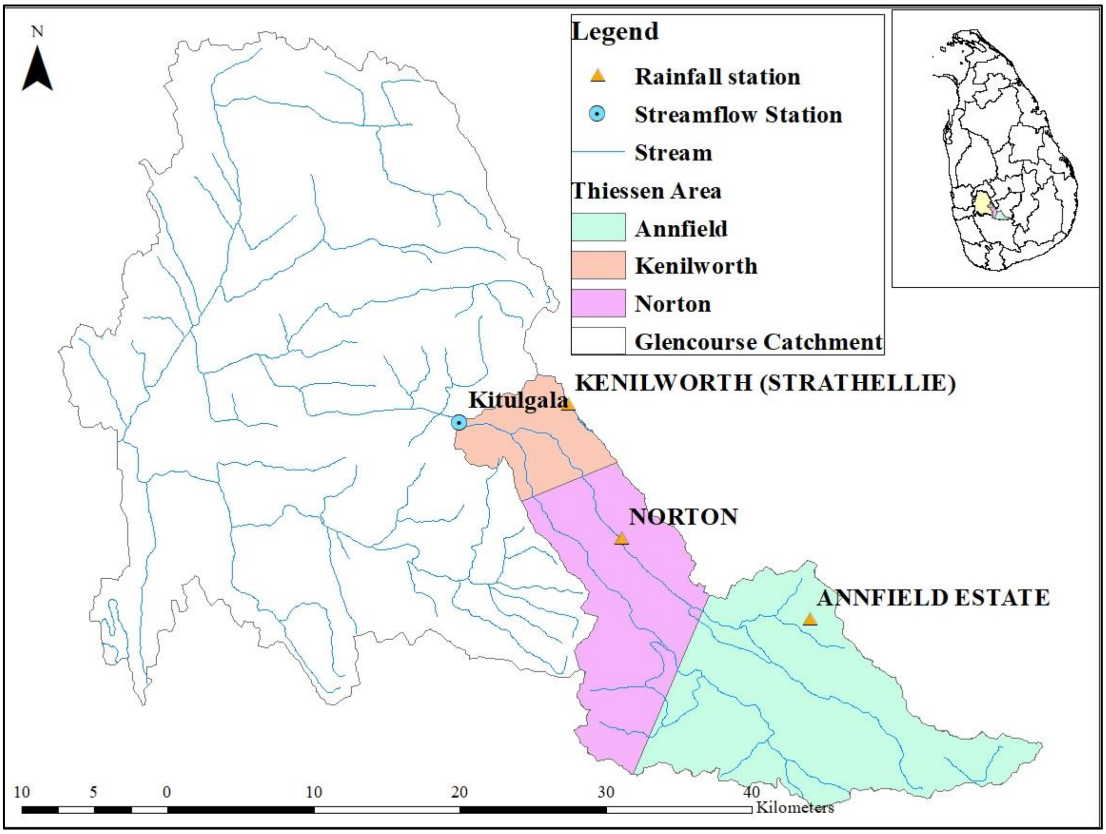

Figure 3-10 Thiessen weights for rainfall stations at Kitulgala watershed

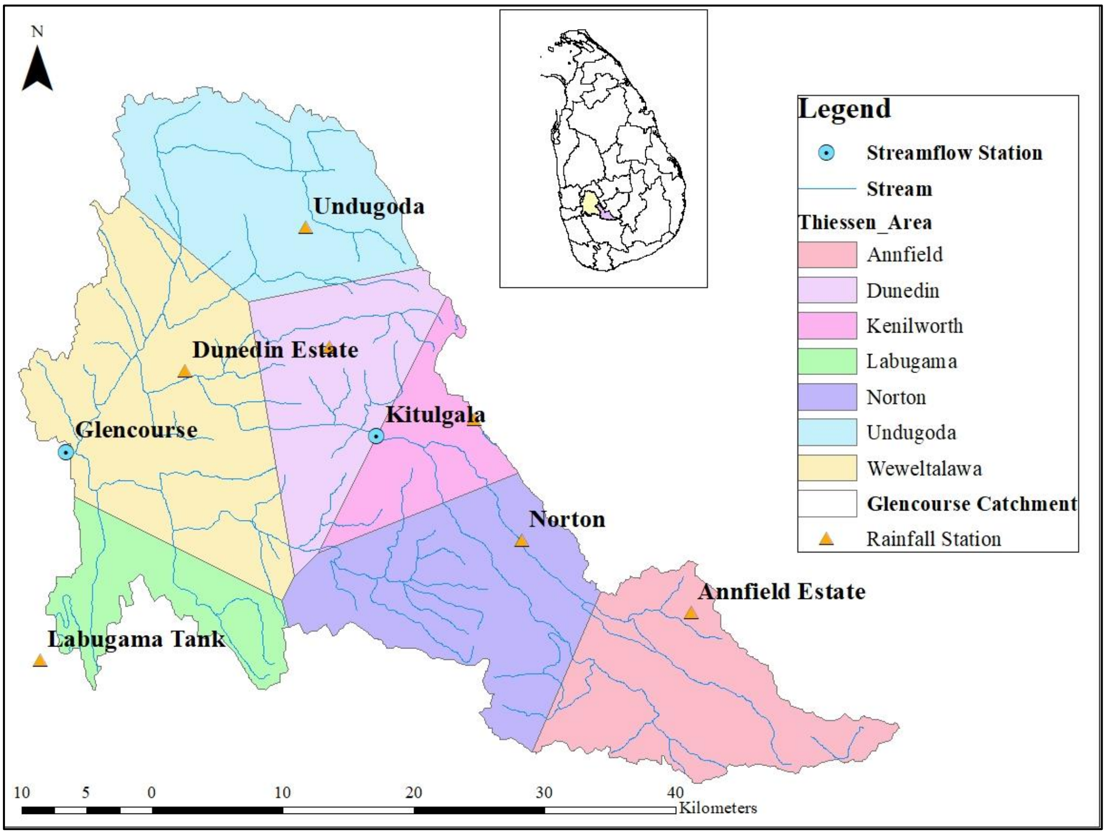

Figure 3-11 Thiessen weights for rainfall stations at Glencourse watershed

3.2.9 Visual checks

Visual checks were done to identify any inconsistencies in the data. The monthly rainfall and streamflow responses were plotted for each year and observed for inconsistencies. Appendix - A shows responses of streamflow to monthly rainfall in Kitulgala and Glencourse sub-catchments. The years where there are not appropriate responses are observed and checked for inconsistencies. The streamflow responses to high rainfall were fairly adequate compared to the low rainfall for Glencourse sub-catchment.

3.2.10 Single mass curve

After filling the missing rainfall data, the single mass curves were plotted again to check if the data are consistent and homogenous. The single mass curve for all the stations is given in Figure 3-12. Missing data were filled by multiplying the slope factor with the closet rainfall station (Xia et al., 2001). The consistency and homogeneity of the filled data were checked after filling the data using single mass curves. Stations with missing data of less than 5% were selected for computation. Accordingly, seven stations were selected which had missing data less than 5%. Schafer, (1999) has said that a missing rate of 5% or less is inconsequential. When 10% or more of the data are missing, the statistical analysis is expected to be biased (Bennett, 2001). While spatially averaging the rainfall stations, the missing data points for the rainfall stations were ignored for the particular months, and the Thiessen weights were calculated for the rest of the stations.

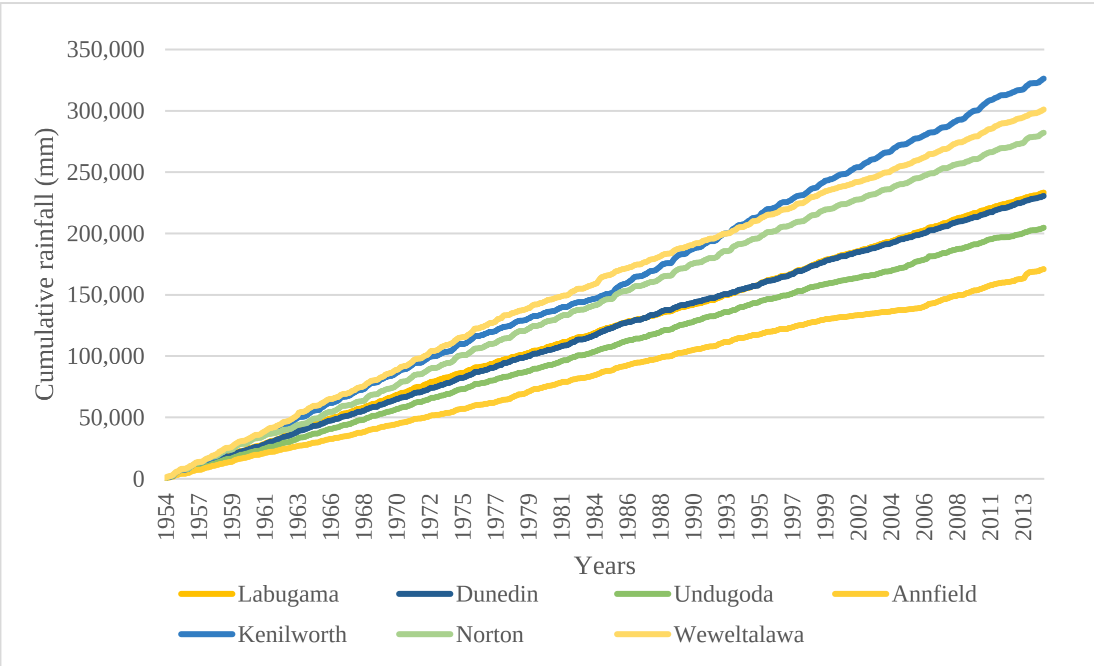

Figure 3-12 Single mass curve

3.2.11 Double mass curve

The double mass curve is used to check the data consistency by comparing data for an individual station with that of data from numerous other stations in the area. Double mass curves were plotted to check the reliability of the rainfall data. The double mass curves for the stations are given in Appendix A. The figures, Figure 3-13 and Figure 3-14 shows the double mass curves for Labugama station and Annfield station. The double mass curves show consistent rainfall data points for all the stations.

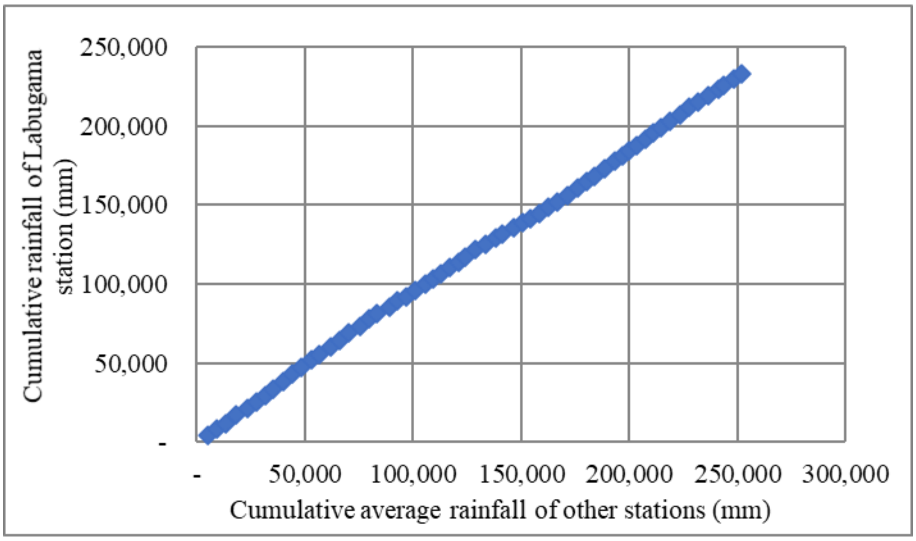

Figure 3-13: Double mass curve for Labugama Station

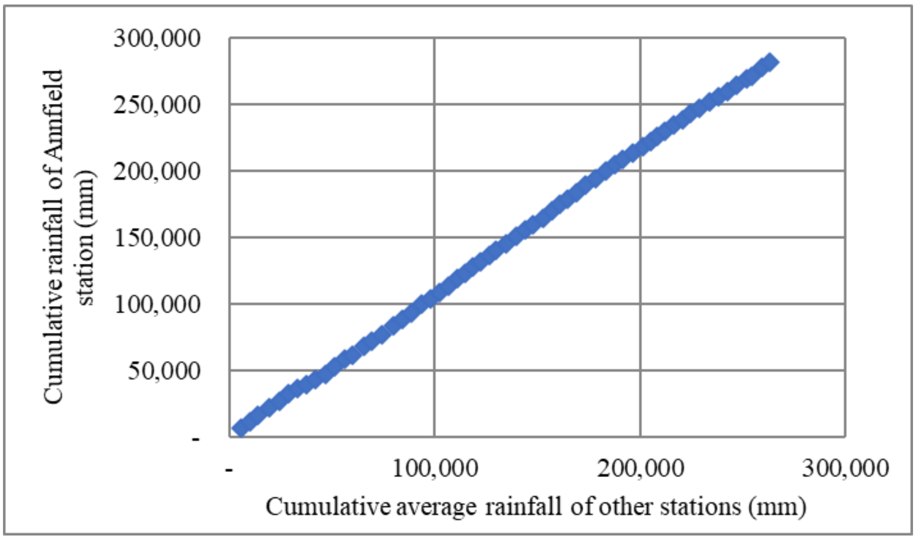

Figure 3-14 Double mass curve for Annfield station

3.3 Methodology

The methodology chart for the current study is as shown in Figure 3-15. The objectives and specific objectives of the study are formulated and then a literature survey is carried out in order to study the current, past and futuristic projections of the climatic conditions in the country and their relation to water resources. The climatic parameters affecting water resources are identified and the methods for detecting trends are selected as per literature. Two watersheds namely Glencourse and Kitulgala are selected within the basin with seven rainfall stations. Spatial and temporal variations in these parameters are examined using a linear regression model, Mann-Kendall trend test and Sen Slope Estimator. The moving average models were used to smooth out the short-term trends. Means, standard deviation, coefficient of variances of decadal periods on a monthly, annual, and seasonal basis are analyzed for temperature, rainfall and streamflow. The results are compared with the trends and thresholds of global and regional scales. Further investigation is carried to evaluate the impacts on water resources in the basin.

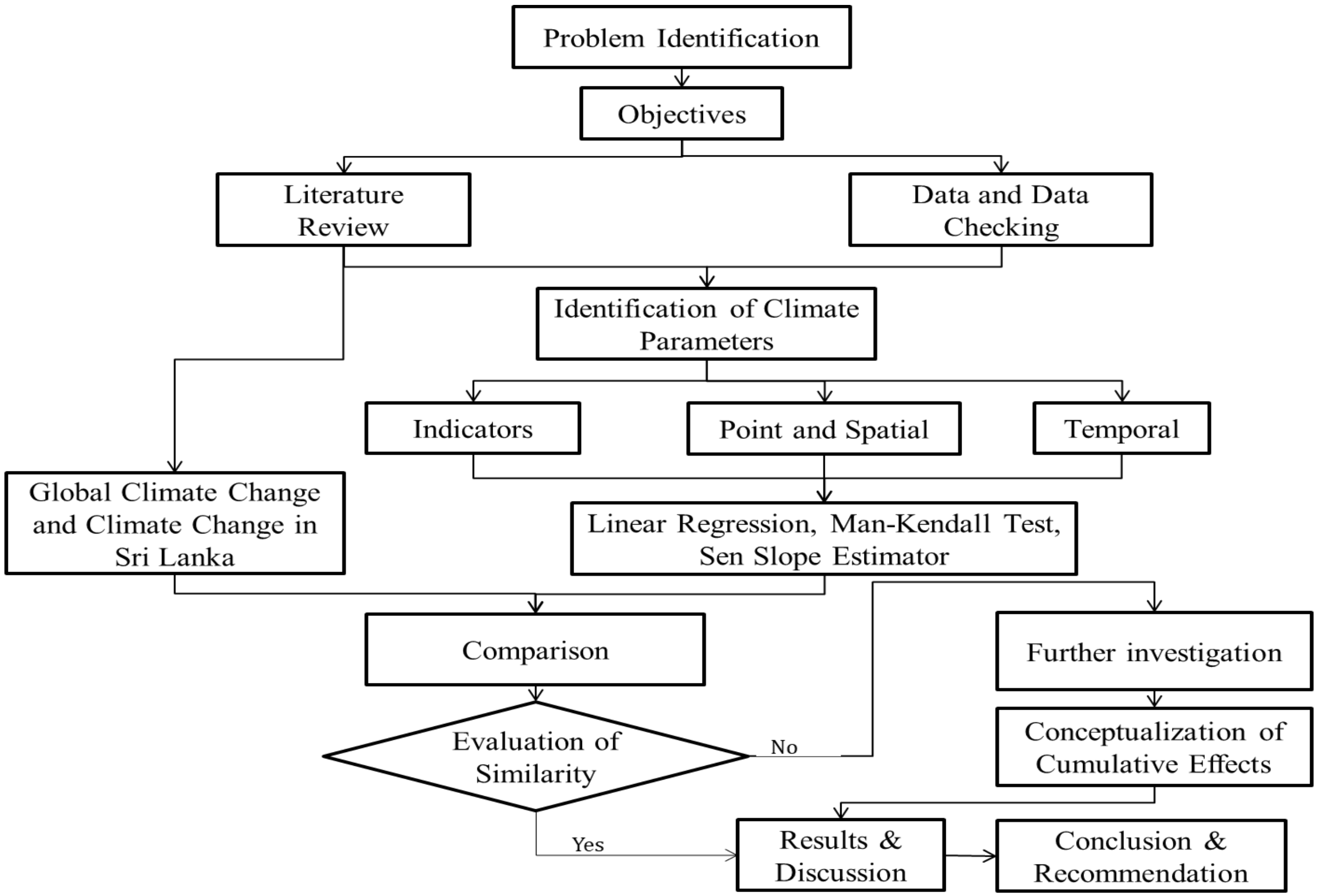

Figure 3-15 Methodology Flow Chart

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3.4 Methods

3.4.1 Linear Regression

Linear regression is one of the best methods to analyze the trend of data in a time series. The equation of the linear regression line is given by:

$$Y = a + bX \qquad (3\text{-}1)$$

where, x is the explanatory variable and Y is the dependent variable, b is the slope line, and a is the intercept. The slope of the regression defines the trend whether positive or negative. When using the Linear regression model, it requires the assumption of normal distribution. The strength of the correlation and relationship between the X and Y variable is defined by the value of R-square (R^2), or the square of the correlation coefficient. The R^2 value lies between 0.0 to 1.0.

3.4.2 Mann-Kendall (MK) Test

The MK test checks if the null hypothesis (H_0) of no trend versus the alternative hypothesis of the existing trend (H_1) whether increasing or decreasing. The Mann-Kendall statistics (S) shows whether there is a trend and whether the trend is increasing (positive) or decreasing (negative).

The successive computation of Kendall's Tau (τ) allows for an assessment of the correlation strength between two data series. Mann-Kendall test evaluates the data values as an ordered time series. Each data value is compared to all subsequent data values. The S value initially is assumed to be 0 (no trend).

Assuming x_1, x_2, … x_n as data points where x_j represents the data point at time j, then the Mann-Kendall statistic (S) is given by:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign\,(x_j - x_k) \qquad (3\text{-}2)$$

where:

$$sign\,(x_j - x_k) = \begin{cases} +1\ jika\ (x_j - x_k) > 0 \\ \ \ 0\ jika\ (x_j - x_k) = 0 \\ -1\ jika(x_j - x_k)\ < 0 \end{cases} \qquad (3\text{-}3)$$

The S statistic, when sample sizes are greater than (n > 10), is approximately normally distributed w. The variance statistic is given as:

$$Var\ (S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p\ (t_p - 1)(2t_p + 5)\right] \quad (3\text{-}4)$$

where t is the extent of any given ties. The test statistic, Z is given by;

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if\ S < 0 \end{cases} \qquad (3\text{-}5)$$

The Z value shows the presence of a statistically significant trend. A positive value of Z indicates an increasing trend while a negative value represents a negative trend. The statistic Z has a normal distribution to test for either increasing or decreasing trend at α level of significance (usually 5% with $Z_{0.025}$=1.96).

3.4.3 Sen's Slope Estimator

Sen's slope estimator is used for determining the magnitude of trend in hydrometeorological time series. The slopes (T_k) of all data pairs are first calculated as:

$$T_k = \frac{x_j - x_i}{j-i} \qquad \text{for k=1,2, ……, } N \qquad (3\text{-}6)$$

where, x_j and x_k are data values at time j and i (j > i).
The median of N values of T_k is Sen's estimator of slope which is calculated as:

$$\beta = \begin{cases} T_{\frac{N+1}{2}} & N\ is\ odd \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{(N+1)/2}\right) & N\ is\ even \end{cases} \qquad (3\text{-}7)$$

A positive value of β indicates a rising trend and a negative value indicates a declining trend in the time series.

4 ANALYSIS AND RESULTS

4.1 Catchment and Climate Parameter Selection

Two sub-catchments of the Kelani river basin namely Kitulgala and Glencourse were selected for the purpose of comparison of catchment parameters and climate change impacts within the basin. The Kelani river is an important source of freshwater for Colombo, the capital of Sri Lanka. The risk of severe flood hazards due to heavy rainfall poses a major challenge to the community and people within the basin. Hence the present study selected these sub-catchments for study based on the risks of climate related impacts on water resources in the basin and also based on data availability.

Climate parameters for the evaluation of impacts on water resources were selected based on a comprehensive literature review (Section 2.3.1). As per findings from the global research community, the impact of climate change is most likely to be felt through changing patterns of water availability because of enhanced glacier melting and changing patterns of precipitation increasing the probability of droughts and floods. These impacts are likely to vary between different regions. The most important climate drivers/parameters influencing water availability as pointed out in literature are precipitation, temperature, and evaporative demand. Most studies have studied the impacts of changing climate parameters on the hydrological cycle and quantified impacts on the streamflow.

Subsequently, the present study selected temperature, rainfall and streamflow for evaluating changes in climate and impacts on water resources in the catchment based on their effect on water availability and also based on data availability.

4.2 Evaluation of Trends in Climate Parameters

Following a review of frequently used models/methods for trend analysis in the literature (Section 2.3), linear regression model, Mann-Kendall trend test and Sen's slope estimator were selected for investigating the climate change in the watershed. Decadal, annual, intra-annual, and monthly trends were computed using these models of the climate parameters. These trends were compared with global changes to check for similarity and significance. Streamflow variation and trends were compared with the contributing rainfall computed using Thiessen weights.

4.2.1 Trends in temperature

The temperature data from the meteorological gauging station at Colombo was used for examining temperature trends in the basin since the variations in temperature within the basin are assumed to not vary much. Regional temperature differences across Sri Lanka are primarily due to altitude, instead of latitude (CCS, 2016).

4.2.1.1 Decadal trends in annual temperature

Decadal changes in mean annual temperature show an increase in the trends of maximum temperature (Tmax), minimum temperature (Tmin), and average temperature (Tavg) with R^2 values ranging from 0.675 to 0.928. The decade wise annual average changes in temperature show higher increases in minimum temperature of 0.02 °C for the 60-year period, which is nearly 1.4 times that of the maximum temperature. The decadal variations in temperature are shown in Figure 4-1.

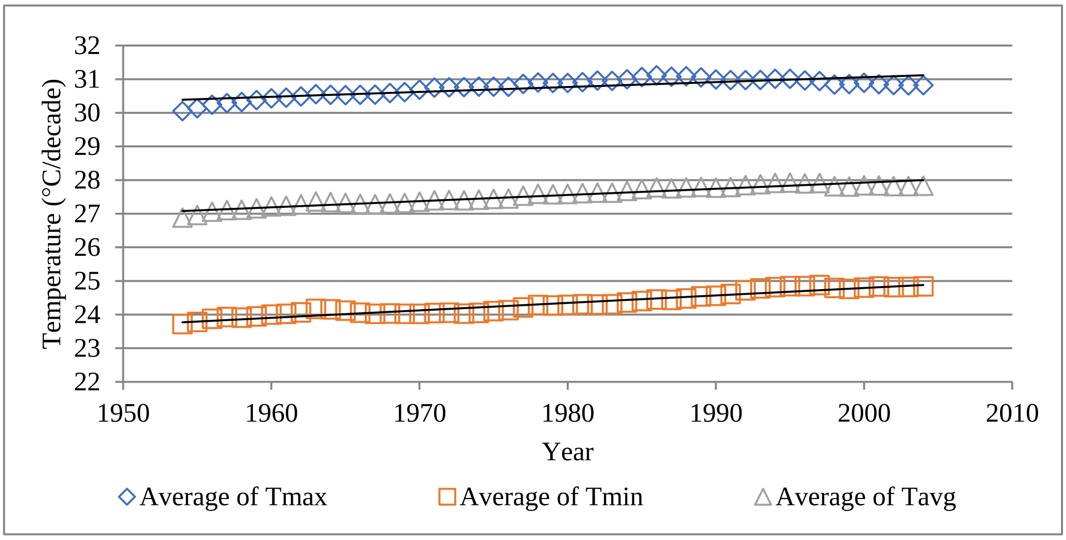

Figure 4-1 Decadal annual average trends in temperature

The ρ-value from the Mann-Kendall's test also shows the slope is lesser than 0.05 indicating an increasing trend with positive τ and S values at 95% confidence level. The τ value of 0.846 in the case of minimum temperature (Tmin) shows a significant linear relation. These indications reflect a warming climate in the Kelani river basin.

Although the null hypothesis (H_o) is rejected with a ρ-value of <0.0001 at 95% confidence level, the Z significance value is lesser than $Z_{0.025}$=1.96 (0.007 to 0.053) indicating only a slight increase in the trend. The Sen slope value also ranged from 0.017 to 0.023 indicating a slight upward trend. The Mann-Kendall statistics, Sen's Slope and R^2 values of decadal annual average temperature is shown in Table 4-1.

Table 4-1 Mann-Kendall statistics, Sen's Slope and R^2 values decadal annual temperature

Temperature	Kendall's Tau (τ)	*S* value	ρ-value (Two-tailed)	*Z* value	R - square	Sen's slope	Hypothesis (H_o) (α = 5%)
Tmax	0.619	789.0	<0.0001	0.052	0.675	0.017	Reject
Tmin	0.846	1079.0	<0.0001	0.053	0.923	0.023	Reject
Tavg	0.873	1113.0	<0.0001	0.007	0.928	0.020	Reject

The details of trends and are given in Table 4-8, Appendix C and Appendix D.

The IPCC has stated that minimum temperatures are increasing at about twice the rate of maximum temperatures per decade. Further, IPCC states that the average annual temperature increased by 0.13 °C per decade in the last 50 years. In the current study, increases of 0.017 °C were identified for the last 60-years. A warming trend of 0.177 ± 0.052 °C/decade for the most recent 25 years (period ended in 2003) as highlighted by other studies (IPCC, 2007a), while a trend of 0.021°C over 60-years was identified for the same in the current study. The decadal trends from the current study reveal increases as mentioned by the IPCC but the rate at which the temperature is increasing is much lesser than those observed by the IPCC.

4.2.1.2 Decadal Trends in Seasonal Temperature

Small scale seasonal variations between 2 °C to 3 °C were observed in the mean monthly temperature whereas the temperature differences (Diurnal temperature) showed higher variations of 4 °C to 10 °C during the 60-year period. The seasonal variation of temperature per decade for Maha season and Yala season is shown in Figure 4-2 and Figure 4-3, respectively.

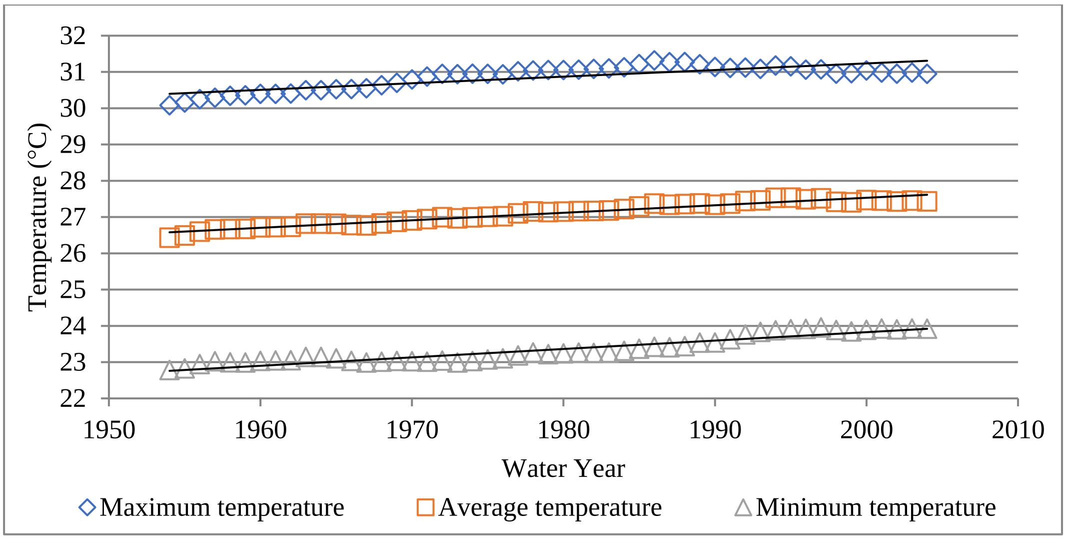

Figure 4-2 Decadal Trends of Temperature in Maha Season

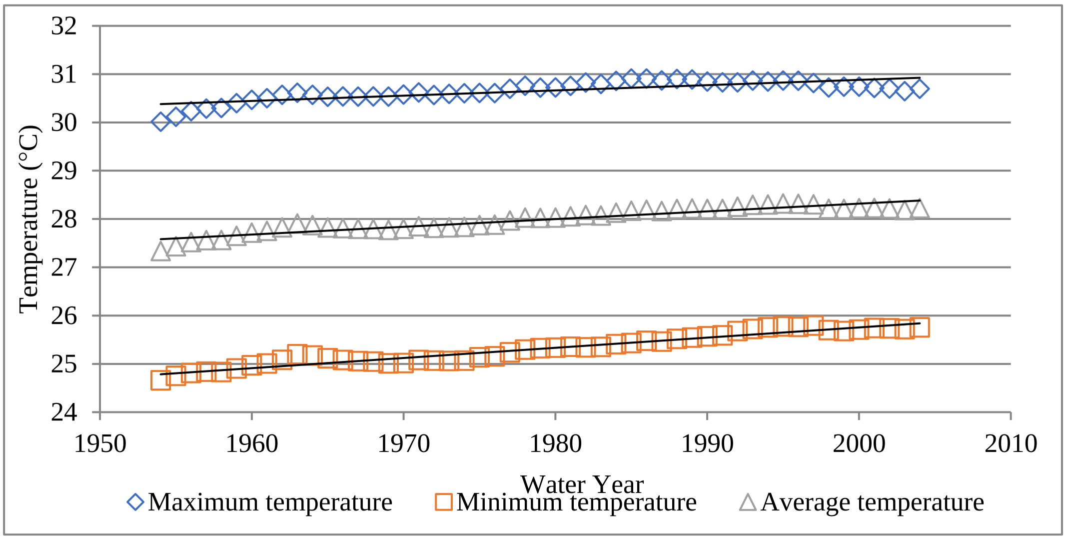

Figure 4-3 Decadal Trends of Temperature in Yala Season

Decadal trends in seasonal temperature show increases in both the cultivation seasons, Maha and Yala seasons, similar to the decadal annual average temperature trends. Slightly higher increases in the Maha season compared to Yala season were identified on the decadal scale with higher increases in minimum temperature and higher values (R^2 value of 0.88 – 0.94) than that of maximum temperature, with 0.023 °C rise over the 60-year period in Maha season and 0.021 °C rise in the Yala season. This indicates higher warming in the Maha season. The Mann-Kendall's test also shows the *ρ*-value lesser than 0.05 in both the seasons indicating an increasing trend with positive τ and S values at 95% confidence level. The presence of an increasing trend is evaluated using the Z value. The lesser values of Z reveals that the increase is only a small rise. The Mann-Kendall test results, Sen's slope results and the R^2 values for decadal trends in seasonal temperature; Maha season and Yala season are given in Table 4-2 and Table 4-3, respectively.

Table 4-2 Mann-Kendall statistics, Sen's Slope and R^2 values decadal seasonal temperature (Maha Season)

Temperature	**Kendall's Tau (τ)**	***S value***	**ρ-value (Two-tailed)**	***Z* value**	**R - square**	**Sen's slope**	**Hypothesis (H_o) (α = 5%)**
Tmax	0.620	791.0	<0.0001	0.012	0.675	1.041	Reject
Tmin	0.834	1075.0	<0.0001	0.111	0.923	1.220	Reject
Tavg	0.896	1142.0	<0.0001	0.010	0.928	1.221	Reject

Table 4-3 Mann-Kendall statistics, Sen's Slope and R^2 values decadal seasonal temperature (Yala Season)

Temperature	**Kendall's Tau (τ)**	***S* value**	**ρ-value (Two-tailed)**	***Z* value**	**R - square**	**Sen's slope**	**Hypothesis (H_o) (α = 5%)**
Tmax	0.593	756.0	<0.0001	0.014	0.675	0.011	Reject
Tmin	0.843	1075.0	<0.0001	0.125	0.923	0.022	Reject
Tavg	0.818	1043.0	<0.0001	0.007	0.928	0.020	Reject

4.2.1.3 Trends in annual, seasonal and monthly temperature

The highest increase in decadal monthly temperature was identified for the months of January, February, and March, with higher increases in minimum temperature than the maximum temperature, the increase being 0.025 °C, 0.029 °C, and 0.028 °C, respectively for 60-years. These months have lower temperatures as compared to other months during the year. The coldest month in Sri Lanka is considered to be January and the warmest months are considered to be April and May (CCS, 2016). This indicates that the colder months of Sri Lanka are getting warmer at rates higher than the other months. This is consistent with global findings. An increase in minimum and maximum temperature was identified for almost all the months for the study period (1954-2014). October and December months showed higher increases in maximum temperature than the minimum temperature signifying that the daytime temperatures are increasing at higher rates than the nighttime temperatures for the two months with

R^2 values of 0.74 and 0.82. The linear regression trend results for decadal monthly temperature are given in Table 4-8 and Appendix C. The Mann-Kendall statistics tests also revealed the presence of increasing trends with *ρ*-value less than 0.05 and positive *S* and *τ* values. The Sen slope values also showed an incremental positive trend ranging from 0.009 to 0.021. However, the *Z* values and Sen's slope values were lesser than 0.12 indicating only a minor increase. The Mann-Kendall test results, Sen's slope results and the R^2 values for decadal monthly temperature is given in Table 4-4.

Table 4-4 Mann-Kendall Statistics, Sen's Slope and Regression results for monthly temperature

Temperature	Kendall's Tau (τ)	*S* value	ρ-value (Two-tailed)	*Z* value	R - square	Sen's slope	Hypothesis (H_o) (α = 5%)
Tmax	0.365	8237.0	<0.0001	0.012	0.111	0.019	Reject
Tmin	0.433	9791.0	<0.0001	0.123	0.190	0.021	Reject
Tavg	0.463	10,485.0	<0.0001	0.005	0.093	0.009	Reject

The trends were also computed for the IPCC standard period to compare with the recent trends. Slightly higher increases in temperature in the Maha season compared to Yala season were identified on decadal and annual scales. Annual average temperature showed considerable year-to-year variation for the basin. The moving average trends are like the decadal trends, with noticeably reduced short-term fluctuations, shown in Figure 4-4.

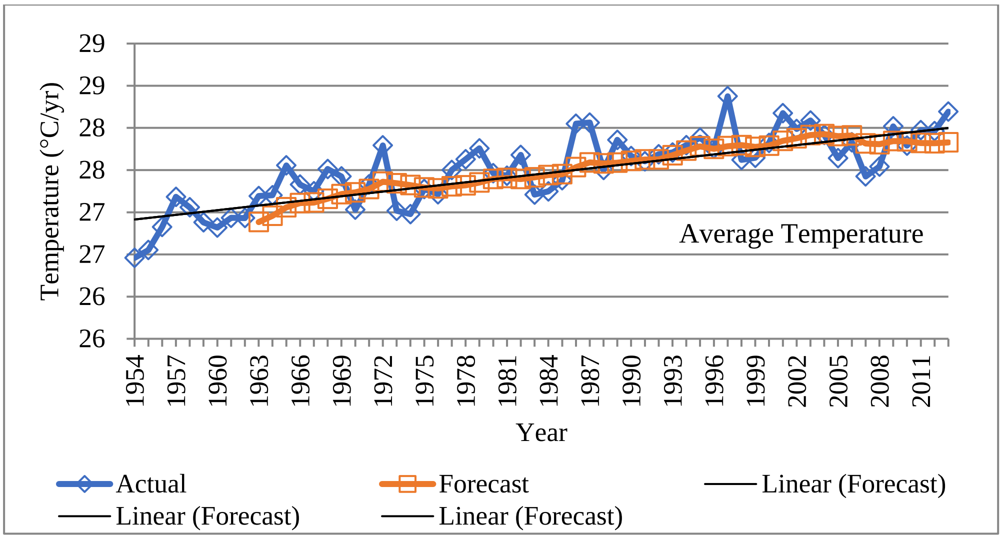

Figure 4-4 Moving Average (Annual Average Temperature)

The annual average temperature increase is 0.02 °C for the 60-year period. The highest increase in annual temperature was observed for the minimum temperature at 0.024 °C over the 60-year period. The annual variations in temperature for the 60-year period are shown in Figure 4-5.

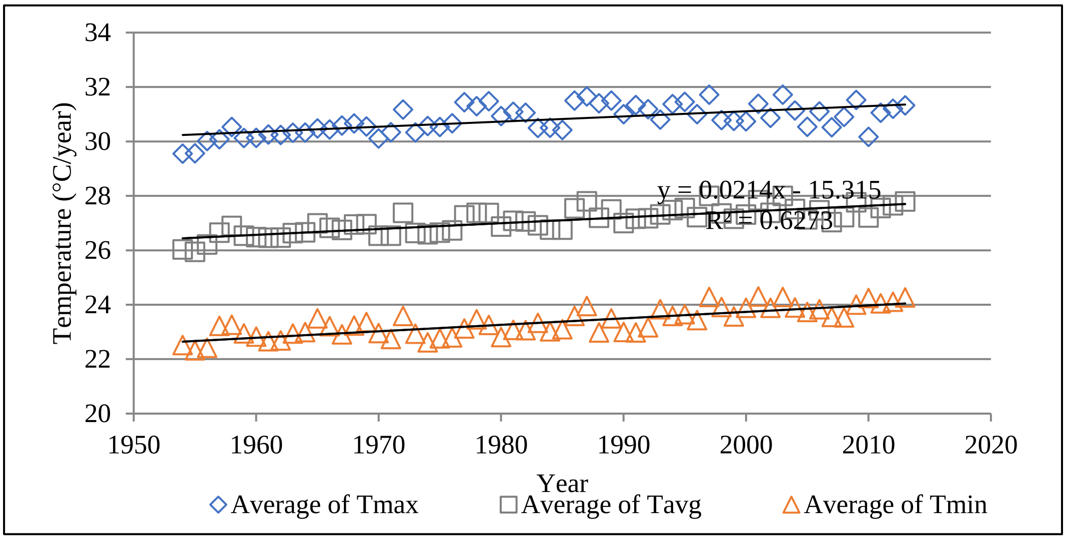

Figure 4-5 Annual trends in temperature

The annual, seasonal, and monthly trends in temperature are given in Table 4-9 and Appendix C. The annual average temperature increase is 0.02 °C for the 60-year period. Table 4-5 below shows the Mann-Kendall test and Sen slope analysis results of the annual average temperature. The p-value was lesser than the significance level

($\alpha = 0.05$) for the catchment indicating an increasing trend with positive S and τ values. It rejected the null (H_o) hypothesis representing no trends in this time series. The Z values were comparatively lesser indicating minor increases and Sen's slope trends ranged from 0.02 to 0.024 indicating small increases.

Table 4-5 Mann-Kendall Statistics, Sen's Slope and Regression results for annual temperature

Temperature	**Kendall's Tau (τ)**	***S***	**ρ-value (Two-tailed)**	***Z***	**R^2**	**Sen's slope**	**Hypothesis (H_o) (α = 5%)**
Tmax	0.597	1,057.0	<0.0001	0.014	0.390	0.022	Reject
Tmin	0.584	1,032.0	<0.0001	0.125	0.640	0.024	Reject
Tavg	0.459	812.0	<0.0001	0.007	0.612	0.020	Reject

Global observed changes in annual temperature over the period of 1880 to 2012 is a warming of 0.85 °C [0.65 to 1.06 °C], and the overall rise in temperature average between the 1850–1900 period and the 2003–2012 period is 0.78 °C [0.72 to 0.85 °C] (IPCC, 2008). In the current study, increases of 0.021 °C over the 60-year period was identified for mean temperature. The ten-year moving average trend also shows the highest increase in minimum temperature of 0.022 °C per year. The minimum temperature is increasing at higher rates, nearly 1.3 times the maximum temperature.

The temperature variations in Maha and Yala seasons are given in Figure 4-6 and Figure 4-7, respectively. Seasonal analysis of temperature trends reveals an increase in temperature for both seasons. Although less, higher increases in the Maha season of 0.0238 °C for minimum temperature for the 60-year period were observed. The same can be observed for the ten-year moving average trends with a greater increase in the minimum temperature compared to the maximum. The Mann-Kendal statistics show an increasing trend in seasonal temperature with a ρ-value lesser than 0.0001.

However, the calculated *Z* values and Sen's slope values show lesser rates of increase. The results for the MK test, Sen's slope and R^2 are shown in Table 4-6 and Table 4-7.

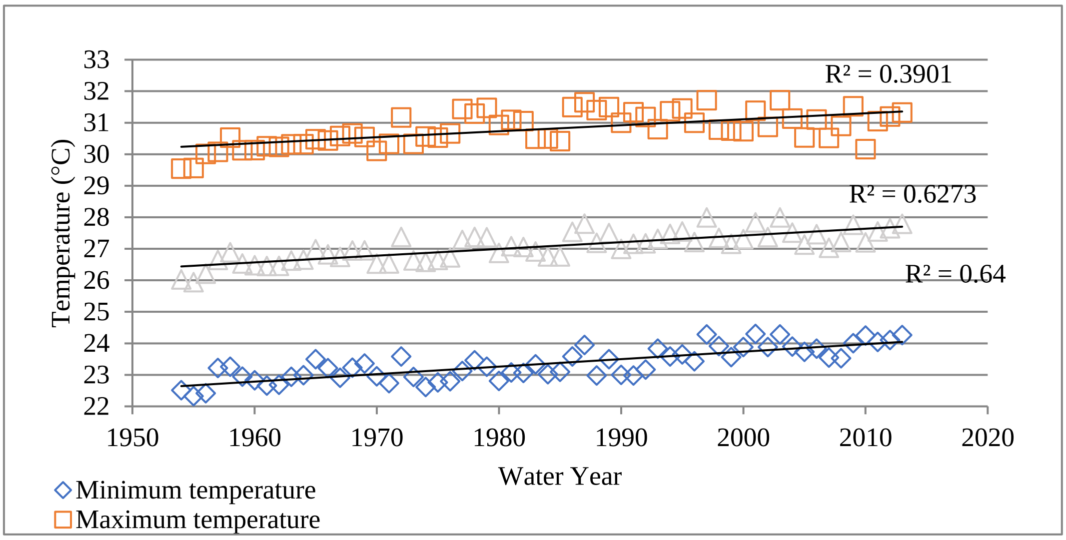

Figure 4-6 Seasonal Variation in Temperature (Maha season)

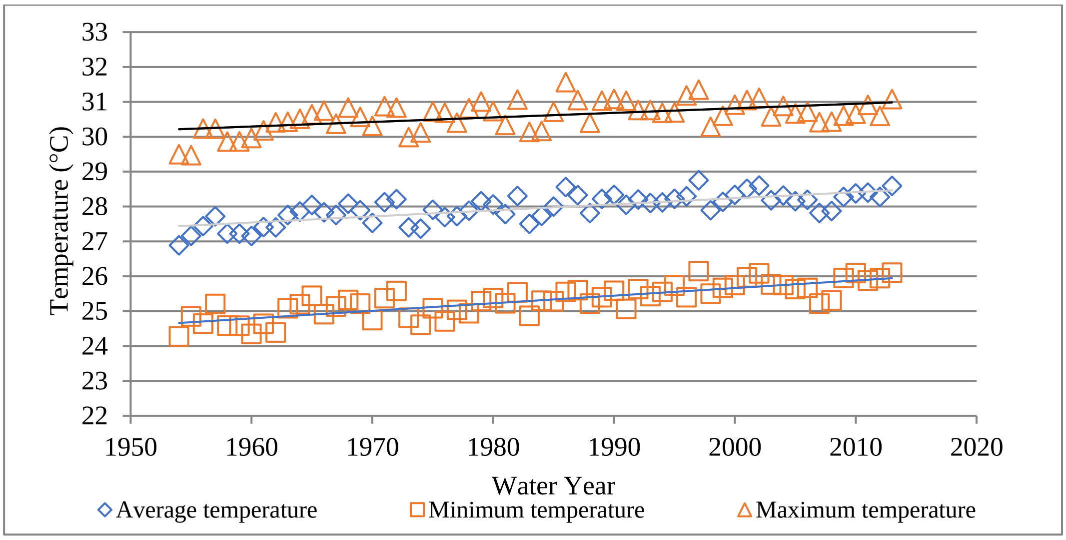

Figure 4-7 Seasonal Variation in Temperature (Yala season)

Table 4-6 Mann-Kendall Statistics, Sen's Slope and Regression results for seasonal temperature (Maha season)

Temperature	Kendall's Tau (τ)	*S*	ρ-value (Two-tailed)	*Z*	R^2	Sen's slope	Hypothesis (H_o) (α = 5%)
Tmax	0.459	812.000	<0.0001	0.032	0.390	0.020	Reject
Tmin	0.584	1032.000	<0.0001	0.042	0.620	0.024	Reject
Tavg	0.597	1057.000	<0.0001	0.042	0.640	0.022	Reject

Table 4-7 Mann-Kendall Statistics, Sen's Slope and Regression results for seasonal temperature (Yala season)

Temperature	**Kendall's Tau (τ)**	***S***	**ρ-value (Two-tailed)**	***Z***	**R^2**	**Sen's slope**	**Hypothesis (H_o) (α = 5%)**
Tmax	0.347	614.0	<0.0001	0.029	0.290	0.012	Reject
Tmin	0.630	1115.0	<0.0001	0.045	0.550	0.022	Reject
Tavg	0.556	983.0	<0.0001	0.040	0.650	0.017	Reject

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Table 4-8 Linear Regression trends of Temperature (Decadal 1954/55 – 2013/14)

Linear regression trends																	
Decadal trends																	
Parameter	Time period	Annual	STD	Season		Month											
				Maha	Yala	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max temp	Base period	0.024	0.152	0.038	0.010	0.017	0.030	0.028	0.020	0.033	0.010	0.011	0.001	0.004	0.030	0.025	0.061
	Entire	0.014	0.263	0.018	0.011	0.017	0.019	0.015	0.080	0.017	0.020	0.012	0.010	0.012	0.021	0.020	0.021
Min temp	Base period	0.017	0.103	0.008	0.012	0.021	0.020	0.003	0.050	0.023	0.010	0.016	0.012	0.004	0.003	0.004	0.003
	Entire	0.024	0.343	0.023	0.021	0.024	0.210	0.029	0.020	0.028	0.010	0.022	0.017	0.02	0.018	0.020	0.020
Avg temp	Base period	0.011	0.116	0.023	0.011	0.039	0.020	0.015	0.040	0.028	0.010	0.014	0.006	0.004	0.013	0.010	0.032
	Entire	0.018	0.284	0.021	0.017	0.020	0.020	0.022	0.010	0.02	0.010	0.017	0.014	0.017	0.019	0.020	0.020

Table 4-9 Linear Regression trends of Temperature (Annual, Intra-annual, monthly - 1954/55 – 2013/14)

Annual and Intra-annual trends																
Parameters	Time period	Annual	Season		Month											
			Maha	Yala	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max temp	Base period	0.024	0.039	0.016	0.046	0.038	0.035	0.022	0.032	0.002	0.015	0.004	0.018	0.035	0.030	0.008
	Entire	0.019	0.019	0.013	0.017	0.019	0.016	0.009	0.017	0.016	0.012	0.011	0.012	0.025	0.019	0.021
Min temp	Base period	0.017	0.015	0.018	0.015	0.017	0.013	0.042	0.028	0.006	0.024	0.001	0.015	0.013	0.003	0.049
	Entire	0.024	0.024	0.022	0.024	0.030	0.030	0.023	0.028	0.018	0.023	0.018	0.022	0.018	0.020	0.020

Annual and Intra-annual trends																
Parameters	**Time period**	**Annual**	**Season**		**Month**											
			Maha	**Yala**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Avg temp	Base period	0.011	0.025	0.017	0.030	0.028	0.024	0.032	0.030	0.003	0.020	0.003	0.016	0.024	0.016	0.029
	Entire	0.021	0.021	0.018	0.020	0.025	0.023	0.016	0.023	0.017	0.018	0.014	0.017	0.019	0.020	0.020

Table 4-10 Moving Average Trends (Temperature -1954/55 – 2013/14)

Annual and Intra-annual trends																
Parameter	**Time period**	**Annual**	**Season**		**Monthly**											
			Maha	**Yala**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Max temp	Base period	0.024	0.040	0.020	0.046	0.040	0.040	0.020	0.030	0.010	0.020	0.010	0.020	0.040	0.030	0.008
	Entire	0.015	0.019	0.013	0.019	0.017	0.015	0.008	0.015	0.011	0.009	0.010	0.011	0.017	0.019	0.024
Min temp	Base period	0.017	0.015	0.018	0.015	0.017	0.013	0.042	0.028	0.006	0.024	0.001	0.015	0.013	0.003	0.049
	Entire	0.022	0.024	0.022	0.026	0.029	0.028	0.024	0.027	0.014	0.022	0.019	0.020	0.017	0.018	0.011
Avg temp	Base period	0.011	0.025	0.017	0.030	0.028	0.024	0.032	0.030	0.003	0.020	0.003	0.016	0.024	0.016	0.029
	Entire	0.018	0.021	0.018	0.022	0.022	0.021	0.016	0.021	0.012	0.015	0.014	0.015	0.016	0.018	0.020

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4.2.2 Trends in point rainfall

The annual rainfall is highly variable for Sri Lanka. This is attributed to the seasonal cyclic nature of monsoon rainfall, along with regional and local topographic characteristics, which leads to spatial and temporal variations in rainfall. The wet zone rainfall is hugely impacted by the orographically influenced low-level wind circulation, which generates Fohn effect weather conditions. Various authors (Domroes, 1971; Domroes, 1974b; Thambyahpillay, 1958; Yoshino, 1982, Yoshino, Urushibara and Nomoto, 1983) have related local winds to change in rainfall as quoted by Malmgren et al. (2003).

4.2.2.1 Decadal trends in point rainfall

The decadal annual trends for the point rainfall station, their standard deviation, and coefficient of variation were computed for the 60-year period. The mean, standard deviation, and coefficient of variation of each station are shown in Table 4-11.

Table 4-11 Decadal annual rainfall mean, STD and CoV

Rainfall Station	Mean (mm)	Standard Deviation (STD)	Coefficient of Variation (CoV)
Labugama	3,889.23	520.51	0.13
Dunedin	3,842.96	535.99	0.14
Undugoda	3,412.51	541.29	0.16
Annfield	4,702.44	810.49	0.17
Kenilworth	5,437.90	820.05	0.15
Wewiltalawa	2,799.70	598.88	0.21
Norton	5,018.21	936.53	0.18

As per the IPCC, monthly mean precipitation variability is anticipated to increase in most areas, with an increase in absolute value (standard deviation) and in relative value (coefficient of variation), though with lesser significance (IPCC, 2008). The coefficient of variation for the decadal rainfall of the current study is less than 0.2, which indicates smaller variability from the mean. The low coefficient of variability values reveals a highly dependable rainfall. The maximum amount of average monthly rainfall was observed for Wewiltalawa station in November (1,823 mm).

In general, all rainfall stations except for Kenilworth show a decrease in their decadal average annual trend. The maximum decrease in the decadal annual average trend was identified for the Wewiltala rainfall station, with a decrease of 28.6 mm over the 60-year period which can be observed in Figure 4-8.

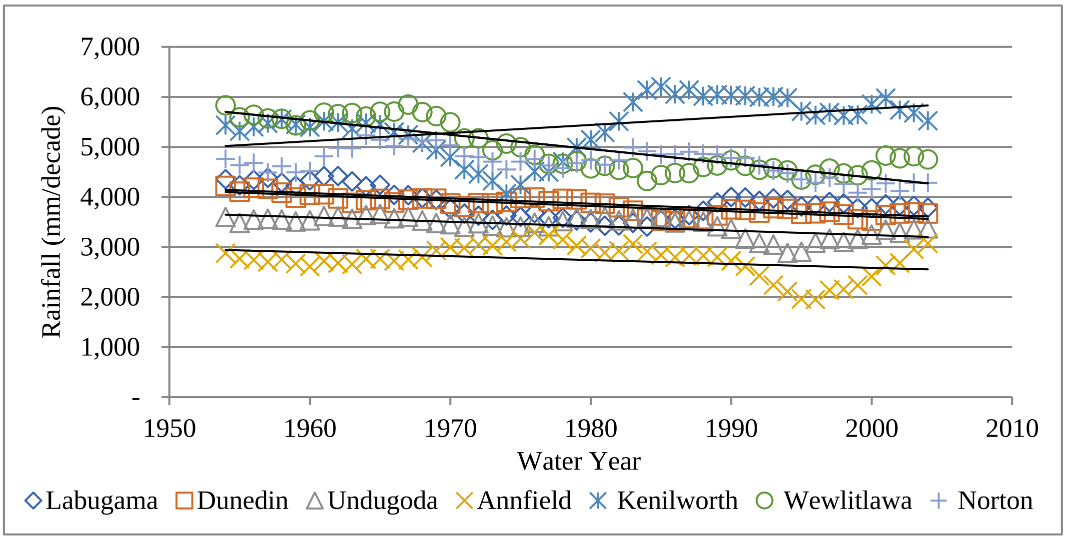

Figure 4-8 Decadal trends in point rainfall

The linear regression trends and the ten-year moving average did not show any significant trends in point rainfall as given in Table 4-13. All the station reveals a reduction in annual rainfall except for Kenilworth. The Mann-Kendall test showed a decreasing trend in decadal annual rainfall for five rainfall stations (Labugama, Dunedin, Undugoda, Wewiltalawa and Norton), while Kenilworth showed increasing trends. However, the Sen's slope and *Z* values showed a minimal decrease in rainfall. The MK test, Sen's slope and R^2 values are given in Table 4-12. The high rainfall in Kenilworth station compared to the other stations can be attributed to the stations' location. The station is located on the exposed southwest windward slopes at elevations between 1,000 and 1,300 m which receives mean annual rainfall as high as 5,500 mm (Malmgren et al., 2003). This can be one of the reasons for the increase in rainfall at that particular rainfall station. Annfield station showed no significant trend. The Sen's Slope value showed the highest decline of -27.94 mm for the 60-year period for Wewiltalawa station. A steep decline in the recent decades can be observed in most stations. The annual average decadal trends show variations in the decadal scale but a general decrease in trend in most stations was identified.

Table 4-12 Mann-Kendall Statistics, Sen’s Slope and Regression results for decadal annual point rainfall

Rainfall Station	Kendall's Tau (τ)	*S*	ρ-value (Two-tailed)	*Z*	R - square	Sen's slope	Hypothesis (H_o) (α = 5%)
Labugama	-0.338	-431.0	<0.0001	-0.03	0.28	-11.42	Reject
Dunedin	-0.658	-839.0	<0.0001	-0.05	0.74	-10.41	Reject
Undugoda	-0.451	-575.0	<0.0001	-0.04	0.46	-7.16	Reject
Annfield	-0.129	-165.0	0.1830	-0.01	0.13	-5.32	Accept
Kenilworth	0.244	311.0	0.0120	0.02	0.19	11.30	Reject
Wewiltalawa	-0.578	-737.0	<0.0001	-0.05	0.72	-27.94	Reject
Norton	-0.363	-463.0	<0.0001	-0.03	0.32	-12.86	Reject

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Table 4-13 Linear regression trends in Rainfall

Linear regression trends																
Decadal trends																
Station	**Time period**	**Annual**	**Decadal Seasonal**		**Decadal Monthly**											
			Maha	**Yala**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Labugama	Base period	-49.92	9.13	-40.76	0.95	-0.36	-1.54	-10.91	-3.68	-3.91	-6.75	-4.32	-9.11	-10.65	7.18	-4.82
	Entire	-10.62	4.20	-2.48	-0.53	-0.86	0.65	0.91	-2.16	-4.01	-0.06	-1.38	0.34	1.52	-0.69	-3.20
Undugoda	Base period	-5.89	-16.37	-10.63	-1.13	1.19	0.17	0.56	-3.08	3.71	-3.51	-0.43	-5.37	-3.22	7.49	-3.94
	Entire	-8.88	-1.60	-7.27	-1.76	-2.11	-1.18	0.38	-2.07	-2.44	0.29	-0.91	0.20	0.59	-0.04	0.58
Dunedin	Base period	-2.65	4.83	-11.78	0.43	-0.26	1.48	-3.16	-3.65	6.01	-2.26	-0.88	-6.36	-0.76	11.30	-5.02
	Entire	-10.73	-2.97	-7.75	-0.64	0.12	-0.28	0.49	-0.70	-0.65	-1.74	0.21	-0.48	-0.01	-0.07	-1.34
Annfield	Base period	23.92	3.12	20.81	0.13	0.47	2.00	-2.45	8.91	13.61	4.59	1.49	0.07	-4.66	6.00	-1.15
	Entire	-7.74	7.46	-0.63	-1.46	-0.95	-0.82	1.67	-0.90	-2.44	-0.84	-1.2	-0.46	3.44	1.05	0.22
Kenilworth	Base period	-41.60	-13.26	-25.23	1.11	-2.74	-5.18	-2.04	-4.57	-0.76	-2.46	-9.0	-13.02	-11.7	2.86	-5.44
	Entire	16.20	-3.12	8.79	-1.46	-0.95	-0.82	1.67	-0.90	-2.44	-1.28	-2.60	-0.48	-1.02	-2.22	-4.37
Norton	Base period	-25.88	-12.2	-12.26	-0.74	-2.00	-2.52	4.72	-1.42	12.09	1.98	-5.61	-7.03	-10.9	4.15	-5.21
	Entire	-10.62	-3.44	-7.66	-0.74	-1.15	-0.21	2.78	-0.46	-3.48	-0.06	-0.21	-0.13	0.36	-1.79	-2.14
Wewiltalawa	Base period	-67.7	-29.1	-38.71	-0.27	-1.53	-2.22	2.89	0.12	-6.34	-8.05	-8.44	-19.1	-19.2	-4.21	-4.97
	Entire	-28.60	-15.2	-17.23	-1.35	-0.37	-0.79	-1.62	-3.10	-2.77	-1.76	-2.11	-1.18	0.38	-2.07	-2.44

Annual and Intra-annual trends																
Station	Time period	Annual	Seasonal		Monthly											
			Maha	Yala	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Labugama	Base period	-49.66	-12.76	-36.9	-1.62	-1.34	0.22	-2.44	-4.37	-3.48	-0.21	2.78	-0.46	-3.48	-0.01	-0.95
	Entire	-10.65	-3.13	-7.16	0.21	-0.60	-1.56	-0.43	-2.59	-1.13	-1.28	-0.35	-1.73	-0.56	0.85	-1.36
Undugoda	Base period	1.95	4.95	-6.58	-1.80	-2.10	-1.20	0.38	-2.10	-2.44	-0.90	-1.21	-0.46	-0.95	-0.82	1.67
	Entire	-9.63	-2.96	-6.68	-0.91	0.12	0.21	-1.21	-0.95	-2.60	-1.15	-0.21	-0.37	-0.86	-1.38	-2.11
Dunedin	Base period	-15.93	-1.15	-14.80	-0.28	0.49	-0.70	-0.70	-0.90	-2.44	-1.20	-0.21	2.78	-0.46	-3.48	-0.01
	Entire	-10.23	-4.43	-5.79	0.29	-0.60	-1.70	-0.80	-1.50	-1.28	-0.70	-0.06	-1.35	-0.53	-0.06	-1.76
Annfield	Base period	14.15	- 4.70	13.69	-1.21	-0.95	-2.59	-1.15	-0.21	-0.37	-0.48	-0.46	-0.82	-0.48	-0.21	-0.12
	Entire	-3.84	4.19	-2.48	0.203	-0.28	-0.47	-0.46	-0.82	-0.48	-0.21	-0.13	-0.79	0.65	0.34	-1.18
Kenilworth	Base period	-2.19	0.45	2.51	-0.01	3.434	1.67	-1.02	2.775	0.36	-1.62	-1.34	0.22	-2.44	-4.37	-3.48
	Entire	9.81	1.36	5.61	0.59	0.49	-0.01	3.44	1.69	-1.02	2.78	0.362	-1.62	0.91	1.52	0.38
Norton	Base period	0.09	-8.54	8.60	-2.14	-2.77	-0.79	-0.46	3.44	1.05	0.21	-1.27	-2.59	-0.47	-1.02	-2.22
	Entire	-13.17	-5.46	-7.71	-0.04	-0.70	-0.07	1.047	-0.90	-2.22	-0.46	-1.78	-3.09	-2.16	-0.69	-2.07
Wewiltalawa	Base period	-59.52	-12.86	-31.78	-0.91	0.124	0.21	-1.21	-0.95	-2.59	0.37	0.59	0.48	-0.01	3.437	1.66
	Entire	-25.68	-13.01	-15.11	0.578	-0.65	-1.34	0.22	-2.44	-4.37	-3.48	-2.14	-2.77	-4.01	-3.19	-2.44

`

4.2.2.2 *Trends in decadal annual and seasonal average point rainfall*

The rainfall statistics are dominated by inter-annual and decadal-scale variations, and the trend estimates are spatially incoherent. Comparison of the annual averages alone would not reveal the cause for the decline as rainfall mechanisms and rainfall patterns differ during various rainfall seasons. Comparing the changes and variability in terms of the different rainfall seasons would provide a better insight into the nature and magnitude of changes that have taken place (Jayatilake et al., 2005). Hence the importance of examining seasonal and monthly trends in rainfall. The decadal variation in seasonal rainfall is given in Figure 4-9 and Figure 4-10.

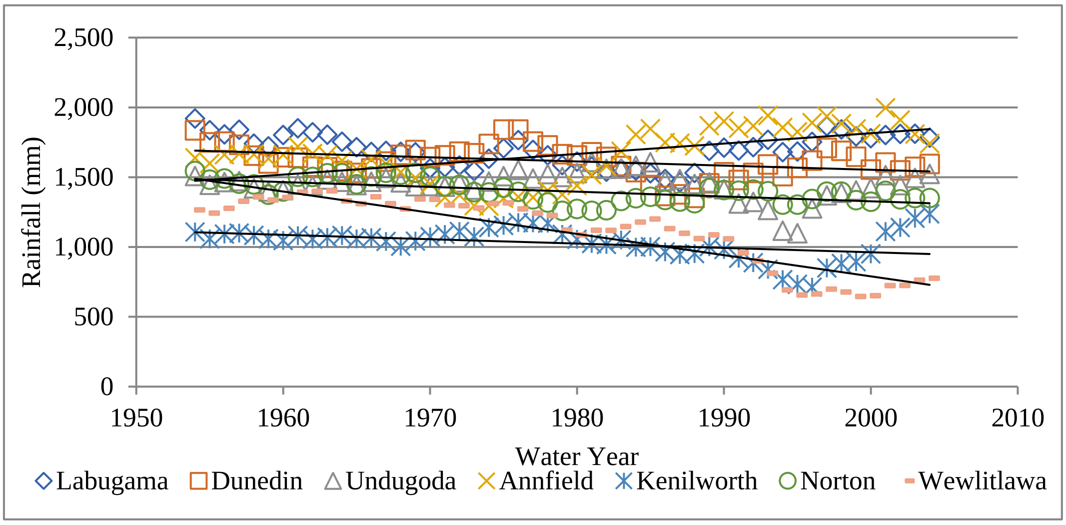

Figure 4-9 Decadal variation in Seasonal Point Rainfall (Maha Season)

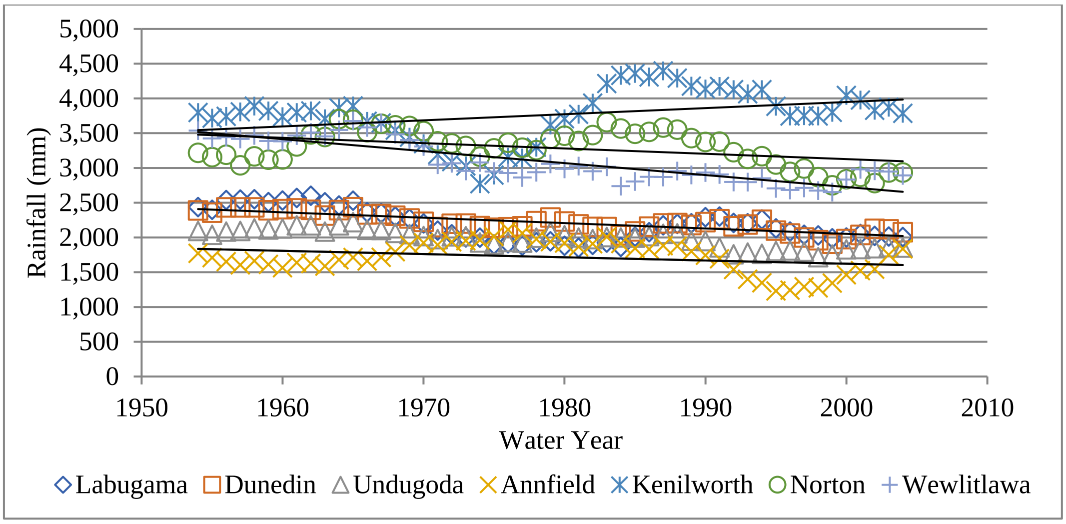

Figure 4-10 Decadal variation in Seasonal Point Rainfall (Yala Season)

The trends for the Maha and Yala seasons were calculated and compared with monthly and annual trends in rainfall. The Maha season shows a decreasing trend for all the stations over the 60-year period on a decadal scale except for the Kenilworth station. The MK statistics revealed Labugama station, Undugoda, Annfield and Norton to show no significant trend. Kenilworth station also showed no significant trend with a positive *Z* value of 0.01 and Sen's slope value of 5.64 mm. This is shown in Table 4-14.

Table 4-14 Mann-Kendall Statistics, Sen's Slope and Regression results for decadal seasonal point rainfall (Maha Season)

Rainfall Station	Kendall's Tau (τ)	*S*	ρ-value (Two-tailed)	*Z*	R - square	Sen's slope	Hypothesis (H_o) (α = 5%)
Labugama	-0.089	-113.0	0.36	-0.01	0.11	-1.033	Accept
Dunedin	-0.247	-325.0	0.01	-0.02	0.71	-2.78	Reject
Undugoda	-0.045	-57.0	0.649	-0.01	0.70	-0.40	Accept
Annfield	-0.122	-155.0	0.211	-0.01	0.09	-3.79	Accept
Kenilworth	0.176	225.0	0.069	0.01	0.12	5.64	Accept
Wewiltalawa	-0.625	-797.0	<0.0001	-0.05	0.72	-17.13	Reject
Norton	-0.258	-329.0	0.008	-0.02	0.19	-8.47	Accept

The Yala season rainfall shows trends in point rainfall similar to the annual trends, with decreasing trends in all stations except for Kenilworth station. However, both Annfield station and Kenilworth station did not show significant trends with *ρ* value greater than 0.05. The rest of the stations (Labugama, Dunedin, Undugoda, Wewiltalawa and Norton) showed decreasing trends although the *Z* values are comparatively lesser. The Sen's Slope value showed the highest decline in Welitalawa with a downward trend of -17.13 mm. This is shown in Table 4-15.

Table 4-15 Mann-Kendall Statistics, Sen's Slope and Regression results for decadal seasonal point rainfall (Yala Season)

Rainfall Station	Kendall's Tau (τ)	*S*	ρ-value (Two-tailed)	*Z*	R - square	Sen's slope	Hypothesis (H_o) (α = 5%)
Labugama	-0.402	-513.0	<0.0001	-0.05	0.11	-10.44	Reject
Dunedin	-0.622	-793.0	<0.0001	-0.05	0.71	-10.41	Reject
Undugoda	-0.608	-775.0	<0.0001	-0.05	0.70	-7.01	Reject
Annfield	-0.122	-155.0	0.211	-0.01	0.09	-3.79	Accept
Kenilworth	0.176	225.0	0.069	0.01	0.12	5.64	Accept
Wewiltalawa	-0.625	-797.0	<0.0001	-0.05	0.72	-17.13	Reject
Norton	-0.258	-329.0	0.008	-0.02	0.19	-8.47	Reject

4.2.2.3 Trends in monthly rainfall

The decadal monthly trends show an increase in point rainfall in all rainfall stations for the month of January and a decrease in the months of August and September. But these declines/increases are very low with values ranging from 0.1 to 4 mm increase/decrease over 60-years with R^2 values of 0.001 to 0.6. The details of the linear regression trends are given in Table 4-13 and Appendix C. It was observed that most stations in the Kelani river basin showed a decreasing trend at a monthly time scale. The highest decrease can be observed in Wewiltalawa station in the month of June with a decrease of 4.37 mm for the 60-year period. Kenilworth station showed an increasing trend in all months except for the months of March, June, and September.

The Mann-Kendall statistics revealed a decreasing trend in the monthly rainfalls except for Kenilworth station. However, the increasing trend at Kenilworth was not significant with a ρ-value of 0.132 and a positive *Z* value of 0.003. Other than the Undugoda station, all the other stations showed a declining trend with a ρ-value lesser than 0.05. However, the rates of decline were comparatively lesser. This is shown in Table 4-16.

Table 4-16 Mann-Kendall Statistics, Sen's Slope and Regression results monthly point rainfall

Rainfall Station	Kendall's Tau (τ)	*S*	ρ-value (Two-tailed)	*Z*	R - square	Sen's slope	Hypothesis (H_o) (α = 5%)
Labugama	-0.069	-1472.0	0.007	-0.005	0.006	-0.860	Reject
Dunedin	-0.072	-1519.0	0.005	-0.005	0.042	-1.191	Reject
Undugoda	-0.045	-57.0	0.649	-0.01	0.005	-0.40	Accept
Annfield	-0.055	-1178.0	0.030	-0.004	0.000	-0.497	Reject
Kenilworth	0.039	820.0	0.132	0.003	0.002	0.174	Accept
Wewiltalawa	-0.094	-1994.0	0.0002	-0.067	0.016	-2.062	Reject
Norton	-0.062	-1310.0	0.016	-0.004	0.003	-0.751	Reject

4.2.2.4 Annual and seasonal trends in point rainfall

The trends in annual rainfall are graphically presented in Figure 4-11. The annual rainfall shows a decreasing trend in all stations except Kenilworth. The largest decrease in annual rainfall was observed for Wewiltalawa station with a decrease of 25.7 mm from 1954 to 2014. The Mann-Kendall statistic shows similar results with an increasing trend for Kenilworth station although not significant. All the other stations showed a decreasing trend. Undugoda, Annfield and Norton did not show any significant trends with a *ρ*-value greater than 0.05. Labugama Dunedin and Wewiltalawa showed decreasing trends with *ρ*-value lesser than 0.05. However, these trends were negligible with *Z* values ranging from -0.014 to -0.019 and Sen's slope values of -9.435 to -24.931. The results from the MK test, Sen's slope test and R^2 values are shown in Table 4-17.

Table 4-17 Mann-Kendall Statistics, Sen's Slope and Regression results for annual point rainfall

Rainfall Station	Kendall's Tau (τ)	*S*	ρ-value (Two-tailed)	*Z*	R - square	Sen's slope	Hypothesis (H_o) (α = 5%)
Labugama	-0.194	-344.0	0.029	-0.014	0.09	-9.808	Reject
Dunedin	-0.221	-392.0	0.013	-0.016	0.101	-9.435	Reject
Undugoda	-0.173	-306.0	0.052	-0.012	0.080	-8.276	Accept
Annfield	-0.041	-72.0	0.651	-0.003	0.085	-2.271	Accept
Kenilworth	0.082	146.0	0.355	0.006	0.025	7.754	Accept
Wewiltalawa	-0.277	-490.0	0.002	-0.019	0.181	-24.931	Reject
Norton	-0.159	-282.0	0.073	-0.011	0.061	-13.615	Accept

The IPCC predicts globally averaged annual precipitation to both increase and decrease by 5% to 20% projected at regional scale in the 21st century. The trend in mean annual rainfall shows decreasing trends of less than 1% of the annual average rainfall with very low R^2 values hence the low significance of the trends.

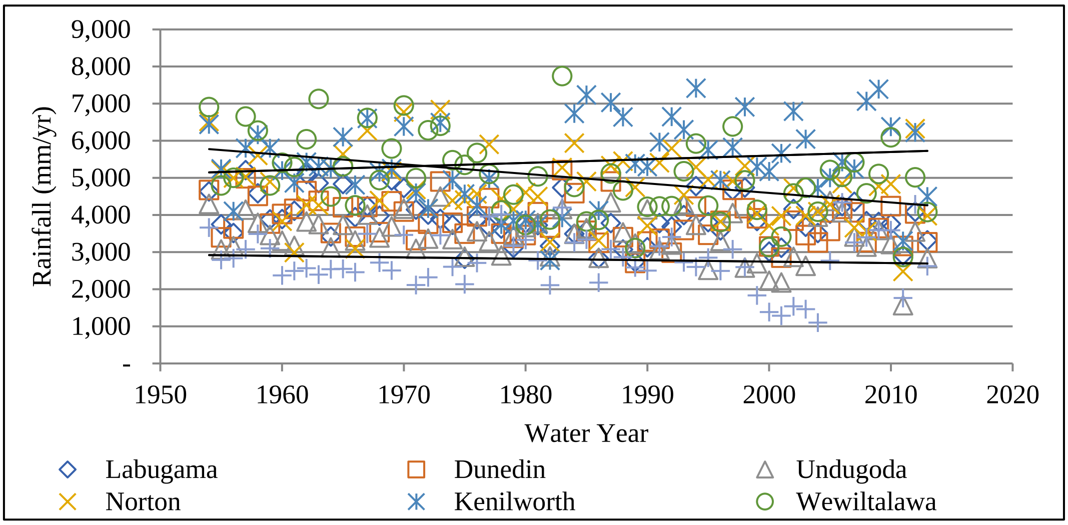

Figure 4-11 Annual Rainfall Trends

The seasonal variation in rainfall for Maha and Yala seasons is shown in Figure 4-12 and Figure 4-13, respectively. The Maha season shows an increase in rainfall at Annfield station of about 4 mm for the 60-year period due to an increase in the rainfall in the station during the recent decades, while a decreasing trend was observed for the rest of the stations. In the Yala season, an increase in trend in Kenilworth of 5.7 mm from 1954 to 2014 can be observed whereas a decrease in trend for the rest was observed. The highest decrease in point rainfall was noted for Wewiltala station, in both seasons of 13 mm for Maha and 15.1 mm over 60-years for Yala season was observed. Annual and intra-annual rainfall trends reveal a reduction in rainfall although at insignificant rates, this decline is more prominent in the Yala season for all stations. The linear regression trend results are shown in Table 4-13. The Mann-Kendall test results reveal a decreasing trend in both seasons except for Kenilworth station. Wewiltalawa and Norton stations are the only two stations that showed a decreasing trend with ρ-values lesser than 0.05 for the Maha season. The Z values and Sen's slope values however show negligible decreasing trends. Trend test results for the Yala season shows a decreasing trend only for Wewiltalawa and Labugama station with ρ-value lesser than 0.05. The Z significance values are however lesser than the $Z_{0.025}$=1.96 and Sen's slope values are comparatively lesser. Table 4-18 and Table 4-19 shows the MK trend values, Sen's slope estimate and R^2 values for the seasonal rainfall in Maha season and Yala season, respectively.

Table 4-18 Mann-Kendall Statistics, Sen's Slope and Regression results for seasonal point rainfall (Maha Season)

Rainfall Station	Kendall's Tau (τ)	*S*	ρ-value (Two-tailed)	*Z*	R - square	Sen's slope	Hypothesis (H_o) (α = 5%)
Labugama	-0.081	-144.0	0.362	-0.006	0.018	-2.738	Accept
Dunedin	-0.112	-198.0	0.209	-0.008	0.037	-4.116	Accept
Undugoda	-0.128	-226.0	0.151	-0.009	0.014	-3.762	Accept
Annfield	0.077	136.0	0.389	-0.005	0.022	2.818	Accept
Kenilworth	-0.089	-158.0	0.317	-0.006	0.004	-2.783	Accept
Wewiltalawa	-0.455	-788.0	<0.0001	-0.032	0.373	-12.524	Reject
Norton	-0.176	-312.0	0.047	-0.013	0.071	-5.389	Reject

Table 4-19 Mann-Kendall Statistics, Sen's Slope and Regression results for seasonal point rainfall (Yala Season)

Rainfall Station	Kendall's Tau (τ)	*S*	ρ-value (Two-tailed)	*Z*	R - square	Sen's slope	Hypothesis (H_o) (α = 5%)
Labugama	-0.199	-352.0	0.025	-0.014	0.084	-8.103	Reject
Dunedin	-0.155	-274.0	0.082	-0.011	0.053	-5.35	Accept
Undugoda	-0.165	-292.0	0.063	-0.012	0.076	-6.140	Accept
Annfield	-0.043	-76.0	0.632	-0.0031	0.007	-2.147	Accept
Kenilworth	0.047	84.0	0.597	0.003	0.012	3.757	Accept
Wewiltalawa	-0.253	448.0	0.004	-0.018	0.118	-14.982	Reject
Norton	-0.145	-256.0	0.104	-0.010	0.029	-9.393	Accept

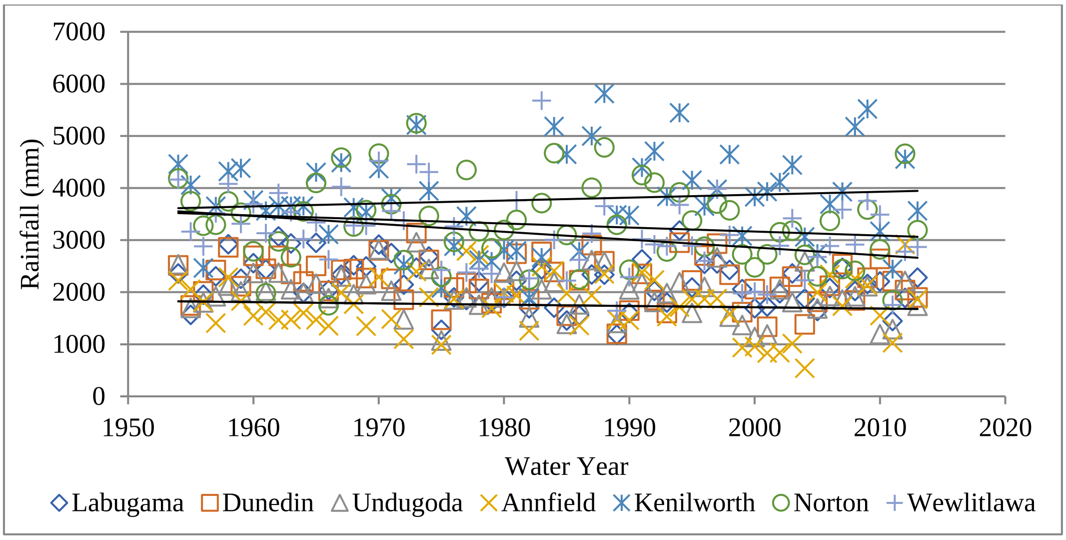

Figure 4-12 Yala season rainfall variation

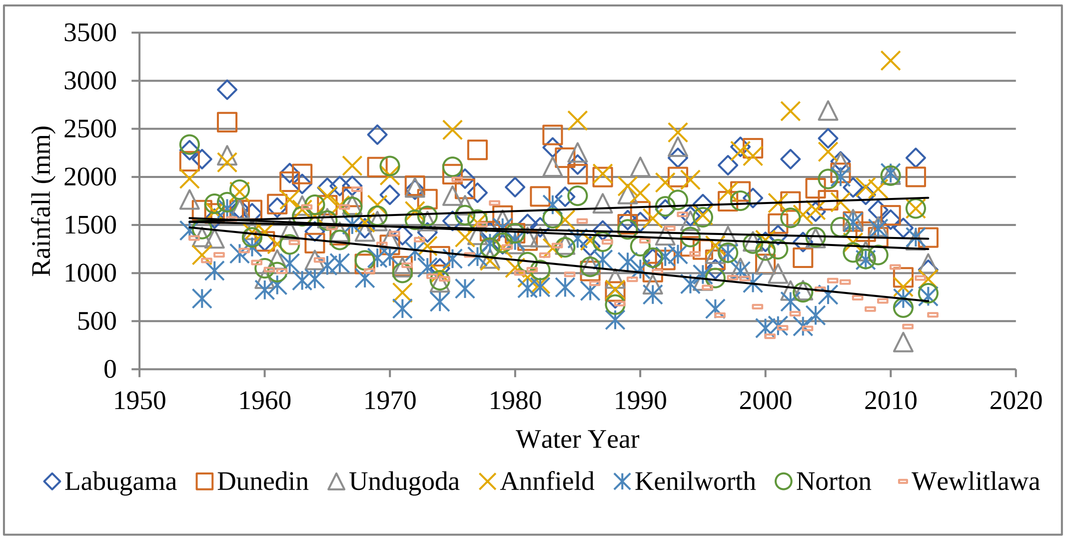

Figure 4-13 Maha season rainfall variation

4.2.3 Trends in catchment rainfall

The catchment average rainfall was calculated using Thiessen Polygon Method. For Kitulgala sub-catchment, three rainfall stations were taken and averaged and for Glencourse sub-catchment, a total of seven stations were taken. The decade wise, annual, and intra-annual trends in catchment rainfall are given in Table 4-34 and Table 4-35.

4.2.3.1 Decadal annual trends in catchment rainfall

The decadal annual variation in catchment rainfall for Kitulgala and Glencourse are shown in Figure 4-14. Both the sub-catchments show a decreasing trend of 6.2 mm and 10.6 mm with R^2 values of 0.19 and 0.77 for Kitulgala and Glencourse, respectively during the 60-year period. The details of linear regression trends of spatially averaged rainfall are mentioned in Table 4-34. The Man-Kendall trend test also shows a decreasing trend for Glencourse catchment rainfall with an ρ value of less than 0.00001. A decreasing trend with Sen's slope value of -10.308 mm was noted for Glencourse catchment rainfall. Kitulgala catchment rainfall also shows a decreasing trend with a Z value of - 0.013 although insignificant. The results from the tests are shown in Table 4-20.

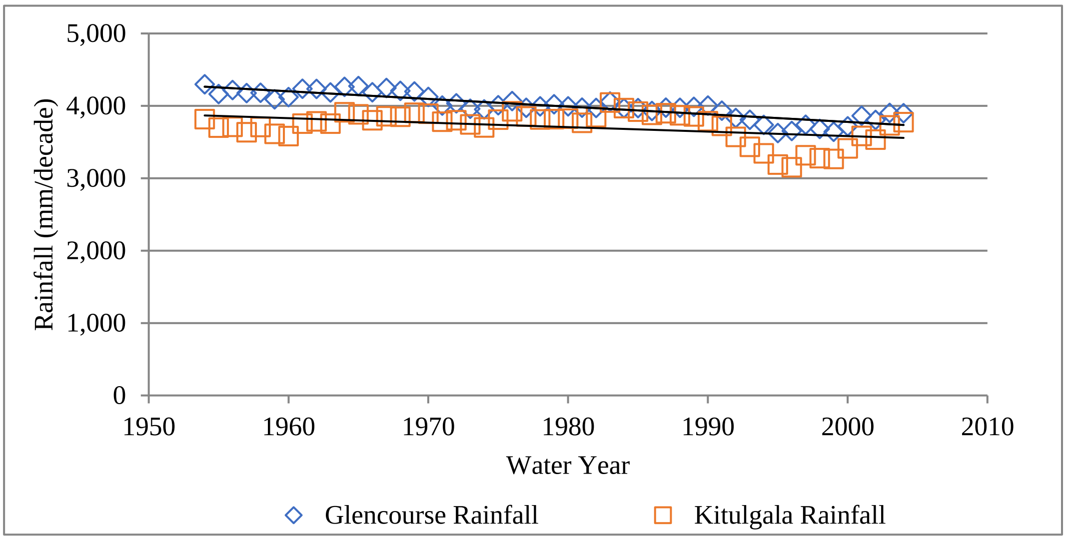

Figure 4-14 Decadal variation of catchment rainfall

Table 4-20 Mann-Kendall Statistics, Sen's Slope and Regression results for decadal annual catchment rainfall

Rainfall Station	**Kendall's Tau (τ)**	***S***	**ρ-value (Two-tailed)**	***Z***	**R - square**	**Sen's slope**	**Hypothesis (H_o) (α = 5%)**
Kitulgala Catchment Rainfall	-0.153	-195.0	0.115	-0.013	0.19	-3.398	Accept
Glencourse Catchment Rainfall	-0.678	-865.0	<0.0001	-0.057	0.768	-10.308	Reject

4.2.3.2 Decadal variations in seasonal catchment rainfall

A decline in rainfall can be observed in both seasons (Figure 4-15 and Figure 4-16) of 4 mm over 60-years and 7.5 mm over 60-years for the Maha season and 3 mm and 2 mm over the 60-year period for Yala season for Kitulgala and Glencourse, respectively. Although the rate of decline is very low, these trends are much higher for Glencourse sub-catchment as compared to Kitulgala sub-catchment with a higher R^2. The Mann-Kendall test results reveal a downward trend for both the sub-catchment rainfall in Maha season, however with lesser Z values of -0.034 and -0.041 for Kitulgala catchment rainfall and Glencourse catchment rainfall, respectively. Sen's slope values of -2.916 and -3.516 were noted for the same showing negligible decreases over the 60-year period. The MK test results for the Yala season shows a decline only for Glencourse catchment rainfall and negative τ values and Z values and a Sen's slope value of -0.046. The Kitulgala catchment rainfall however showed no significant downward trend with Sen's slope value of -1.637. The MK trend results, Sen's slope estimate and R2 values for the seasonal catchment rainfall in Maha season and Yala season is shown in Table 4-21 and

Table 4-22, respectively.

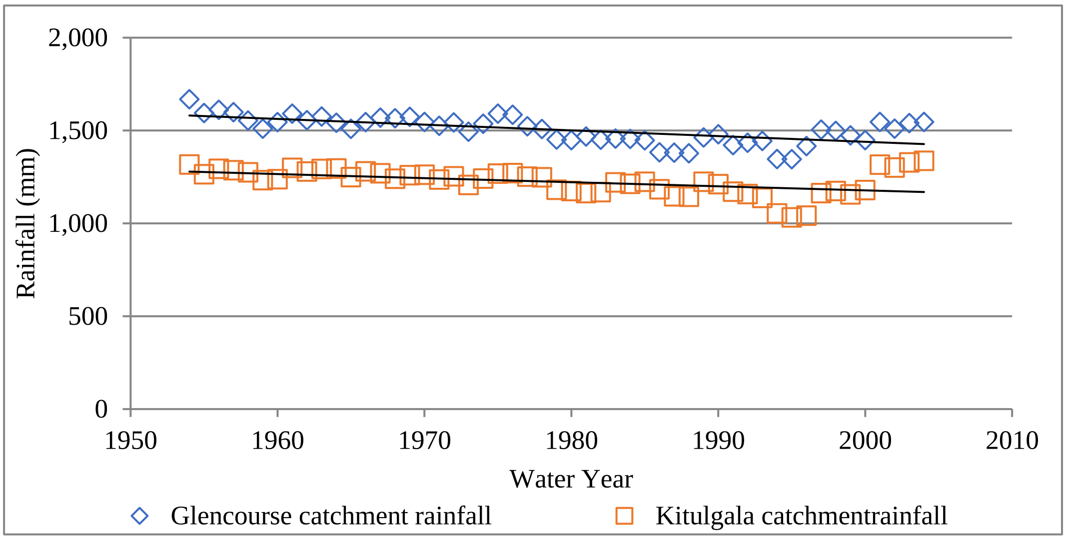

Figure 4-15 Decadal variations in seasonal Catchment Rainfall (Maha Season)

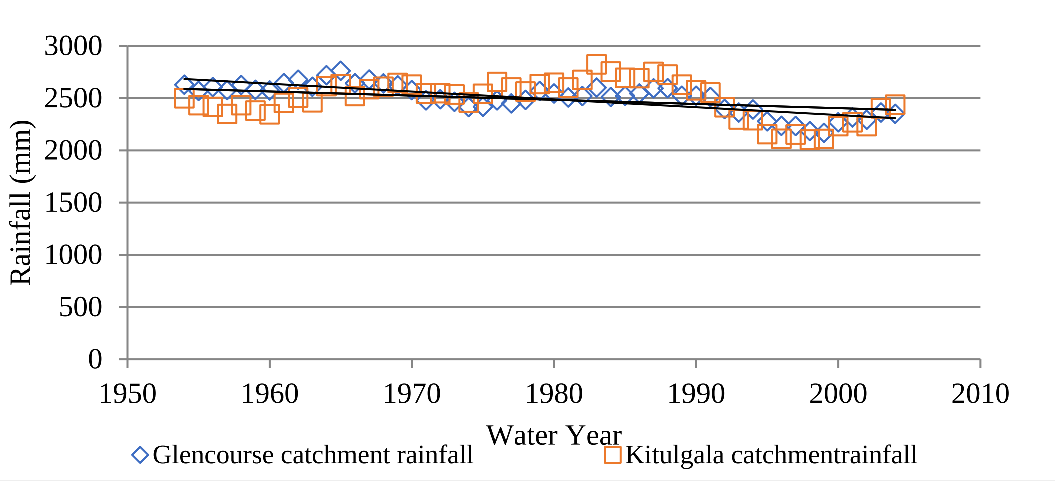

Figure 4-16 Decadal trends in Seasonal Catchment Rainfall (Yala Season)

Table 4-21 Mann-Kendall Statistics, Sen's Slope and Regression results for decadal seasonal catchment rainfall (Maha season)

Rainfall Station	**Kendall's Tau (τ)**	***S***	**ρ-value (Two-tailed)**	***Z***	**R - square**	**Sen's slope**	**Hypothesis (H_o) (α = 5%)**
Kitulgala Catchment Rainfall	-0.409	-521.0	<0.0001	-0.034	0.216	-2.916	Reject
Glencourse Catchment Rainfall	-0.487	-621.0	<0.0001	-0.041	0.404	-3.516	Reject

Table 4-22 Mann-Kendall Statistics, Sen's Slope and Regression results for decadal seasonal catchment rainfall (Yala season)

Rainfall Station	**Kendall's Tau (τ)**	***S***	**ρ-value (Two-tailed)**	***Z***	**R - square**	**Sen's slope**	**Hypothesis (H_o) (α = 5%)**
Kitulgala Catchment Rainfall	-0.065	-83.0	0.505	-0.005	0.105	-1.637	Accept
Glencourse Catchment Rainfall	-0.544	-693.0	<0.0001	-0.046	0.615	-7.119	Reject

4.2.3.3 Annual, seasonal and monthly variations in catchment rainfall

The rainfall at both sub-catchments show increases in the months of January and April. The Kitulgala catchment rainfall shows an increasing trend for the months of May, April, and November, but Glencourse catchment rainfall shows a decreasing trend. These trend rates are considerably low with very low significance values (R^2 values). The Mann-Kendall test results reveal a downward trend for the Glencourse catchment rainfall on a monthly scale, however with a lesser Z value of -0.004. Kitulgala catchment rainfall did not show a statistically significant trend on a monthly scale with a Z value of -0.003. Sen's slope values of -0.443 and -0.926 for Kitulgala catchment rainfall and Glencourse catchment rainfall showing negligible decreases over the 60-year period. The MK trend results, Sen's slope estimate and R^2 values for the monthly catchment rainfall are shown in Table 4-23.

Table 4-23 Mann-Kendall Statistics, Sen's Slope and Regression results for monthly catchment rainfall

Rainfall Station	**Kendall's Tau (τ)**	***S***	**ρ-value (Two-tailed)**	***Z***	**R - square**	**Sen's slope**	**Hypothesis (H_o) (α = 5%)**
Kitulgala Catchment Rainfall	-0.042	-896.0	0.099	-0.003	0.001	-0.443	Accept
Glencourse Catchment Rainfall	-0.063	-1334.0	0.014	-0.004	0.005	-0.926	Reject

The mean annual catchment rainfall variations are shown in Figure 4-17. Both Kitulgala and Glencourse catchment rainfall show a decrease in their annual trends of 5.4 mm and 10.4 mm for the 60-year period with R^2 values of 0.01 and 0.09, respectively. The ten-year moving average trend shows decreases of 6.2 and 11.2 mm for Kitulgala and Glencourse catchment rainfall, respectively over the 60-year period. The Man-Kendall test results show no statistically significant trend with a ρ-value greater than 0.05. The τ value and Z value shows a negative value indicating a declining trend, however, these values are quite insignificant. The Sen's slope value shows a decline of -6.611 mm/annum and -8.727 mm/annum for Kitulgala catchment rainfall and Glencourse catchment, respectively. The MK and Sen's slope estimates are shown in Table 4-24.

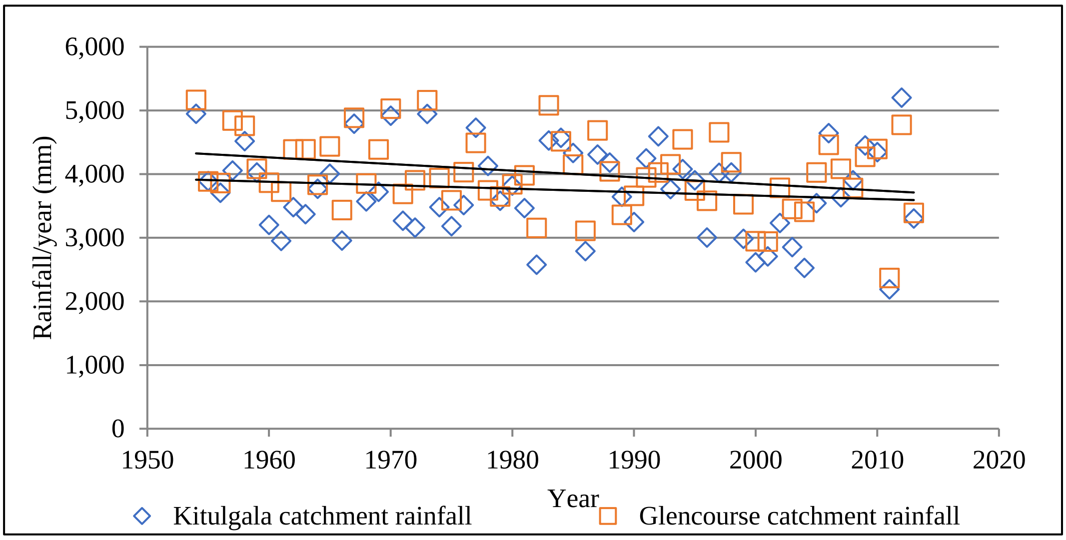

Figure 4-17 Annual variation in catchment rainfall

Table 4-24 Mann-Kendall Statistics, Sen's Slope and Regression results for annual catchment rainfall

Rainfall Station	Kendall's Tau (τ)	*S*	ρ-value (Two-tailed)	*Z*	R - square	Sen's slope	Hypothesis (H_o) (α = 5%)
Kitulgala catchment rainfall	-0.080	-142.0	0.368	-0.006	0.018	-6.611	Accept
Glencourse catchment rainfall	-0.171	-302.0	0.060	-0.012	0.097	-8.727	Accept

The seasonal trends in catchment rainfall show decreases of 2.2 and 4.0 mm from 1954 to 2014 in Maha for Kitulgala and Glencourse sub-catchments, respectively (Figure 4-18). In the Yala season, declines of 3.2 and 6.5 mm for 60-years were observed for Kitulgala and Glencourse sub-catchment rainfall (Figure 4-19). The Mann-Kendall statistics also show statistically insignificant declines in rainfall for both the sub-catchments with negative *Z* and *τ* values during Maha and Yala season. The Sen's slope values for the catchment rainfall showed declines ranging from (-2.137 mm to -5.927 mm) for the catchment rainfalls indicating slight declines in seasonal rainfall. The MK test results, Sen's slope estimate and R^2 values are shown in Table 4-25 and Table 4-26 for Maha season and Yala season, respectively.

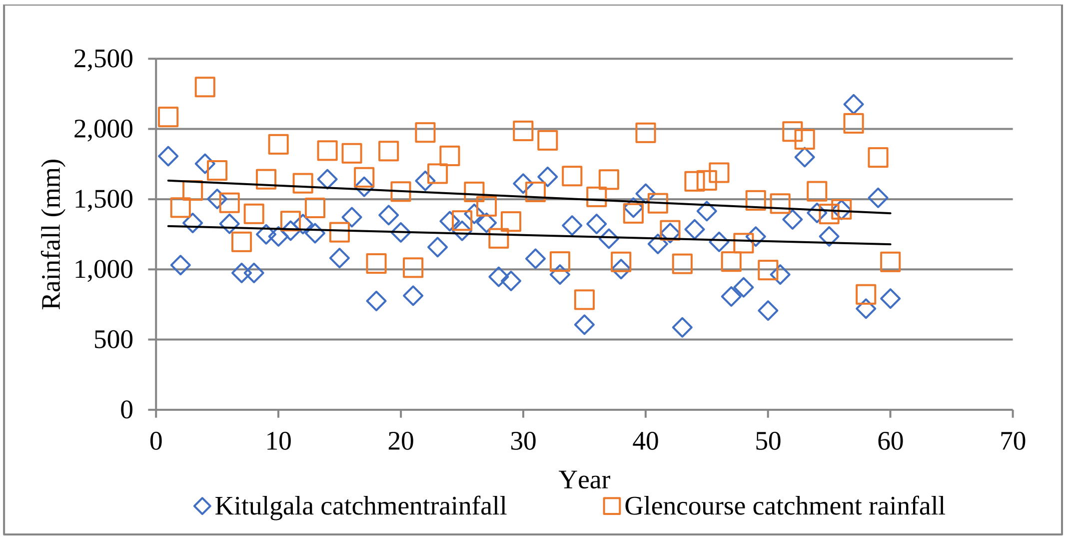

Figure 4-18 Rainfall variation in Maha season

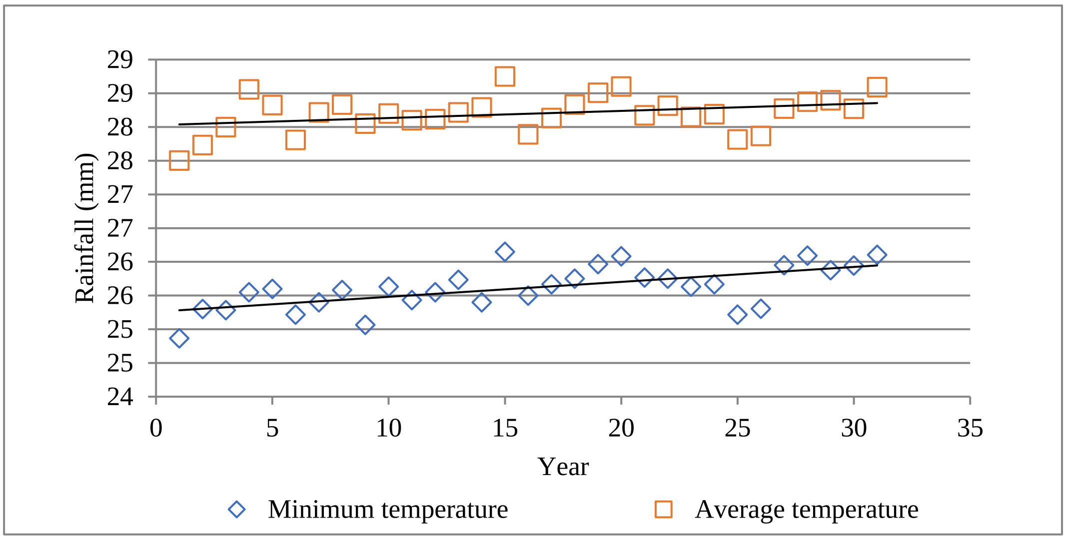

Figure 4-19 Rainfall variation in Yala season

Table 4-25 Mann-Kendall Statistics, Sen's Slope and Regression results for seasonal catchment rainfall (Maha season)

Rainfall Station	Kendall's Tau (τ)	*S*	ρ-value (Two-tailed)	*Z*	R - square	Sen's slope	Hypothesis (H_o) (α = 5%)
Kitulgala catchment rainfall	-0.086	-152.0	0.336	-0.006	0.014	-2.137	Accept
Glencourse catchment rainfall	-0.127	-224.0	0.155	-0.009	0.04	-3.894	Accept

Table 4-26 Mann-Kendall Statistics, Sen's Slope and Regression results for seasonal catchment rainfall (Yala season)

Rainfall Station	Kendall's Tau (τ)	*S*	ρ-value (Two-tailed)	*Z*	R - square	Sen's slope	Hypothesis (H_o) (α = 5%)
Kitulgala catchment rainfall	-0.073	-130.0	0.411	-0.00525	0.010	-3.409	Accept
Glencourse catchment rainfall	-0.167	-296.0	0.06	-0.012	0.063	-5.927	Accept

4.2.4 Trends in streamflow

The trends for the recent thirty-year period was considered for streamflow since data prior to that period showed inconsistent data. The streamflow period from 1984/85 to 2013/2014 was selected for analysis since responses of streamflow to rainfall in prior years were quite high resulting in negative water balance and high runoff coefficients in both the catchments. The recent decades showed more consistent data with comparable evaporation and water balance and lower runoff coefficients.

4.2.4.1 Decadal annual trends in streamflow

Decadal annual trends in streamflow were computed for the selected period of 1983/84 to 2013/2014. The decadal annual streamflow trends show a decreasing trend in both the sub-catchments of about 68.5 mm and 69.6 mm in thirty years for Kitulgala and Glencourse, respectively. This is shown in Figure 4-20. These decreases are comparable to the decreases identified in rainfall in both sub-catchments. Although these rates are very low, the R^2 values are higher for Kitulgala (0.83) and suggestive of the higher significance of the decline in Kitulgala. On comparing the decadal rainfall trends of catchment rainfall for the recent period (1983/84 to 2013/14) to the streamflow trends, the recent period shows declines of about 26 mm and 12 mm, respectively for Kitulgala and Glencourse sub-catchment, respectively. The decrease in rainfall is much higher for Kitulgala, almost 2.1 times more as compared to its Glencourse but the decreasing streamflow trends are almost equal. This difference may be due to the reservoir releases in Kitulgala sub-catchment that tend to mask the declines in the streamflow of the basin. The linear regression trends in streamflow for both sub-catchments on decadal, annual, and intra-annual scales are given in Table 4-35. The Mann-Kendall trend test shows a decreasing streamflow trend for both the sub-catchments with negative τ and Z values. The Sen's slope shows higher declines for Glencourse of -75.339 mm for the 30-years of observation. This is shown in Table 4-27.

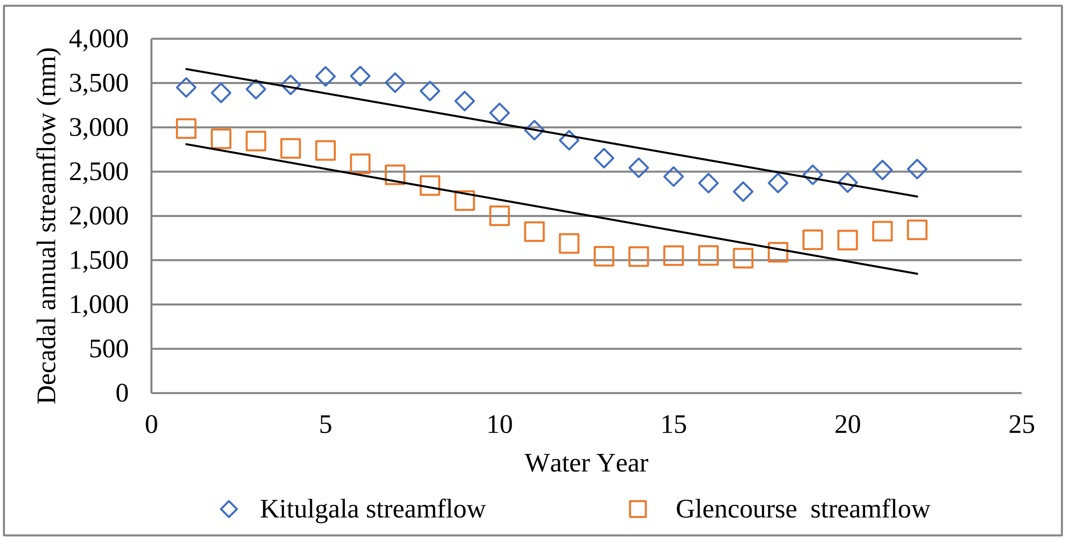

Figure 4-20 Decadal variation of average streamflow

Table 4-27 Mann-Kendall Statistics, Sen's Slope and Regression results for decadal annual streamflow

Rainfall Station	Kendall's Tau (τ)	*S*	ρ-value (Two-tailed)	*Z*	R - square	Sen's slope	Hypothesis (H_o) (α = 5%)
Kitulgala Streamflow	-0.654	-151.0	<.0.0001	-0.119	0.832	-70.567	Reject
Glencourse Streamflow	-0.610	-141.0	<.0.0001	-0.111	0.755	-75.339	Reject

The IPCC states a coherent pattern of change, (increase in high latitudes and decrease in other parts) can be observed in streamflow and most studies failed to find significant trends in streamflow. In the current study decrease in decadal annual streamflow of 69.6 mm for 60-years in Glencourse catchment and 68.5 mm in Kitulgala catchment were identified which were less than 1% of the annual average and comparatively insignificant.

4.2.4.2 Decadal trends in seasonal streamflow

The decadal variations of seasonal streamflow at Kitulgala and Glencourse for Maha and Yala season are shown in Figure 4-21 and Figure 4-22, respectively.

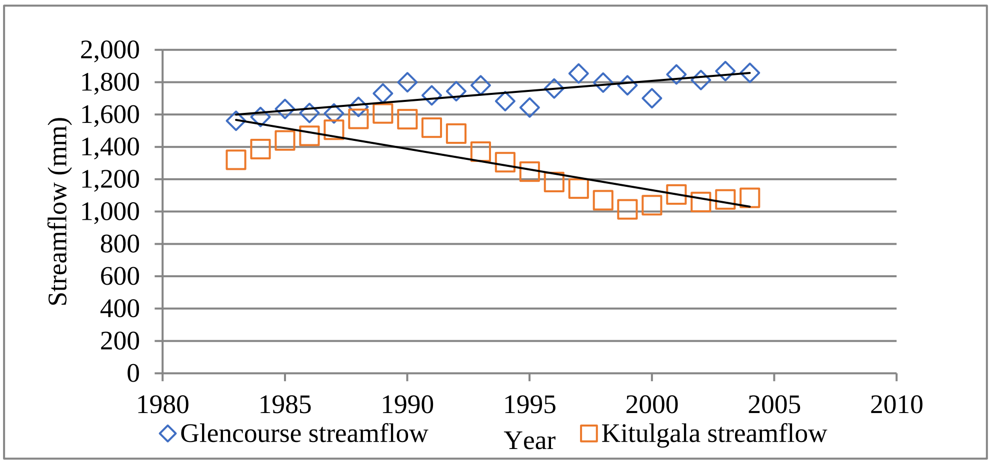

Figure 4-21 Decadal variations in seasonal streamflow (Maha season)

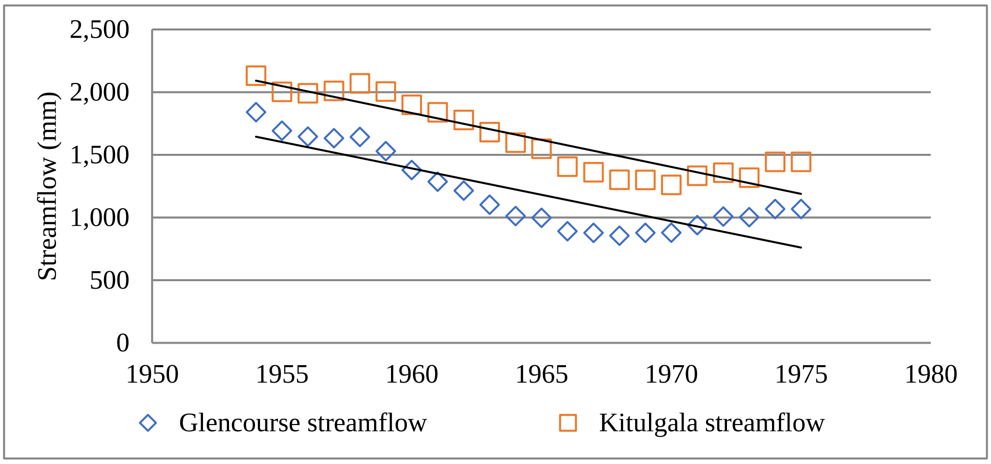

Figure 4-22 Decadal variations in seasonal streamflow (Yala season)

Glencourse streamflow shows an increasing trend in the recent decades of 12.3 mm for the 30- year period for an increase in rainfall of 5.1 mm for the thirty years, whereas Kitulgala shows a declining trend of 21.5 mm for Maha season for the recent thirty years although the rainfall trends for the recent period (1983/84-2013/14) for Maha season shows an increasing trend at an insignificant level (3 mm). These linear regression trends are shown in Table 4-35. The Northeast monsoon (Maha season) is low in rainfall for the south-western part of the country creating a dry period for the Kelani river basin. Kitulgala has six reservoirs within its catchment. The trends in the streamflow in the Maha season for Kitulgala catchment may be masked by the reservoir during that season when the rainfall is comparatively lesser. Hence the reservoir storages and releases during those periods may have affected the streamflow responses for Kitulgala. The Mann-Kendall statistics results show an increasing trend in Glencourse catchment during the Maha season with a ρ-value of 0.003. The τ and Z value shows a positive trend of 0.66 and 0.122, respectively for Glencourse catchment indicating an upward trend. The Sen's slope also shows an increasing trend of 12.997 mm for Glencourse in the Maha season. The Kitulgala streamflow however shows a declining trend similar to linear regression results with negligible decreases indicated by the Z value of -0.102 and Sen's slope of -26.902 over the 60-year period. The Yala season also shows declining trends in both the streamflow with Z values of -0.129 and -0.111 and Sen's slope value of -44.710 and -45.299 for Kitulgala streamflow and Glencourse streamflow, respectively. The MK test results, Sen's slope estimate and R^2 values for decadal streamflow are shown in Table 4-28 and Table 4-29 for Maha season and Yala season, respectively.

Table 4-28 Mann-Kendall Statistics, Sen's Slope and Regression results for decadal seasonal streamflow (Maha season)

Rainfall Station	**Kendall's Tau (τ)**	***S***	**ρ-value (Two-tailed)**	***Z***	**R - square**	**Sen's slope**	**Hypothesis (H_o) (α = 5%)**
Kitulgala Streamflow	-0.558	-129.0	0.0003	-0.102	0.668	-26.902	Reject
Glencourse Streamflow	0.662	153.0	<0.0001	0.122	0.688	12.997	Reject

Table 4-29 Mann-Kendall Statistics, Sen's Slope and Regression results for decadal seasonal streamflow (Yala season)

Rainfall Station	**Kendall's Tau (τ)**	***S***	**ρ-value (Two-tailed)**	***Z***	**R - square**	**Sen's slope**	**Hypothesis (H_o) (α = 5%)**
Kitulgala Streamflow	-0.706	-163.0	<0.0001	-0.129	0.839	-44.710	Reject
Glencourse Streamflow	-0.610	-141.0	<0.0001	-0.111	0.722	-45.299	Reject

4.2.4.3 *Trends in monthly streamflow*

The decadal monthly trends in streamflow for Kitulgala shows decreasing decadal trends for all the months from 1983/84 to 2013/14 of less than 11 mm whereas Glencourse shows no trends in the month of February, March, and April while a decreasing trend can be identified for the rest of the months. The linear regression trends of monthly streamflow in Glencourse although insignificant are similar to the trends in catchment rainfall as shown in Table 4-35. Kitulgala streamflow on the other hand shows declines of insignificant figures, (less than 3 mm for the 30-year period) even for an increase in rainfall of less than 4 mm for the 30-year period. The Mann Kendall test results reveal a decreasing trend in monthly streamflow for both the catchments with ρ-value lesser than 0.0001 and negative τ and Z values. The Sen's slope values of -2.663 and -2.493 shows slight declining trends for both the catchments. This is shown in Table 4-30.

Table 4-30 Mann-Kendall Statistics, Sen's Slope and Regression results for monthly streamflow

Streamflow Station	Kendall's Tau (τ)	*S*	ρ-value (Two-tailed)	*Z*	R - square	Sen's slope	Hypothesis (H_o) (α = 5%)
Kitulgala Streamflow	-0.244	-1271.0	<0.0001	-0.033	0.055	-2.663	Reject
Glencourse Streamflow	-0.167	-872.0	<0.0001	-0.023	0.064	-2.493	Reject

4.2.4.4 Annual, seasonal and monthly variations in streamflow

The annual trends in streamflow from 1983/84 to 2013/14 are shown in Figure 4-23. The annual streamflow at Glencourse shows decreases of 57.26 mm for the 30-year period for a decrease in catchment rainfall of 16.5 mm. The annual streamflow trend at Kitulgala shows a decrease of 43.4 mm for the 30-year period for a decrease in catchment rainfall at Kitulgala of 17.45 mm which is lesser than that of Glencourse. The Mann-Kendall statistics show similar results with a decreasing trend for both the catchments. However, the Z values are comparatively lesser indicating only slight decreases. The Sen's slope also shows a slight decline of -44.047 and -54.398 over the 30-year period for Kitulgala and Glencourse streamflow, respectively.

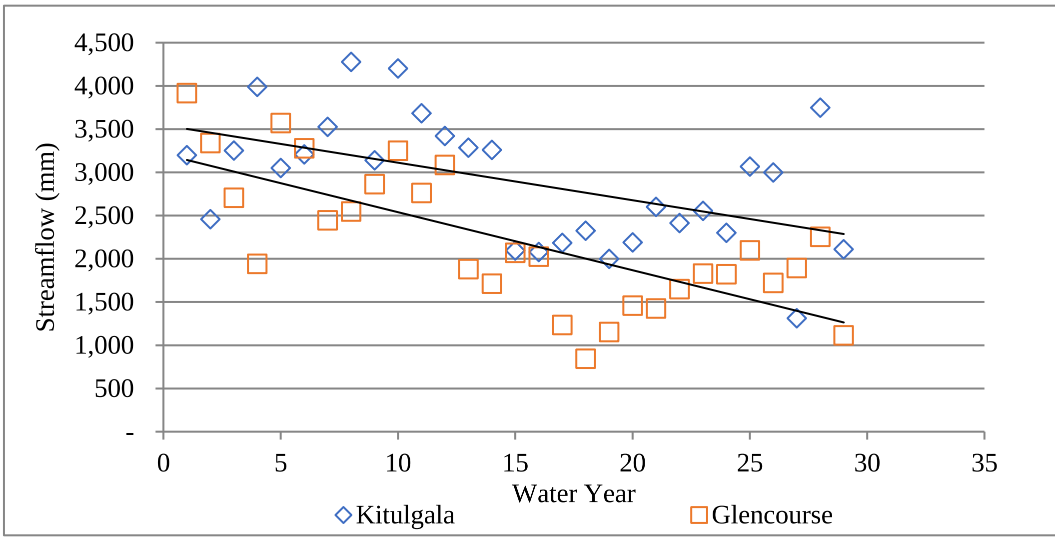

Figure 4-23 Annual variations in streamflow

Table 4-31 Mann-Kendall statistics, Sen's slope and R^2 values for Annual Streamflow

Streamflow Station	**Kendall's Tau (τ)**	***S***	**ρ-value (Two-tailed)**	***Z***	**R - square**	**Sen's slope**	**Hypothesis (H_o) (α = 5%)**
Kitulgala Streamflow	-0.359	-167.0	0.005	-0.048	0.253	-44.047	Reject
Glencourse Streamflow	-0.432	-201.0	0.001	-0.0583	0.510	-54.398	Reject

On a seasonal scale, the Maha season trend for Glencourse shows an increasing trend of 5.5 mm from 1984/84 to 2013/14 whereas Kitulgala shows a declining trend of 12.77 mm in the Maha season. The trend in catchment rainfall for that period reveals an increasing trend of less than 2 mm for both the catchments. Kitulgala, which is the smaller catchment and lies upstream of Glencourse, has six reservoirs within its catchment. The catchment receives lesser rainfall in the Maha compared to the Yala season, hence the reservoirs are operated in Maha season, which may have masked the trends. This may be the reason for the difference in trends between the catchments and the rainfall responses. The Yala season streamflow trend on the other hand shows comparable and almost equal responses in both the catchments. The seasonal variations in streamflow are shown in Figure 4-24 and Figure 4-25. The Mann-Kendall statistics show similar results with an increasing trend for the Glencourse catchment and a decreasing trend for Kitulgala streamflow in the Maha season. However, the streamflow trends in the Yala season are both decreasing trends with a ρ-value of less than 0.05. Negative Z values and Sen's slope values are comparatively lesser indicating only slight decreases.

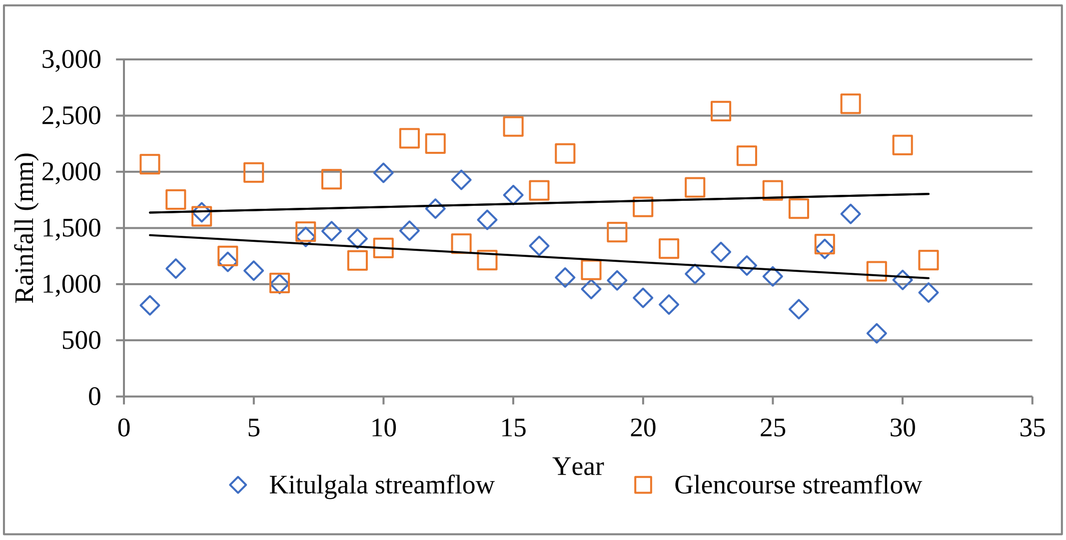

Figure 4-24 Streamflow variations in Maha season

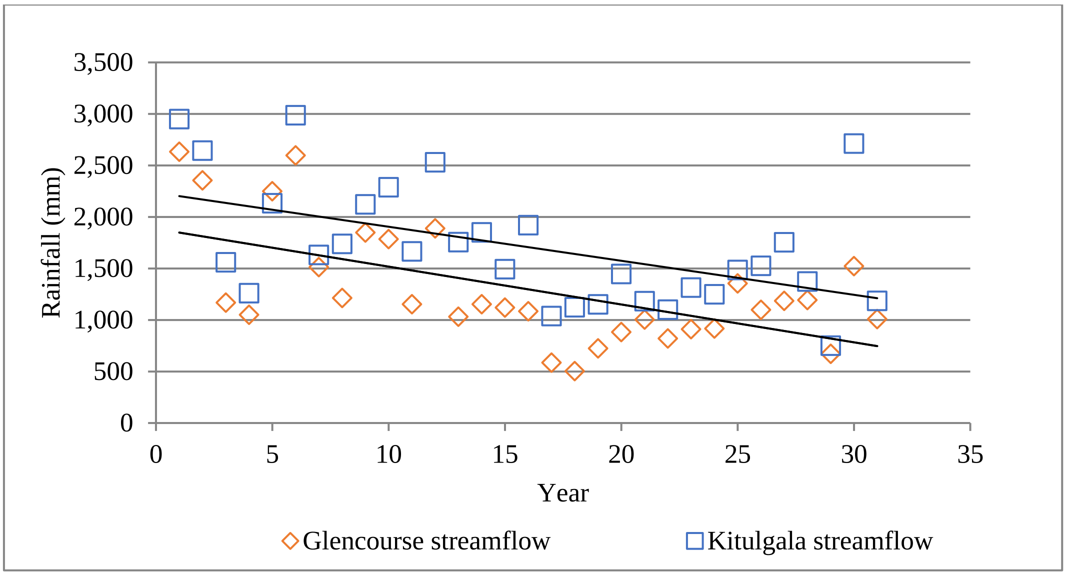

Figure 4-25 Streamflow variations in Yala Season

Table 4-32 Mann-Kendall Statistics, Sen's Slope and Regression results for seasonal streamflow (Maha season)

Rainfall Station	**Kendall's Tau (τ)**	***S***	**ρ-value (Two-tailed)**	***Z***	**R - square**	**Sen's slope**	**Hypothesis (H_o) (α = 5%)**
Kitulgala Streamflow	-0.226	-105.0	0.077	-0.030	0.108	-12.768	Accept
Glencourse Streamflow	0.037	17.0	0.786	0.005	0.011	4.417	Accept

Table 4-33 Mann-Kendall Statistics, Sen's Slope and Regression results for seasonal streamflow (Yala season)

Rainfall Station	**Kendall's Tau (τ)**	***S***	**ρ-value (Two-tailed)**	***Z***	**R - square**	**Sen's slope**	**Hypothesis (H_o) (α = 5%)**
Kitulgala Streamflow	-0.346	-161.0	0.007	-0.0462	0.262	-33.818	Reject
Glencourse Streamflow	-0.359	-167.0	0.005	-0.048	0.350	-29.908	Reject

Annual streamflow in both catchments shows a decline faster than 29% of the spatially averaged rainfall. While trends in 10-year moving averages and decadal trends are roughly the same in both catchments, the rainfall declines were more for the Kitulgala sub-catchment. On an annual scale, the streamflow decline rate is 24% higher for Glencourse. The linear regression trends in streamflow are given in Table 4-34 and Table 4-35.

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Table 4-34 Linear Regression Trends (Catchment Rainfall and Streamflow 1954/55 to 2013/14)

Linear regression trends																
Decadal trends																
Station	**Time period**	**Annual**	**Season**		**Month**											
			Maha	**Yala**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Glencourse																
Rainfall	Base period	-16.44	-6.17	-7.10	0.31	-0.54	-0.49	-2.40	-0.84	5.17	-1.44	-2.8	-7.10	-7.34	5.82	-4.21
	Entire	-10.58	-3.08	-4.00	0.73	-0.33	-0.84	0.07	-1.00	-0.96	-1.26	-1.68	-2.46	-0.56	-0.60	-1.66
Streamflow	Base period	-34.53	-30.4	-0.90	-0.50	-0.17	-1.32	-1.70	-8.63	8.63	-1.56	-5.93	-7.99	-12.0	3.20	-2.59
	Entire	-40.20	-11.4	-25.1	-1.00	-0.61	-1.31	0.63	-4.90	-4.09	-4.81	-4.55	-4.82	-5.83	-3.90	-2.80
Kitulgala																
Rainfall	Base period	-0.50	-3.36	10.67	-0.04	-0.73	-0.37	-3.15	3.87	11.37	2.85	-2.13	-3.87	-7.60	5.01	-3.02
	Entire	-6.20	-2.19	-7.50	0.35	-0.34	-0.54	0.47	0.18	-0.02	-0.32	-1.55	-2.53	-0.25	-0.20	-1.44
Streamflow	Base period	-6.17	-2.92	0.77	0.56	0.90	-2.73	0.001	-4.90	5.32	1.66	-3.32	-8.10	7.85	1.93	-1.18
	Entire	-11.21	1.59	-12.8	1.36	1.08	0.26	0.87	-3.06	-2.7	-2.51	-2.49	-2.7	-2.09	-0.5	0.612

Annual and Intra-annual trends																
Station	**Time period**	**Annual**	**Seasonal**		**Month**											
			Maha	**Yala**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Glencourse																
Rainfall	Base period	11.90	-6.20	-7.10	0.90	-0.70	-0.40	-3.00	-1.00	7.80	0.00	-1.90	-3.90	-4.50	2.60	-3.00
	Entire	-10.40	-3.90	-6.40	0.40	-0.40	-0.80	-0.10	-1.20	-1.90	-0.90	-0.60	-1.50	-1.10	-0.60	-1.70
Streamflow	Base period	-26.20	-30.40	0.90	-0.50	-0.40	-0.90	-1.50	-6.20	10.30	0.80	-4.00	-6.20	-9.50	1.70	-2.80
	Entire	-33.20	-10.6	-20.10	-0.90	-0.50	-1.00	-1.20	-3.80	-4.00	-3.80	-3.00	-2.90	-5.10	-3.20	-2.30
Kitulgala																
Rainfall	Base period	7.54	-3.36	10.66	0.57	-0.57	-0.36	-1.80	3.56	12.79	4.55	-0.40	-0.38	-4.39	3.07	-2.20
	Entire	-5.42	-2.19	-3.20	0.17	-0.34	-0.29	0.51	-0.54	-1.17	0.16	-0.60	-1.49	-0.69	0.09	-1.30
Streamflow	Base Period	0.05	-2.93	0.77	1.18	1.25	-0.08	1.35	-3.33	5.23	2.74	-0.62	-4.99	-6.68	0.31	-0.47
	Entire	-11.45	-0.04	-11.41	0.86	0.72	0.17	0.52	-3.23	-3.60	-1.80	-1.49	-1.69	-2.12	-0.60	0.40

Table 4-35 Linear Regression Trends (Catchment Rainfall and Streamflow 1983/84 to 2013/14)

Linear regression trends																
Decadal trends																
Station	**Time period**	**Annual**	**Season**		**Month**											
			Maha	**Yala**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Glencourse																
Rainfall	1983/84 to 2013/14	-12	5.11	-17.34	0.00	1.00	4.98	4.06	-3.03	-10.29	-2.1	-2.47	-1.15	-2.2	-3.57	-1.83

Linear regression trends															
Decadal trends															
Station	**Time period**	**Annual**	**Season**		**Month**										
			Maha	**Yala**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Streamflow	1983/84 to 2013/14	-69	12.26	-42.9	-1.37	-0.81	0.5	0.3	-5.50	-17.6	-8.57	-6.37	-4.59	-13.08	-9.8	-2.01
Kitulgala																
Rainfall	1983/84 to 2013/14	-26	3.726	-30.06	0.83	0.54	4.4	3.54	-3.7	-14.06	-4.28	-5.24	-2.02	-3.64	-3.2	1.9
Streamflow	1983/84 to 2013/14	-68	-25.54	-42.9	-3.14	-3.6	-3.5	-2.3	-4.1	-11.5	-7.1	-9.8	-4.9	-8.9	-2.65	-1.41

Annual and Intra-annual trends																
Station	**Time period**	**Annual**	**Seasonal**		**Monthly**											
			Maha	**Yala**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Glencourse																
Rainfall	1983/84 to 2013/14	-57.25	1.99	-36.73	0.35	-0.34	-0.54	0.47	0.18	-0.02	-0.32	-1.55	-2.53	-0.25	-0.20	-1.44
Streamflow	1983/84 to 2013/14	-16.49	5.50	-13.04	-1.74	-0.79	-0.90	-1.74	-4.31	-17.5	-10.76	-4.37	-2.38	-7.87	-7.46	-1.73
Kitulgala																
Rainfall	1983/84 to 2013/14	-43.42	1.55	-17.48	0.35	-0.34	-0.54	0.47	0.18	-0.02	-0.32	-1.55	-2.53	-0.25	-0.20	-1.44
Streamflow	1983/84 to 2013/14	-45.80	-12.76	-33.04	-1.75	-1.88	-2.01	-1.62	-4.34	-8.24	-6. 14	-5.40	-2.13	-4.14	-2.80	0.00

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4.2.5 Variations between catchments

The trends in both catchment rainfall and streamflow follow a similar pattern of decline on decadal and annual scales but higher rates of decline for Glencourse catchment was observed as compared to Kitulgala catchment. These reflect spatial variation within the basin.

4.2.6 Comparison with global and regional changes

The IPCC states that the average annual temperature increased by 0.13°C per decade in the last 50 years and 0.177 ± 0.052°C/decade for the most recent 25 years (period ended at 2003) (IPCC, 2007a). In the current study, decadal increases of 0.017°C and 0.02°C over 60-years were identified for the same period, which is much lesser compared to globally observed increases. It is evident from the study results that the temperature is increasing in the basin which is consistent with global observations but the rate at which the temperature is increasing is much lesser than global and regional observed changes.

Global averaged annual precipitation is projected to both increases and decrease by 5% to 20% projected at a regional scale in the 21st century. As per IPCC, the trend in global average annual rainfall was statistically insignificant, but a decline in trend in South Asia since 1901 has been seen (IPCC, 2008). This can also be seen in most stations for the current study. Warming associated with increasing greenhouse gas concentrations is expected to cause an increase in Asian summer monsoon precipitation variability. The wet periods are expected to become wetter. In this study, insignificant decreasing trends in decadal mean rainfall in both the monsoon seasons of less than 7 mm were observed for both catchments. De Silva (2006a) found a minor increase in annual rainfall because of an increase in rainfall during the southwest monsoon and a decline in the northeast monsoon rains along with an increase in annual average temperature.

It is also projected that the monthly mean precipitation variability will increase in most areas. The current study also saw higher variability in mean precipitation from month to month with insignificant decreasing trends in mean precipitation.

Most of the historical studies on climate change in the Sri Lanka show a significant increase in temperature followed by a reduction in annual rainfall with higher declines in the SWM season (Ampitiyawatta and Guo, 2009; De Costa, 2008; De Silva and Sonnadara, 2009; Herath and Ratnayake, 2004; Manawadu and Fernando, 2008; Piyasiri, Peiris and Samita 2004; Shantha and Jayasundara, 2004; Wijesuriya, Sepalika and Amarasekera, 2005). De Silva, Weatherhead, Knox and Roriguez (2007) predicted a 17% decline in average rainfall in the wet season under Special Report on Emission Scenarios (SRES) (A2), and 9% in (B2), with rains ending earlier. These findings are consistent with the present findings showing increasing temperature and decreasing annual rainfall and more prominent decreases in the Yala season although the rates of decline/increases are not substantial. Malmgren, Hulugalla, Hayashi and Mikami (2003) found in their study that stations which indicated a decline in rainfall were restricted to higher elevation areas and those displaying increased rainfall were in the lower elevations.

4.2.7 Comparison with base period trends

The IPCC base period (1961 to 1990) was considered for comparing changes relative to that period. Comparisons between the standard IPCC period trends (1961 to 1990) to the trends in recent years (1991-2014) show higher increases in temperature and higher reduction in rainfall and streamflow in the recent years as compared to the base period of 1961 to 1990 (Table 4-8, Table 4-9, Table 4-13 and Table 4-34). Although less these rates are much higher in the recent decades. The graphical representation of trends for the IPCC base period on decadal, annual, seasonal, and monthly scales is shown in Appendix E.

4.2.8 Correlation of climatic parameters

The correlation between the climatic parameters was checked based on their behaviour observed in the trend analysis. The variations in temperature, catchment rainfall, and streamflow were studied and their relation was analyzed. Both catchment rainfall and streamflow showed a decline in their annual trends. It was observed that decreasing rainfall contributed to decreasing streamflow. Seasonal trends were also analyzed to get a proper idea of the relation between the two. Both the catchment rainfall showed decreasing trends similar to the annual trends in both seasons but the streamflow for Glencourse catchment showed an increasing trend in the Maha season for an increase in rainfall over the period of 1983/84. The rainfall and streamflow responses are clearer for the Glencourse catchment since it has a much bigger catchment and has many other inflows other than the inflow from Kitulgala. Further linear regression models were used to check these correlations on annual and intra-annual scales, which are given in Appendix G. Both the catchments show a positive correlation between the rainfall and streamflow. Both the maximum and minimum temperatures showed an increasing trend on annual and seasonal scales whereas the streamflow showed declining trends similar to the catchment rainfall. It was observed that with increasing temperature, the streamflow decreases in both the catchments. Temperature shows a negative correlation with streamflow for Glencourse and Kitulgala suggesting that with increasing temperature, streamflow decreases.

4.3 Conceptualization of Cumulative Impacts

The changes in climate parameters did not show significant rates of changes in climate in the basin. However, the fact that the climate is changing cannot be ignored. In the current study, further investigation was carried out to analyze the behaviour of these parameters and a cumulative index was developed to analyze the watershed wetness. The changes in the annual scale identified through the conventional method show a loss of water when the catchment rainfall is converted to streamflow. This is attributed to the replenishment of watershed storage that is significantly decreased by an increase of evaporation due to an increase of both minimum and maximum temperature. These variations observed at each time scale were combined to attempt composite evaluations of each climate parameter. The variations and shifts in the rainfall patterns observed were compared with the long-term averages. The cumulative impact of climate change on the watershed and resulting streamflow was investigated and compared with the observations made from the gauged data.

4.3.1 Cumulative index

The results from the conventional method show a decrease in both the point and catchment rainfall and streamflow with an increase in temperature. These rates of decline are higher for the streamflow as compared to the rainfall. In the long run, such conditions could be problematic on the available water resources in the catchment. The decrease in rainfall and increasing temperature would affect the moisture status of the catchment and the resulting streamflow. Hence, a cumulative index was developed to study the impacts of these changes over time on the watershed wetness and the percentage deficits of the rainfall and streamflow were calculated based on their long-term averages.

The percentage deficit in the rainfall over a year can be calculated by considering the annual average and the long-term annual average as follows.

$$\text{Percentage deficit in rainfall} = \frac{(\text{Annual avg rainfall} - \text{Long term annual avg rainfall})}{\text{Longterm annual avg rainfall}} \tag{4-1}$$

The long-term averages were used since the period of moving averages which affect the wetness are not known and the status of wetness in both catchments was checked. The percentage deficit in rainfall calculated at Glencourse catchment (Figure 4-26) showed more years with deficit periods and few years with wet periods. The wet periods and the rainfall deficit periods were seen to occur mostly at consecutive periods with more prolonged deficit periods.

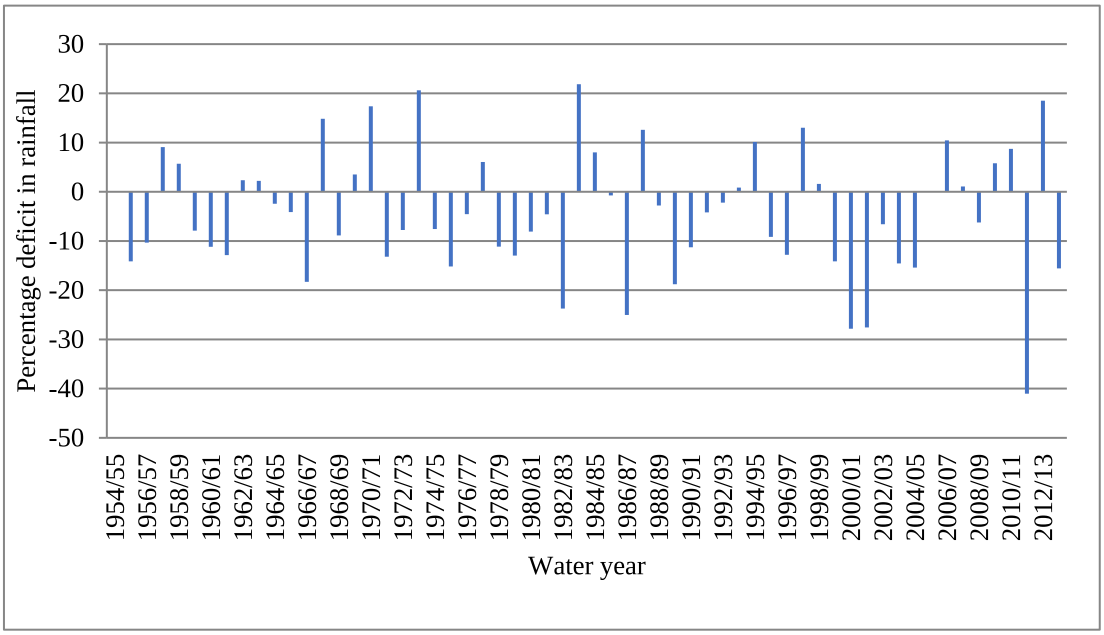

Figure 4-26 percentage deficit of rainfall at Glencourse

The cumulative percentage deficit was then calculated for the catchment rainfall. Figure 4-27 shows the cumulative percentage deficit in rainfall for Glencourse sub-catchment. The results show a gradual increase in the deficit periods over the years with a higher increase in the recent years.

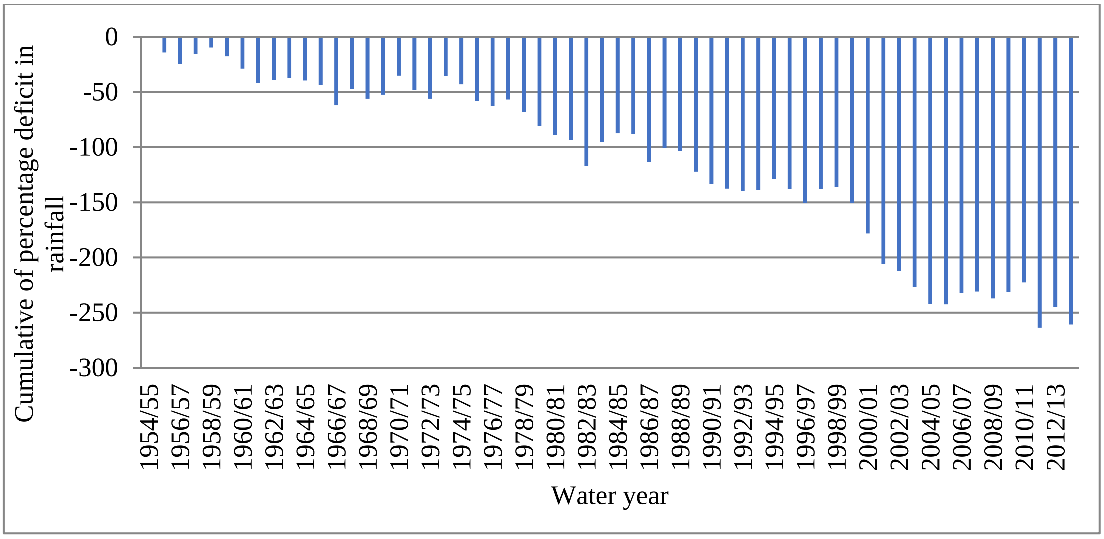

Figure 4-27 Cumulative percentage deficit in rainfall

Similarly, these deficit periods were calculated at a seasonal scale to see the variations in both the seasons and annual scales. The percentage rainfall deficit for Maha and Yala seasons are shown in Figure 4-28 and Figure 4-29. Both seasons show similarity with annual results. More years with a deficit in rainfall and consecutive years with wet periods were identified in both seasons.

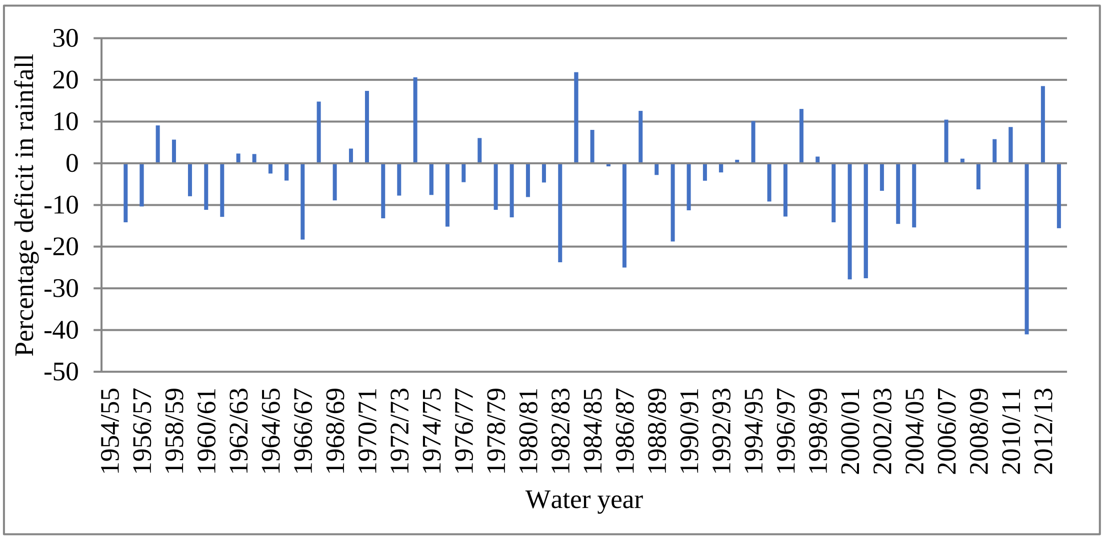

Figure 4-28 Percentage deficit in rainfall during Yala season at Glencourse

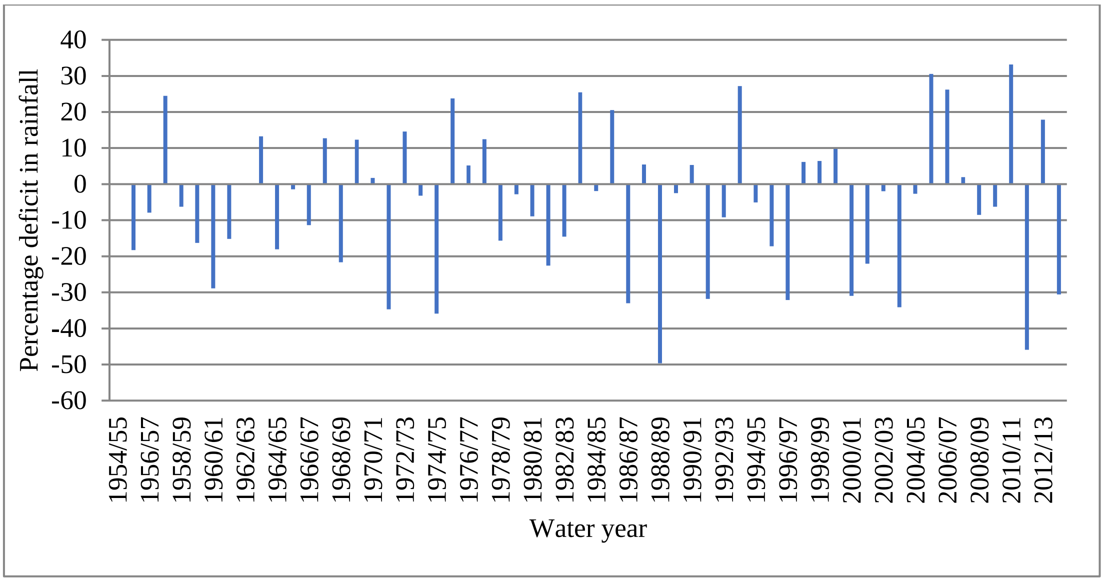

Figure 4-29 Percentage deficit in rainfall during Maha season at Glencourse

4.3.1.1 Percentage deficit in rainfall at Kitulgala catchment

Similarly, the rainfall at Kitulgala station was checked with the developed concept. Figure 4-30 and Figure 4-31 shows the percentage deficit in rainfall at Kitulgala and the cumulative deficit, respectively. These results are similar to that of Glencourse catchment showing a higher increase in deficit periods in recent years. The seasonal comparisons are given in Appendix H.

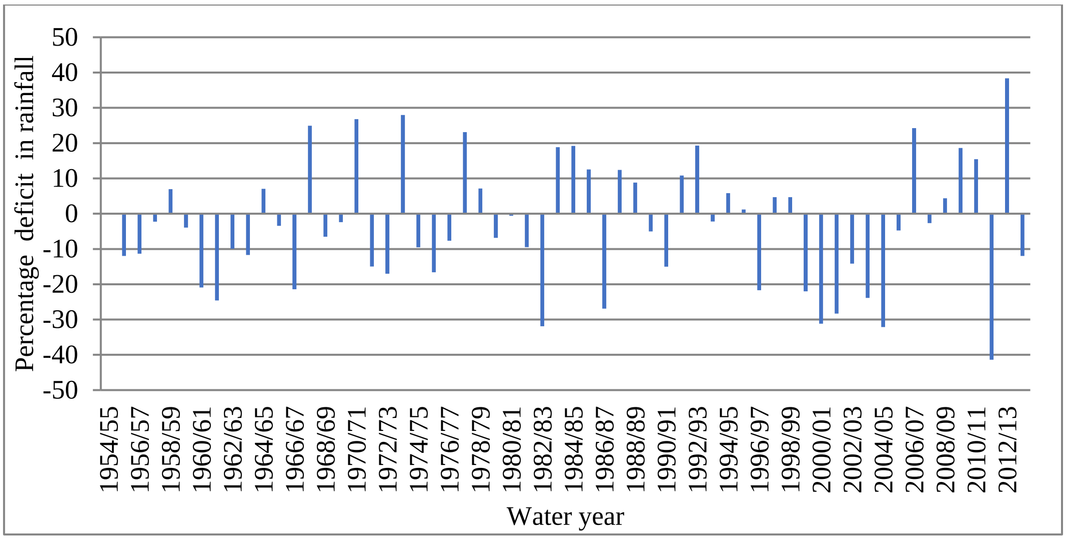

Figure 4-30 Percentage rainfall deficit at Kitulgala

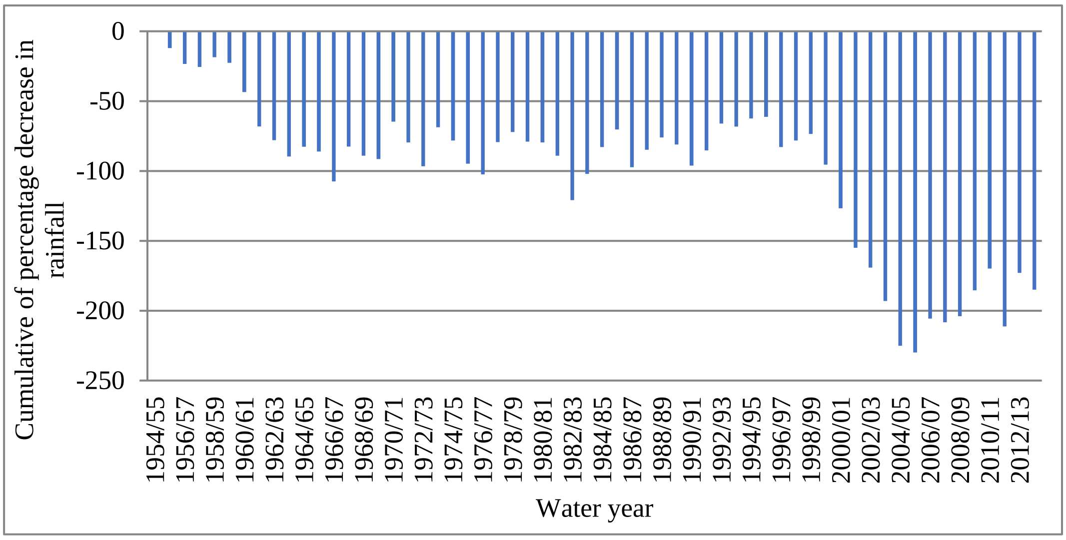

Figure 4-31 Cumulative of rainfall deficit at Kitulgala

4.3.1.2 Percentage deficit in Streamflow

The cumulative of percentage deficit in streamflow was also calculated as follows.

$$\text{Percentage deficit in streamflow} = \frac{(\text{Annual avg streamflow} - \text{Long term annual avg streamflow})}{\text{Longterm annual avg streamflow}} \quad (4\text{-}2)$$

The deficit period in streamflow was calculated for the recent period (1983/94 to 2013/14). The percentage deficit in streamflow shows gradual increases in the deficit periods in both catchments in recent years. The yearly deficit in Kitulgala and Glencourse catchments are shown in Figure 4-32 and Figure 4-33.

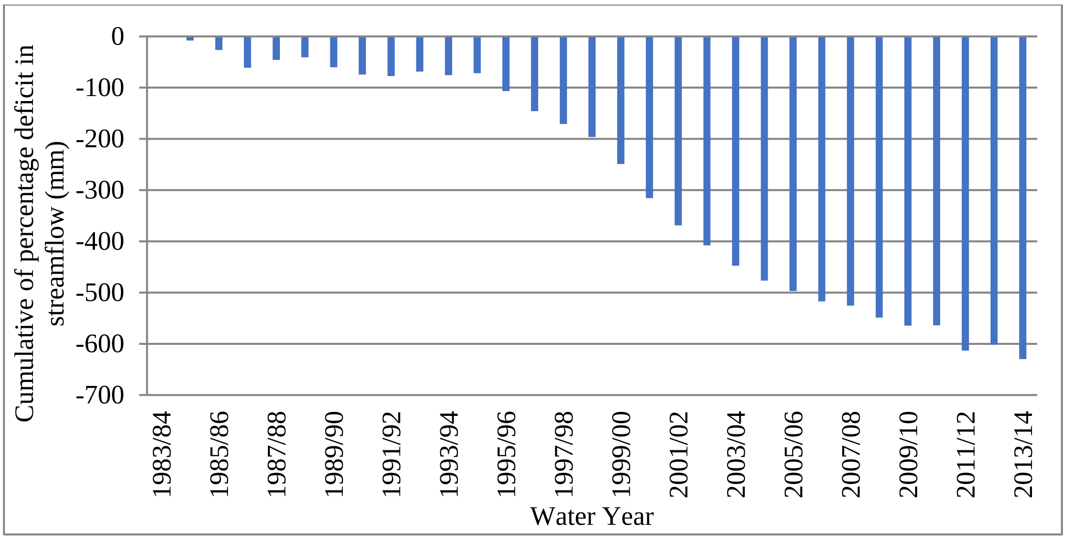

Figure 4-32 Cumulative of percentage deficit of streamflow at Kitulgala

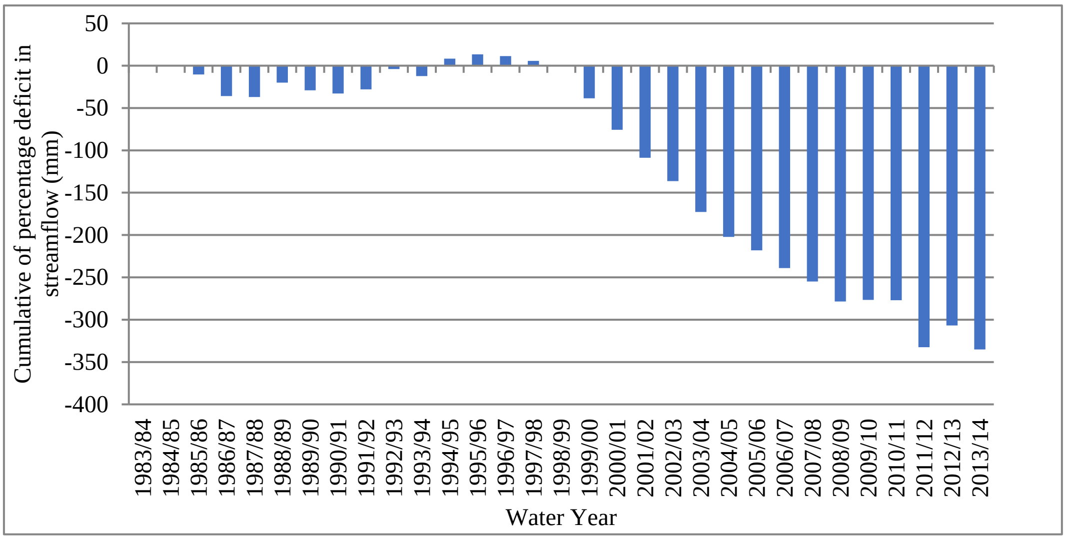

Figure 4-33 Cumulative percentage deficit in streamflow at Glencourse

The cumulative index for streamflow at Glencourse catchment in Maha season shows an increase in wetness in recent years. This is shown in Figure 4-34. However, no such behaviour was observed in the Yala season (Figure 4-36). Kitulgala catchment on the other hand shows a steady increase in the deficit periods in the recent years in both seasons. This is true for the earlier assumption of reservoir releases and storages that tend to mask the trends in streamflow of the basin during the Maha season. This is shown in Figure 4-35 and Figure 4-37.

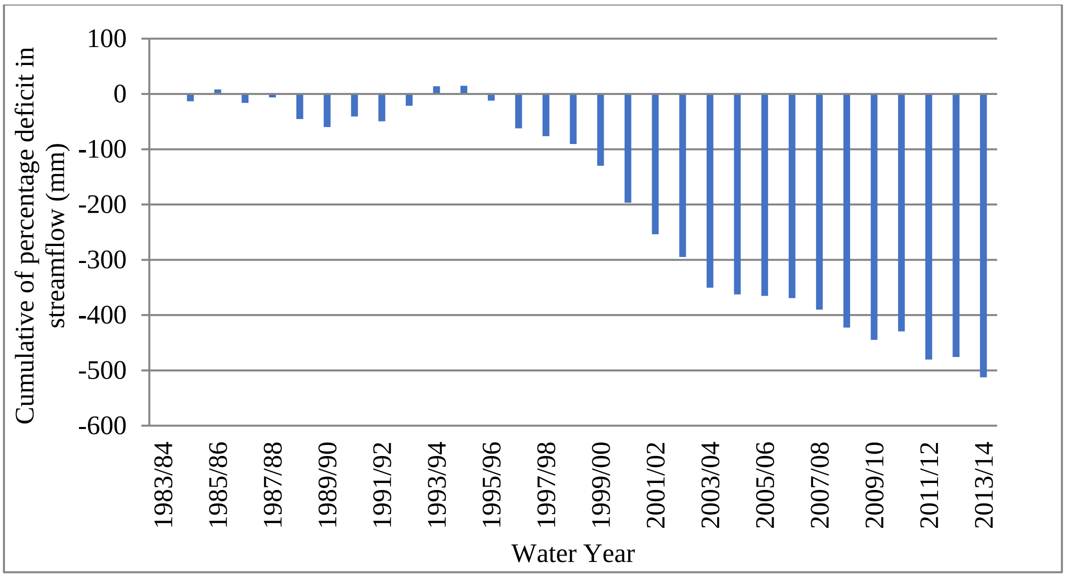

Figure 4-34 Cumulative of percentage deficit/wetness in streamflow at Kitulgala in Maha season

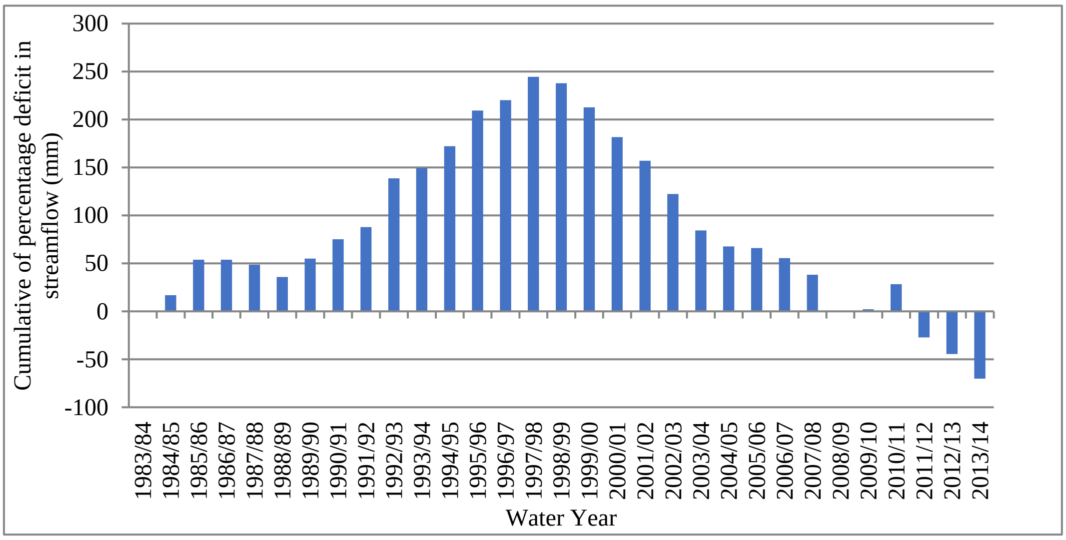

Figure 4-35 Cumulative of percentage deficit/wetness in streamflow at Glencourse in Maha season

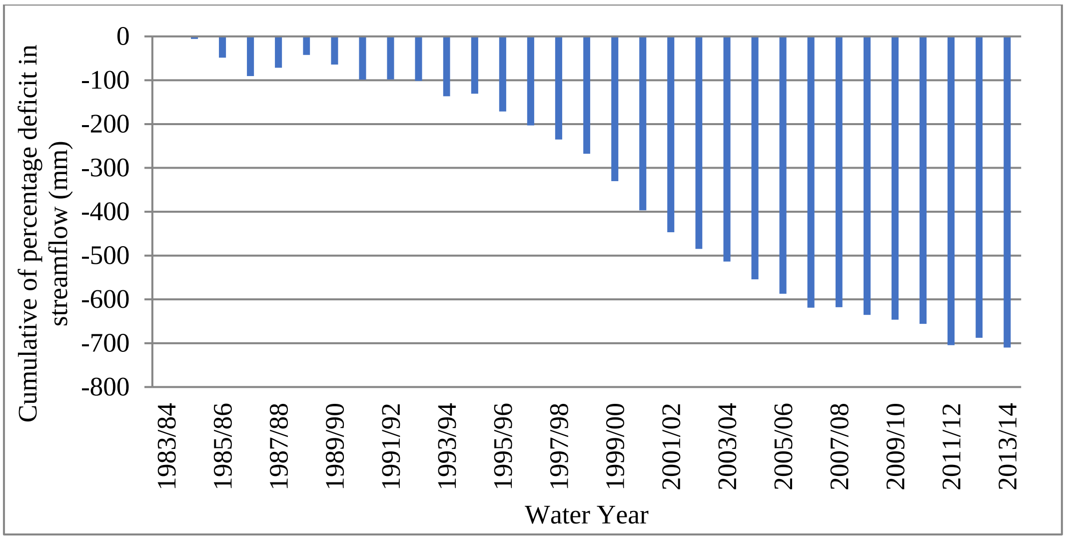

Figure 4-36 Cumulative of percentage deficit/wetness in streamflow at Kitulgala in Yala season

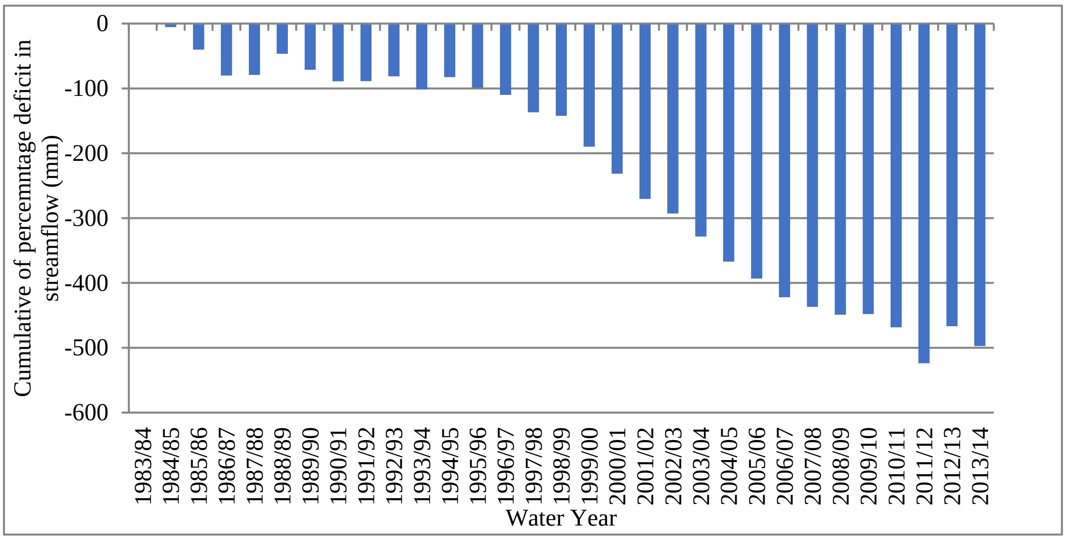

Figure 4-37 Cumulative of percentage deficit/wetness in streamflow at Glencourse in Yala season

4.3.2 Identification of dry months

The monthly rainfall trend analysis results revealed that most months showed a decline in their trends for the 60-year period. These are different for different months, hence the importance of analyzing the deficit periods of each month separately and identifying dry months, which are the months that show continuous deficit periods. The dry months were calculated with respect to the long-term averages. The IPCC has stated that the dry months will become drier in the future. Hence, identification of dry months is important which will affect the streamflow. In this study, the months showing continuous dry periods were identified as dry months. The dry months for each point station were calculated. December and January months showed a continuous decrease in the rainfall compared to other months which has declined in recent years.

- The dry months were calculated with respect to the long-term averages.

$$\text{Percentage deficit of rainfall in a month} = \frac{(\text{Rainfall of a month} - \text{Long term Average Rainfall})}{\text{Long term Average Rainfall}} * 100 \quad (4\text{-}3)$$

Long-term averages were selected since the periods contributing to the percentage deficit in rainfall are not certain. The behaviour of the months over the years can be checked and their contribution to the wetness or deficit periods. The behaviour of both the catchment rainfalls in the month of January is shown in Figure 4-38 and Figure 4-39. Earlier trend results for temperature revealed higher increases in temperature in the colder months (January, February, and March). Hence, the combined effect of both deficit periods and increasing temperature would be problematic in the dry months.

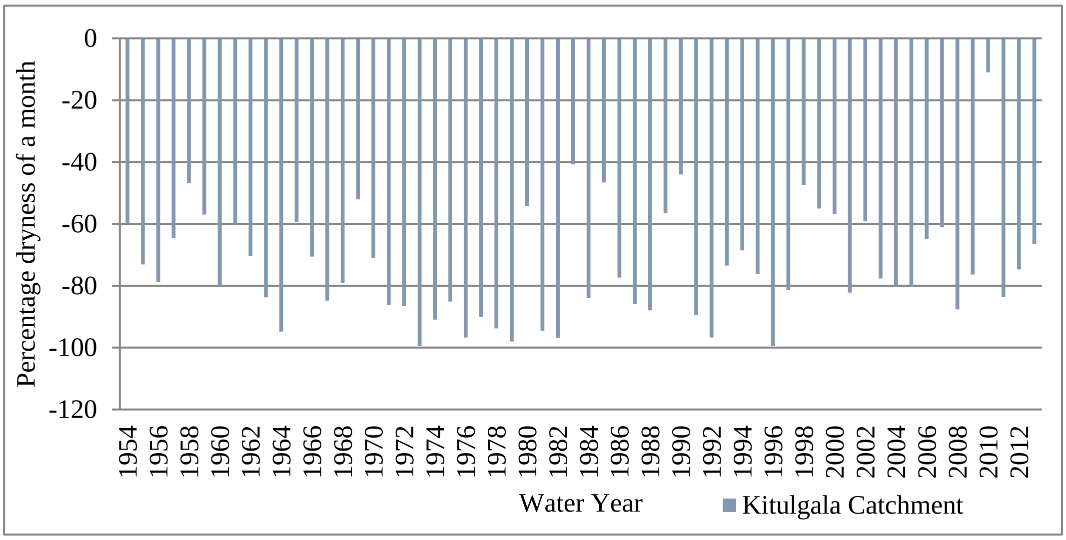

Figure 4-38 Percentage deficit for January month at Kitulgala

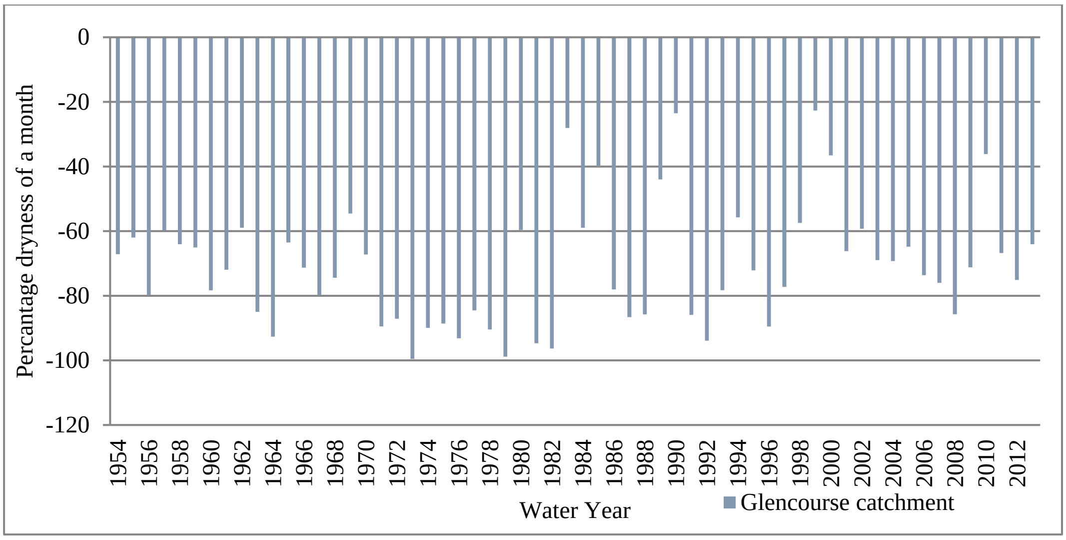

Figure 4-39 Percentage deficit for January month at Glencourse

4.4 Summary of Results

4.4.1 Data checking

The various data checks carried out in this study and their results are mentioned in Table 4-36.

Table 4-36 Data Checking Results

Sl. No.	Data component	Remark	Judgement
1.	Annual water balance	Higher runoff coefficient at the downstream side.	
1.1	Kitulgala catchment	The annual runoff coefficient variation for the 60-year period is 0.8,	High runoff coefficient This may be due to releases from the dams present in the catchment

Sl. No.	Data component	Remark	Judgement
1.2	Glencourse catchment	The annual runoff coefficient variation for the 60-year period is 0.54	Fairly adequate runoff
2.	Visual check	The streamflow responses to spatially averaged rainfall were fairly adequate for most of the data points during the 60-year period except for some errors in streamflow data	Consistent data
3.	Single mass curves	The single mass curves plotted for each station showed consistent and homogenous data points	Consistent and homogenous data points
4.	Double mass curves for rainfall	The double mass curves showed homogenous data points	Consistent data points

4.4.2 Trend analysis

The Mann-Kendall trend test and the linear regression trend test revealed similar test results. The results of the Mann- Kendall trend test reveal an increasing trend in temperature in the basin on decadal, annual and seasonal scales. However, *Z* significance of these trends was small suggesting negligible increasing trends. Sen's slope estimator was also used to comprehend the change per unit time of the trends. The values of Sen's slope also demonstrate comparatively lesser changes per unit time. The seasonal trends reveal higher increases in temperature during the Maha season and a higher increase in minimum temperature in the colder months of Sri Lanka.

The point rainfall trends in decadal annual rainfall show a decreasing trend for all stations except Kenilworth station, which is located on the exposed southwest windward slopes. The decadal annual average rainfall shows a decreasing trend for all the rainfall stations except for the Annfield station. However, the rates of decline/increase are comparatively lesser. The decadal seasonal trends for the point rainfall during the Maha season revealed an insignificant decreasing trend for Labugama, Undugoda, Annfield and Norton rainfall stations, while Dunedin and Welwiltalawa station showed a declining trend with negligible negative *Z* values and Sen's slope values indicating a lesser rate of decline. The stations Labugama, Dunedin, Undugoda, Wewiltalawa and Norton showed decreasing trends in the Yala season, though the *Z* values are comparatively lesser. The decadal monthly trends show an increase in point rainfall in all rainfall stations for the month of January and a decrease in the months of August and September. But these declines/increases are very low with values ranging from 0.1 to 4.0 mm increase/decrease over 60-years. The Mann-Kendall test also revealed a monthly decreasing trend for all stations except Kenilworth and Undugoda stations, though with lesser *Z* values.

The Glencourse catchment rainfall shows a decreasing trend in the decadal annual scale with lower *Z* values and Sen's slope values while Kitulgala catchment rainfall showed no significant trend. The decadal seasonal trends showed a decreasing trend during Maha season for both catchments, however with lower *Z* significance values and Sen's slope estimates. There were also no significant trends in the annual and seasonal scale for both catchments. The monthly trends in catchment rainfall over the 60-year period showed trend rates with considerably low significance values (R^2 values). The rainfall at both catchments show increases in the months of January and April. While Kitulgala catchment rainfall shows an increasing trend for the months of May, April, and November, Glencourse catchment rainfall showed a decreasing trend.

The streamflow trend for both the catchment showed a decreasing trend with relatively low negative *Z* values. The Sen's slope showed higher declines for decadal streamflow at Glencourse of -75.339 mm for the 30-years of the observation period. The Yala season also shows declining trends in both the streamflow while Glencourse showed an increasing trend in the Maha season. The decrease in rainfall earlier showed higher decreases for Kitulgala, catchment almost 2.1 times more as compared to its Glencourse but the decreasing streamflow trends are almost equal.

4.4.3 Cumulative index

The percentage deficit of rainfall shows more years with deficit periods and lesser wet periods. The cumulative percentage deficit in rainfall clearly shows the increase in the deficit periods over the years. In the case of rainfall, gradual increases followed by consecutive stable periods were identified. The Glencourse catchment shows a gradual increase in the percentage deficit of both rainfall and streamflow in recent years. Deficits in rainfall and streamflow in the recent 30-year period are increasing at higher rates compared to the past 30 years, at 37% and 47%, respectively for Kitulagala sub-catchment and 36% and 43% for Glencourse sub-catchment.

5 DISCUSSION

5.1 Data and Data Period

This study initially carried out a thorough literature review to assess and compare available studies in the country with global and regional studies on climate change impacts on water resources in terms of the methods for assessments, outputs provided, spatial and temporal resolution requirements, and adequacy of data, models used to relate climate inputs with water resources and spatial coverage. The data period and resolution for the study were selected based on reviewed literature. For the assessment of climate change impacts on water resources, it is recommended to use monthly or higher temporal resolution since seasonal patterns and inter-annual fluctuations of precipitation significantly alter the availability of surface water resources. The Present work evaluated the climate of the Kelani river basin with monthly rainfall, temperature, and streamflow data. A long set of monthly data sets from 1954 to 2014 were collected from the Meteorological department for seven rainfall stations, two streamflow and one temperature station for the two sub-basins, Glencourse and Kitulgala. Thirty years of data for evaporation was collected since data for earlier years were not available and a detailed quality check was carried out for the data collected.

5.1.1 Data error and inconsistencies

The single mass curves and double mass curves plotted for each station showed consistent and homogenous data points for rainfall. On checking the water balance and evaporation values, the annual average runoff coefficient variation for the 60-year period is much more for the Kitulgala watershed (0.8) while the annual runoff coefficient variation for the Glencource watershed is 0.54. The higher runoff coefficient for Kitulgala is assumed to be due to the releases from the dams present in the watershed. The streamflow is much higher in the earlier periods compared to the recent decades, showing a negative water balance for most years. The recent decades showed more consistent data with comparable evaporation and water balance and lower runoff coefficients. Accordingly, taking into consideration these inconsistencies, data after 1984/85 was used for examining the rainfall streamflow relationship in the basin.

5.2 Evaluation of Trends in Climate Parameters

Linear regression model, Mann-Kendall trend test and Sen's slope estimator were used to check for trends in temperature, rainfall, and streamflow at decadal, annual, seasonal, and monthly scales for the 60-year period. The ten-year moving averages were used to smooth out the short term and long-term trends and standard deviation and coefficient of variations were calculated to comprehend variability of the data in relation to the mean. Apart from the study period trends, the base period (1961 to 1990) trends were also calculated to compare changes relative to that period. The IPCC suggests using recent baseline periods such as 1961 to 1990 due to the availability of observational climate data coverage for this period compared to earlier ones (IPCC, 2001).

5.2.1 Trends in temperature

The temperature data at the Colombo station was used to calculate the trends in temperature for the basin assuming that it is representative of the basin temperature. The decadal mean annual temperature was calculated to reduce year-to-year variation. The decadal annual temperature trends show an increasing trend in both the maximum and minimum annual temperature with an increase of about 0.015°C and 0.02°C over 60-years and R^2 values of 0.67 and 0.93, respectively. This gives a clear sign that warming in the basin is happening but the rate at which it is occurring is low. The Mann-Kendall test and Sen's slope estimate revealed a presence of an increasing trend, but the rate of change was noted to be rather less. It is also apparent that there are higher increases in minimum temperature than the maximum temperature, almost 1.3 times higher than the increase in maximum temperature. The ten-year moving average trends also showed similar results. The increasing minimum temperature at rates higher than the maximum temperature has reduced the long-term diurnal temperature which is consistent with global observations, indicating that the climate in this region is part of a larger global climate change that has been occurring over the last century. The seasonal trends in both seasons of cultivation, Maha and Yala were computed at a decadal scale to check variations between seasons and with annual scale variation. Both seasons showed an increase in minimum temperature higher than that of maximum temperature with decadal increases of 0.023°C over the 60-year period for Maha and 0.021°C increase for Yala. The MK test results revealed an increasing trend but with low *Z* values and Sen's slope values. The rate of increase of minimum temperature for Maha season was found to be slightly higher; almost 10% more than the Yala season. This signifies higher warming in the Maha season (NEM) which is also the drier period for the basin with low rainfall. The highest increases in temperature are for the months of January, February, and March, with higher increases in minimum temperature than the maximum temperature. This signifies that the colder months of Sri Lanka are getting warmer at rates higher than the other months. All the months showed a presence of trend although at a reduced rate. It was also observed that all months have higher increases in their minimum temperature with R^2 values ranging from 0.63 to 0.89 except for the months of October and December which showed higher increases in maximum temperature. The October and December month shows higher increases in daytime temperatures than the nighttime temperatures with higher increases in maximum temperature.

Annual mean temperature showed considerable year-to-year variation for the basin. On average, the maximum temperature varies between 27 to 33 °C per year and the average minimum temperature varies from 20 to 27 °C per year from 1954 to 2014. The annual average temperature increase for the 60-year period is about 0.02 °C for 60-years. The highest increase in annual temperature was observed for the minimum temperature at 0.024 °C. The ten-year moving average trend also shows the highest increase in minimum temperature of 0.022 °C. Seasonal temperature also shows higher increases in Maha season of 0.023 °C over 60 years for minimum temperature.

5.2.2 Trends in point rainfall

A general decreasing trend in decadal annual rainfall was observed for all stations except for Kenilworth station. The location of the Kenilworth station which is on the southwest windward slopes between elevations of 1,000 and 1,300 m receiving annual rainfall as high as 5,500 mm (Malmgren et al., 2003) is assumed as the reason for the station showing an increasing trend in comparison to other stations. Although an overall decline was noted for most stations, the rates were much lower with less than 1% decline in comparison to the annual average rainfall. The Mann-Kendal test and Sen's slope estimate also showed a decline in rainfall in these stations but at comparatively lesser rates. The maximum decrease in the decadal annual average trend was observed for the Wewiltala rainfall station, with a decrease of 28.6 mm per decade and an R^2 value of 0.72. The coefficient of variation for the decadal rainfall is less than 0.3, which indicates lower variability from the mean and highly dependable rainfall.

The decadal seasonal trends in Yala season rainfall shows trends in point rainfall similar to the annual trends, with decreasing trends in all stations except for Kenilworth station. Annfield station showed no significant trend in the Yala season, although the negative Z value reveals a downward trend. Only Dunedin and Wewiltalawa stations showed higher decreasing trends in the Maha season with ρ-value less than 0.05, although at lesser rates.

The decadal trends for monthly rainfall show an increase in point rainfall for the month of January for all stations and a decrease in the months of August and September but at very low R^2 values. The highest amount of average monthly rainfall was observed for Wewiltalawa station in November (1823 mm) which contributed to about 25% of annual rainfall, followed by July with 15%, and the lowest was observed in January with 1% of the annual total followed by February with 1.2%. These declines in rainfall are considered insignificant since the rates of decadal declines are very less, less than 1% of the annual average rainfall with comparatively low R^2 values. The MK statistics also showed insignificant trends for Kenilworth and Undugoda stations at a monthly scale.

5.2.2.1 Annual, seasonal and monthly trends in rainfall

The annual rainfall in Sri Lanka is highly inconsistent due to the nature of the seasonal cycle of monsoon rainfall and the topography. The annual rainfall shows a decreasing trend in all stations except Kenilworth. The largest decrease in annual rainfall was observed for Wewiltalawa station with a decrease of 25.7 mm for the 60- year period. The ten-year moving average for the same shows a decrease of 28 mm for the station. Mann-Kendall statistics showed a decreasing trend in all stations except for Kenilworth and Annfield.

The seasonal trends reveal a reduction in rainfall and this decline is more prominent in the Yala season for all stations. Hence, increasing temperature and decrease in rainfall together in the Yala season would be problematic on the available water resources. It was observed that the highest decrease is for the Wewiltalawa station in the month of June with a decrease of 4.37 mm.

5.2.3 Trends in catchment rainfall

The decreasing trends in catchment rainfall for both Glencourse and Kitulgala were considered insignificant, as their rates were lower than 1% of annual rainfall. The trends in both sub-catchments show a similar pattern of decline but higher rates of decline were observed for Glencourse catchment as compared to Kitulgala sub-catchment, almost 2 times higher. The Mann Kendall statistics revealed a decreasing trend for decadal annual rainfall at Glencourse with low Sen's slope values, and the Z significance indicating minimal changes while Kitulgala sub-catchment rainfall did not show any significant trends in decadal average rainfall. These observations reflect variation in rainfall within the basin.

Seasonal decline in rainfall can be observed in both the sub-catchments and in both seasons. An increase in temperature and decrease in rainfall together in the Yala season would be problematic on the available water resources. In the Kitulgala sub-catchment, rainfall reveals a higher decrease in the Maha season with a higher increase in temperature in the Maha season, which would intensify the problems on available water.

The rainfall at both sub-catchments show increases in the months of January and April. For April, May and November month, the Kitulgala sub-catchment rainfall shows an increasing trend but the Glencourse sub-catchment rainfall shows a decreasing trend. These trends in rainfall show variations in between the sub-catchments and unevenly distributed rainfall over the catchment. The coefficient of variation for the months of December, January, and February are quite high as a function of low rainfall but high spottiness. These reveal strong variability in the rainfall for these months in the catchment.

5.2.4 Trends in streamflow

The decadal average annual streamflow trends show a decreasing trend in both the sub-catchments of 69 mm and 68 mm for Kitulgala and Glencourse, respectively over the period of 1983/84 to 2013/14. These are reflective of the rainfall decreases in both sub-catchments which are shown to be magnified in the streamflow. The MK statistics for decadal streamflow reveals a decreasing trend for both sub-catchments. Sen's slope values are however lesser, and the *Z* significance is also lesser.

The decadal trends for the Yala season show a decreasing trend of 42 mm for both sub-catchments similar to the decadal annual trends, whereas Maha season shows an increasing trend for Glencourse and a decreasing trend in Kitulgala. The declining trend in Kitulgala is due to the decrease in streamflow values in recent years while the Glencourse sub-catchment shows an increase in streamflow in recent years. This declining trend in Kitulgala is assumed to be due to the reservoirs present in the sub-catchment. During the low rainfall period in the Maha season, water storage and releases from the reservoir at Kitulagala when the rainfall is comparatively lesser is assumed to affect the streamflow trends. In this study, the decline in streamflow at rates higher than that of the rainfall is related to the catchment storage characteristics. The decline in rainfall and increase in evaporation is assumed to have affected the catchment water storage. The decrease in streamflow is assumed as an attempt to replenish the lost water stored. Kitulgala has six reservoirs within its catchment. In the Yala season, however, both Glencourse and Kitulgala show declining trends of 25 mm and 12 mm per decade.

Kitulgala streamflow shows increases in the months from December to March of less than 2 mm/decade whereas Glencourse shows a continuous decline in all months. These trends are far less and insignificant with low R^2 values and insignificant Mann Kendall test values.

5.2.5 Comparison with IPCC base period trends

The base period (1961 to 1990) was considered for comparing changes relative to that period. Recent decades showed a warmer climate, higher declining trends in rainfall and streamflow compared to the base period of 1961 to 1990.

5.2.6 Variations between sub-catchments

The decadal trends in rainfall and streamflow in both sub-catchments follow a similar pattern of decline but higher rates of decline for Glencourse sub-catchment as compared to Kitulgala sub-catchment showing variation in between the two sub-catchments. The Yala season streamflow trends show decreases for both the sub-catchments except for Maha season in the Glencourse sub-catchment. This suggests that the streamflow in the low rainfall period is increasing in recent years with increasing rainfall. The Kitulgala streamflow gets affected due to the reservoir storages at Kitulagala which are assumed to mask the trend in streamflow in Maha season. On the other hand, the impacts of reservoir operation on streamflow at Glencourse may be relatively neglected since the reservoirs affect only 10% of the Glencourse sub-catchment (Zubair, 2003). The decrease in streamflow at rates faster than the rainfall is assumed as an attempt to replenish the lost water stored which gets considerably reduced as a result of longer dry periods as established in this study. Glencourse streamflow shows a decrease in all the months except for March and April. This is consistent with the assumptions of a relatively dry ground condition. During summer the soil is comparatively dry and groundwater recharge is reduced. Therefore, even after a heightened rainfall in the Yala season, the stream-flow signal does not react immediately, it takes months for the streamflow to really pick up the signal.

5.3 Conceptualization of Cumulative Index and Calculation of Dry Months

Evaluation through the conventional methods revealed an increasing temperature in the Kelani basin and a decreasing trend in rainfall and streamflow. These trends although insignificant at present would ultimately distress the catchment moisture condition. Considering the catchment hydrological characteristics, a conceptual method was developed to investigate the cumulative impacts of the changes in catchment rainfall and streamflow on the watershed wetness. Considering the increasing minimum temperature and the decrease in rainfall in both sub-catchments, the cumulative effects of such events were studied, and a conceptualization of cumulative effects was developed to understand the behaviour of the parameters and their effect on the watershed wetness. The percentage deficit in the rainfall and streamflow over a year was calculated by considering the annual monthly average and the long term annual monthly average and the long-term cumulative impacts of these changes were calculated for Glencourse and Kitulgala basin. These were calculated on annual and seasonal scales. The cumulative percentage deficit in streamflow reveals gradual increases in the deficit periods followed by stable periods and further increases in such periods over the recent years. The results show persistent dry periods in recent years and hence a risk to the water resources availability in the basin. The percentage deficit of rainfall shows more years with deficit periods and lesser wet periods. Cumulative percentage deficit in rainfall clearly shows the increase in the deficit periods over the years. In the case of rainfall, gradual increases followed by consecutive stable periods were identified. The Glencourse sub-catchment shows a gradual increase in the percentage deficit of both rainfall and streamflow in recent years. Deficits of streamflow in the recent 30-year period are increasing at 5% and 10% respective rates for Kitulagala sub-catchment in Maha and Yala season and for Glencourse sub-catchment 5% and 2% respectively.

The dry months were calculated with respect to the annual average rainfall and the long-term averages. The months that showed prolonged deficit periods in rainfall were classified as dry months. December and January months showed a continuous decrease in the rainfall compared to other months and hence were classified as dry months. The IPCC has stated that the dry months will become drier in the future. Hence, identification of dry months is important which affect the reduction of rainfall. As per earlier trend results temperatures in the colder months are increasing at a rate higher than the other months. Hence, the combined effect of both deficit periods and increasing temperature would be problematic in the dry months. There are prolonged deficit periods in both the rainfall and streamflow parameters with a more prominent decline in recent decades, the loss of water through replenishment of the catchment water storage needs to be measured and monitored for proper water resources management since data on soil moisture within the country are limited.

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

1. The study found a constant warming trend in Kelani River Basin over the last 60 years with an increase in mean temperature of 0.018°C over 60-years and a decrease in rainfall and streamflow amounting to values less than 40 mm over the 60-year period.
2. The linear regression and Mann- Kendall analysis showed an increase in temperature followed by decreasing rainfall and decreasing streamflow. However, the rates of increase/decrease were relatively lesser.
3. Global trends show an increase in rainfall during the wet season and a decline during the rest of the year, the present study found rainfall declines in both seasons (Maha and Yala) except for the Kenilworth station which showed a statistically insignificant increasing trend. The findings are consistent with regional study findings of decreasing annual rainfall due to a more prominent reduction in the SWM.
4. On a seasonal scale, slightly higher increases in minimum temperature of nearly 10%, for Maha season was identified indicating higher warming in the NEM season. This is consistent with the global findings of higher warming in the NEM than the SWM in the South Asian region.
5. The highest increases in temperature were identified for the colder months with higher increases in minimum temperature of about 0.0296°C for the 60-year period than the maximum temperature, signifying that the colder months of Sri Lanka are getting warmer at rates higher than the other months. This is consistent with global findings.
6. Annual streamflow in both sub-catchments shows a decline faster than 29% of the spatially averaged rainfall and these trends are higher for Glencourse sub-catchment, showing variation in between the two basins.
7. The decrease in streamflow at rates faster than the rainfall were true for the assumptions of relatively dry ground conditions during summer that alters the

stream-flow signal. This is seen for Glencourse streamflow that shows the streamflow signal only after 2 months or so even after a heightened rainfall in October, November, and December.

8. The cumulative index calculated for percentage deficit in rainfall and streamflow in the basin showed escalations in the deficit wet periods of almost 10% higher in the recent decades.
9. The cumulative index for the basin shows a steady increase in the deficit periods for Glencourse streamflow of about 24% from 1983/84 while Kitulgala shows an increase in deficit periods of about 12%.
10. The Glencourse streamflow shows an inclination towards an increase in the deficit periods from a somewhat wet period in the earlier years with cumulative increases of 2% while the recent decades show a collective decline of 32.5% compared to earlier years.
11. Similarly, for Kitulgala the deficit periods for the recent 30 years have increased by about 5% compared to the past 30 years crediting to a more prominent and incessant decline in streamflow in the recent years.
12. The dry months calculated in the study with prolonged deficit periods in rainfall were December and January that showed a continuous increase in the deficit periods of rainfall compared to other months and hence were classified as dry months.
13. The cumulative index calculated for the basin reveals a rather distressing situation for the available water in the two sub-catchments of Kelani with an increase in the rainfall deficit periods over the years and a higher declining rate of streamflow as a result of increased temperature and evaporation resulting in an increase in moisture deficit in the catchments.
14. The loss of water through replenishment of the catchment water storage needs to be measured and monitored for proper water resources management since data on soil moisture within the country are limited. The method adopted in this study was helpful to capture the current situation of water resources in the basin and the moisture status within the sub-catchments.

6.2 Recommendations

1. The cumulative index method can be used in other catchments of the Country to check the status of available water resources and especially the watershed wetness so that it can be monitored.

2. Although the method adopted in the study was useful to capture the status of the watershed wetness, it may be helpful to carry out verifications with soil moisture data in the future.

3. It is also necessary to explore and extend such techniques using other climate parameters to assess climate change impacts on water resources at catchment scale

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Appendix A - Data checking

Annual Water Balance

Table A-1. Water balance (Kitulgala)

Years	Thiessen Avg. Rainfall (mm)	Q	RC	Water balance
1954/55	4,949.07	4,168.60	0.84	780.47
1955/56	3,889.74	2,567.88	0.66	1321.85
1956/57	3,707.06	2,718.35	0.73	988.71
1957/58	4,057.38	3,258.53	0.80	798.85
1958/59	4,519.07	3,413.07	0.76	1106.01
1959/60	4,027.37	3,155.65	0.78	871.72
1960/61	3,202.78	2,778.85	0.87	423.93
1961/62	2,950.51	3,079.49	1.04	-128.97
1962/63	3,481.49	3,355.48	0.96	126.01
1963/64	3,369.79	3,590.39	1.07	-220.60
1964/65	4,123.82	2,941.83	0.71	1181.98
1965/66	3,654.26	2,667.18	0.73	987.08
1966/67	2,956.75	3,970.55	1.34	-1013.80
1967/68	4,793.11	2,919.38	0.61	1873.72
1968/69	3,570.68	2,800.38	0.78	770.29
1969/70	3,722.22	3,955.81	1.06	-233.58
1970/71	4,917.03	3,141.02	0.64	1776.01
1971/72	3,269.02	2,988.73	0.91	280.29
1972/73	3,160.62	3,788.48	1.20	-627.86
1973/74	4,945.94	2,847.10	0.58	2098.83
1974/75	3,481.16	2,443.74	0.70	1037.42
1975/76	3,183.62	2,572.07	0.81	611.55
1976/77	3,512.83	3,310.41	0.94	202.41
1977/78	4,730.22	3,010.31	0.64	1719.91
1978/79	4,128.57	2,946.26	0.71	1182.30
1979/80	3,580.57	2,779.83	0.78	800.73
1980/81	3,819.56	3,115.86	0.82	703.701
1981/82	3,466.77	2,316.23	0.67	1150.53
1982/83	2,577.67	3,047.65	1.18	-469.97
1983/84	4,528.26	3,760.87	0.83	767.39
1984/85	4,571.78	3,783.51	0.83	788.27
1985/86	4,332.87	3,198.45	0.74	1134.4
1986/87	2,790.60	2,457.81	0.88	332.78
1987/88	4,308.12	3,253.09	0.76	1055.03
1988/89	4,181.33	3,989.28	0.95	192.05
1989/90	3,644.34	3,050.90	0.84	593.43
1990/91	3,246.75	3,209.23	0.99	37.52
1991/92	4,246.21	3,526.37	0.83	719.84
1992/93	4,594.67	4,278.35	0.93	316.32

Years	Thiessen Avg. Rainfall (mm)	Q	RC	Water balance
1993/94	3,764.98	3,140.21	0.83	624.71
1994/95	4,079.53	4,201.62	1.03	-122.09
1995/96	3,902.17	3,683.66	0.94	218.51
1996/97	3,005.28	3,421.83	1.14	-416.55
1997/98	4,020.47	3,285.49	0.82	734.98
1998/99	4,025.81	3,260.49	0.81	765.31
1999/00	2,985.11	2,095.88	0.70	889.23
2000/01	2,615.87	2,079.39	0.79	536.47
2001/02	2,707.68	2,184.72	0.81	522.96
2002/03	3,233.12	2,325.32	0.72	907.79
2003/04	2,854.24	2,000.42	0.70	853.82
2004/05	2,528.25	2,190.51	0.87	337.73
2005/06	3,543.76	2,600.91	0.73	942.84
2006/07	4,644.56	2,414.45	0.52	2230.10
2007/08	3,637.61	2,554.15	0.70	1083.45
2008/09	3,902.51	2,302.02	0.59	1600.48
2009/10	4,451.14	3,067.00	0.69	1384.14
2010/11	4,344.37	2,998.76	0.69	1345.61
2011/12	2,190.28	1,313.22	0.60	877.06
2012/13	5,202.42	3,749.19	0.72	1453.22
2013/14	3,303.11	2,110.18	0.64	1192.92
Average	**3752.26**	**3018.94**	**0.81**	**733.32**

Table A-2. Water balance (Glencourse)

Years	Thiessen Average Rainfall (mm)	Streamflow (mm)	RC	Water balance
1954/55	5,167.48	3,467.69	0.67	1,699.79
1955/56	3,886.38	2,749.50	0.71	1,136.88
1956/57	3,859.34	2,726.64	0.71	1,132.70
1957/58	4,842.47	3,102.62	0.64	1,739.86
1958/59	4,759.13	3,286.27	0.69	1,472.87
1959/60	4,082.88	2,844.04	0.70	1,238.85
1960/61	3,865.34	2,933.74	0.76	931.61
1961/62	3,724.00	2,773.36	0.74	950.63
1962/63	4,386.77	3,279.43	0.75	1,107.35
1963/64	4,391.16	3,897.70	0.89	493.45
1964/65	4,255.18	3,598.45	0.85	656.73
1965/66	4,012.11	1,348.83	0.34	2,663.28
1966/67	3,436.03	3,663.07	1.07	(227.04)
1967/68	4,884.65	4,450.57	0.91	434.08
1968/69	3,851.96	2,807.76	0.73	1,044.19
1969/70	4,386.96	3,275.82	0.75	1,111.14
1970/71	5,027.93	4,142.46	0.82	885.46
1971/72	3,690.23	2,764.68	0.75	925.55
1972/73	3,903.90	2,540.63	0.65	1,363.27
1973/74	5,161.61	4,049.34	0.78	1,112.27
1974/75	3,939.62	3,424.27	0.87	515.36
1975/76	3,589.59	2,988.41	0.83	601.19
1976/77	4,031.97	3,032.97	0.75	999.00
1977/78	4,490.59	3,368.32	0.75	1,122.27
1978/79	3,744.91	3,352.33	0.90	392.58
1979/80	3,650.19	2,455.81	0.67	1,194.38
1980/81	3,841.65	2,718.39	0.71	1,123.26
1981/82	3,981.65	2,979.70	0.75	1,001.95
1982/83	3,155.71	2,122.26	0.67	1,033.45
1983/84	5,081.14	3,916.83	0.77	1,164.31
1984/85	4,515.04	3,340.66	0.74	1,174.39
1985/86	4,148.53	2,707.05	0.65	1,441.48
1986/87	3,109.87	1,941.57	0.62	1,168.30
1987/88	4,687.23	3,570.89	0.76	1,116.35
1988/89	4,043.04	3,278.95	0.81	764.09
1989/90	3,360.93	2,445.60	0.73	915.34
1990/91	3,659.75	2,547.42	0.70	1,112.32
1991/92	3,947.67	2,863.31	0.73	1,084.37
1992/93	4,026.93	3,250.04	0.81	776.89
1993/94	4,153.95	2,761.78	0.66	1,392.17
1994/95	4,546.37	3,086.84	0.68	1,459.54
1995/96	3,741.94	1,880.29	0.50	1,861.65
1996/97	3,582.00	1,712.88	0.48	1,869.11
1997/98	4,656.17	2,070.04	0.44	2,586.12

Years	Thiessen Average Rainfall (mm)	Streamflow (mm)	RC	Water balance
1998/99	4,187.66	2,026.20	0.48	2,161.46
1999/00	3,527.03	1,234.40	0.35	2,292.63
2000/01	2,946.74	843.94	0.29	2,102.80
2001/02	2,940.48	1,154.44	0.39	1,786.04
2002/03	3,786.40	1,459.52	0.39	2,326.88
2003/04	3,454.22	1,426.59	0.41	2,027.63
2004/05	3,409.38	1,649.82	0.48	1,759.56
2005/06	4,025.75	1,829.81	0.45	2,195.94
2006/07	4,459.95	1,821.12	0.41	2,638.83
2007/08	4,082.86	2,097.13	0.51	1,985.73
2008/09	3,782.01	1,722.09	0.46	2,059.92
2009/10	4,272.07	1,894.89	0.44	2,377.18
2010/11	4,396.60	2,255.82	0.51	2,140.78
2011/12	2,368.38	1,114.94	0.47	1,253.44
2012/13	4,774.57	2,470.32	0.52	2,304.25
2013/14	3,392.13	1,572.95	0.46	1,819.18
Average	**4,017.80**	**2,634.89**	**0.65**	**1,382.92**

Double Mass Curve

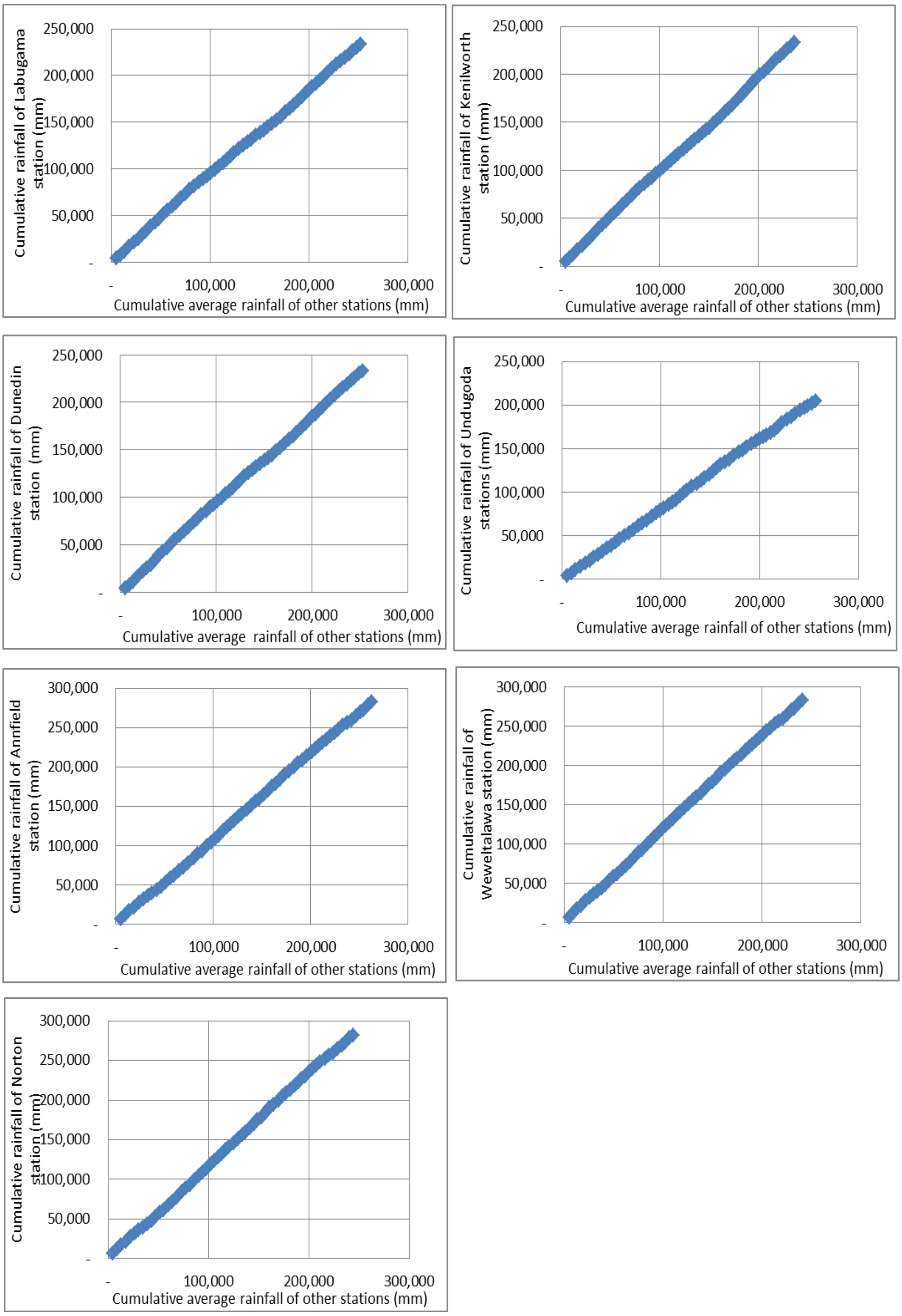


Figure A-0-1 Double Mass Curves of Rainfall stations

Rainfall Station and streamflow responses

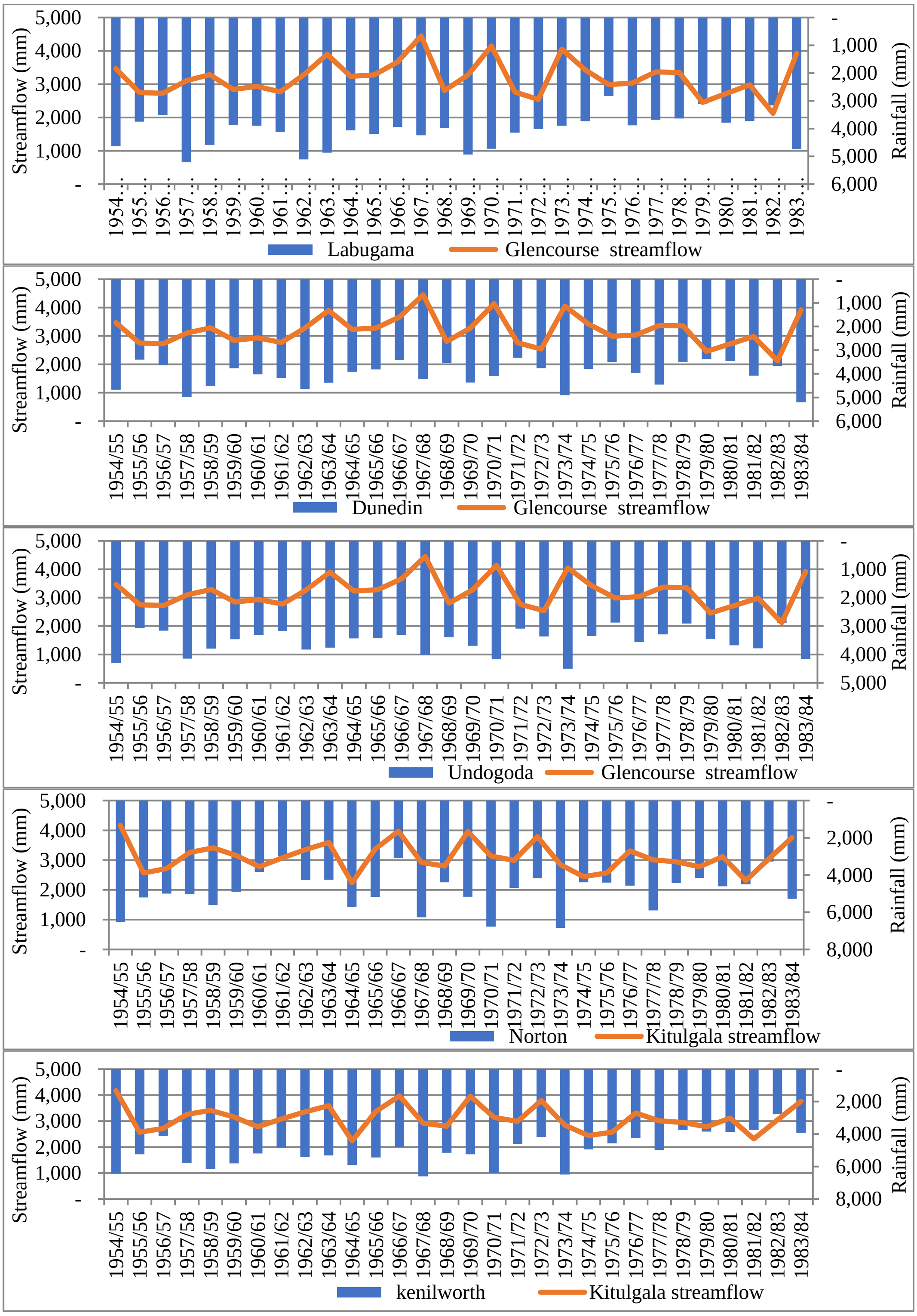


Figure A-0-2 Rainfall station and Streamflow response (1954/55 – 1983/84)

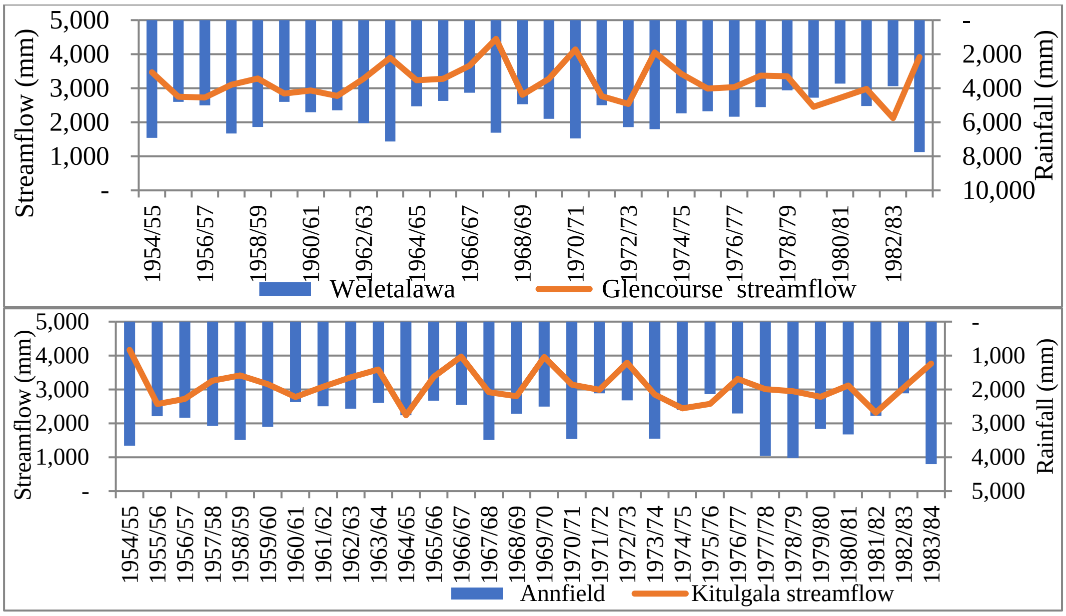


Figure A-0-3 Rainfall station and Streamflow response (1954/55 – 1983/84)

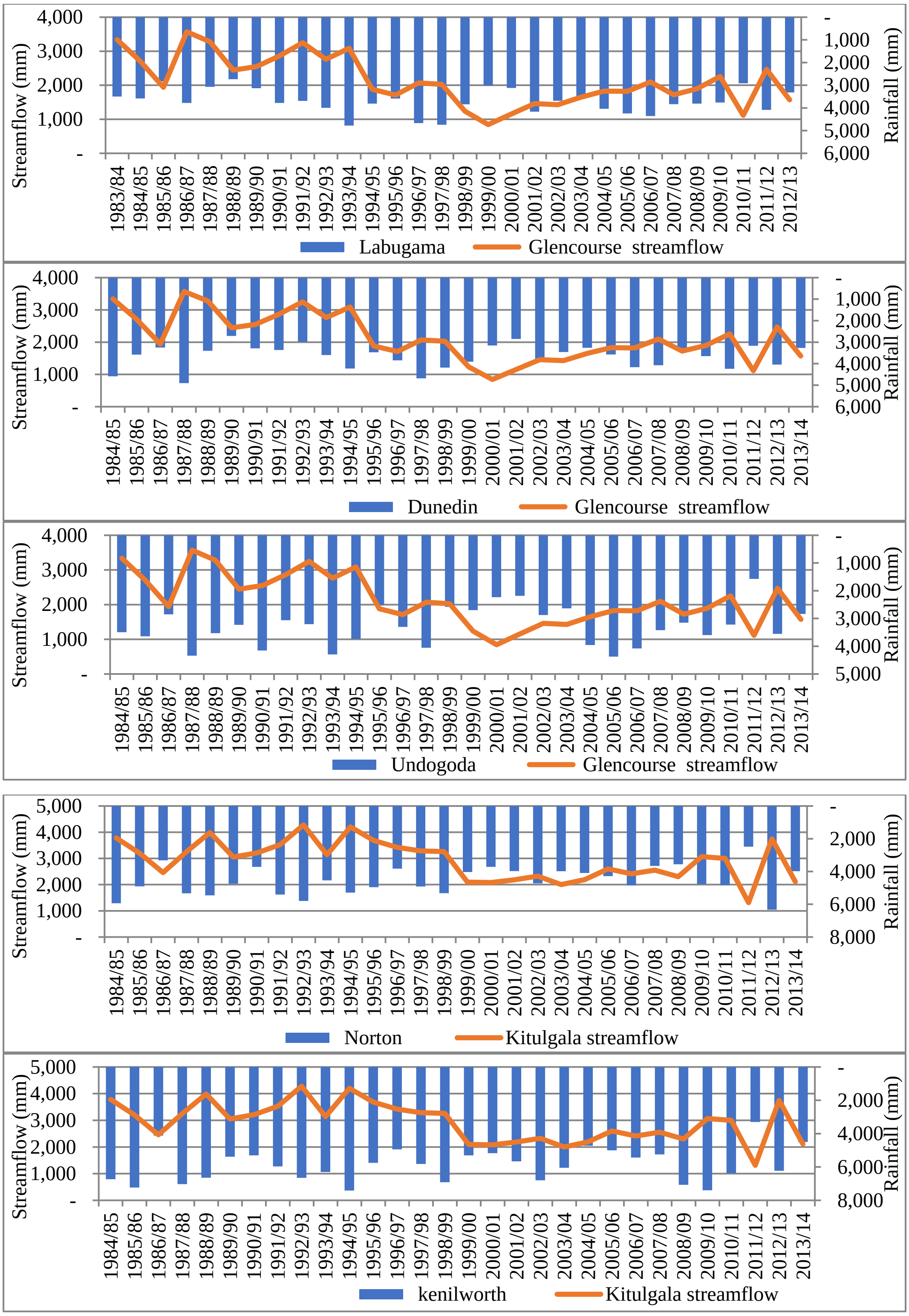


Figure A-0-4 Rainfall station and Streamflow response (1984/85 – 2013/14)

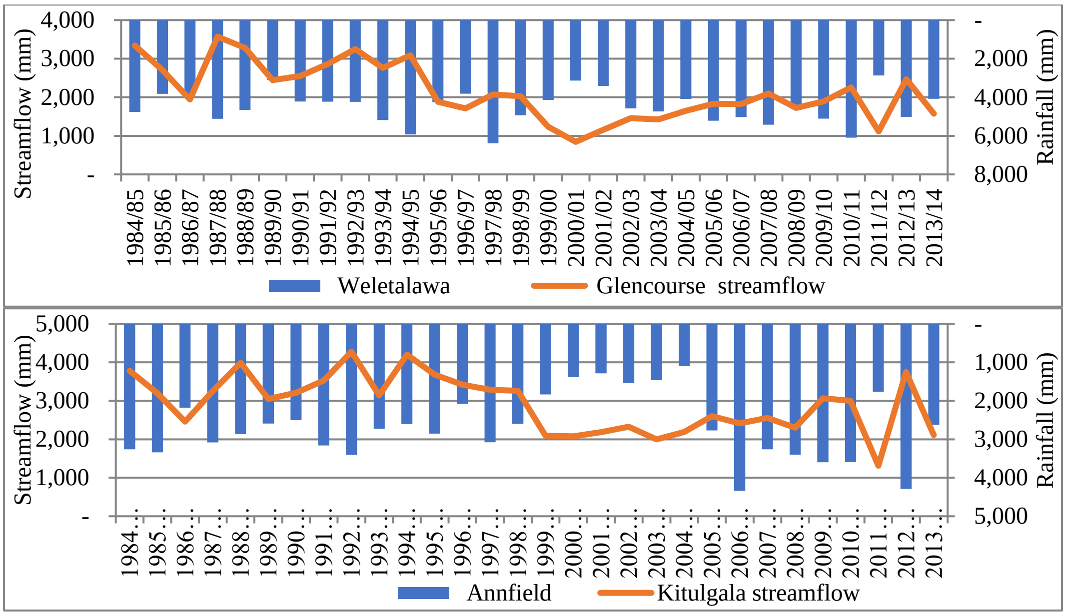


Figure A-0-5 Rainfall station and Streamflow response (1984/85 – 2013/14)

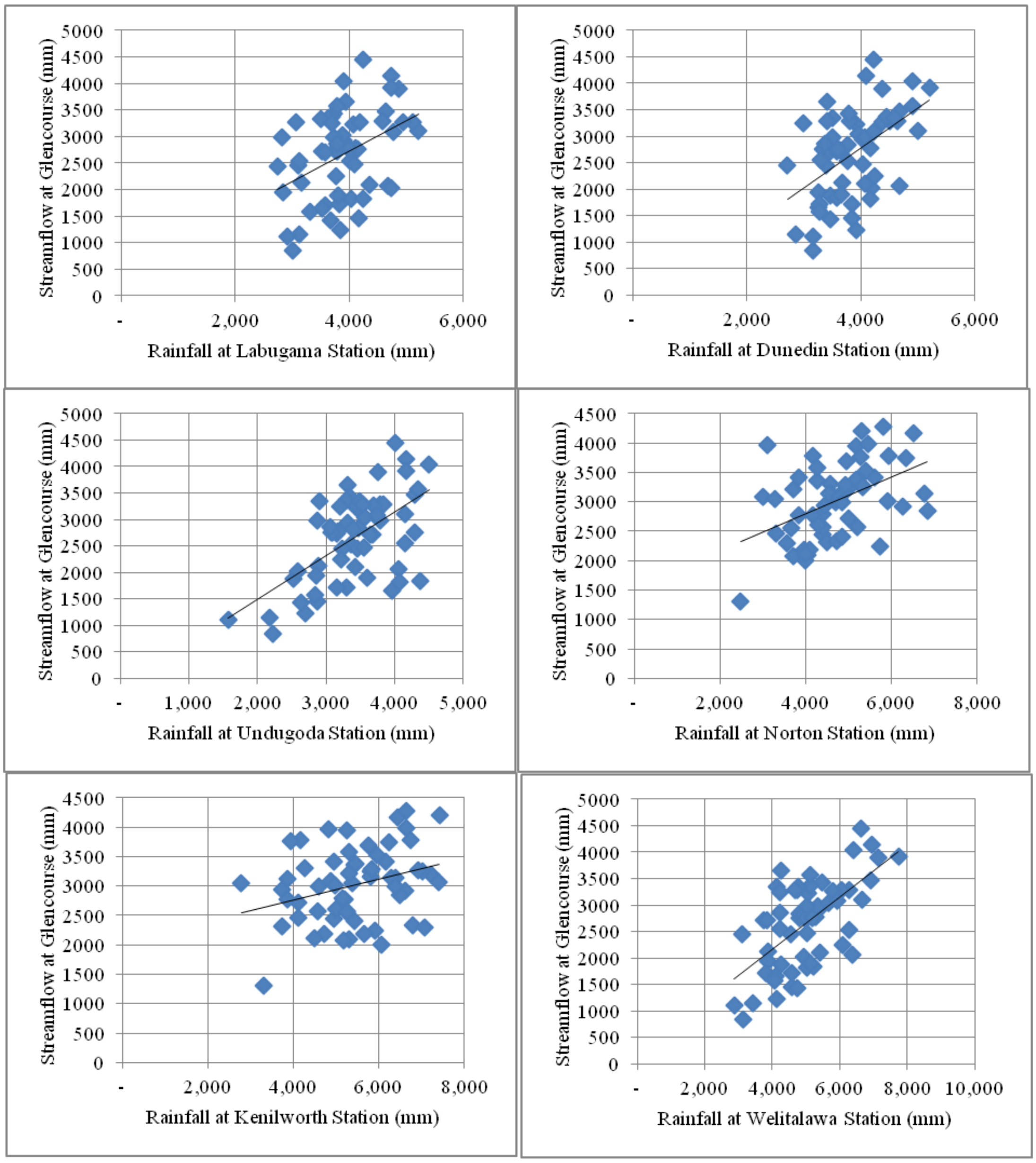


Figure A-0-6 Rainfall station and Streamflow correlation

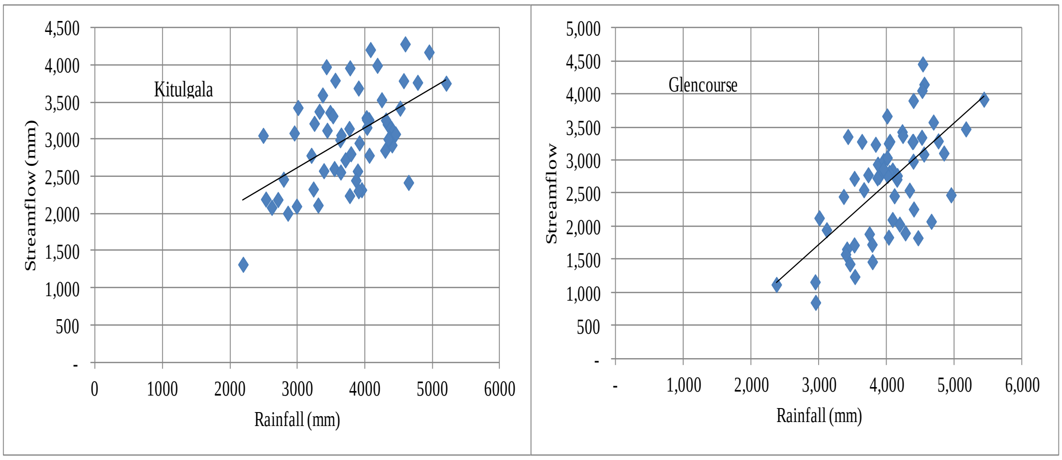


Figure A-0-7 Rainfall Station and Streamflow relation

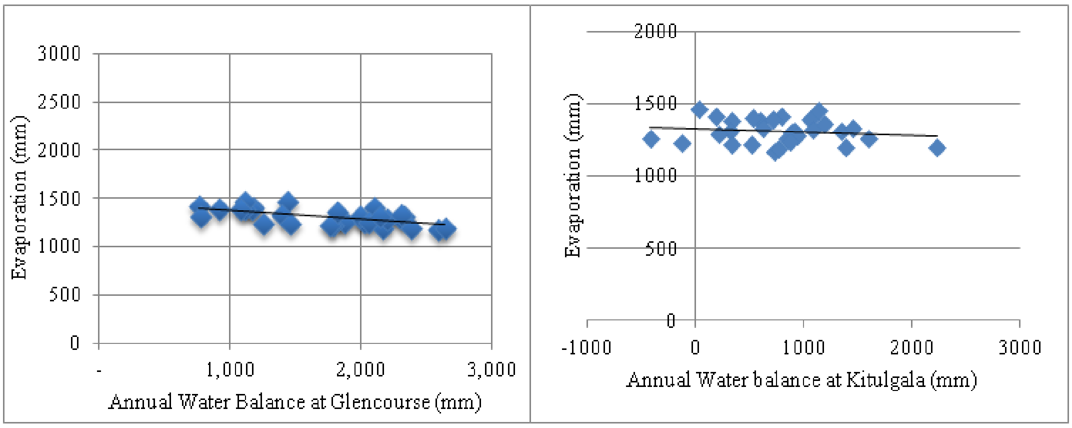


Figure A-0-8 Annual Water Balance and Evaporation at Kitulgala and Glencourse

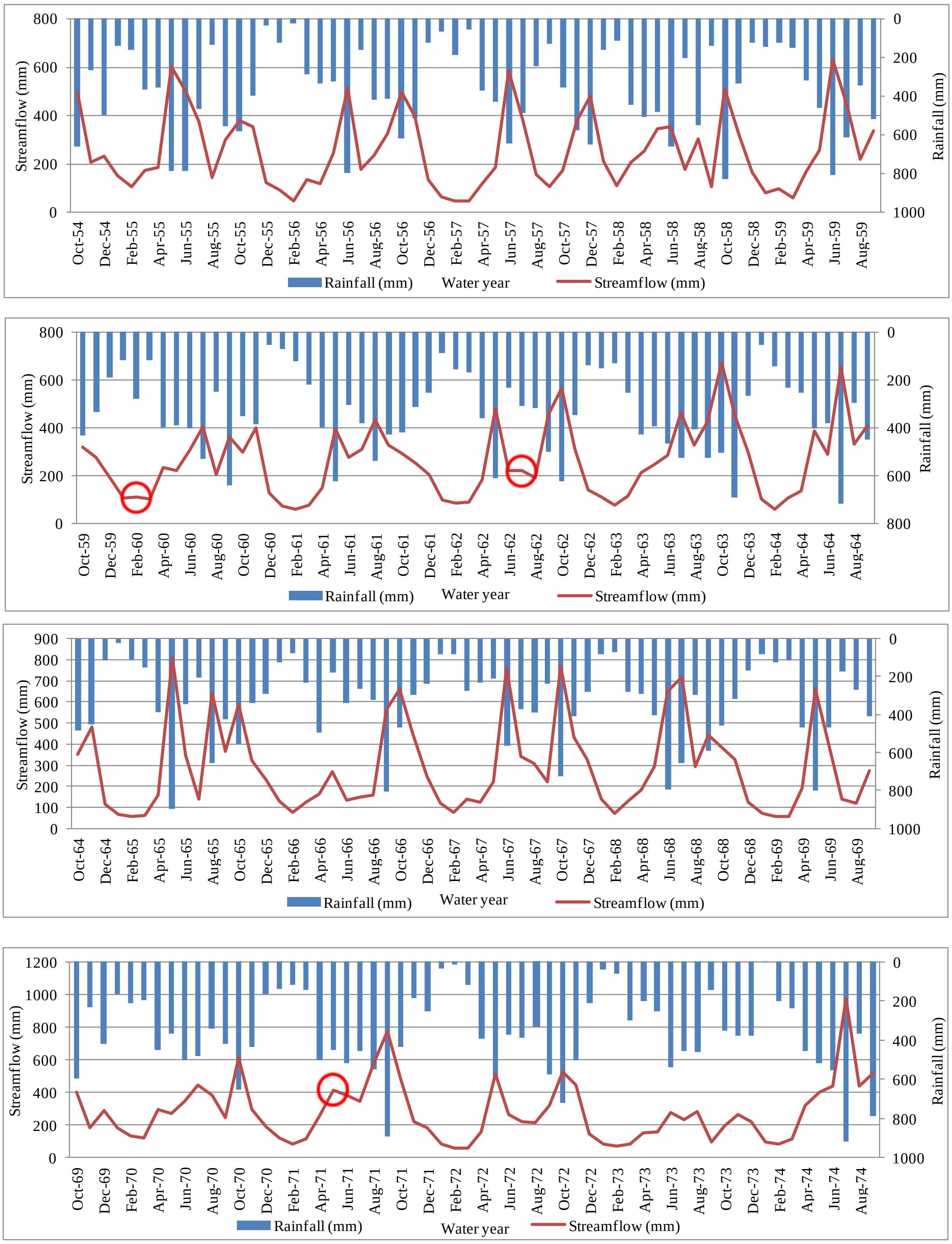


Figure A-0-9: Streamflow response to rainfall from 1954/55 to 1973/74 at Glencourse sub-catchment

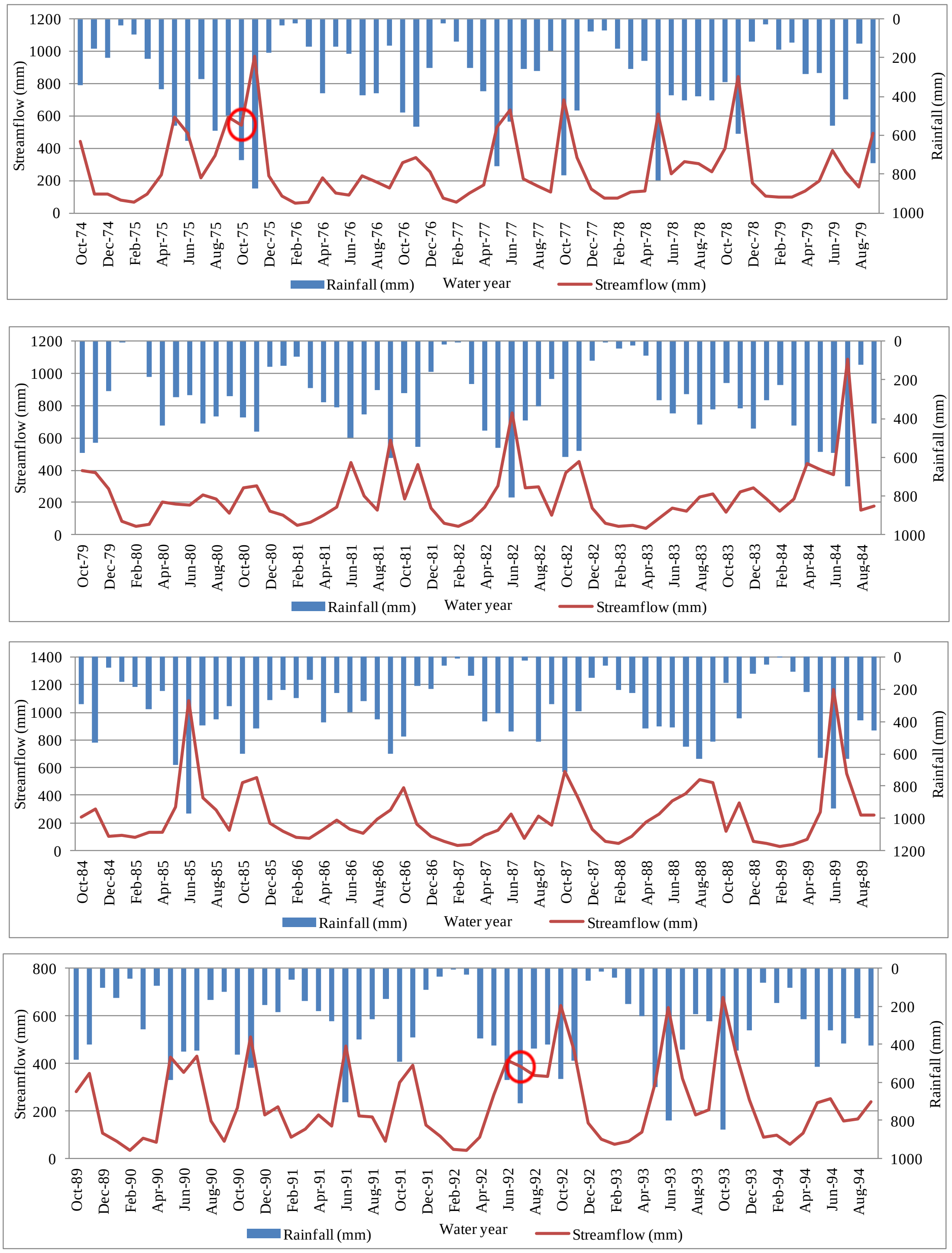


Figure A-0-10 Streamflow response to rainfall from 1974/75 to 1994/95 at Glencourse sub-catchment

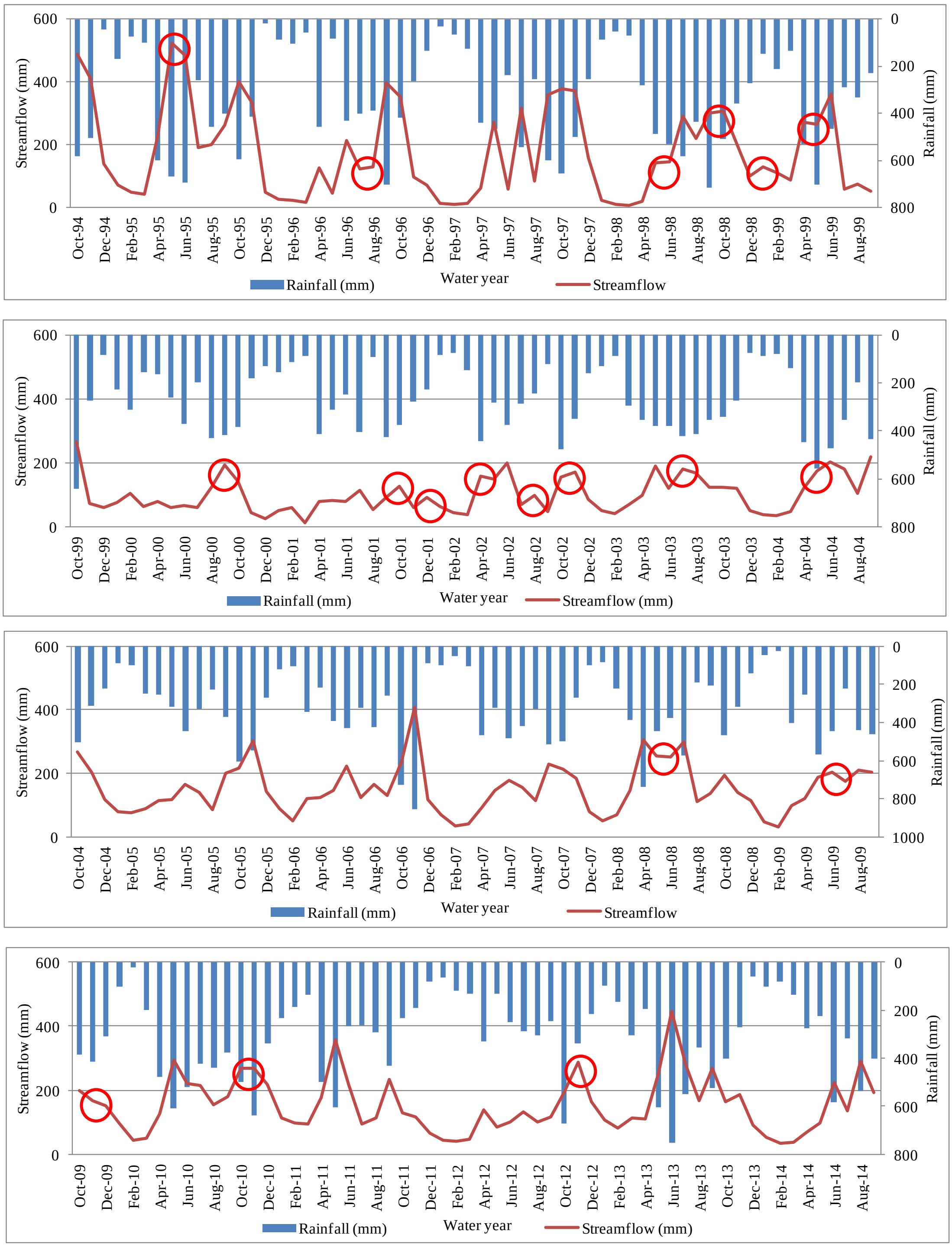


Figure A-0-11 Streamflow response to rainfall from 1994/95 to 2013/2014 at Glencourse

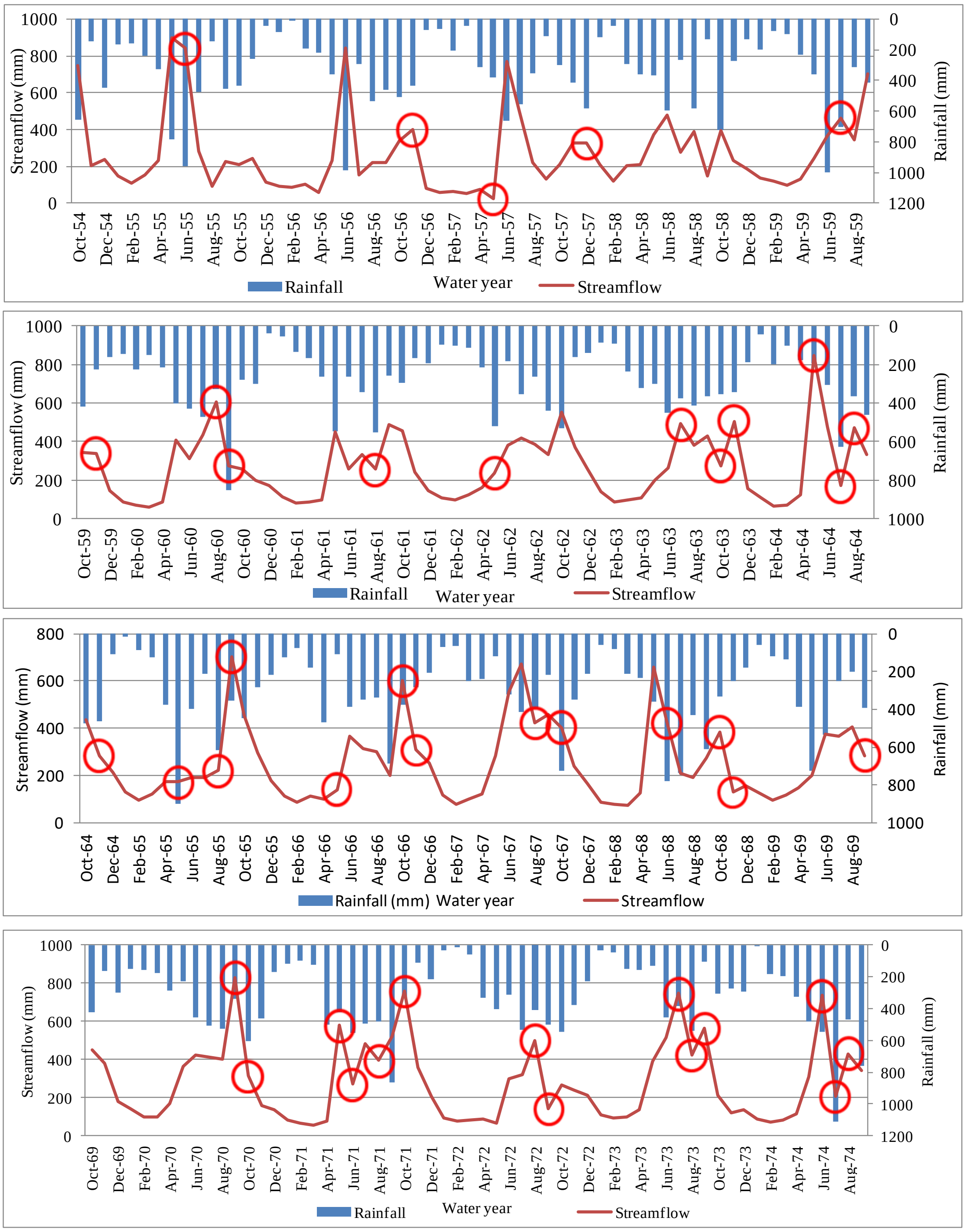


Figure A-0-12 Streamflow response to rainfall from 1954/55 to 1973/74 at Kitulgala

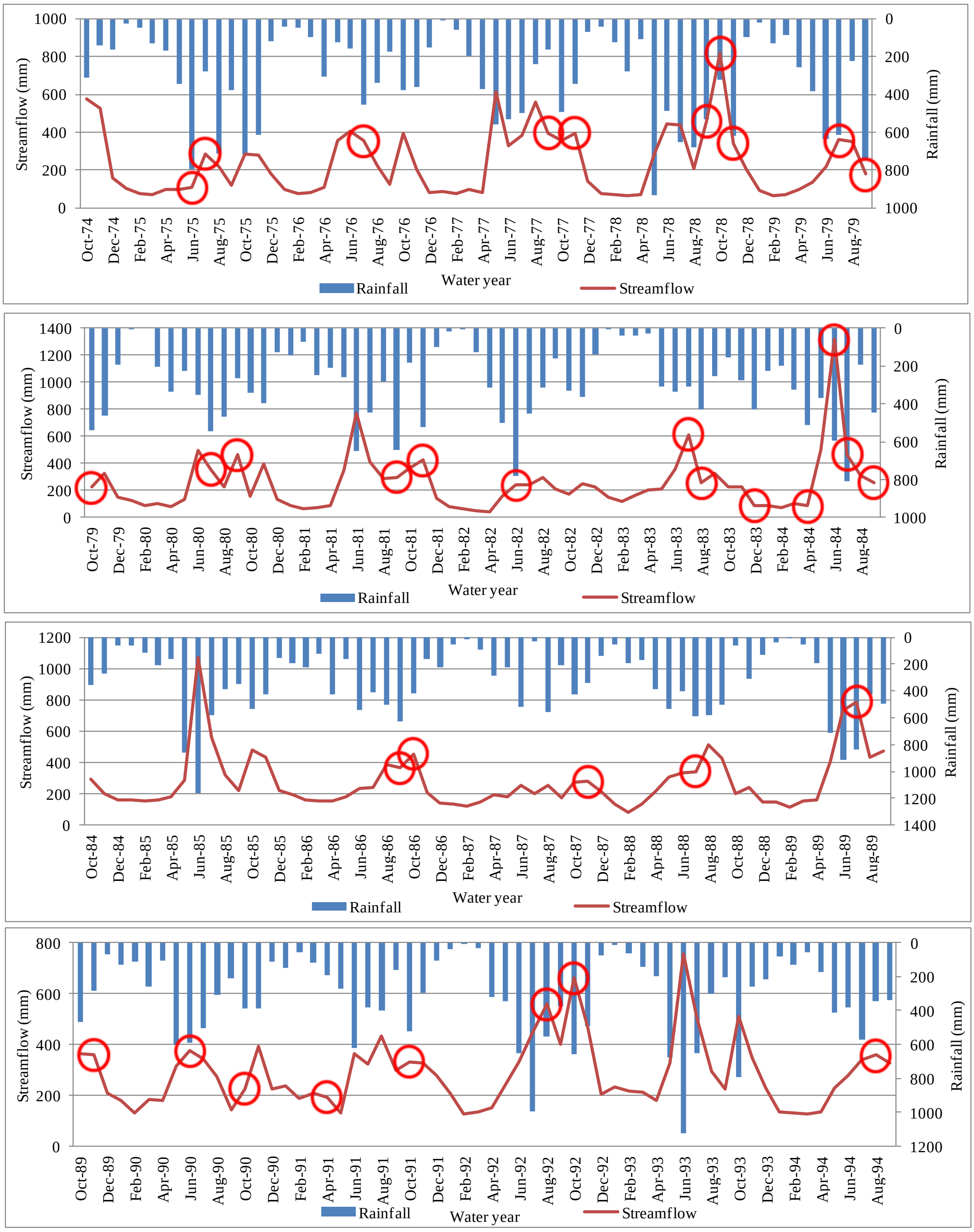


Figure A-0-13 Streamflow response to rainfall from 1974/75 to 1993/94 at Kitulgala

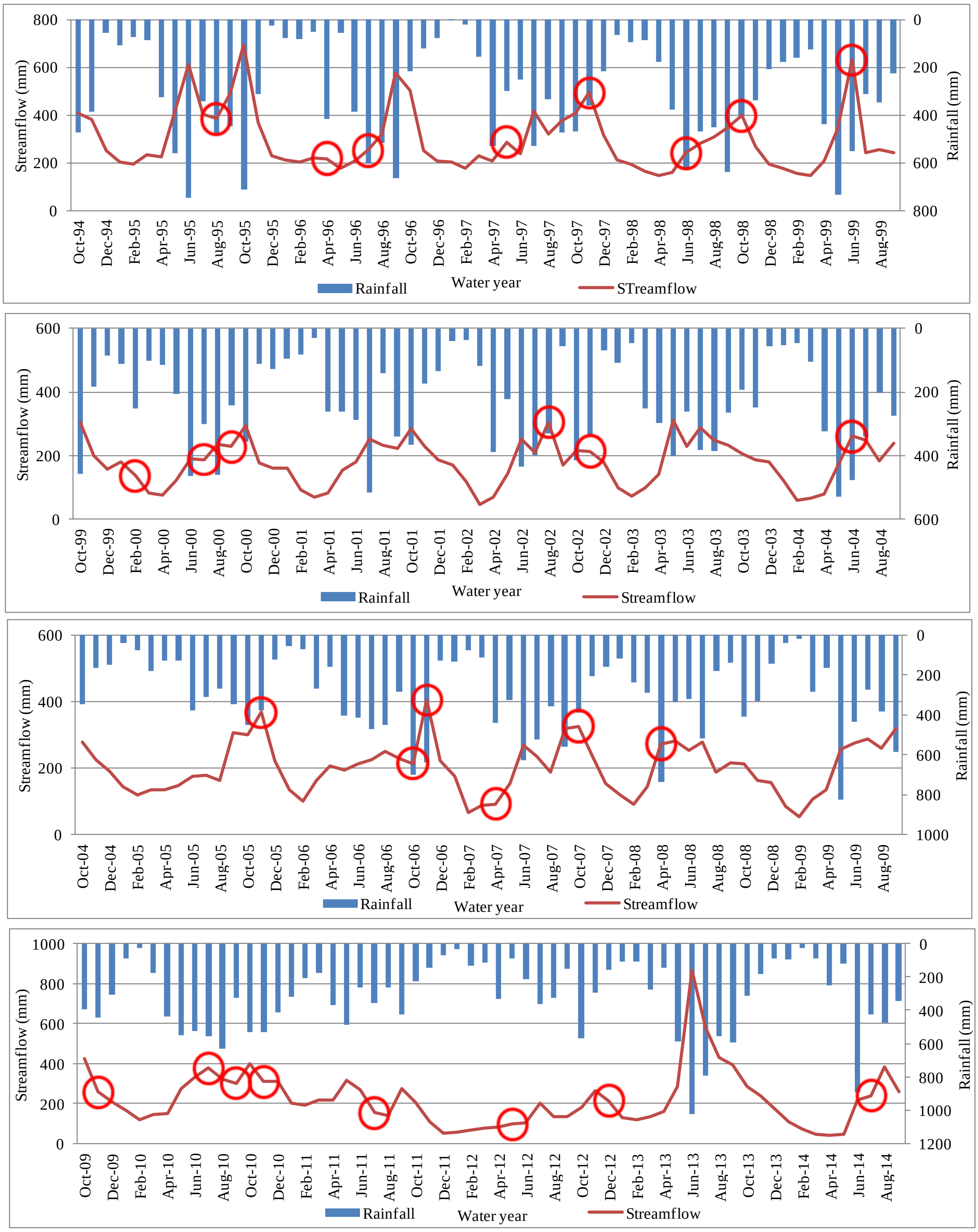
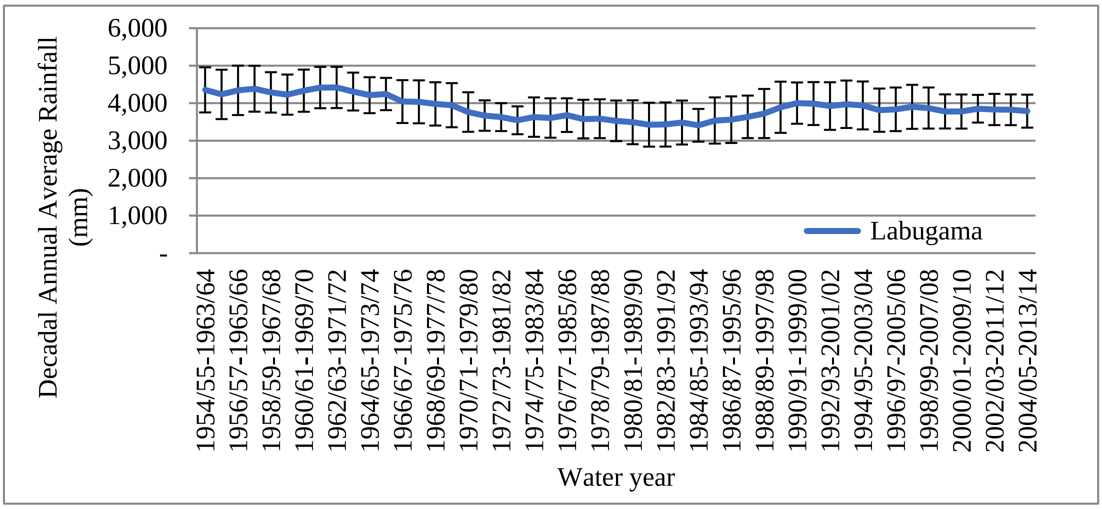
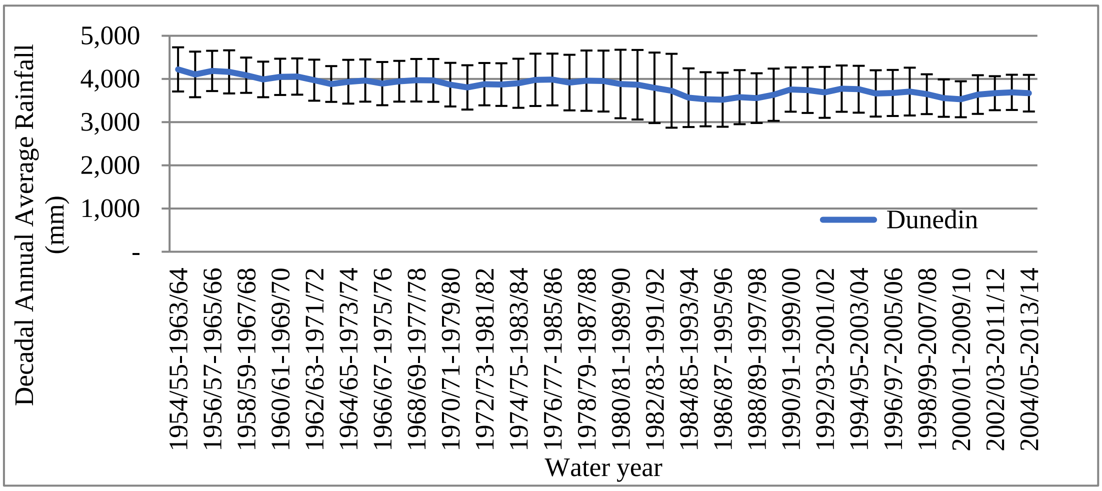


Figure A-0-14 Streamflow response to rainfall from 1994/95 to 2013/14 at Kitulgala

Appendix B - STD, Coefficient of Variation and Mean





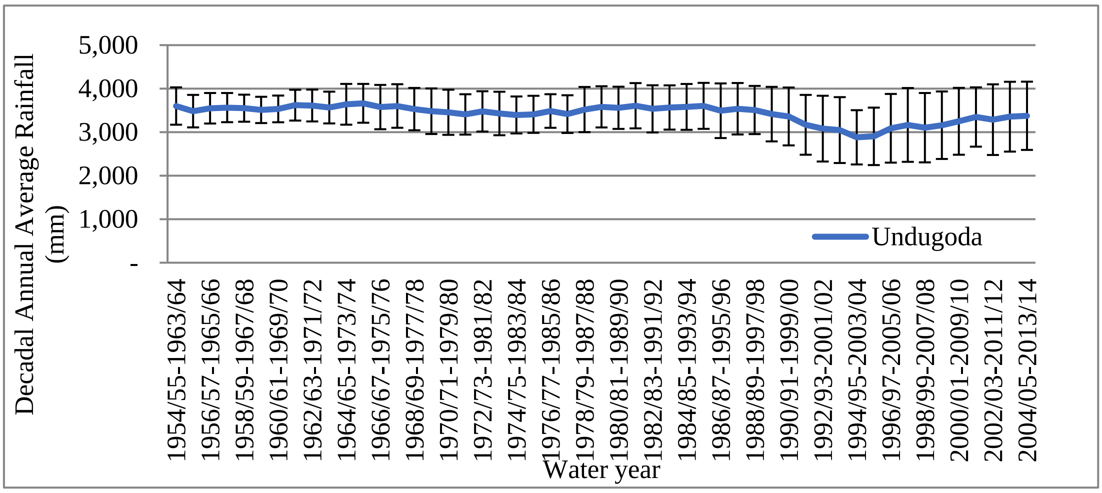


Figure B-0-1 Standard Deviation of Point Rainfall

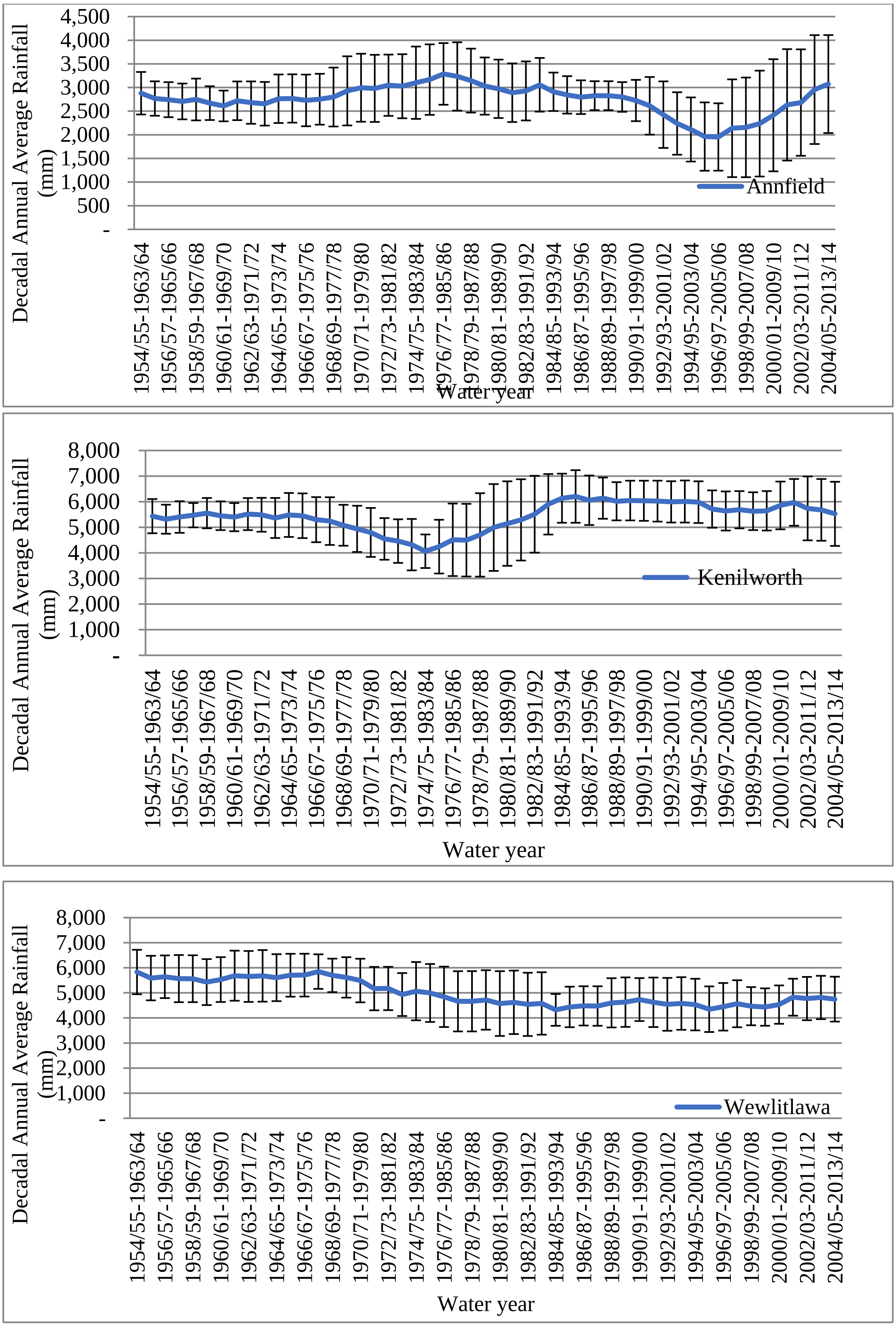


Figure B-0-2 Standard Deviation of Point Rainfall Stations

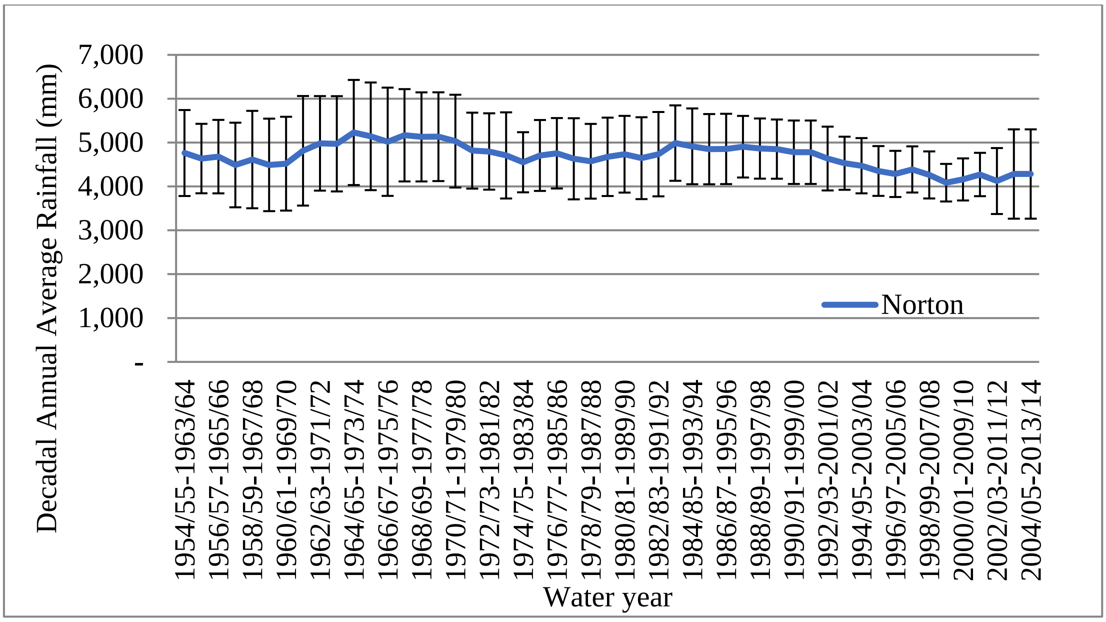


Figure B-0-3 Standard Deviation of Point Rainfall Stations

Table B-0-1 Standard Deviation (Decadal Annual Average Rainfall)

Year	Rainfall Station						
	Labugama	Dunedin	Undugoda	Annfield	Kenilworth	Wewiltalawa	Norton
1954/55-1963/64	601.81	511.28	429.30	449.60	668.24	886.39	980
1955/56-1964/65	658.75	527.84	373.46	364.26	567.48	888.24	791.51
1956/57-1965/66	659.31	466.25	350.70	370.38	617.88	851.14	837.24
1957/58-1966/67	611.84	499.32	335.09	379.04	476.77	940.23	964.26
1958/59-1967/68	538.93	408.57	311.02	442.13	592.06	935.02	1,110.22
1959/60-1968/69	535.81	411.64	302.03	357.16	561.70	917.02	1,054.23
1960/61-1969/70	562.68	419.85	306.77	325.17	550.57	894.27	1,069.43
1961/62-1970/71	551.62	420.00	353.93	409.25	626.06	998.01	1,249.44
1962/63-1971/72	550.01	475.58	365.86	448.23	661.64	1,015.42	1,077.86
1963/64-1972/73	504.99	414.52	364.78	461.58	782.39	1,028.39	1,085.86
1964/65-1973/74	479.58	506.82	468.57	513.78	858.91	936.33	1,198.45
1965/66-1974/75	429.90	488.64	446.17	511.09	873.50	855.31	1,227.30

Year	Rainfall Station						
	Labugama	Dunedin	Undugoda	Annfield	Kenilworth	Wewiltalawa	Norton
1966/67-1975/76	571.49	500.47	509.01	546.32	881.22	853.53	1,233.75
1967/68-1976/77	573.06	471.61	500.79	538.28	931.68	689.09	1,052.41
1968/69-1977/78	577.94	492.26	486.63	623.31	800.09	667.40	1,015.38
1969/70-1978/79	588.25	496.41	524.25	731.50	902.92	806.32	1,012.05
1970/71-1979/80	527.38	505.00	518.91	718.71	956.60	869.14	1,057.69
1971/72-1980/81	406.50	513.13	464.12	710.05	813.10	865.07	865.75
1972/73-1981/82	372.36	489.84	463.22	648.33	851.13	864.14	870.90
1973/74-1982/83	371.80	493.49	499.46	677.38	1,004.05	856.05	982.25
1974/75-1983/84	525.55	568.04	424.99	765.19	655.16	1,162.13	685.21
1975/76-1984/85	525.68	605.73	425.69	745.66	1,049.35	1,156.22	808.35
1976/77-1985/86	448.92	599.23	386.09	651.96	1,415.63	1,203.92	803.00
1977/78-1986/87	514.72	643.24	433.47	722.21	1,419.03	1,200.79	924.70
1978/79-1987/88	517.86	697.96	519.17	676.03	1,629.35	1,201.29	852.16
1979/80-1988/89	542.08	705.48	473.24	604.82	1,696.14	1,186.33	893.45
1980/81-1989/90	585.73	792.93	484.96	617.84	1,649.96	1,291.68	874.71
1981/82-1990/91	585.81	804.89	520.13	620.09	1,587.39	1,265.05	933.14
1982/83-1991/92	589.18	815.91	542.60	624.10	1,499.93	1,261.26	961.28
1983/84-1992/93	586.06	855.32	508.52	567.69	1,182.09	1,245.09	860.12
1984/85-1993/94	436.86	678.95	527.10	405.98	958.81	634.67	863.91
1985/86-1994/95	615.97	626.31	528.13	396.03	1,027.64	807.96	800.69
1986/87-1995/96	621.85	626.36	628.01	356.73	967.58	782.68	801.24
1987/88-1996/97	567.09	626.13	591.59	305.99	806.34	787.89	702.12

Year	Rainfall Station						
	Labugama	Dunedin	Undugoda	Annfield	Kenilworth	Wewiltalawa	Norton
1988/89-1997/98	655.47	575.71	553.87	305.75	745.85	981.44	686.18
1989/90-1998/99	682.58	604.71	626.23	313.79	775.80	987.02	675.04
1990/91-1999/00	551.45	512.68	664.93	436.68	784.18	855.90	723.30
1991/92-2000/01	572.74	528.05	687.80	609.26	798.82	987.02	723.25
1992/93-2001/02	634.79	589.76	755.81	703.67	806.94	1,054.22	727.03
1993/94-2002/03	632.96	535.75	757.03	660.99	821.31	1,048.82	605.51
1994/95-2003/04	639.34	542.65	623.73	678.15	815.18	1,029.59	629.52
1995/96-2004/05	577.17	536.41	660.32	722.74	730.01	910.03	567.67
1996/97-2005/06	581.50	533.14	789.22	712.01	763.19	948.92	526.76
1997/98-2006/07	586.92	553.65	848.37	1,033.93	728.18	936.79	526.39
1998/99-2007/08	548.21	461.00	796.93	1,053.89	738.99	761.23	536.63
1999/00-2008/09	455.53	432.63	775.67	1,119.63	769.93	745.37	428.46
2000/01-2009/10	455.23	416.38	768.47	1,185.67	933.14	765.47	479.55
2001/02-2010/11	369.52	447.60	681.41	1,178.12	913.11	736.99	494.04
2002/03-2011/12	416.45	393.77	812.18	1,125.79	1,247.53	863.64	751.91
2003/04-2012/13	410.49	407.85	802.15	1,151.23	1,206.21	863.83	1,018.51
2004/05-2013/14	439.95	424.25	784.11	1,036.39	1,252.53	894.95	1,018.55

Table B-0-2 Coefficient of Variation Decadal Average Annual Rainfall

Years	Labugama	Dunedin	Undugoda	Annfield	Kenilworth	Wewlitlawa	Norton
1954/55-1963/64	0.14	0.12	0.12	0.16	0.12	0.15	0.21
1955/56-1964/65	0.16	0.13	0.11	0.13	0.11	0.16	0.17
1956/57-1965/66	0.15	0.11	0.10	0.14	0.11	0.15	0.18

Years	Labugama	Dunedin	Undugoda	Annfield	Kenilworth	Wewlitlawa	Norton
1957/58-1966/67	0.14	0.12	0.09	0.14	0.09	0.17	0.21
1958/59-1967/68	0.13	0.10	0.09	0.16	0.11	0.17	0.24
1959/60-1968/69	0.13	0.10	0.09	0.13	0.10	0.17	0.23
1960/61-1969/70	0.13	0.10	0.09	0.12	0.10	0.16	0.24
1961/62-1970/71	0.12	0.10	0.10	0.15	0.11	0.18	0.26
1962/63-1971/72	0.12	0.12	0.10	0.17	0.12	0.18	0.22
1963/64-1972/73	0.12	0.11	0.10	0.17	0.15	0.18	0.22
1964/65-1973/74	0.11	0.13	0.13	0.19	0.16	0.17	0.23
1965/66-1974/75	0.10	0.12	0.12	0.18	0.16	0.15	0.24
1966/67-1975/76	0.14	0.13	0.14	0.20	0.17	0.15	0.25
1967/68-1976/77	0.14	0.12	0.14	0.20	0.18	0.12	0.20
1968/69-1977/78	0.15	0.12	0.14	0.22	0.16	0.12	0.20
1969/70-1978/79	0.15	0.13	0.15	0.25	0.18	0.14	0.20
1970/71-1979/80	0.14	0.13	0.15	0.24	0.20	0.16	0.21
1971/72-1980/81	0.11	0.13	0.14	0.24	0.18	0.17	0.18
1972/73-1981/82	0.10	0.13	0.13	0.21	0.19	0.17	0.18
1973/74-1982/83	0.10	0.13	0.15	0.22	0.23	0.17	0.21
1974/75-1983/84	0.14	0.15	0.13	0.25	0.16	0.23	0.15
1975/76-1984/85	0.15	0.15	0.12	0.24	0.25	0.23	0.17
1976/77-1985/86	0.12	0.15	0.11	0.20	0.31	0.25	0.17
1977/78-1986/87	0.14	0.16	0.13	0.22	0.32	0.26	0.20
1978/79-1987/88	0.14	0.18	0.15	0.21	0.35	0.26	0.19
1979/80-1988/89	0.15	0.18	0.13	0.20	0.34	0.25	0.19

Years	Labugama	Dunedin	Undugoda	Annfield	Kenilworth	Wewlitlawa	Norton
1980/81-1989/90	0.17	0.20	0.14	0.21	0.32	0.28	0.18
1981/82-1990/91	0.17	0.21	0.14	0.21	0.30	0.27	0.20
1982/83-1991/92	0.17	0.21	0.15	0.21	0.27	0.28	0.20
1983/84-1992/93	0.17	0.23	0.14	0.19	0.20	0.27	0.17
1984/85-1993/94	0.13	0.19	0.15	0.14	0.16	0.15	0.18
1985/86-1994/95	0.17	0.18	0.15	0.14	0.17	0.18	0.17
1986/87-1995/96	0.17	0.18	0.18	0.13	0.16	0.17	0.17
1987/88-1996/97	0.16	0.17	0.17	0.11	0.13	0.18	0.14
1988/89-1997/98	0.18	0.16	0.16	0.11	0.12	0.21	0.14
1989/90-1998/99	0.18	0.17	0.18	0.11	0.13	0.21	0.14
1990/91-1999/00	0.14	0.14	0.20	0.16	0.13	0.18	0.15
1991/92-2000/01	0.14	0.14	0.22	0.23	0.13	0.21	0.15
1992/93-2001/02	0.16	0.16	0.25	0.29	0.13	0.23	0.16
1993/94-2002/03	0.16	0.14	0.25	0.30	0.14	0.23	0.13
1994/95-2003/04	0.16	0.14	0.22	0.32	0.14	0.23	0.14
1995/96-2004/05	0.15	0.15	0.23	0.37	0.13	0.21	0.13
1996/97-2005/06	0.15	0.15	0.26	0.36	0.14	0.21	0.12
1997/98-2006/07	0.15	0.15	0.27	0.48	0.13	0.21	0.12
1998/99-2007/08	0.14	0.13	0.26	0.49	0.13	0.17	0.13
1999/00-2008/09	0.12	0.12	0.25	0.50	0.14	0.17	0.10
2000/01-2009/10	0.12	0.12	0.24	0.49	0.16	0.17	0.12
2001/02-2010/11	0.10	0.12	0.20	0.45	0.15	0.15	0.12
2002/03-2011/12	0.11	0.11	0.25	0.42	0.22	0.18	0.18

Years	Labugama	Dunedin	Undugoda	Annfield	Kenilworth	Wewlitlawa	Norton
2003/04-2012/13	0.11	0.11	0.24	0.39	0.21	0.18	0.24
2004/05-2013/14	0.12	0.12	0.23	0.34	0.23	0.19	0.24

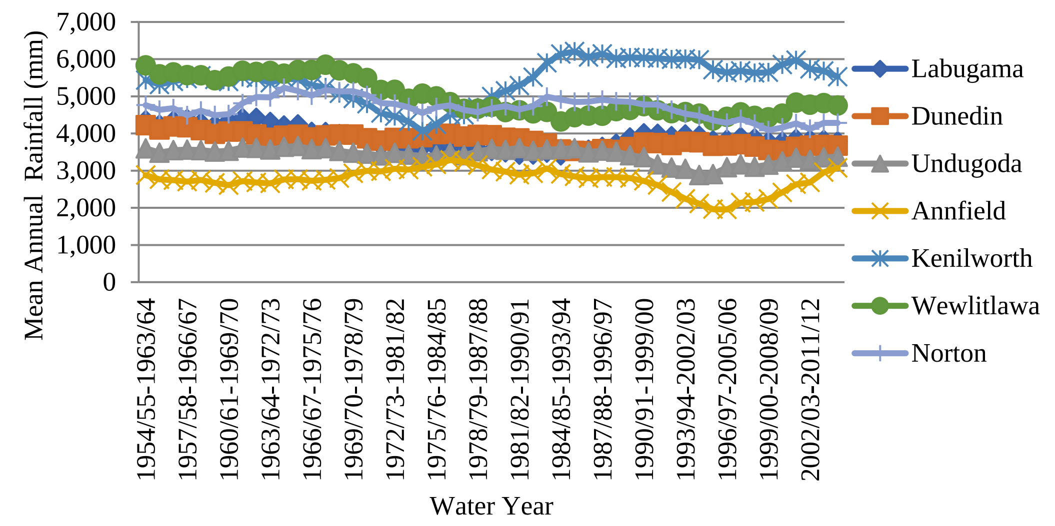


Figure B-0-4 Decadal Annual Mean Variation

Table B-0-3 Mean (Decadal Annual Average Rainfall)

Years	Labugama	Dunedin	Undugoda	Annfield	Kenilworth	Wewlitlawa	Norton
1954/55-1963/64	4,355.79	4,221.55	3,600.58	2,879.45	5,435.34	5,831.42	4,762.11
1955/56-1964/65	4,234.23	4,105.53	3,483.28	2,767.15	5,316.14	5,590.13	4,636.10
1956/57-1965/66	4,342.59	4,186.48	3,549.54	2,743.17	5,401.60	5,641.94	4,679.87
1957/58-1966/67	4,385.41	4,164.35	3,564.68	2,705.33	5,472.64	5,568.06	4,489.19
1958/59-1967/68	4,288.51	4,087.11	3,551.24	2,747.02	5,553.06	5,563.95	4,613.05
1959/60-1968/69	4,228.23	3,989.43	3,511.28	2,669.85	5,451.98	5,430.60	4,491.41
1960/61-1969/70	4,333.59	4,049.48	3,534.25	2,610.07	5,396.54	5,530.17	4,518.89
1961/62-1970/71	4,417.25	4,056.25	3,620.30	2,719.19	5,515.68	5,684.59	4,812.78
1962/63-1971/72	4,420.02	3,972.21	3,612.36	2,681.10	5,488.94	5,654.53	4,982.55
1963/64-1972/73	4,310.25	3,883.99	3,566.25	2,656.62	5,363.95	5,678.51	4,972.25
1964/65-1973/74	4,213.26	3,936.20	3,640.32	2,762.51	5,482.02	5,606.18	5,230.06

Years	Labugama	Dunedin	Undugoda	Annfield	Kenilworth	Wewlitlawa	Norton
1965/66-1974/75	4,244.48	3,963.77	3,662.69	2,768.92	5,451.32	5,704.00	5,142.83
1966/67-1975/76	4,043.19	3,892.54	3,576.67	2,727.48	5,298.16	5,707.67	5,018.95
1967/68-1976/77	4,036.88	3,947.35	3,601.53	2,752.43	5,242.23	5,848.59	5,166.63
1968/69-1977/78	3,981.19	3,971.01	3,529.95	2,799.14	5,079.78	5,697.81	5,129.92
1969/70-1978/79	3,946.42	3,966.92	3,481.61	2,929.49	4,939.05	5,615.83	5,134.15
1970/71-1979/80	3,764.29	3,868.42	3,457.33	2,995.74	4,799.15	5,491.81	5,032.73
1971/72-1980/81	3,670.05	3,805.04	3,407.97	2,982.08	4,546.91	5,169.62	4,816.14
1972/73-1981/82	3,628.37	3,879.99	3,477.36	3,048.42	4,461.51	5,174.30	4,797.27
1973/74-1982/83	3,543.83	3,869.95	3,429.35	3,027.29	4,322.05	4,933.53	4,707.33
1974/75-1983/84	3,628.74	3,900.36	3,395.60	3,101.91	4,065.30	5,067.48	4,551.54
1975/76-1984/85	3,604.84	3,979.94	3,409.73	3,167.61	4,244.74	4,995.68	4,706.39
1976/77-1985/86	3,681.22	3,987.83	3,486.60	3,287.66	4,511.33	4,842.95	4,756.37
1977/78-1986/87	3,576.38	3,916.52	3,415.20	3,234.62	4,497.67	4,662.73	4,630.80
1978/79-1987/88	3,585.98	3,961.13	3,519.80	3,146.46	4,702.89	4,663.92	4,573.69
1979/80-1988/89	3,529.67	3,951.74	3,581.90	3,030.60	4,992.32	4,717.80	4,675.43
1980/81-1989/90	3,491.93	3,884.01	3,559.90	2,972.62	5,145.88	4,573.62	4,734.44
1981/82-1990/91	3,426.65	3,866.83	3,607.76	2,890.20	5,289.97	4,622.85	4,644.71
1982/83-1991/92	3,432.11	3,795.19	3,535.51	2,928.20	5,511.93	4,541.73	4,735.63
1983/84-1992/93	3,484.33	3,727.33	3,567.37	3,057.64	5,898.98	4,578.04	4,988.41
1984/85-1993/94	3,409.90	3,566.45	3,580.61	2,910.25	6,136.51	4,321.59	4,914.50
1985/86-1994/95	3,538.12	3,530.50	3,604.71	2,844.38	6,204.40	4,438.45	4,849.82
1986/87-1995/96	3,560.47	3,519.64	3,492.76	2,795.76	6,056.28	4,481.45	4,854.95
1987/88-1996/97	3,635.67	3,578.95	3,538.33	2,827.58	6,138.30	4,475.67	4,906.02

Years	Labugama	Dunedin	Undugoda	Annfield	Kenilworth	Wewlitlawa	Norton
1988/89-1997/98	3,724.70	3,556.65	3,509.46	2,827.32	6,017.19	4,602.57	4,864.06
1989/90-1998/99	3,891.65	3,634.60	3,414.62	2,800.62	6,044.66	4,629.77	4,851.19
1990/91-1999/00	4,001.94	3,754.88	3,361.42	2,725.34	6,036.23	4,732.68	4,779.78
1991/92-2000/01	3,990.26	3,741.22	3,168.89	2,613.34	6,023.03	4,623.94	4,779.81
1992/93-2001/02	3,923.76	3,690.31	3,081.00	2,426.07	5,992.95	4,542.69	4,636.26
1993/94-2002/03	3,971.31	3,776.37	3,047.90	2,239.42	6,007.52	4,576.74	4,528.80
1994/95-2003/04	3,939.74	3,762.41	2,881.79	2,112.77	5,982.28	4,532.23	4,472.85
1995/96-2004/05	3,813.72	3,665.76	2,904.01	1,962.40	5,712.42	4,348.51	4,352.69
1996/97-2005/06	3,836.81	3,676.21	3,089.18	1,954.27	5,637.28	4,444.68	4,285.38
1997/98-2006/07	3,902.53	3,708.34	3,166.51	2,138.74	5,686.47	4,566.33	4,387.78
1998/99-2007/08	3,871.00	3,647.76	3,103.19	2,157.12	5,628.96	4,469.55	4,262.45
1999/00-2008/09	3,780.29	3,556.65	3,159.87	2,237.42	5,644.46	4,434.50	4,085.77
2000/01-2009/10	3,777.65	3,530.45	3,249.88	2,413.33	5,853.82	4,531.46	4,159.97
2001/02-2010/11	3,852.17	3,639.21	3,348.58	2,633.96	5,974.22	4,827.42	4,272.20
2002/03-2011/12	3,832.05	3,670.77	3,287.56	2,681.85	5,737.84	4,772.39	4,123.13
2003/04-2012/13	3,824.60	3,690.15	3,355.74	2,956.69	5,680.91	4,815.96	4,283.70
2004/05-2013/14	3,787.95	3,670.80	3,376.15	3,072.96	5,525.97	4,750.34	4,283.57

Table B-0-4 Mean (Mean Annual Monthly Average Rainfall)

Catchment rainfall (kitulgala)					
Month	Mean	Minimum	Maximum	STD	CoV
Jan	82.81	1.25	322.00	62.24	0.75
Feb	95.15	-	253.19	67.47	0.71
Mar	157.52	29.49	358.85	80.30	0.51
Apr	290.56	27.19	735.99	126.82	0.44
May	402.19	53.20	933.91	217.51	0.54
Jun	543.58	158.63	1,160.45	241.32	0.44
Jul	481.23	32.75	1,108.00	187.02	0.39
Aug	400.44	142.20	709.66	133.79	0.33
Sep	389.78	56.44	866.25	194.90	0.50
Oct	430.94	64.23	794.70	152.95	0.35
Nov	316.13	113.41	636.60	128.73	0.41
Dec	163.17	24.09	579.31	105.15	0.64

Table B-0-5 Mean (Mean Annual Monthly Average Rainfall)

Catchment rainfall (Glencourse)					
Month	Mean	Minimum	Maximum	STD	CoV
Jan	97.07	1.86	304.59	63.93	0.66
Feb	110.87	-	309.65	74.21	0.67
Mar	199.72	24.62	443.74	102.89	0.52
Apr	364.31	77.36	736.79	127.36	0.35
May	450.69	85.27	896.41	187.48	0.42
Jun	504.06	178.77	969.99	185.20	0.37
Jul	407.96	24.79	918.78	160.90	0.39
Aug	353.64	90.40	653.66	124.61	0.35
Sep	419.38	123.60	893.96	183.66	0.44
Oct	510.85	160.11	851.27	152.95	0.30
Nov	407.07	151.57	875.89	149.19	0.37
Dec	192.51	20.64	650.23	121.46	0.63

Appendix C – Trends (1954/55 – 2013/14)

Decadal Average Annual Trends

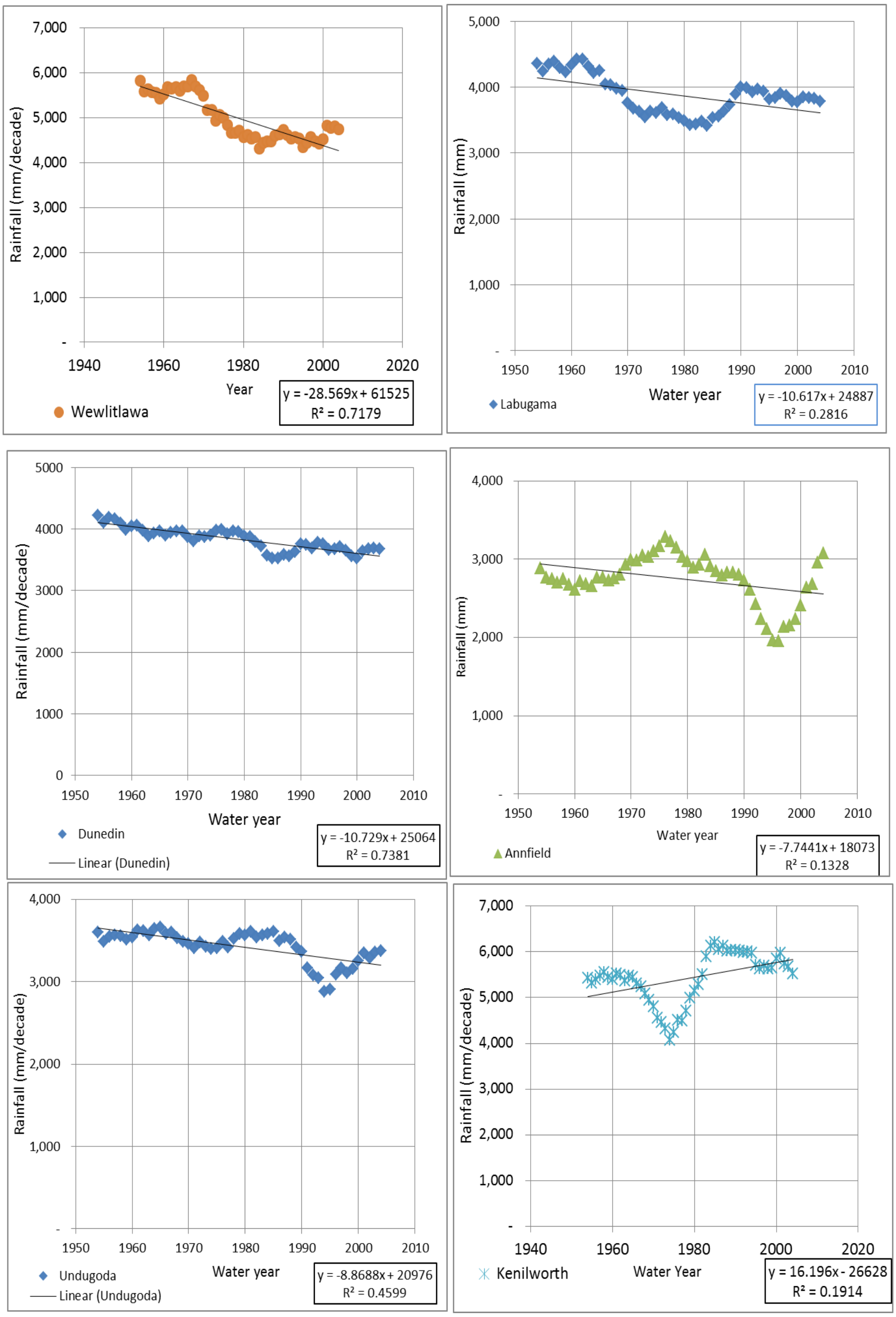


Figure C-0-1 Decadal Annual Average Rainfall Trends at Point rainfall stations

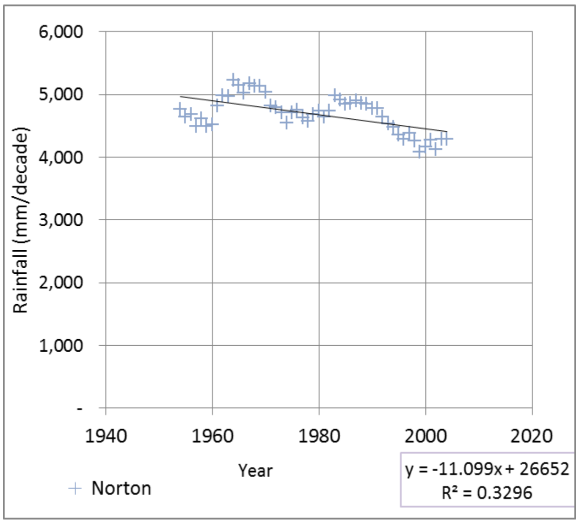


Figure C-0-2 Decadal Annual Average Rainfall Trends at Point rainfall stations

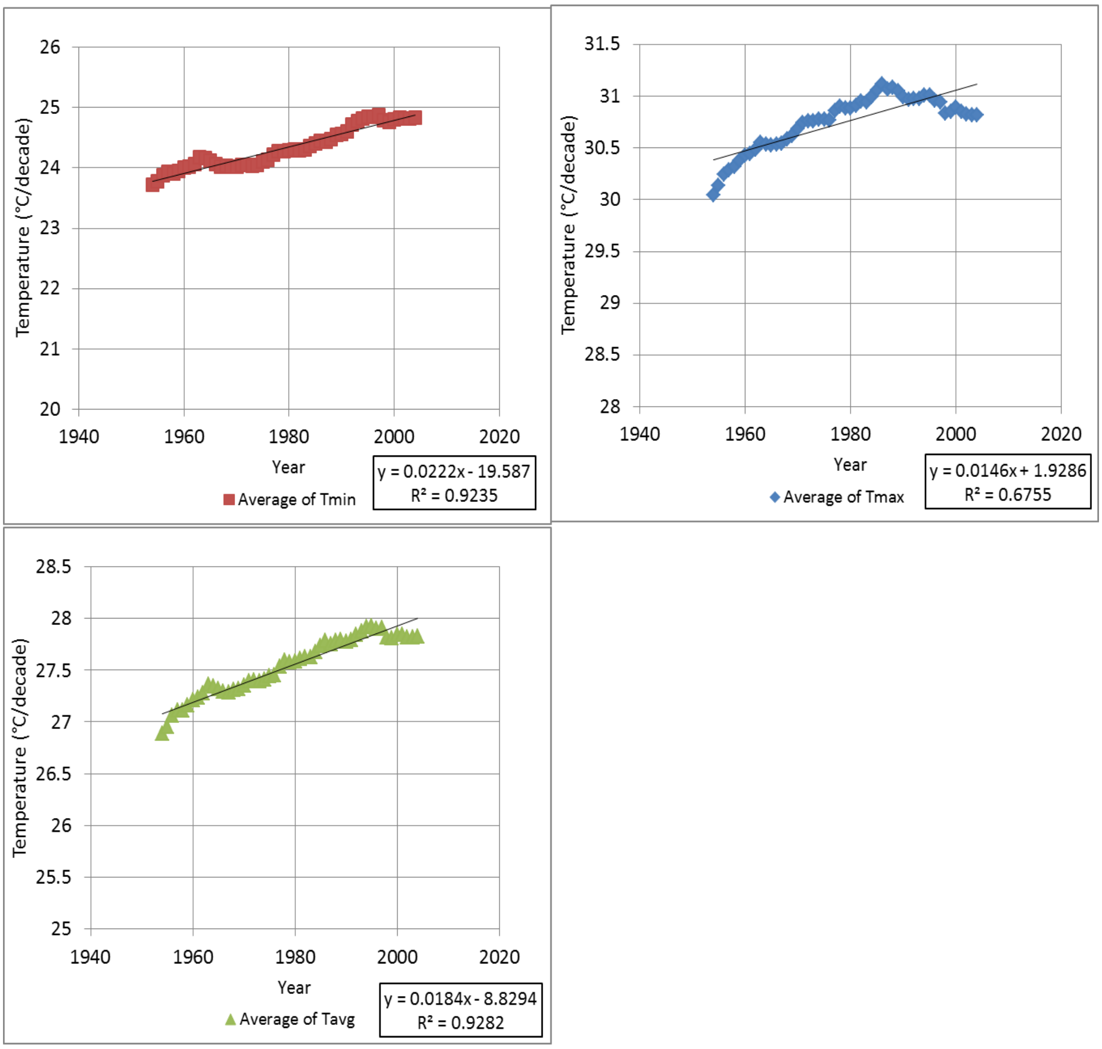


Figure C-0-3 Decadal Average Annual Temperature Trends

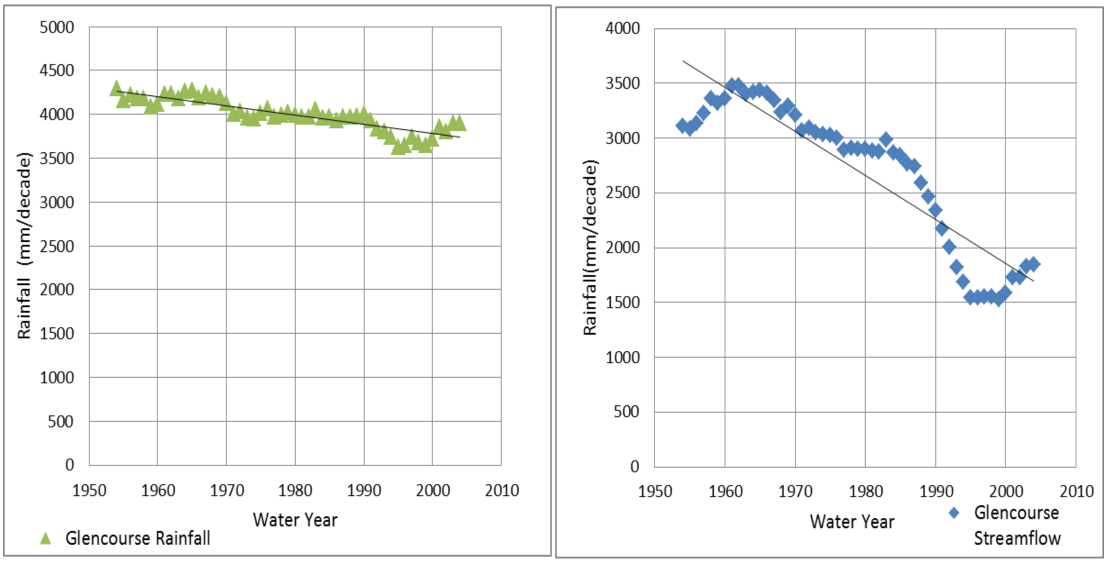


Figure C-0-4 Decadal Annual Average Catchment Rainfall and streamflow trends at Glencourse

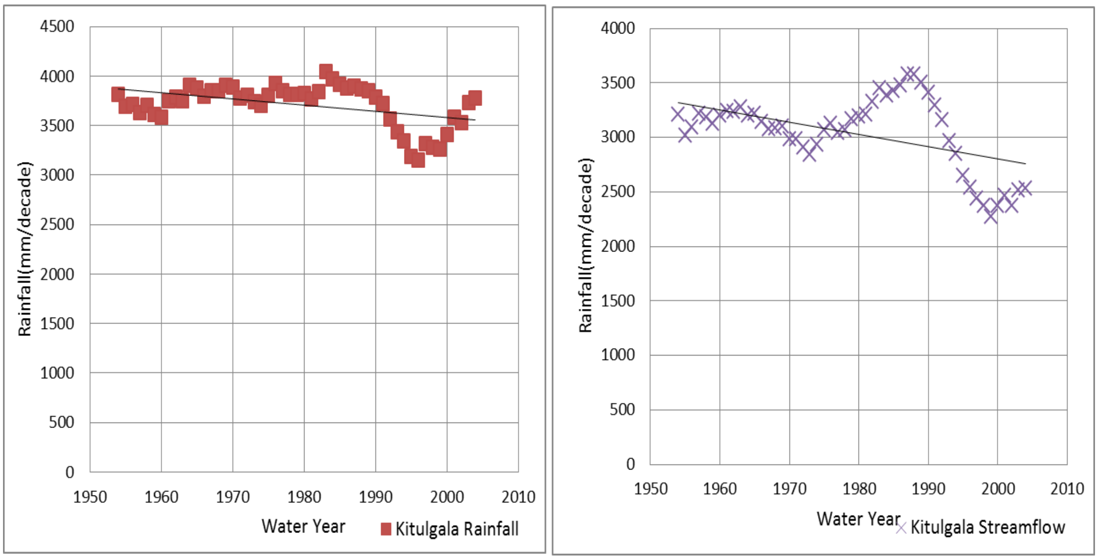


Figure C-0-5 Decadal Annual Average Catchment Rainfall and streamflow trends at Kitulgala

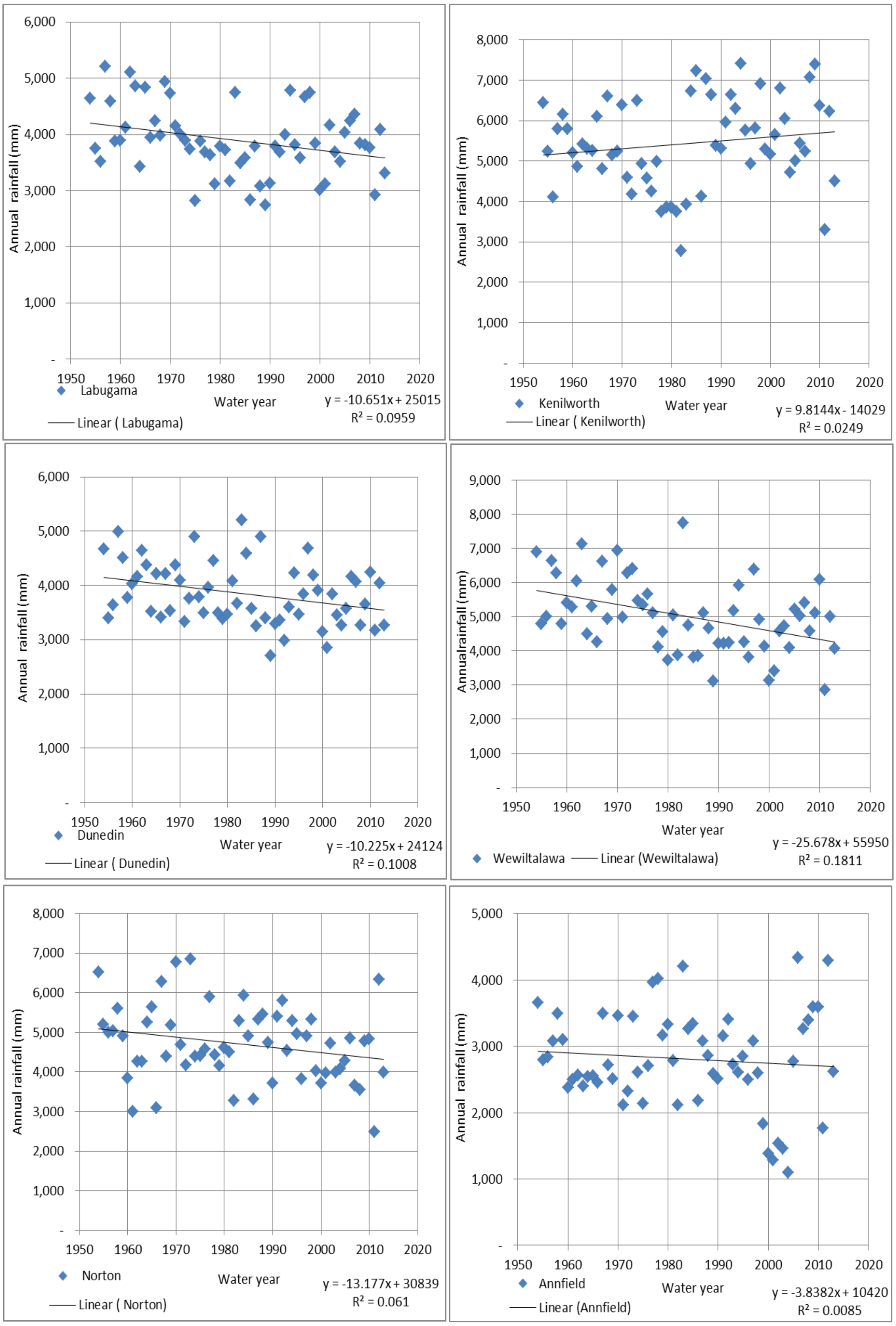


Figure C-0-6 Annual Rainfall Trends at Point rainfall stations

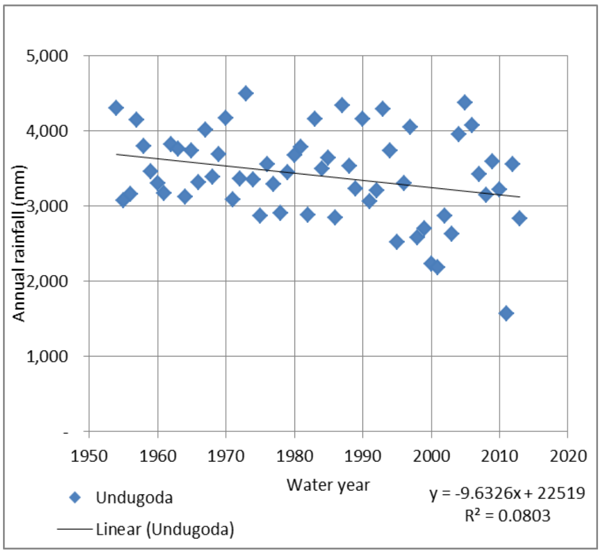


Figure C-0-7 Annual Rainfall Trends at Point rainfall stations

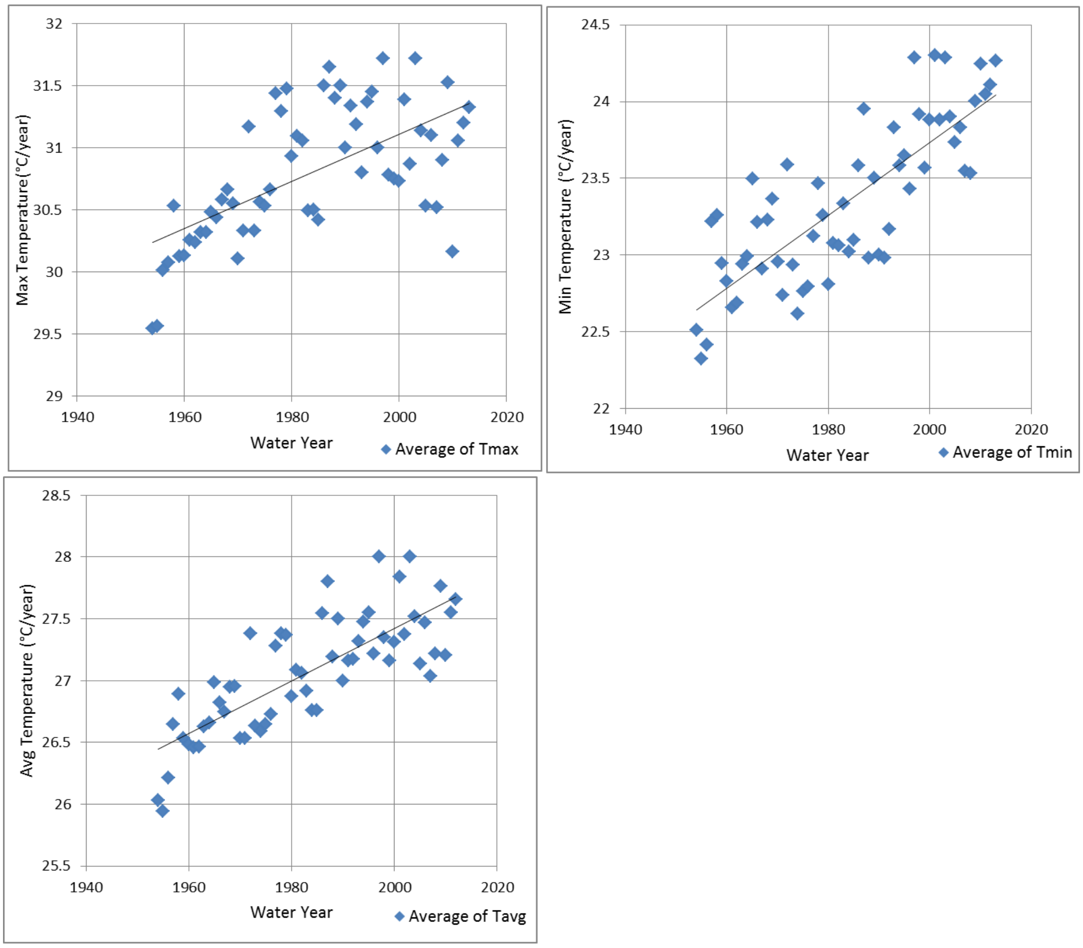
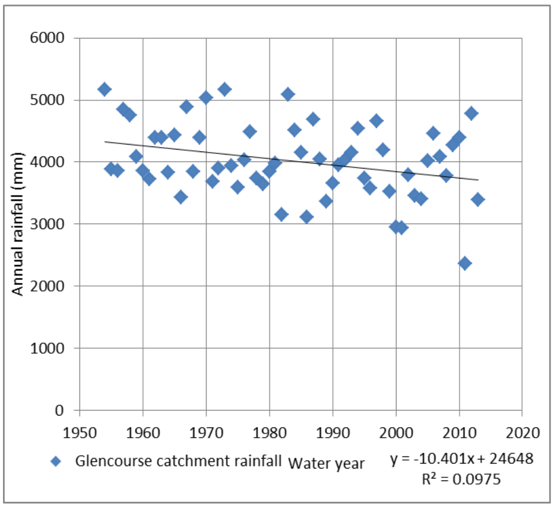


Figure C-0-8 Annual Temperature Trends (Maximum, Minimum and Average)



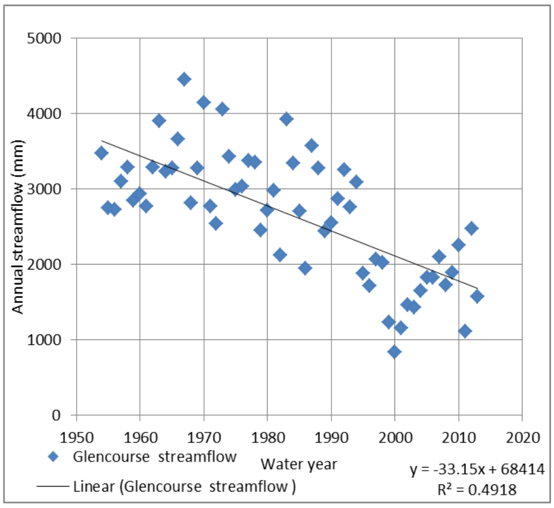
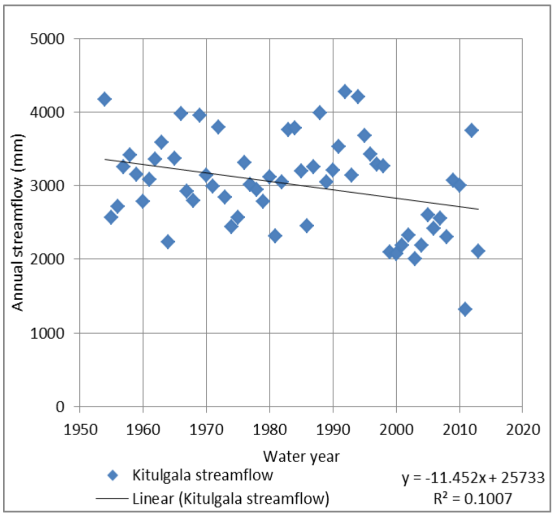


Figure C-0-9 Annual Catchment Rainfall and Streamflow Trends at Glencourse



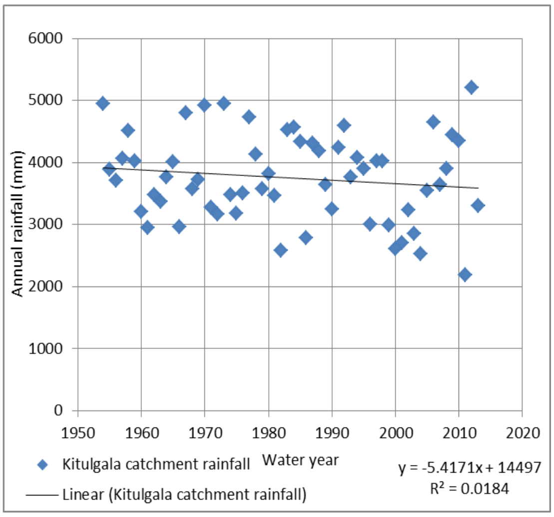


Figure C-0-10 Annual Catchment Rainfall and Streamflow Trends at Kitulgala

Decadal Monthly Trends

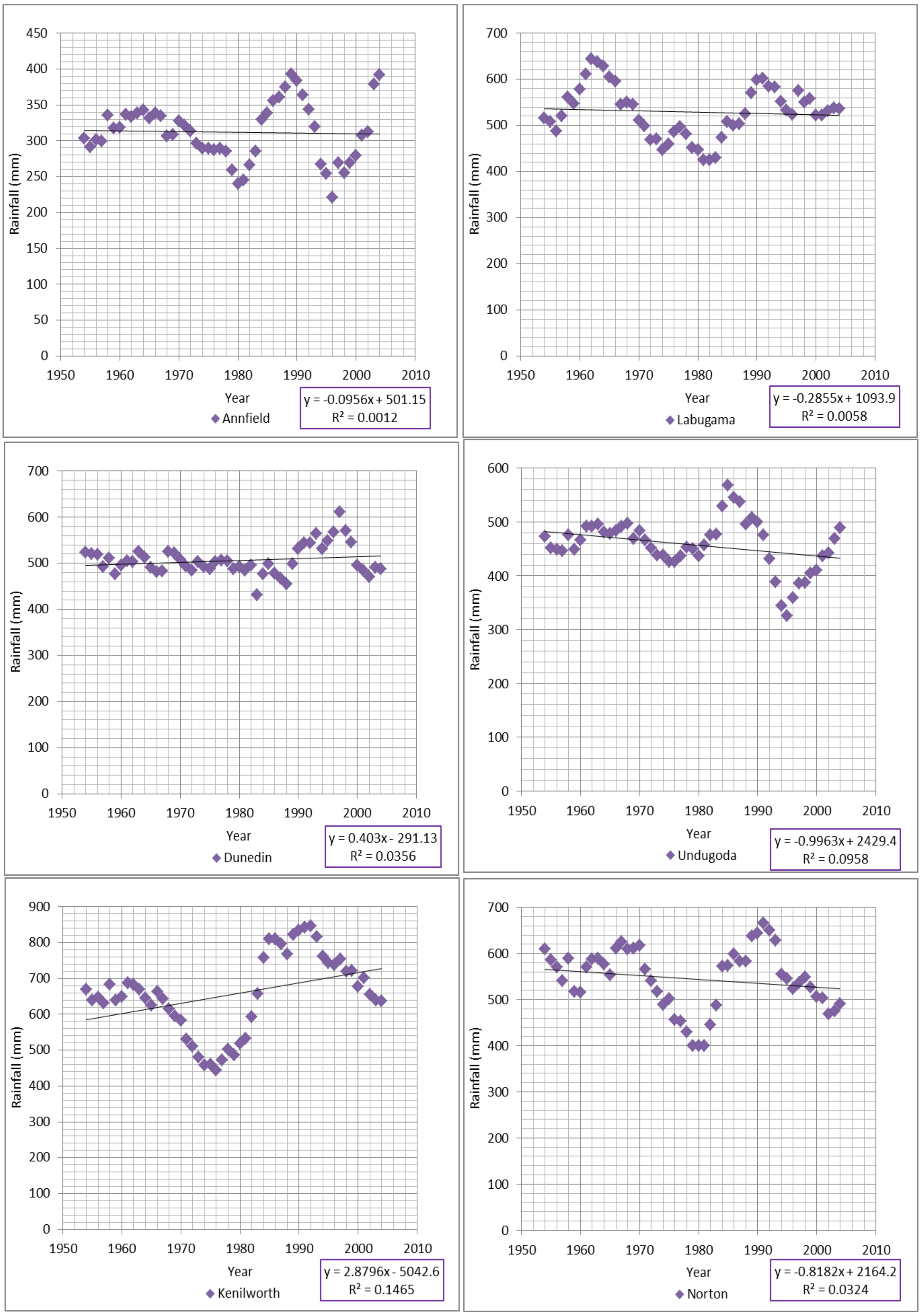


Figure C-0-11 Decadal Monthly Trends of Point Rainfall Stations (October)

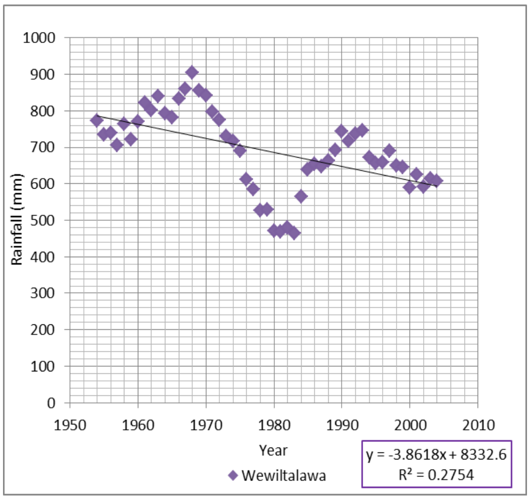
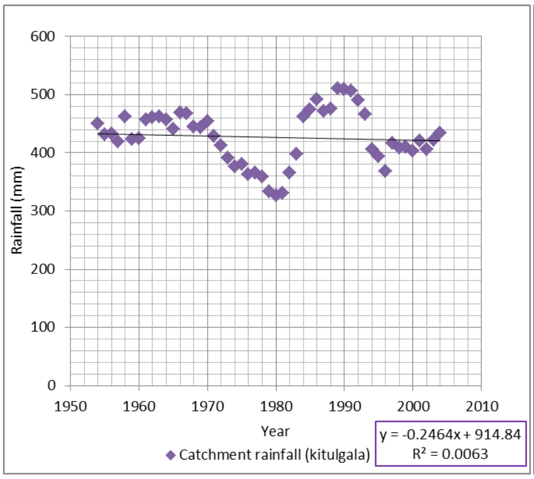


Figure C-0-12 Decadal Monthly Trends of Point Rainfall Stations (October)



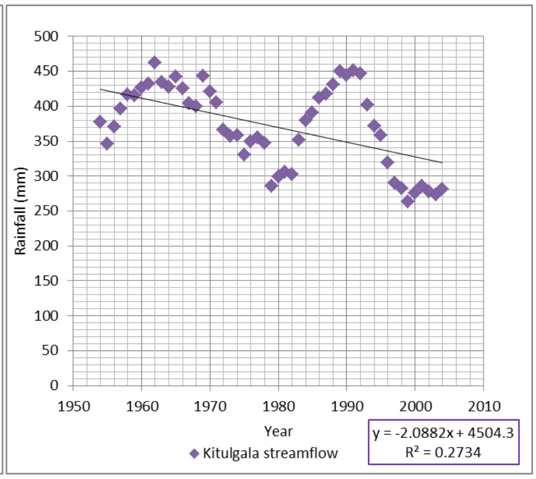
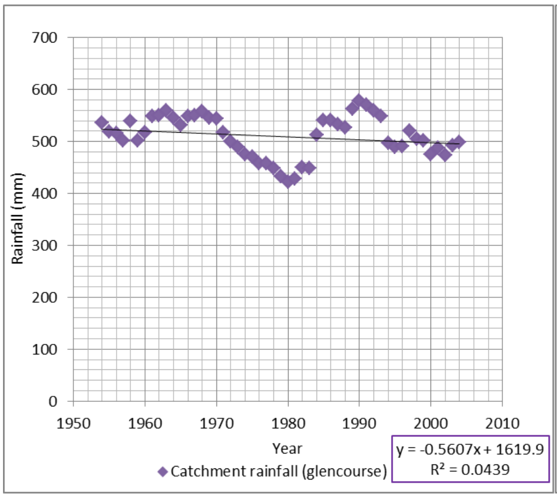


Figure C-0-13 Decadal Catchment Rainfall and streamflow trends at Kitulgala (October)



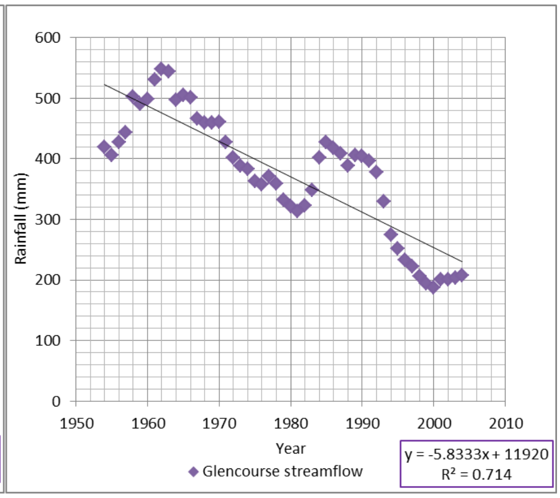


Figure C-0-14 Decadal Catchment Rainfall and streamflow trends at Glencourse (October)

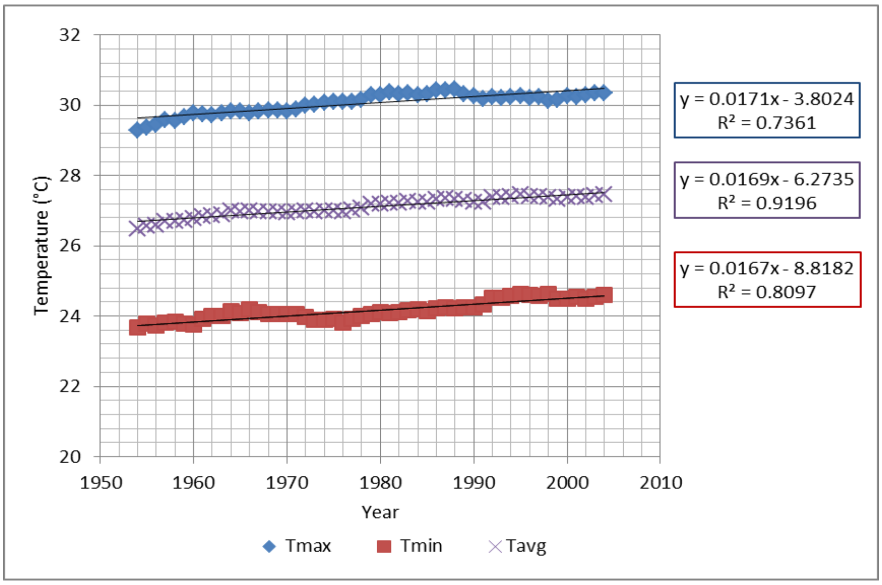


Figure C-0-15 Decadal Temperature trends, Maximum, Minimum and Average (October)

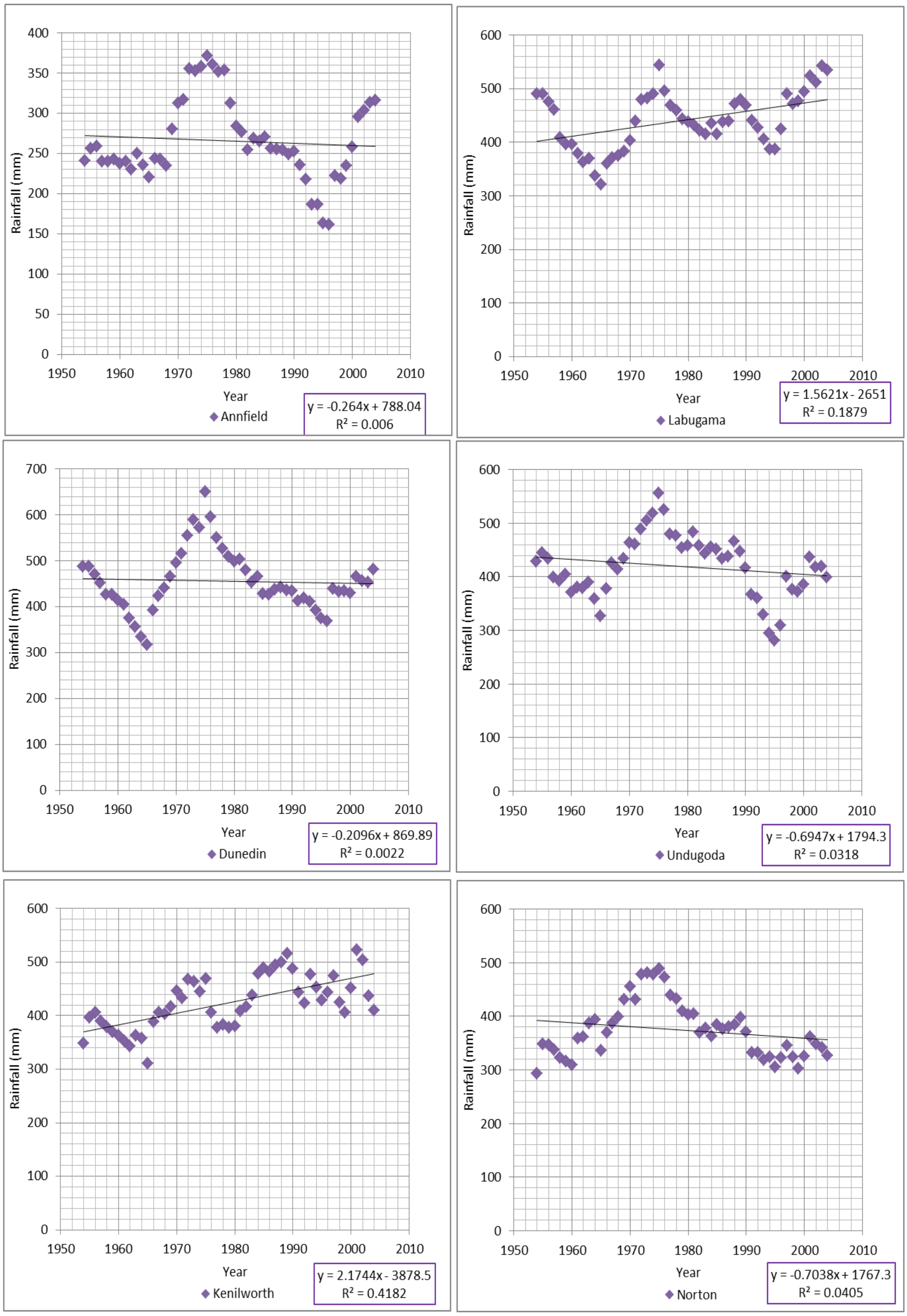


Figure C-0-16 Decadal Monthly Trends of Point Rainfall Stations (November)

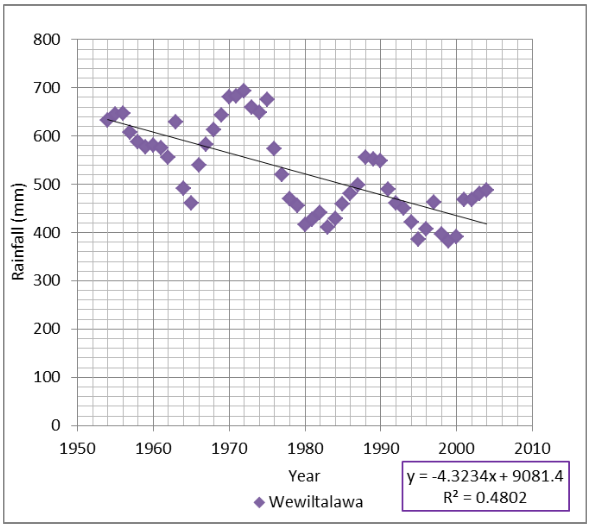


Figure C-0-17 Decadal Monthly Trends of Point Rainfall Stations (November)

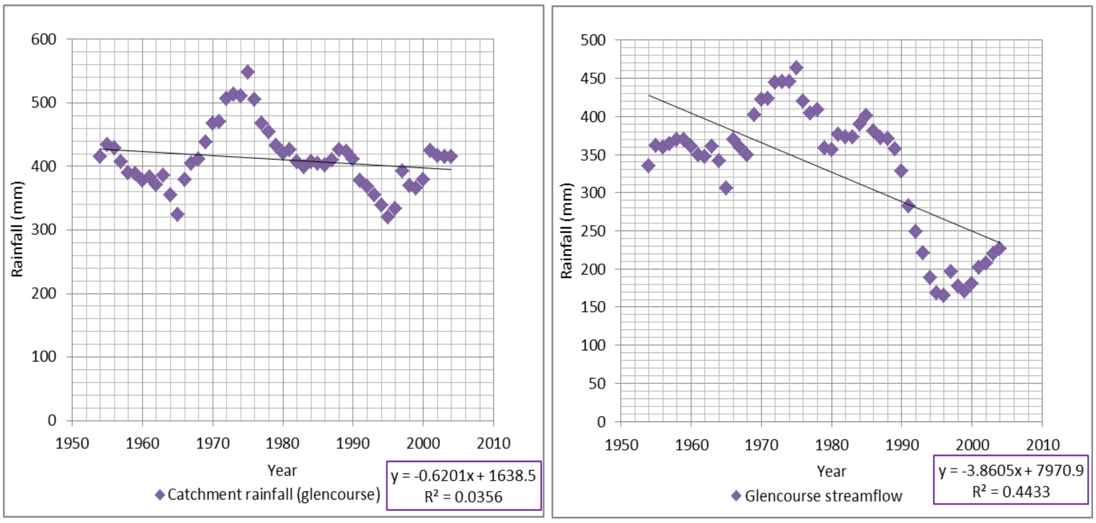


Figure C-0-18 Decadal Monthly Catchment Rainfall and streamflow trends at Glencourse (November)

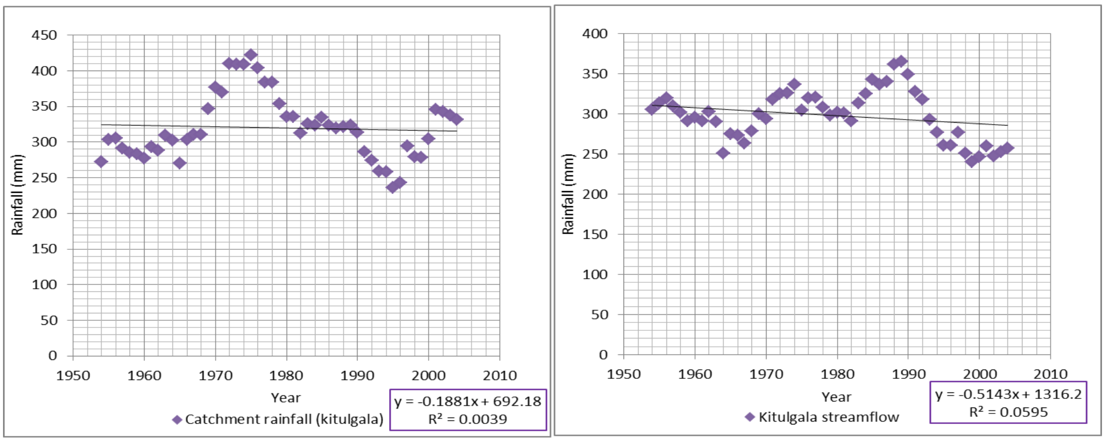


Figure C-0-19 Decadal Monthly Catchment Rainfall and streamflow trends at Kitulgala (November)

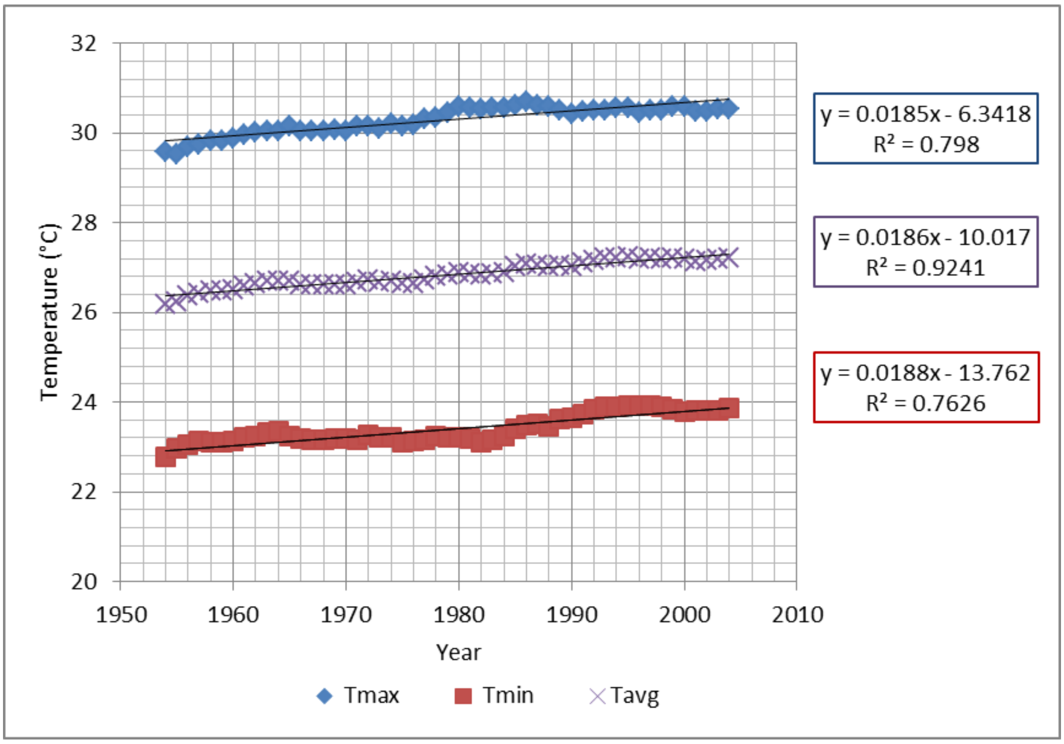


Figure C-0-20 Decadal Monthly Trends in Temperature (November)

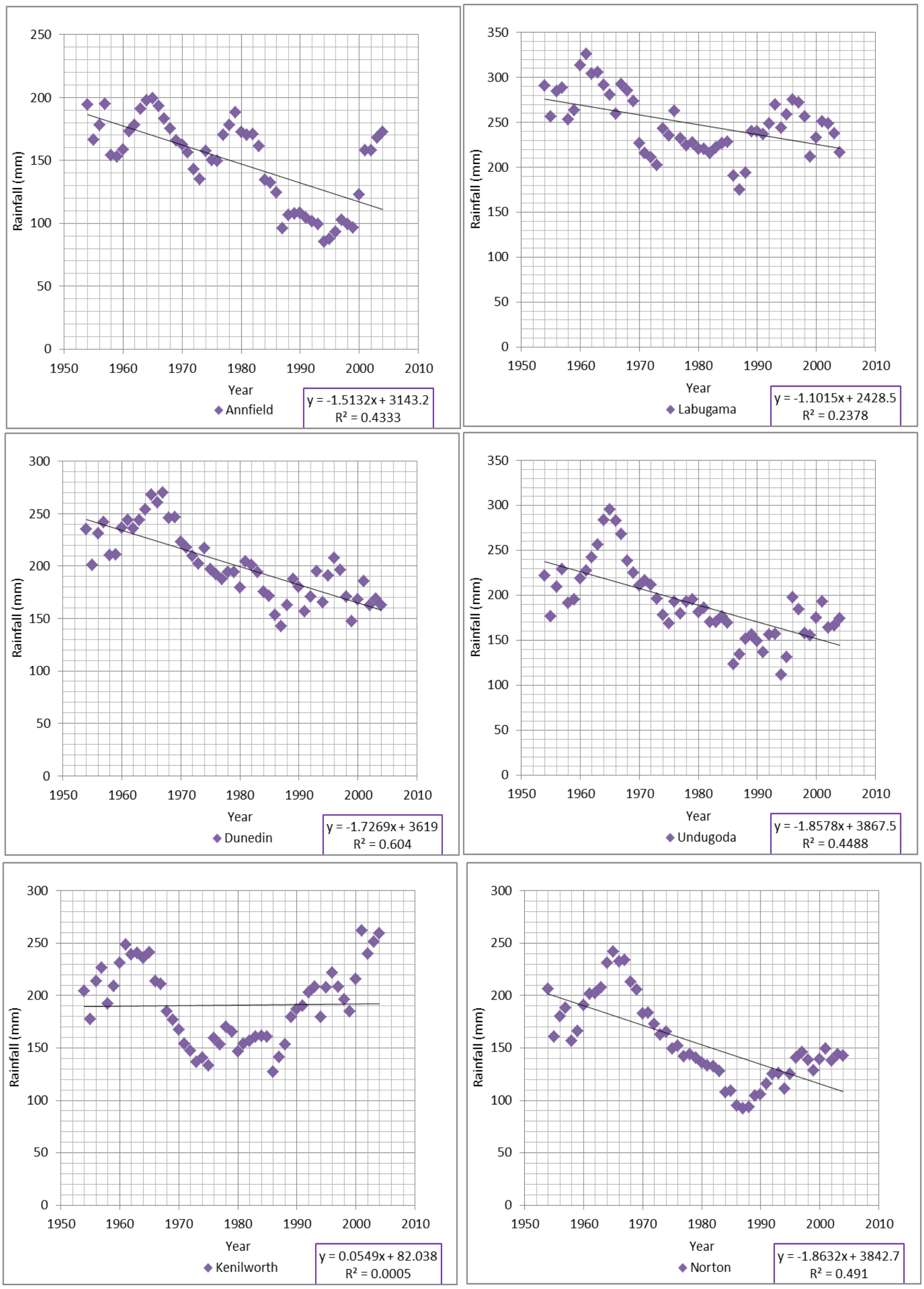


Figure C-0-21 Decadal Monthly Trends of Point Rainfall Stations (December)

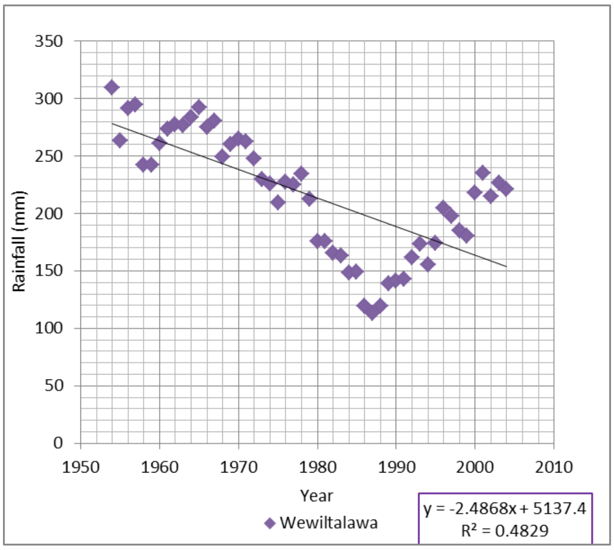


Figure C-0-22 Decadal Monthly Trends of Point Rainfall Stations (December)

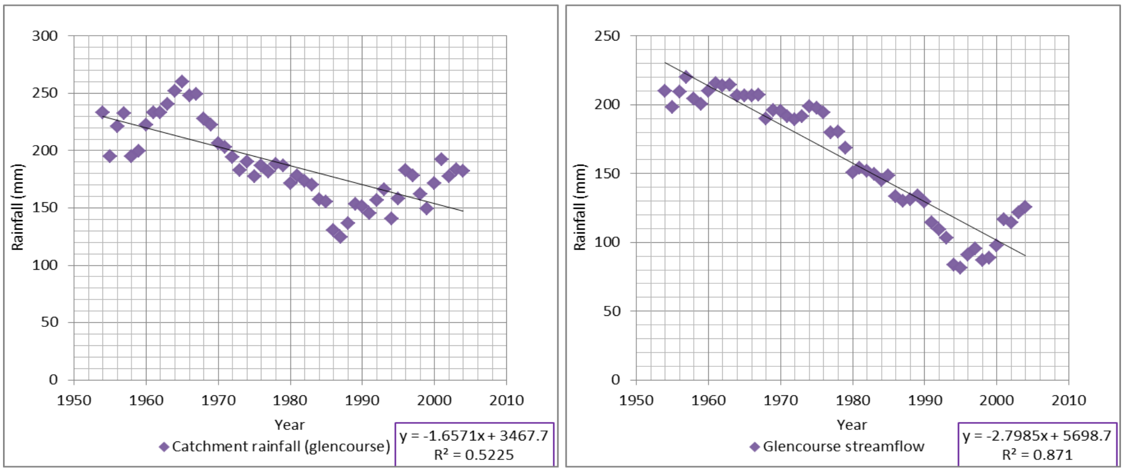


Figure C-0-23 Decadal Monthly Catchment Rainfall and streamflow trends at Glencourse (December)

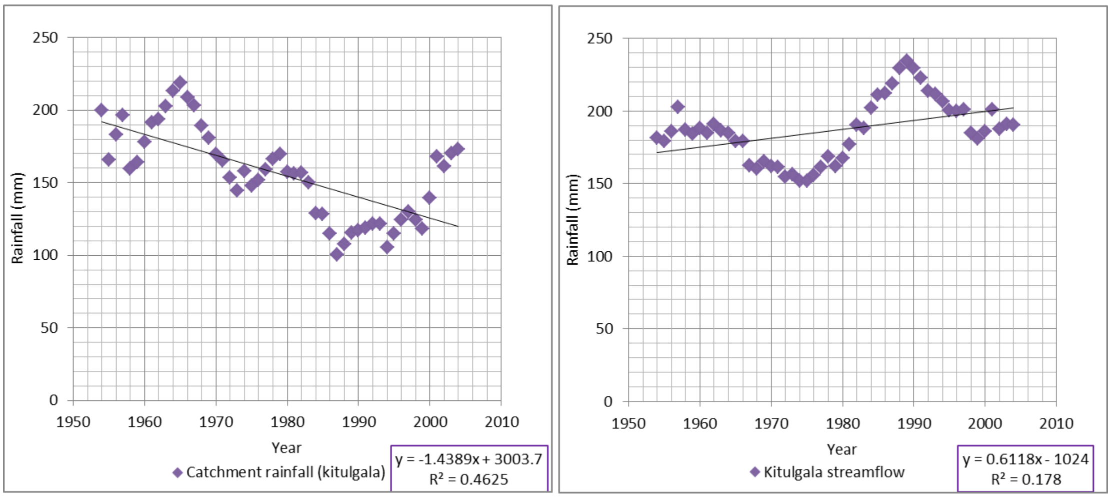


Figure C-0-24 Decadal Monthly Catchment Rainfall and streamflow trends at Kitulgala (December)

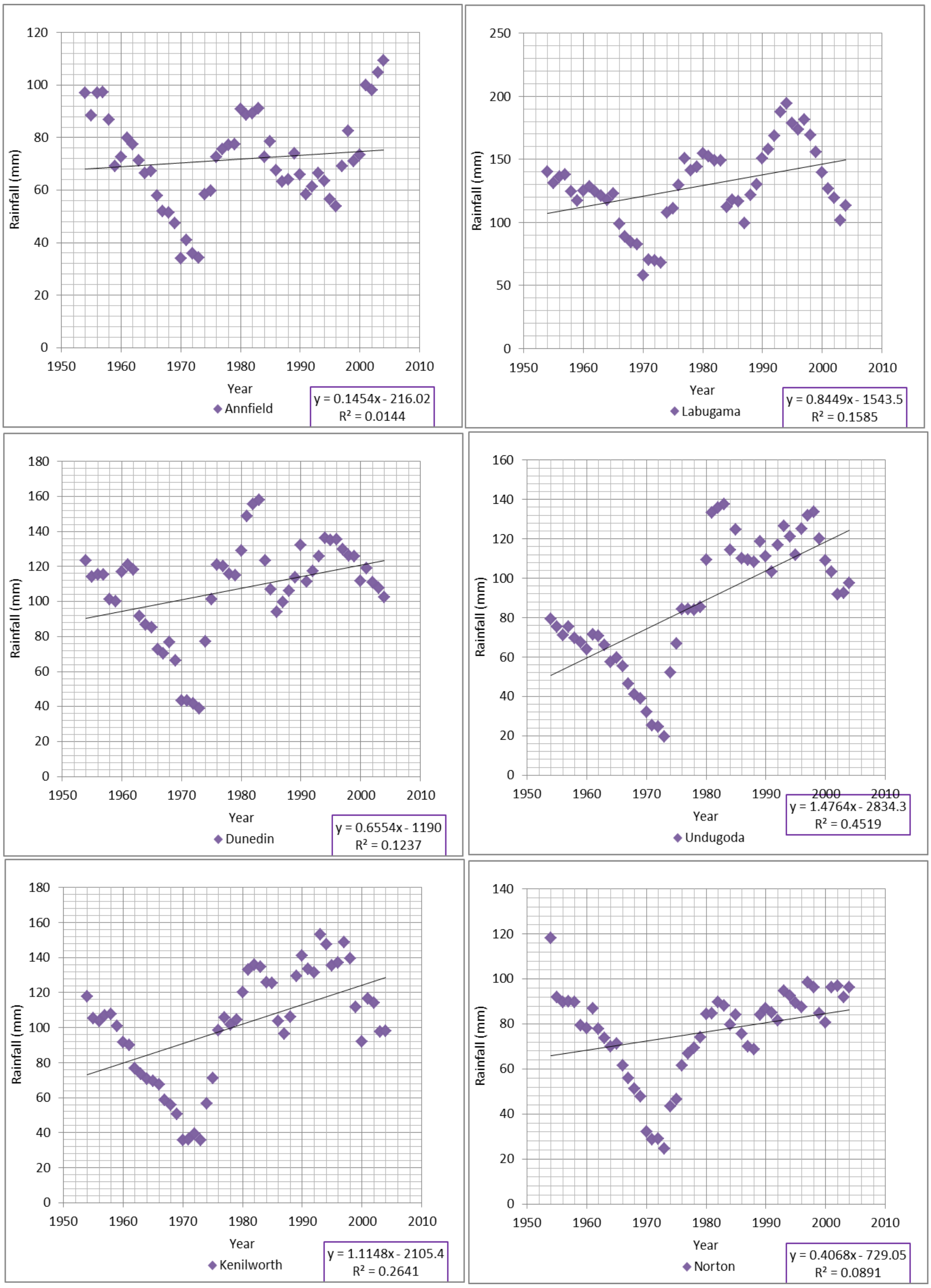


Figure C-0-25 Decadal Monthly Trends of Point Rainfall Stations (January)

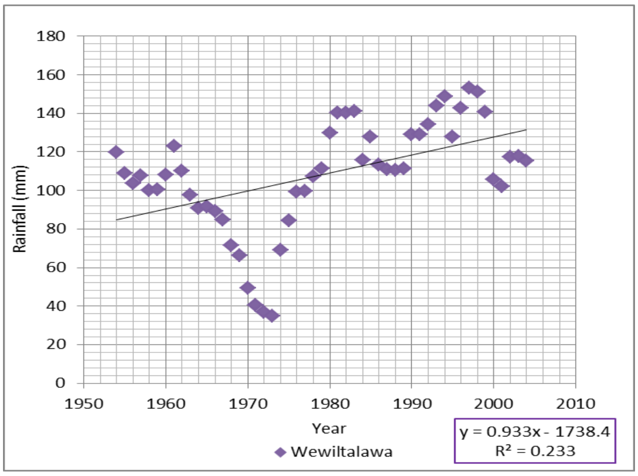


Figure C-0-26 Decadal Monthly Trends of Point Rainfall Stations (January)

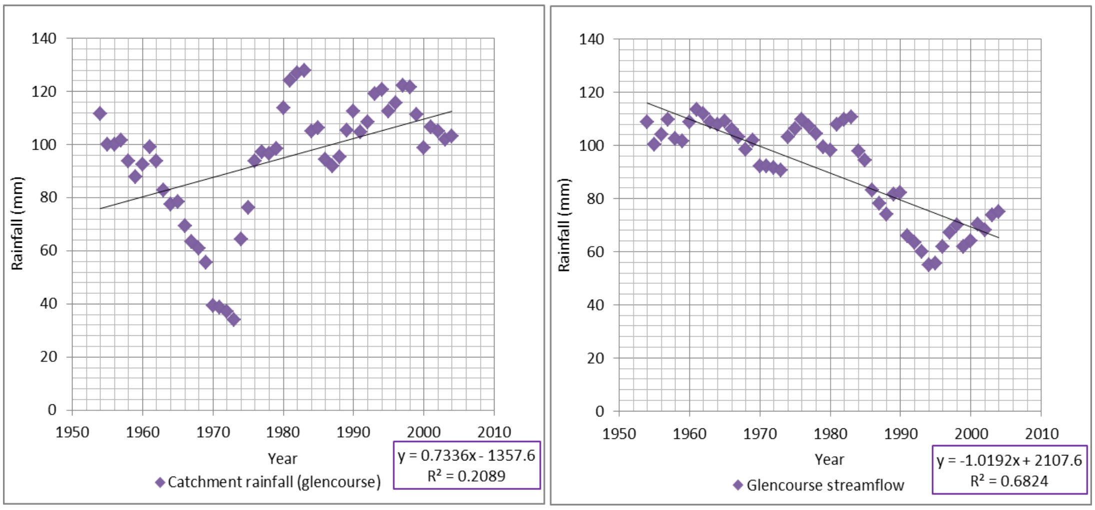


Figure C-0-27 Decadal monthly catchment rainfall and streamflow trends at Glencourse (January)

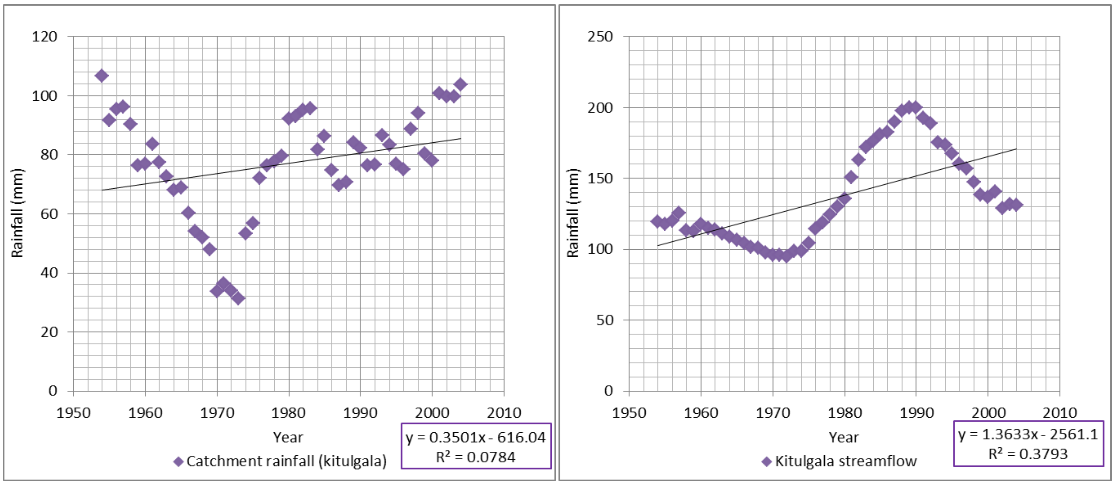


Figure C-0-28 Decadal monthly catchment rainfall and streamflow trends at Kitulgala (January)

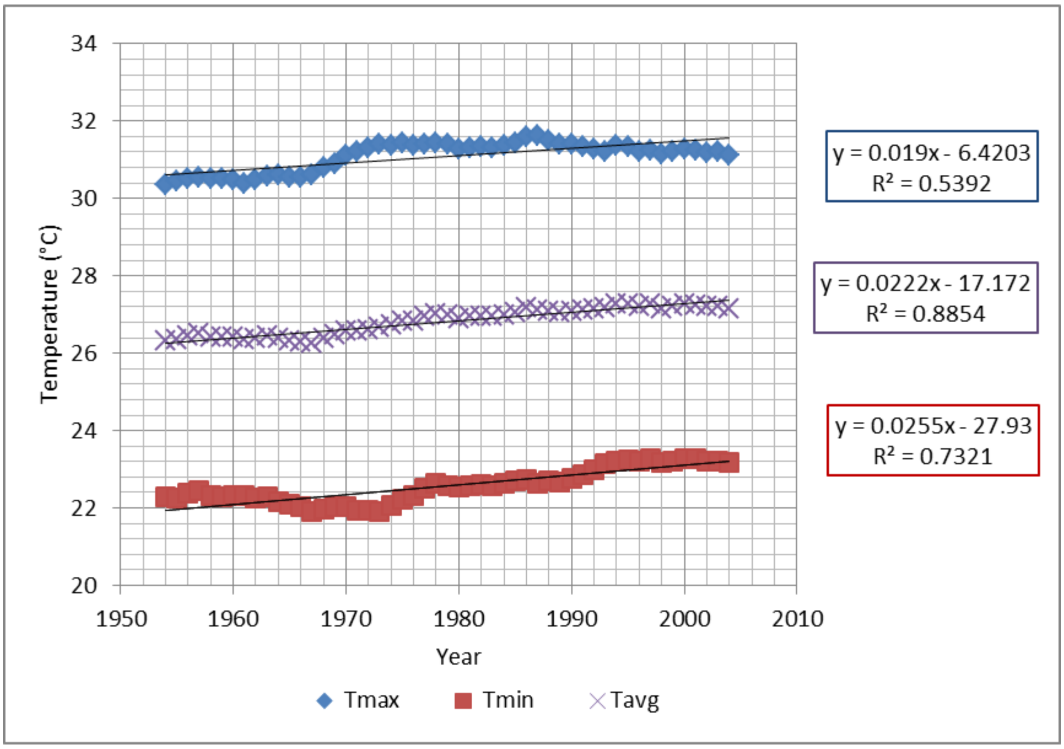


Figure C-0-29 Decadal monthly temperature trends (January)

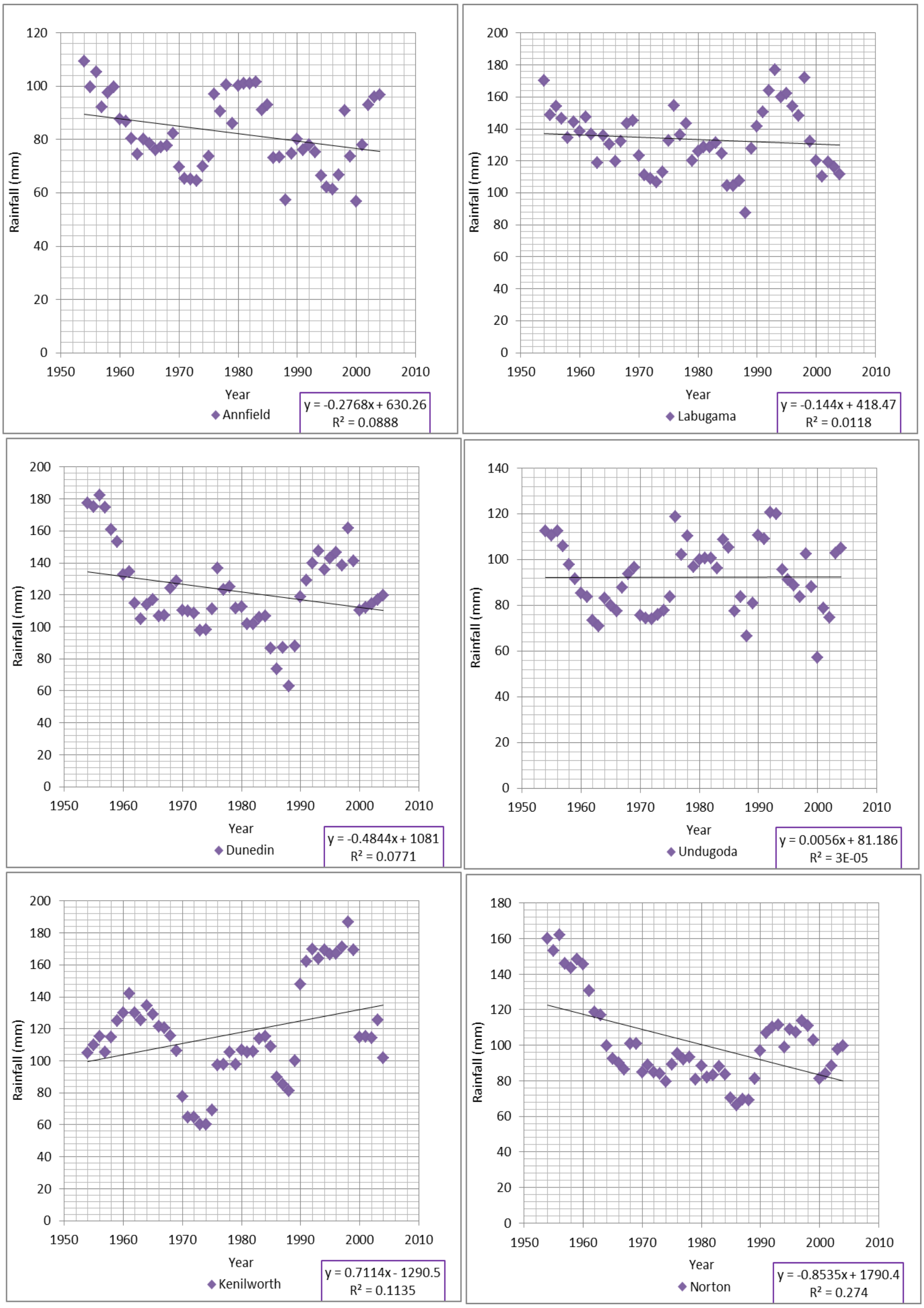


Figure C-0-30 Decadal Monthly Trends of Point Rainfall Stations (February)

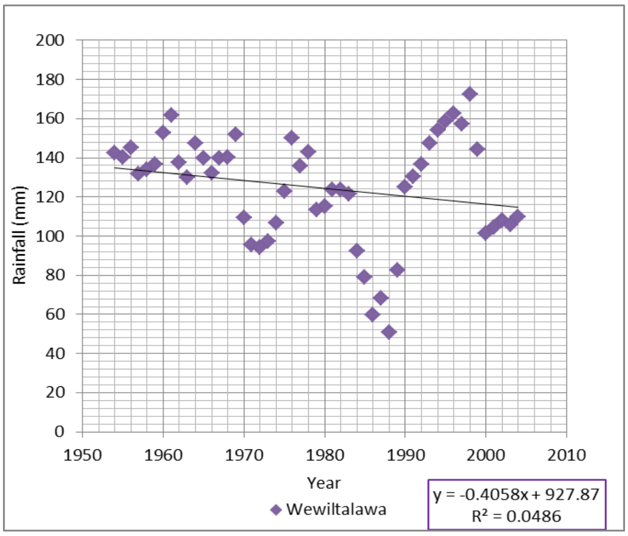
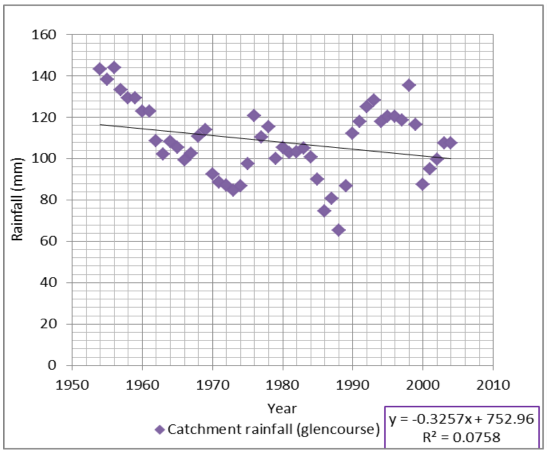


Figure C-0-31 Decadal Monthly Trends of Point Rainfall Stations (February)



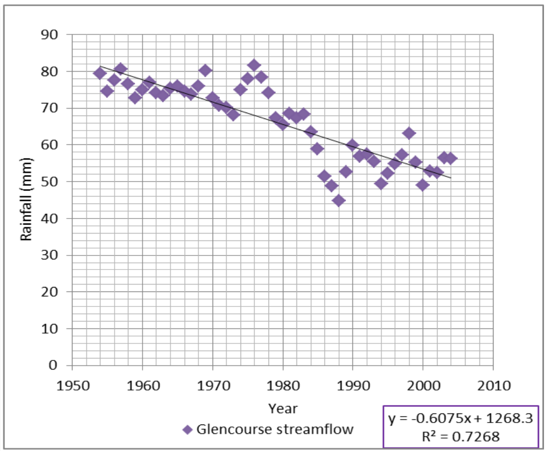
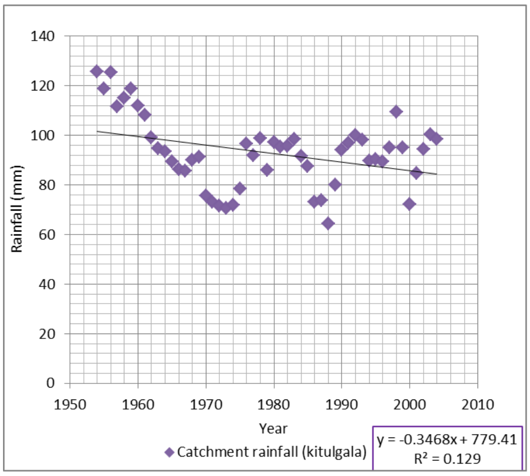


Figure C-0-32 Decadal monthly catchment rainfall and streamflow trends at Glencourse (February)



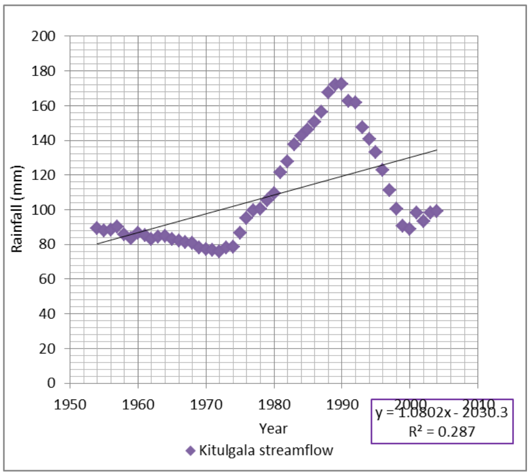


Figure C-0-33 Decadal monthly catchment rainfall and streamflow trends at Kitulgala (February)

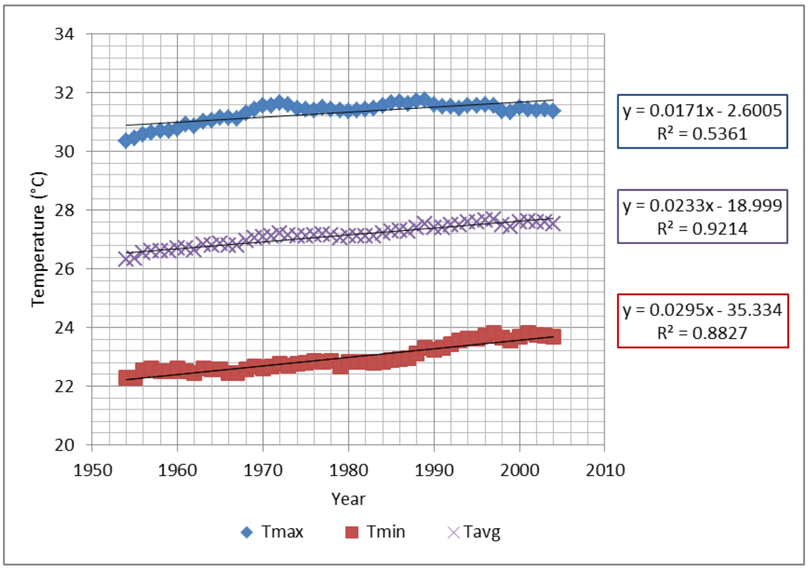


Figure C-0-34 Decadal monthly temperature trends (February)

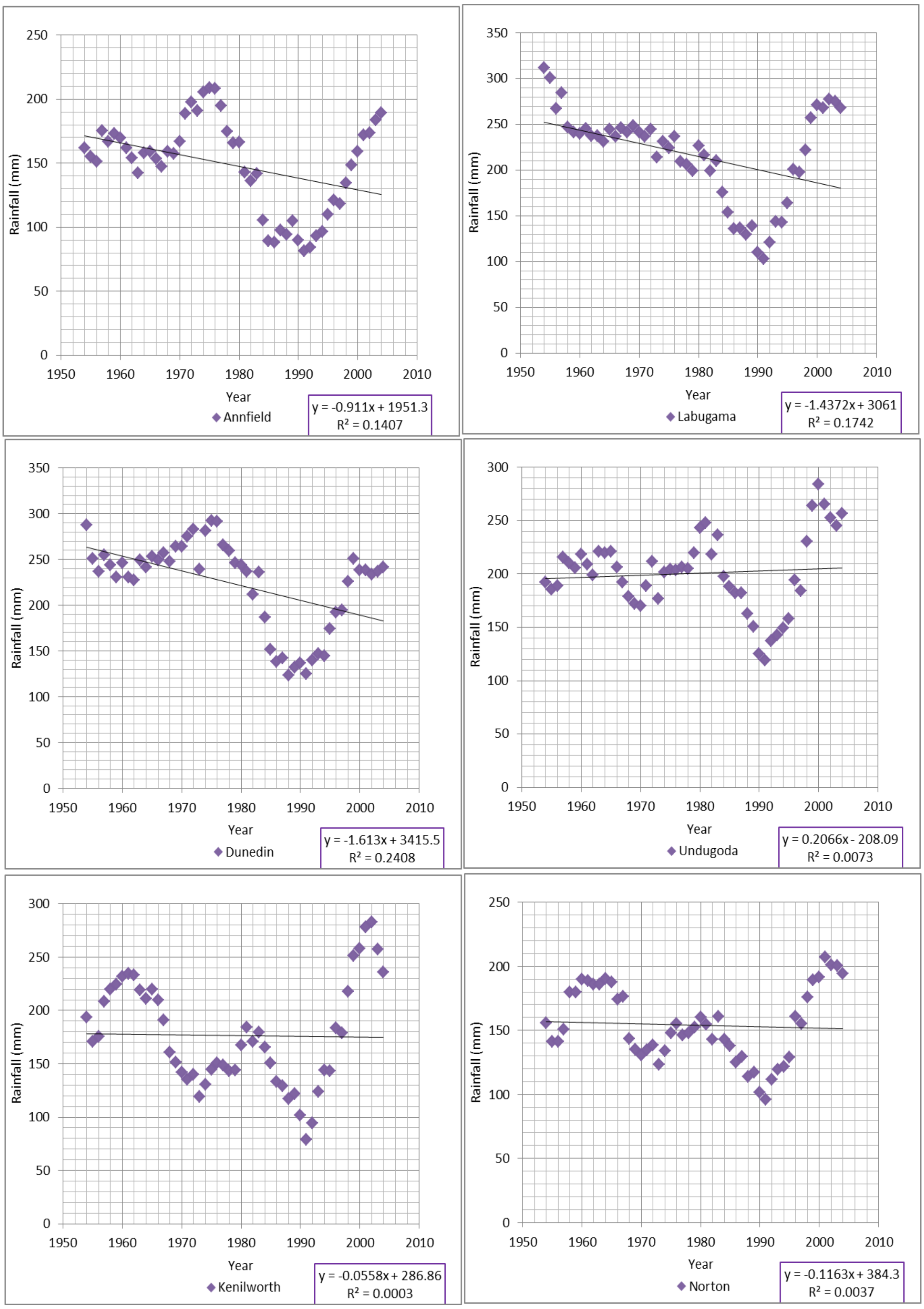


Figure C-0-35 Decadal Monthly Trends of Point Rainfall Stations (March)

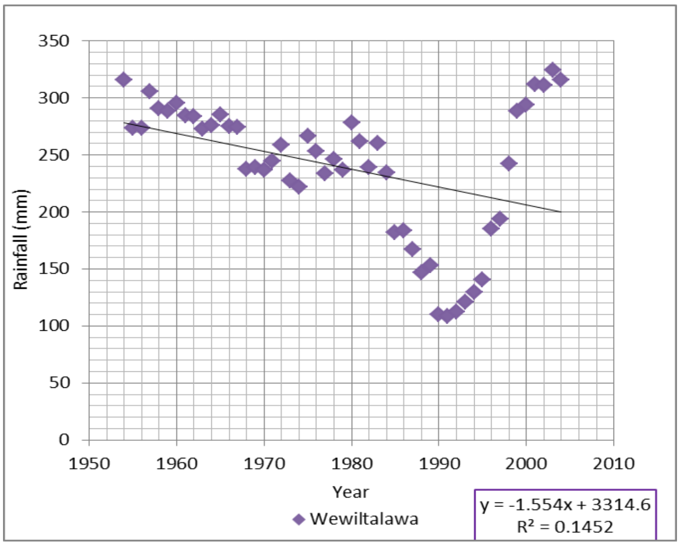


Figure C-0-36 Decadal Monthly Trends of Point Rainfall Stations (March)

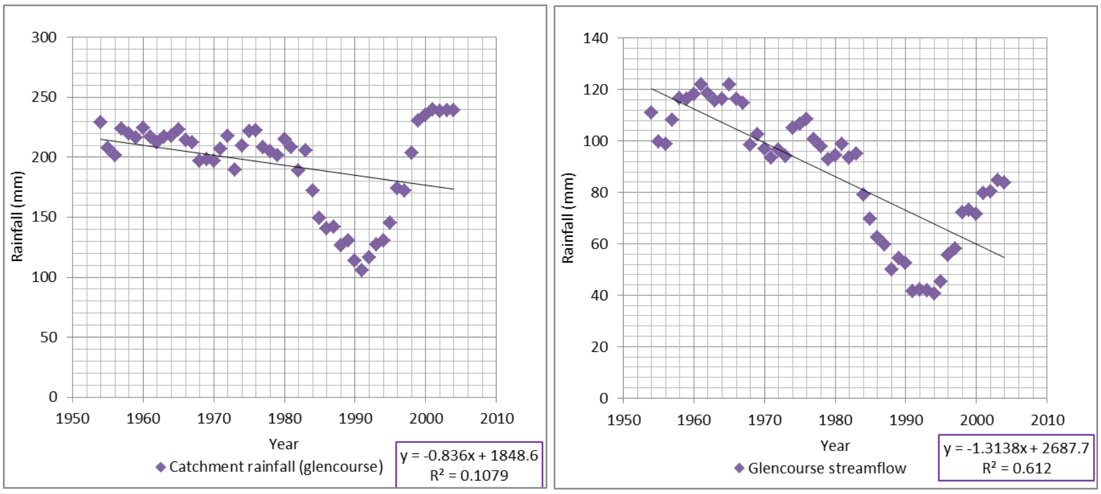


Figure C-0-37 Decadal monthly catchment rainfall and streamflow trends at Glencourse (March)

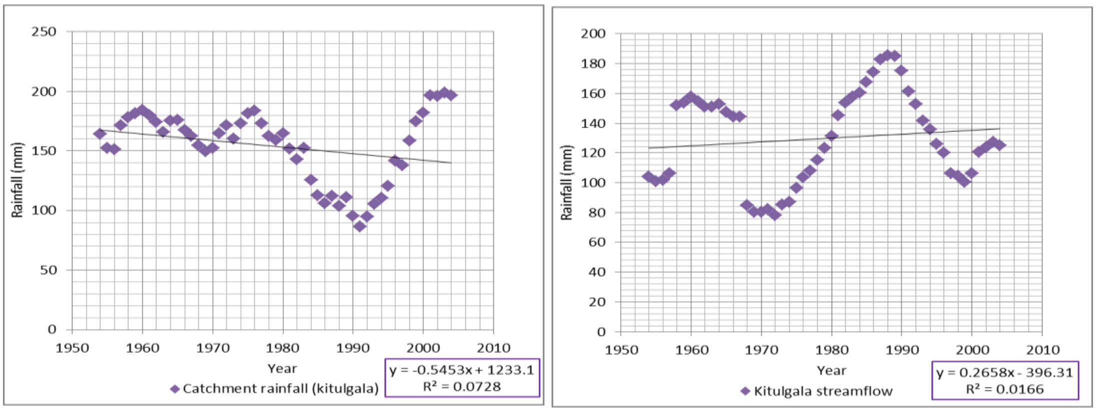


Figure C-0-38 Decadal monthly catchment rainfall and streamflow trends at Kitulgala (March)

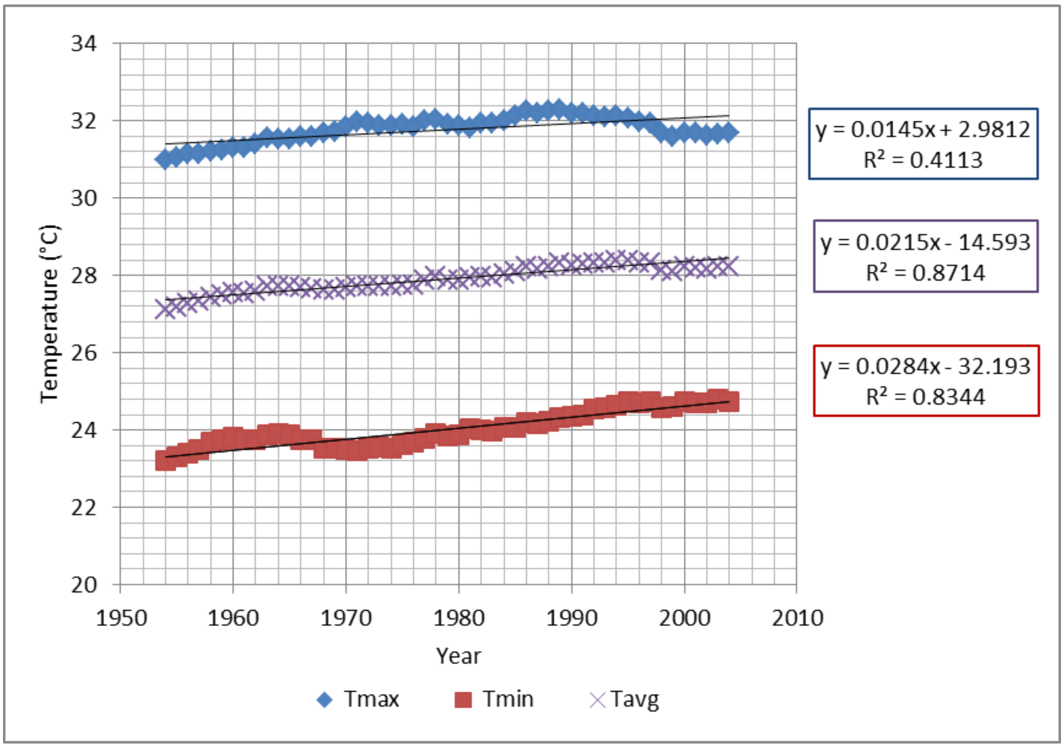


Figure C-0-39 Decadal monthly temperature trends (March)

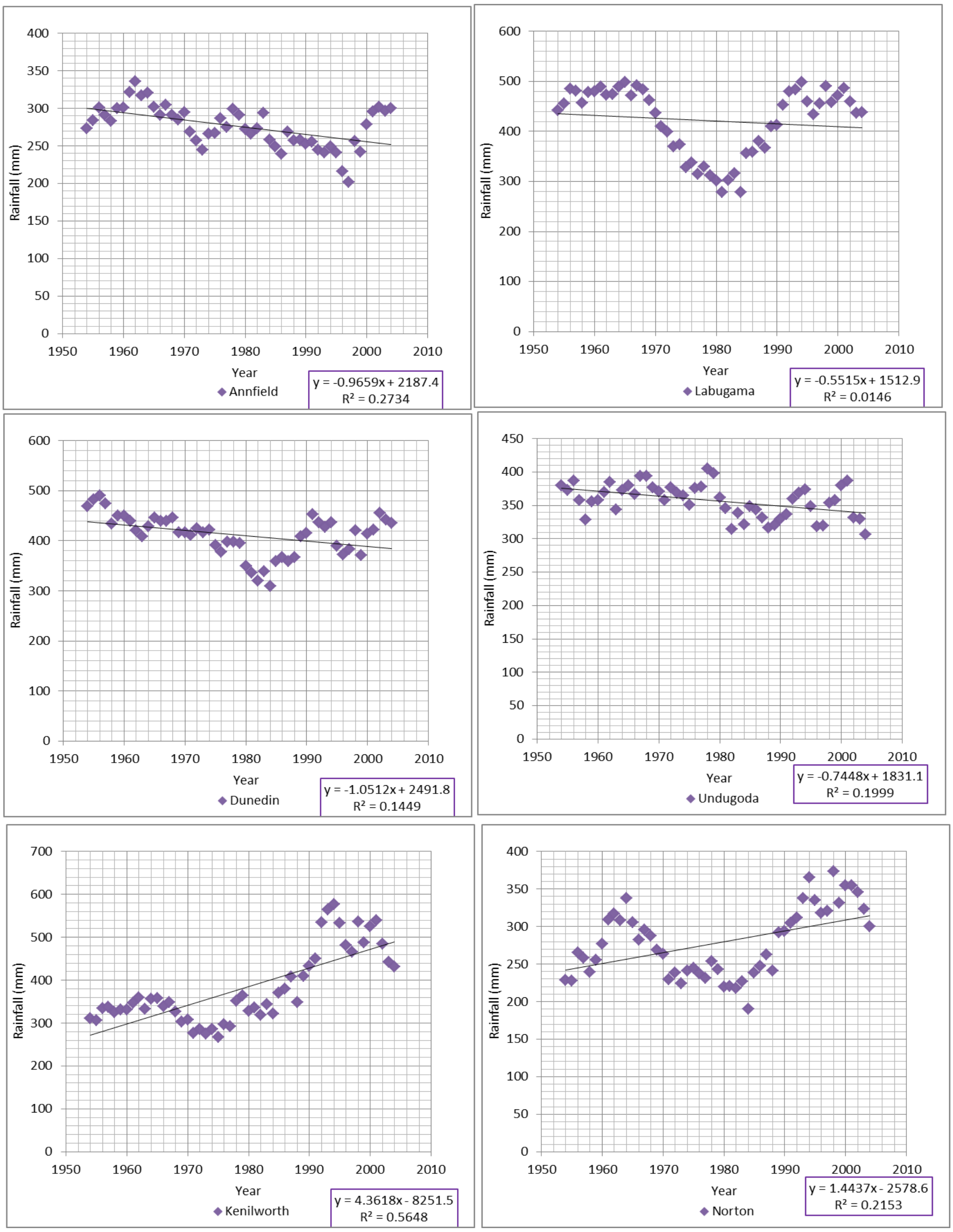


Figure C-0-40 Decadal Monthly Trends of Point Rainfall Stations (April)

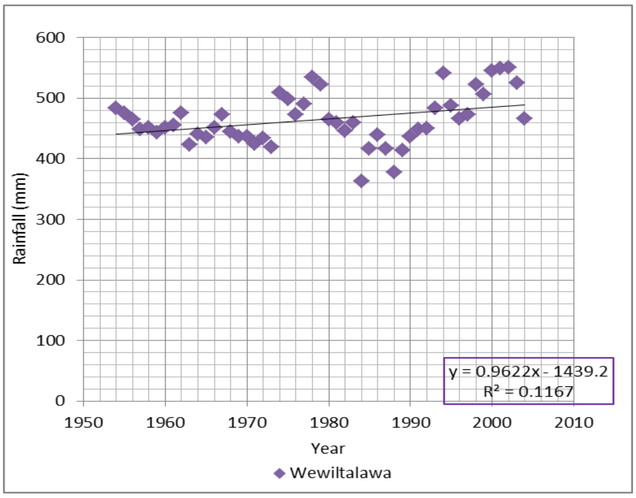
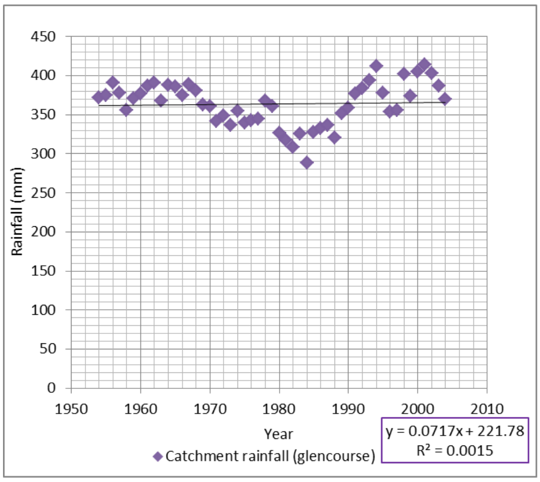


Figure C-0-41 Decadal Monthly Trends of Point Rainfall Stations (April)



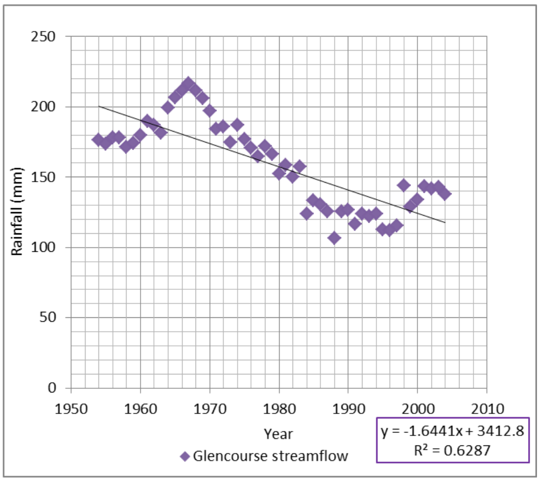
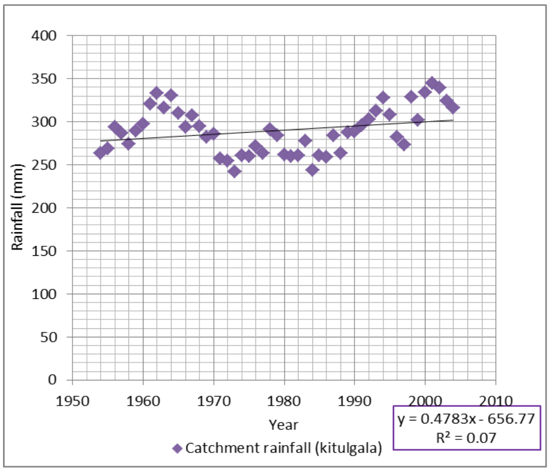


Figure C-0-42 Decadal monthly catchment rainfall and streamflow trends at Glencourse (April)



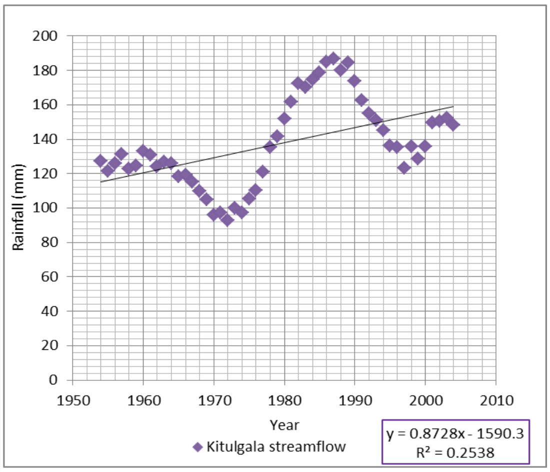


Figure C-0-43 Decadal monthly catchment rainfall and streamflow trends at Kitulgala (April)

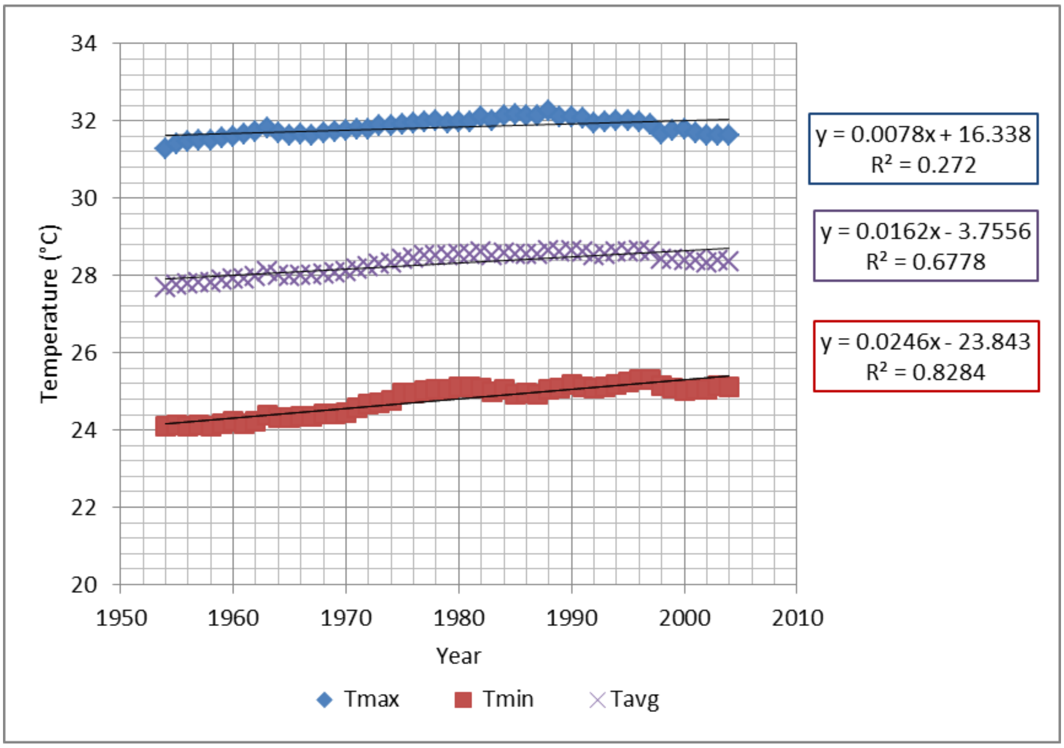


Figure C-0-44 Decadal monthly temperature (April)

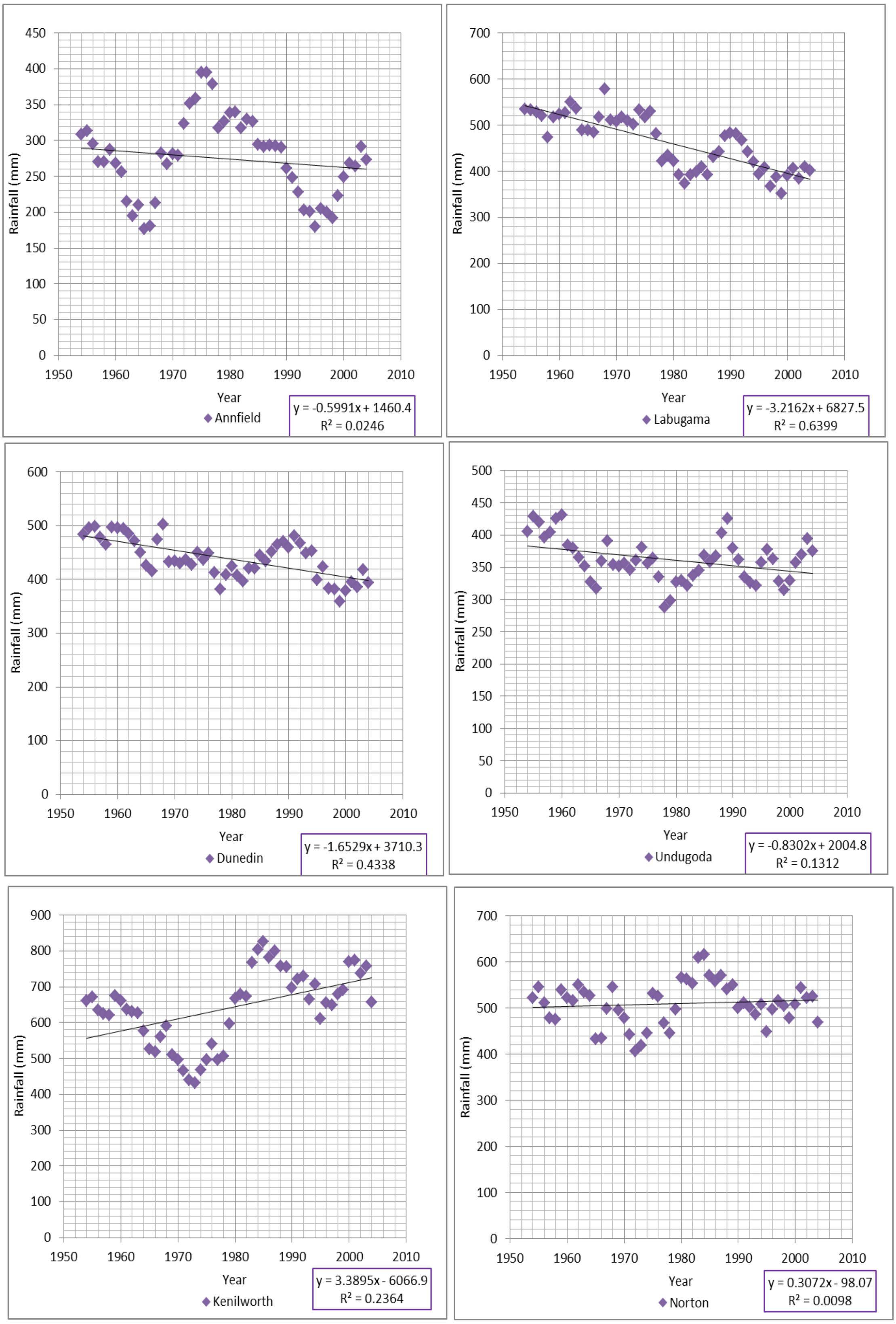


Figure C-0-45 Decadal Monthly Trends of Point Rainfall Stations (May)

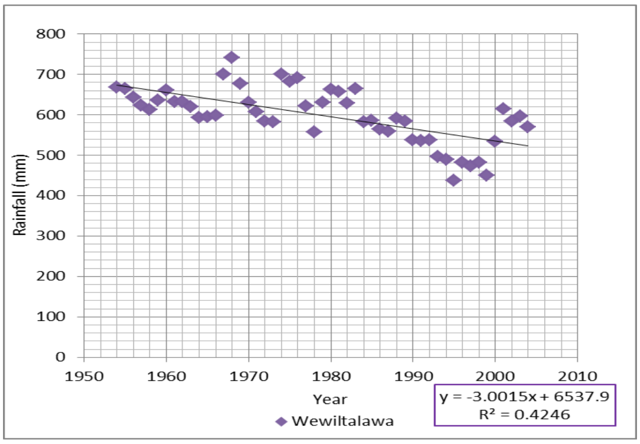
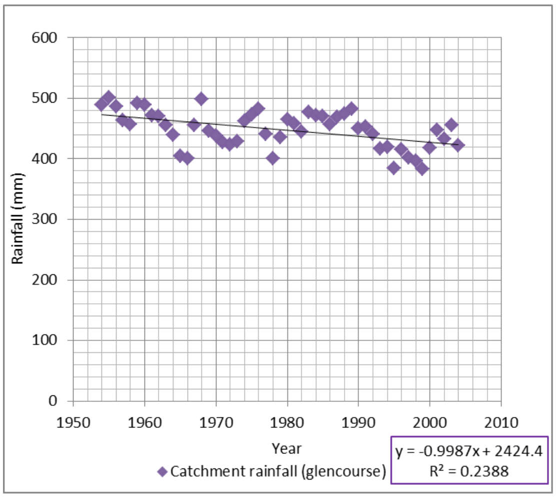


Figure C-0-46 Decadal Monthly Trends of Point Rainfall Stations (May)



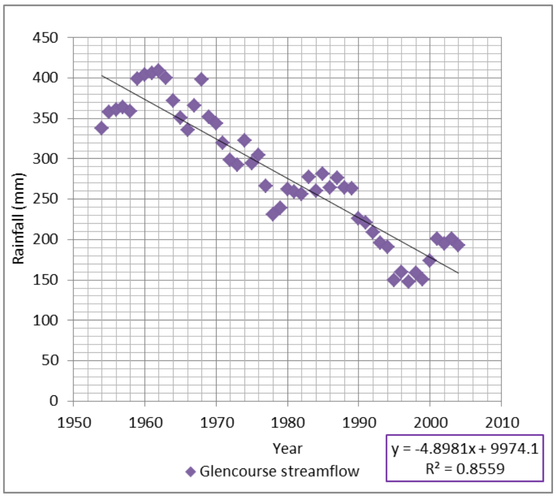
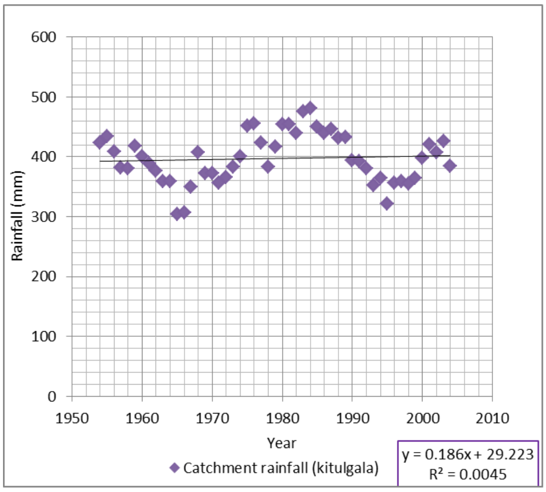


Figure C-0-47 Decadal monthly catchment rainfall and streamflow trends at Glencourse (May)



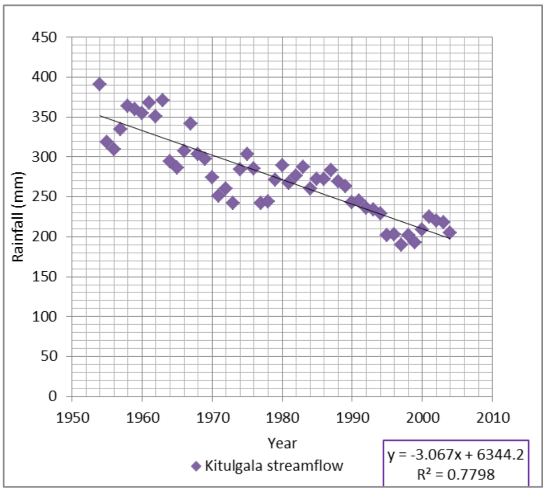


Figure C-0-48 Decadal monthly catchment rainfall and streamflow trends at Kitulgala (May)

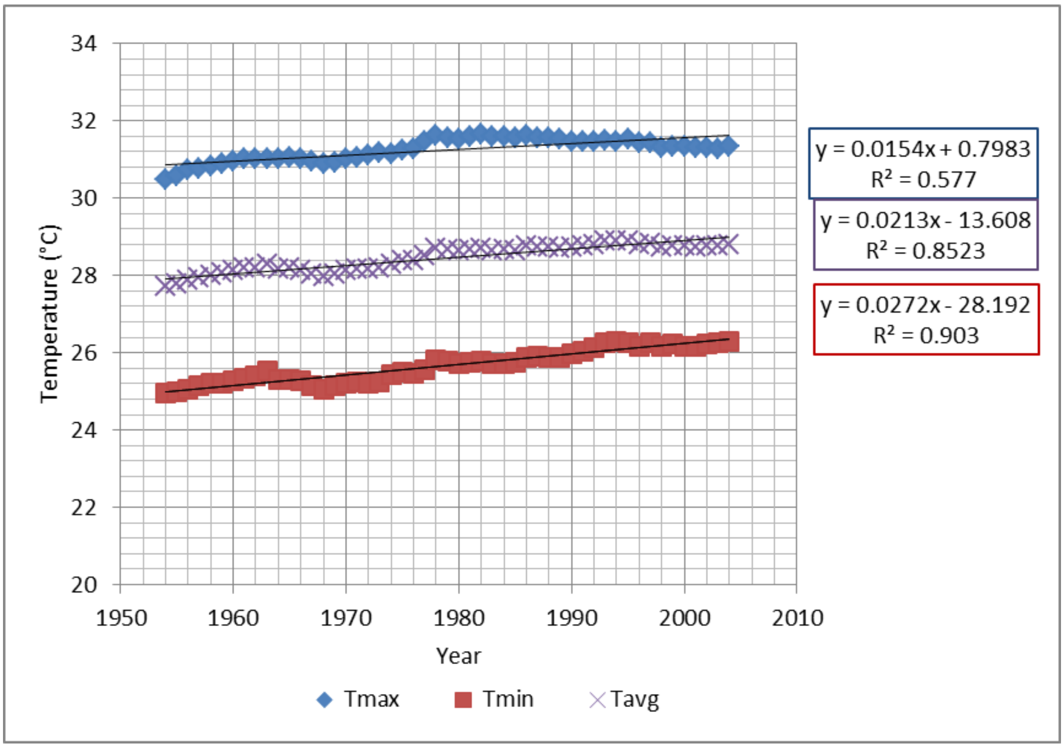


Figure C-0-49 Decadal monthly temperature trends (May)

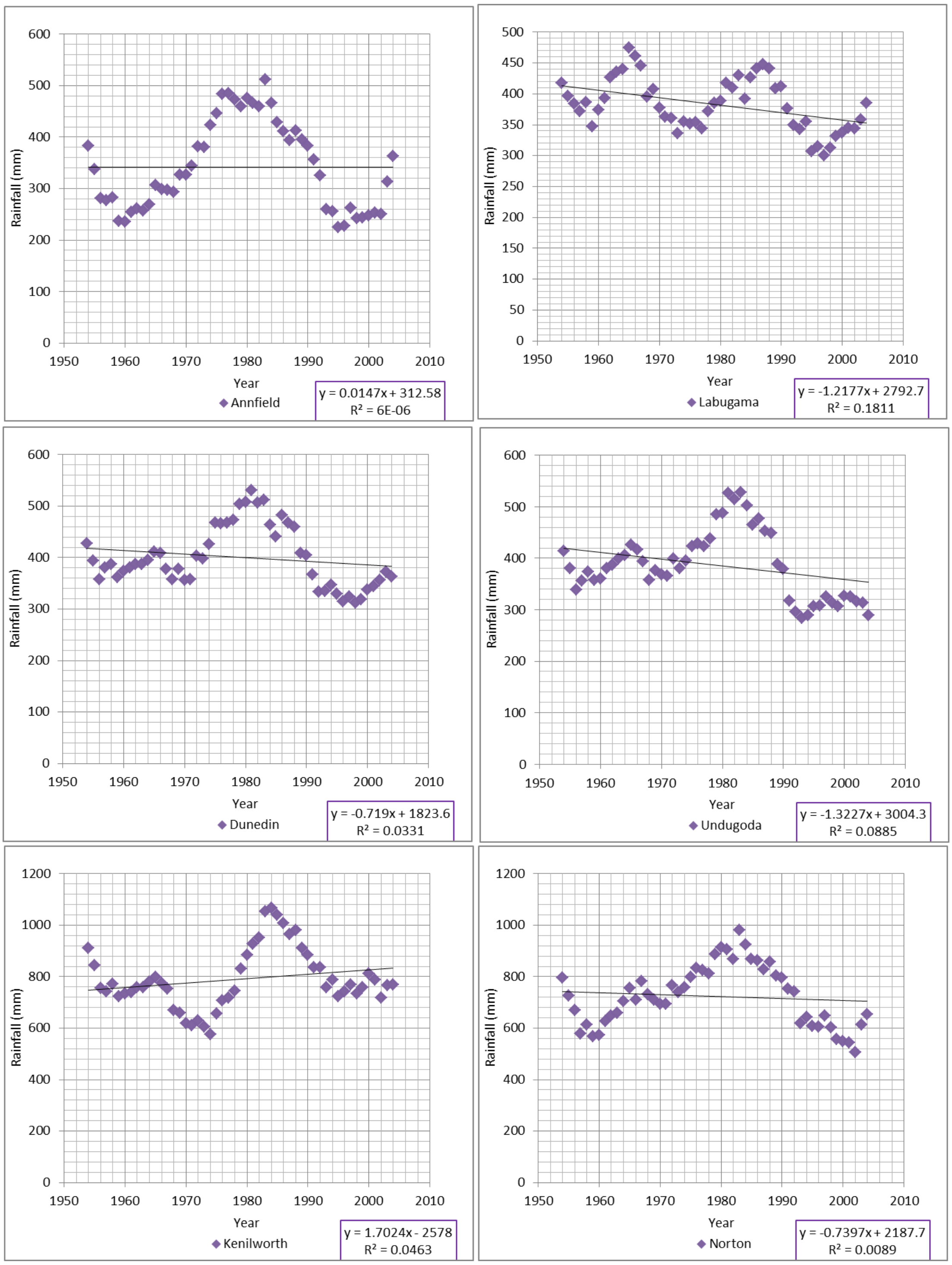


Figure C-0-50 Decadal Monthly Trends of Point Rainfall Stations (June)

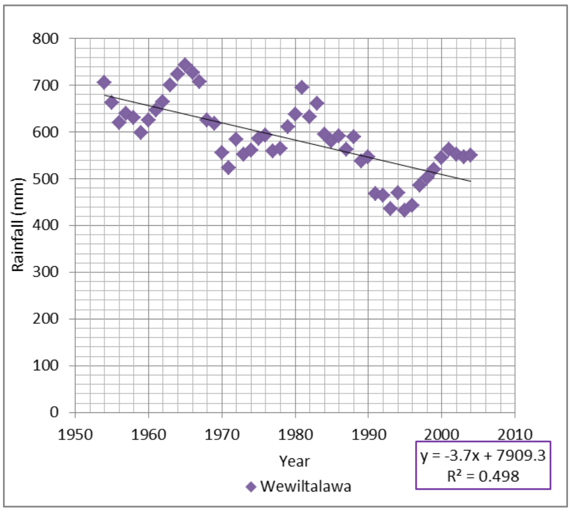
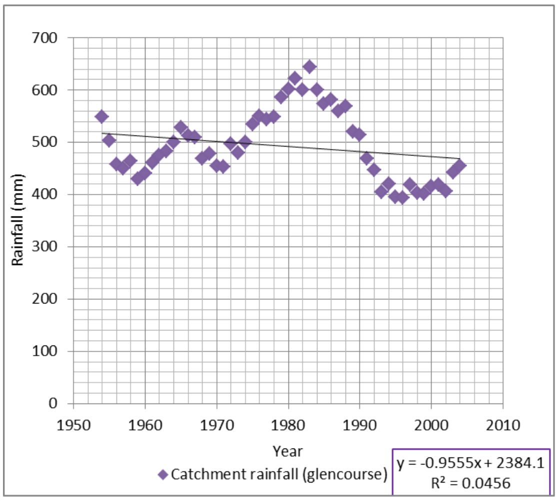


Figure C-0-51 Decadal Monthly Trends of Point Rainfall Stations (June)



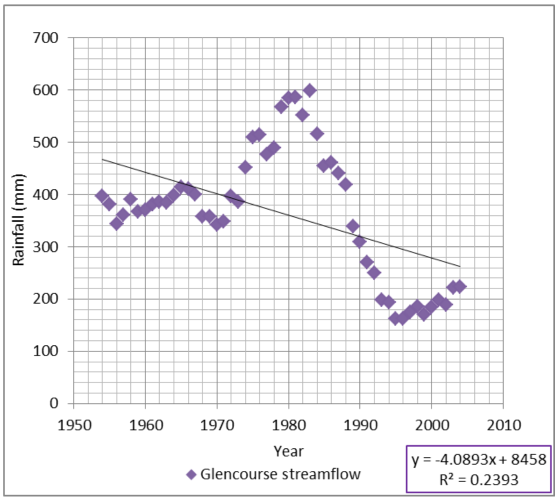


Figure C-0-52 Decadal monthly catchment rainfall and streamflow trends at Glencourse (June)

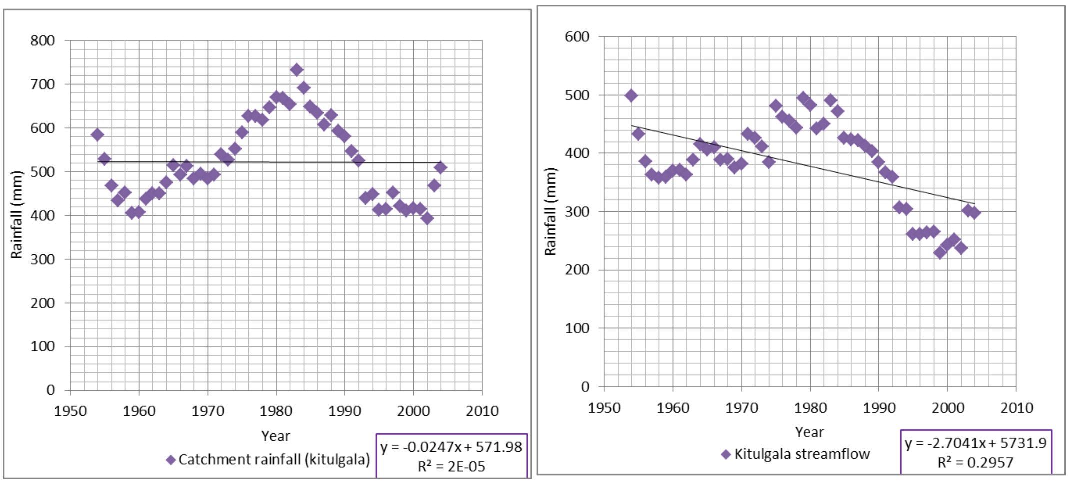


Figure C-0-53 Decadal monthly catchment rainfall and streamflow trends at Kitulgala (June)

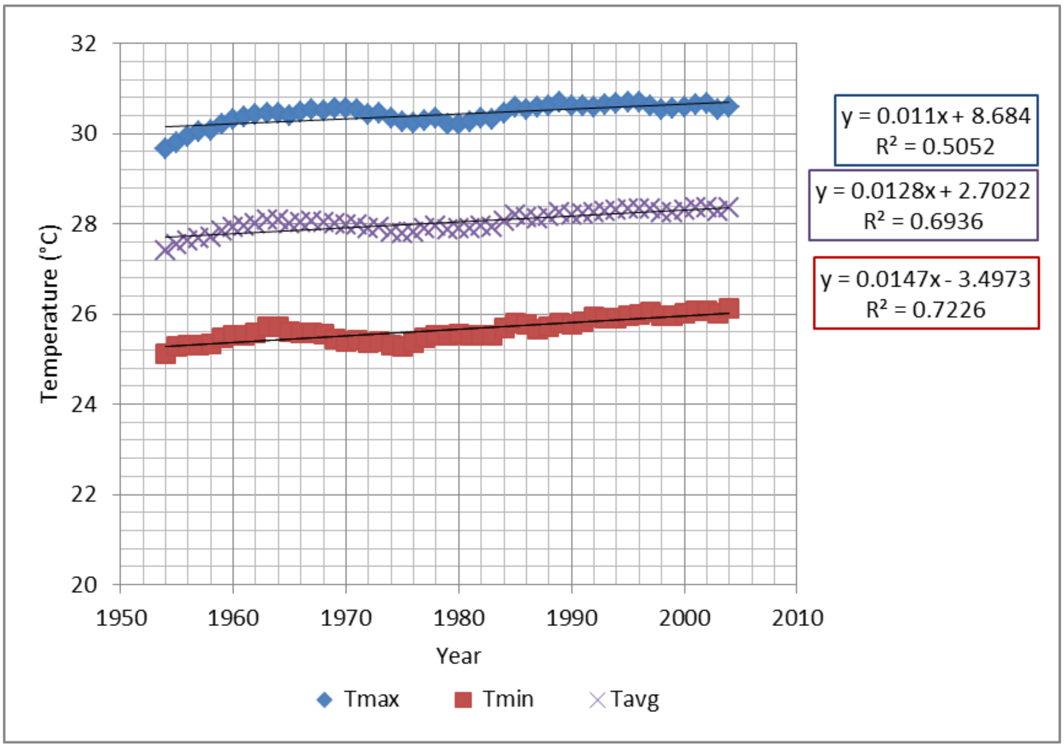


Figure C-0-54 Decadal monthly temperature trends (June)

Figure C-0-55 Decadal Monthly Trends of Point Rainfall Stations (July)

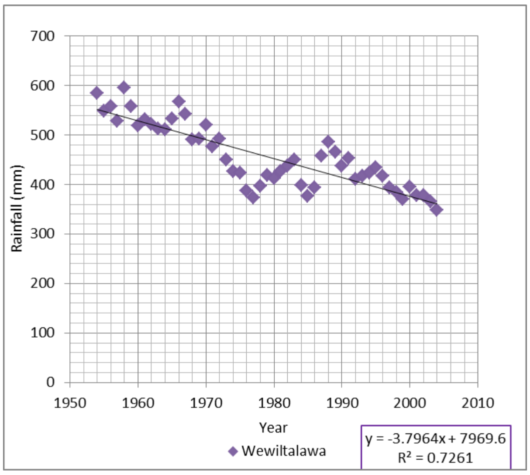
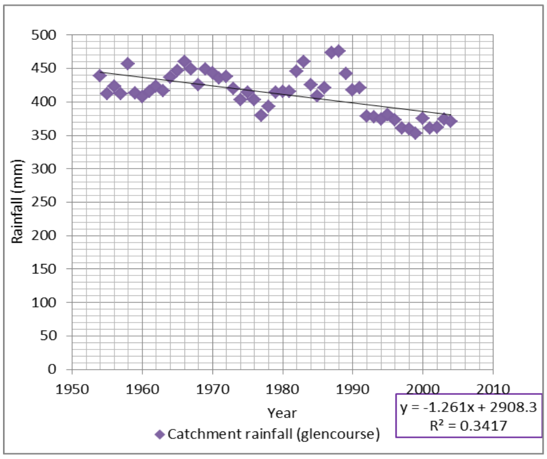


Figure C-0-56 Decadal Monthly Trends of Point Rainfall Stations (July)



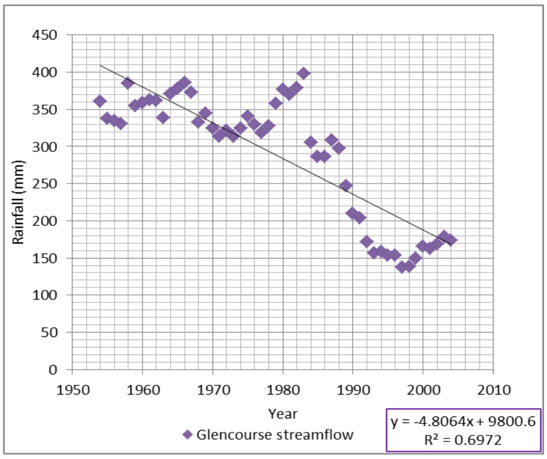
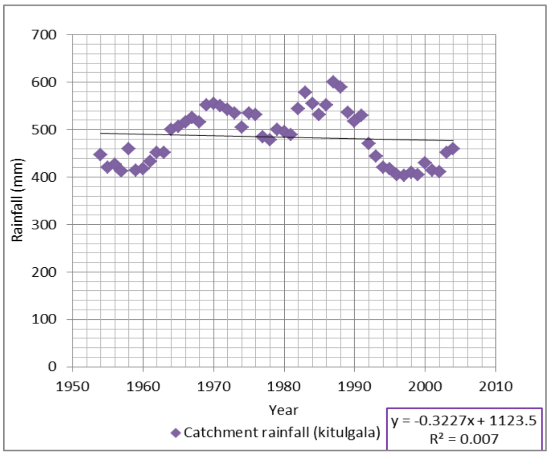


Figure C-0-57 Decadal monthly catchment rainfall and streamflow trends at Kitulgala (July)



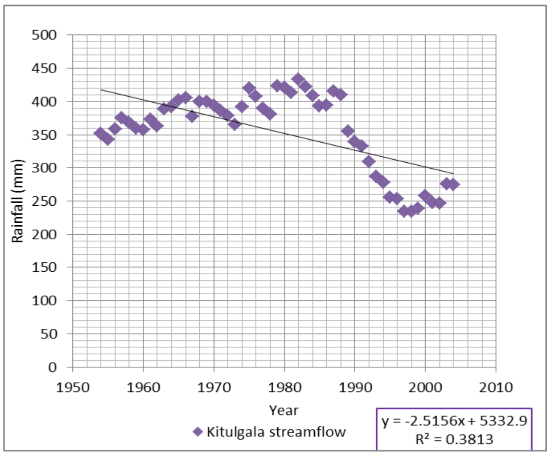


Figure C-0-58 Decadal monthly catchment rainfall and streamflow trends at Kitulgala (July)

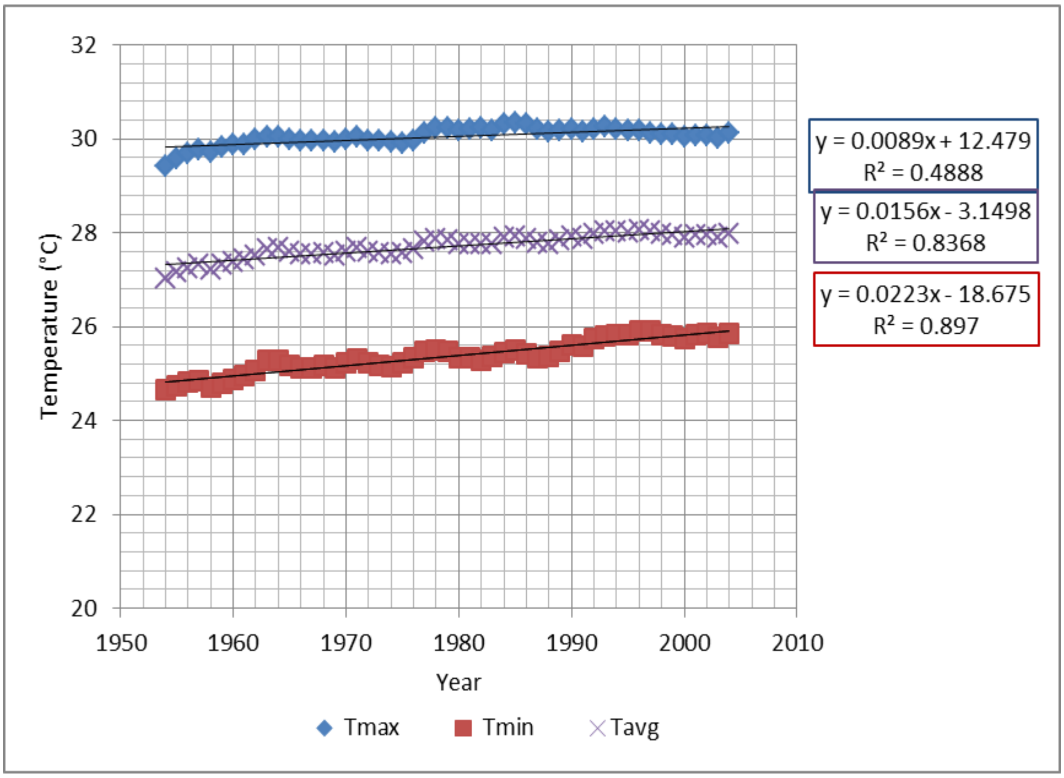


Figure C-0-59 Decadal monthly temperature trends (July)

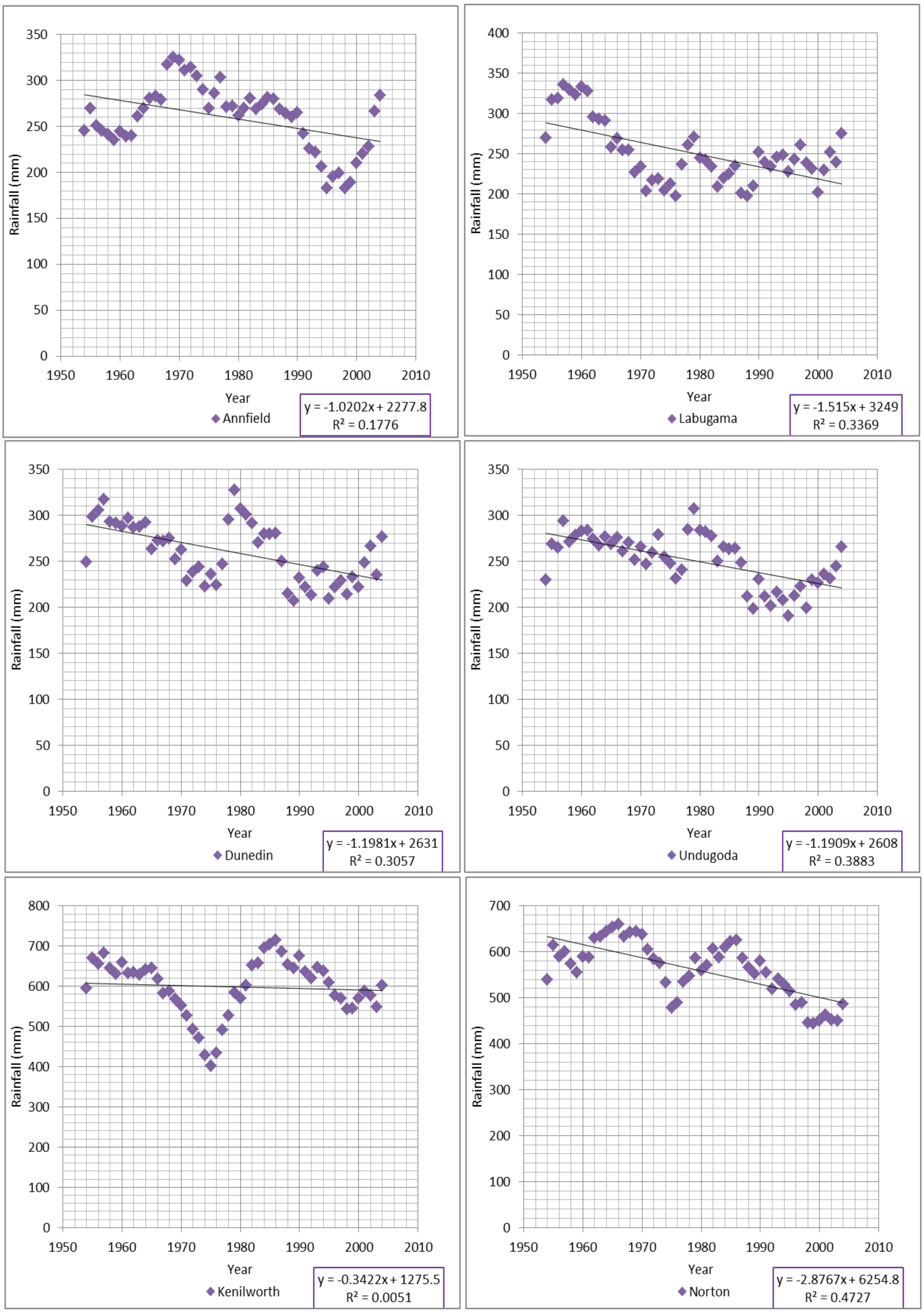


Figure C-0-60 Decadal Monthly Trends of Point Rainfall Stations (August)

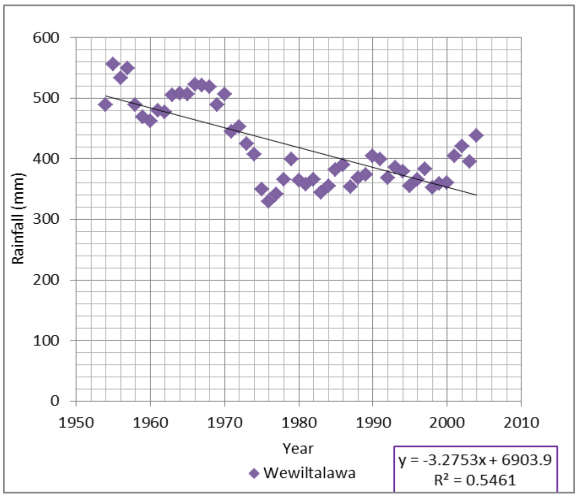
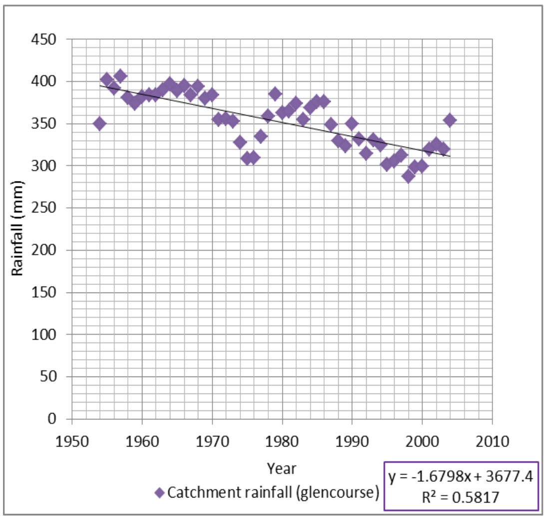


Figure C-0-61 Decadal Monthly Trends of Point Rainfall Stations (August)



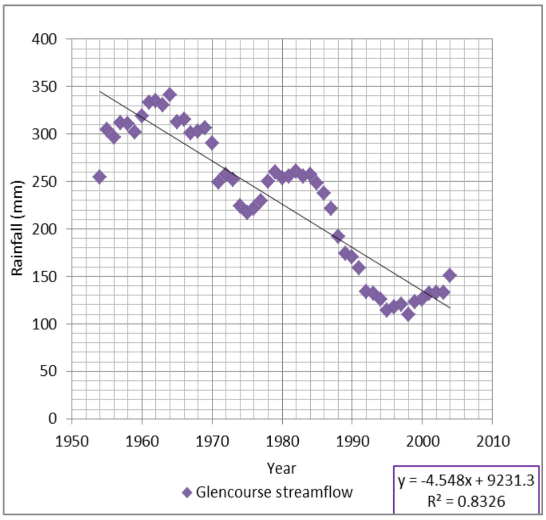
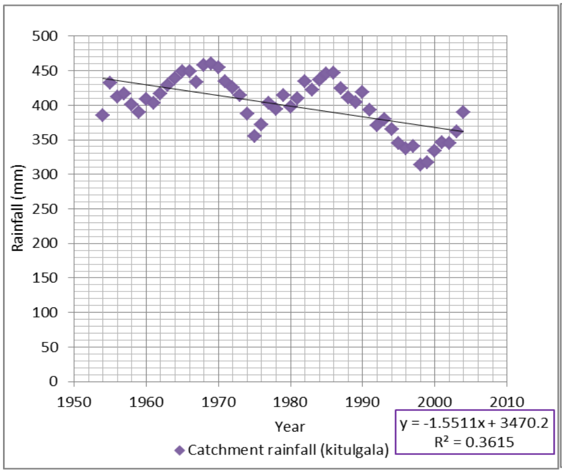


Figure C-0-62 Decadal monthly catchment rainfall and streamflow trends at Glencourse (August)



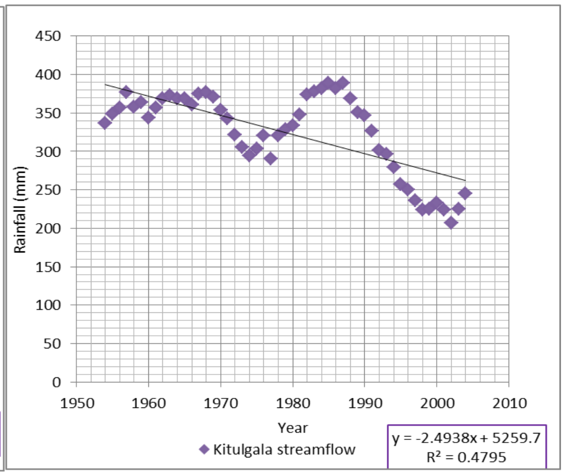


Figure C-0-63 Decadal monthly catchment rainfall and streamflow trends at Kitulgala (August)

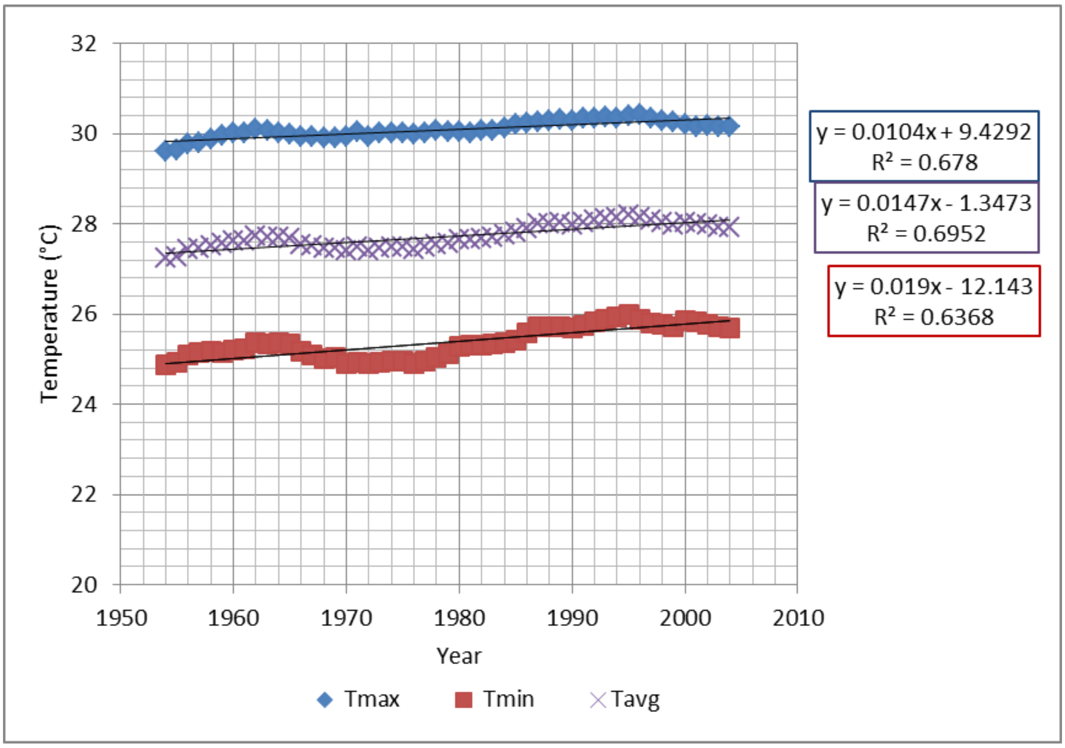


Figure C-0-64 Decadal Monthly Temperature trends (August)

Mean Monthly Trends from 1954 to 2015

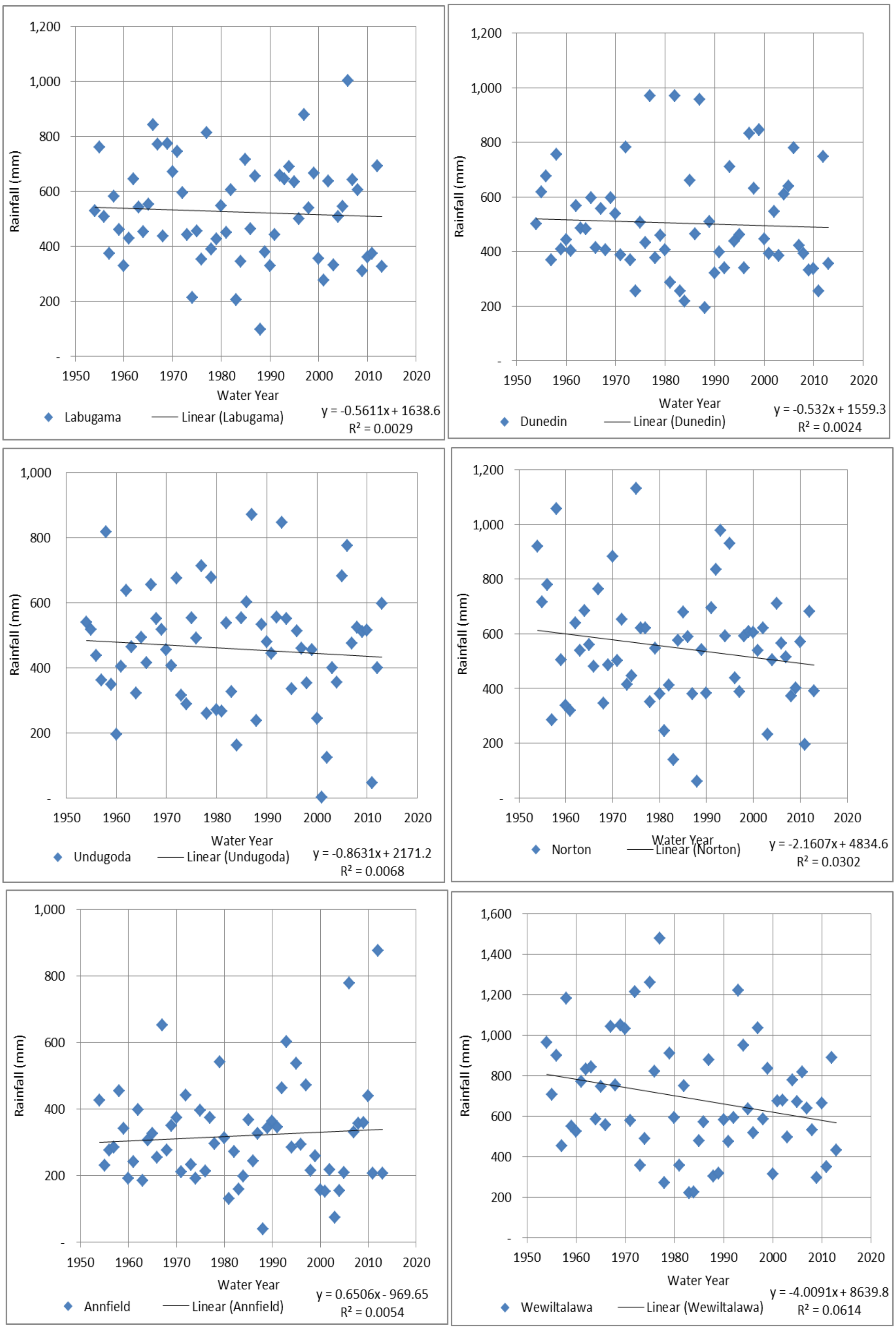


Figure C-0-65 October trends at point rainfall stations

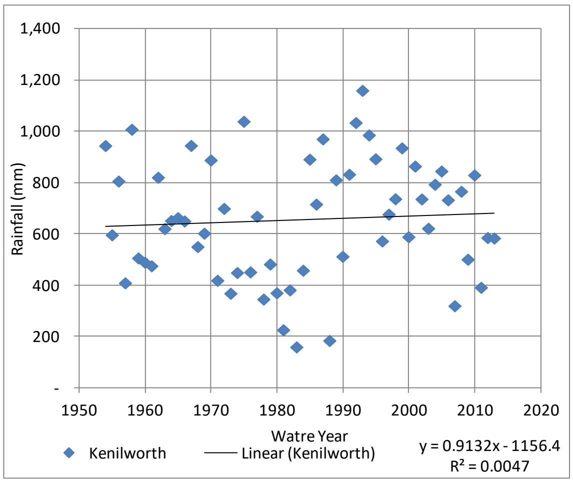


Figure C-0-66 October trends at point rainfall stations

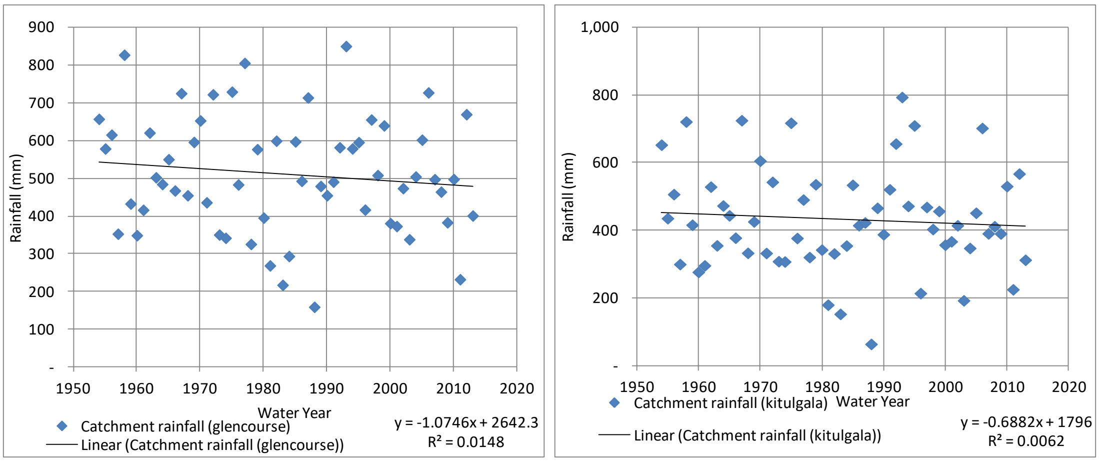


Figure C-0-67 October trends in catchment rainfall

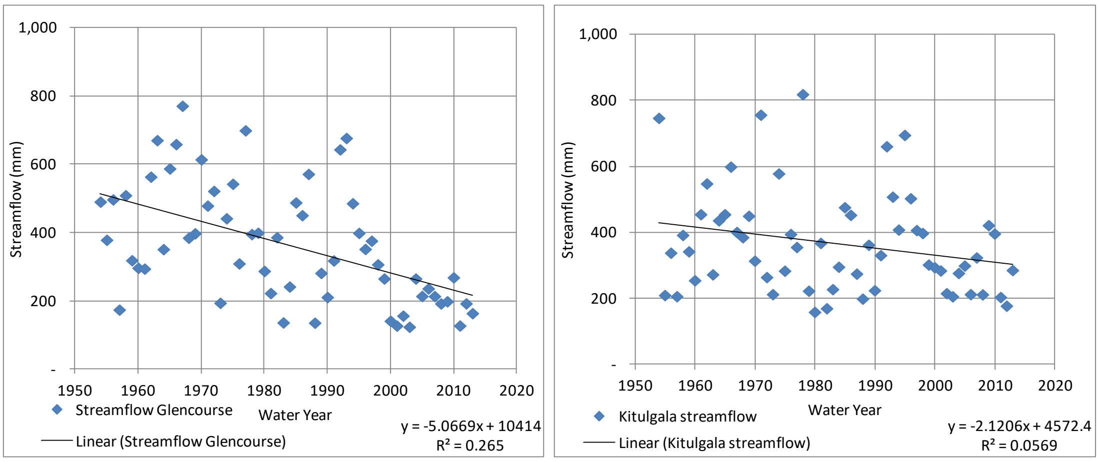
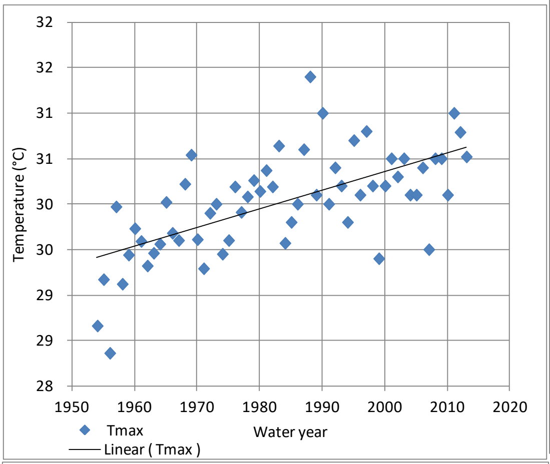
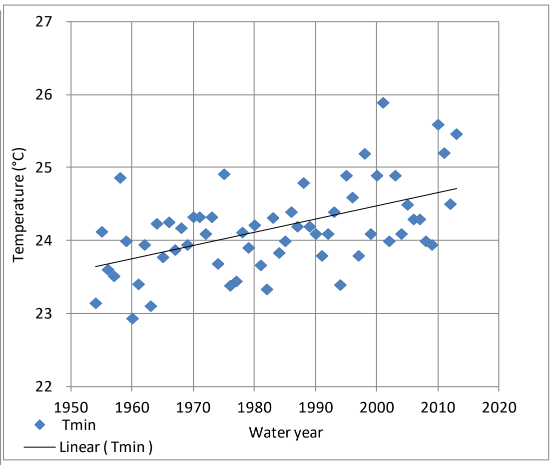


Figure C-0-68 October trends in streamflow





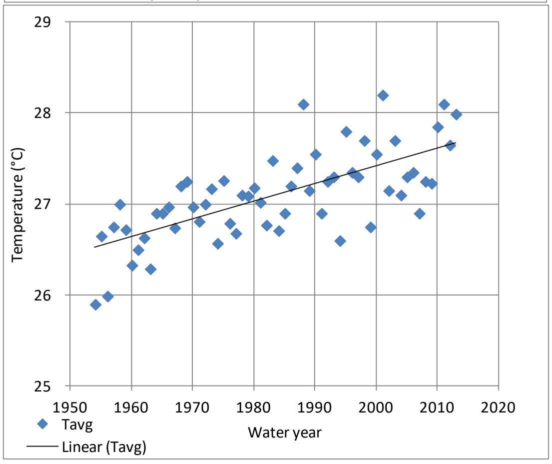


Figure C-0-69 October trends in temperature

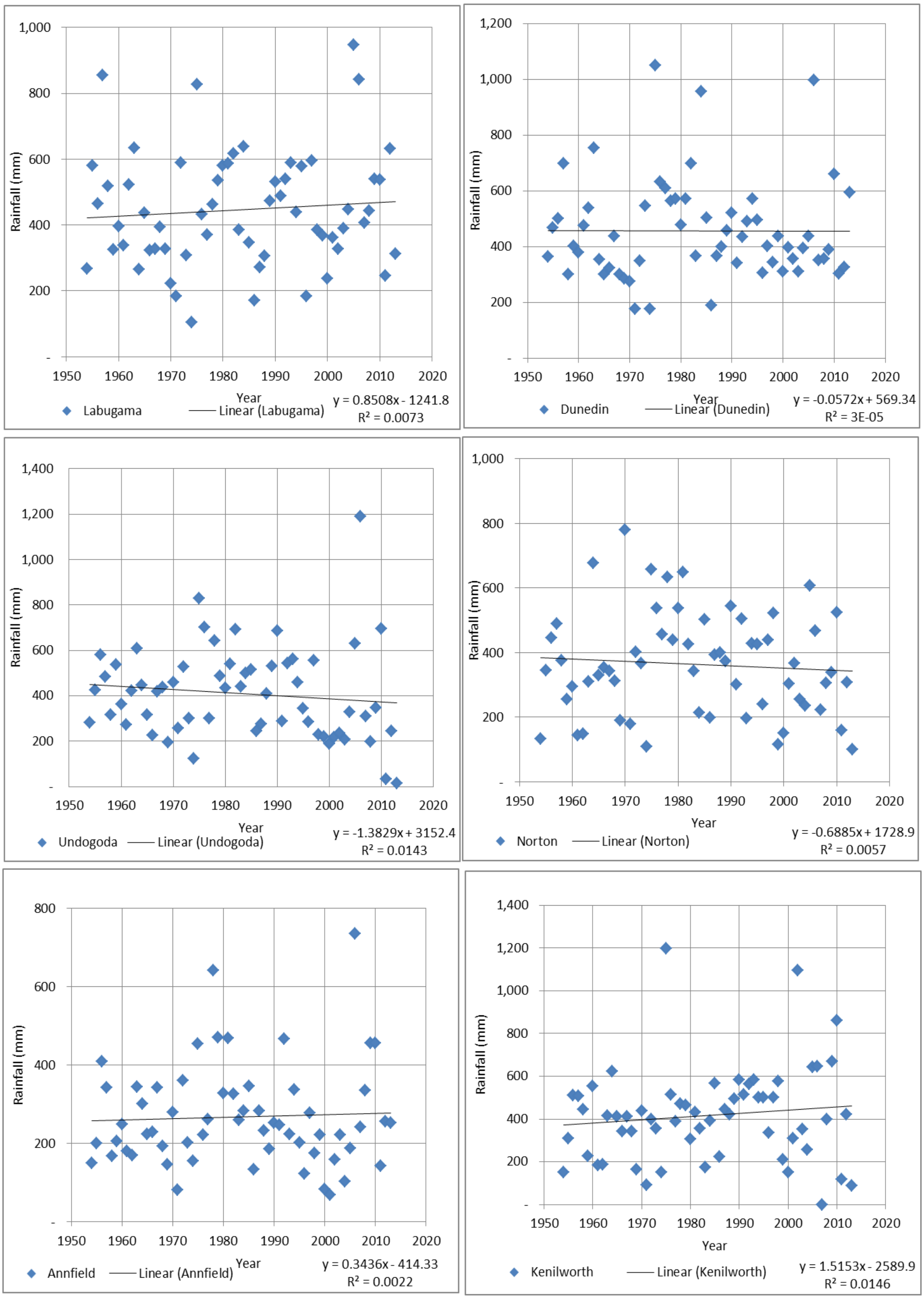


Figure C-0-70 November trends in point rainfall stations

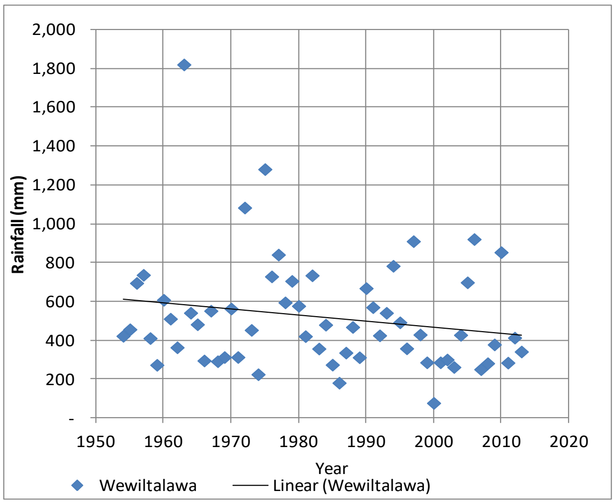


Figure C-0-71 November trends in point rainfall stations

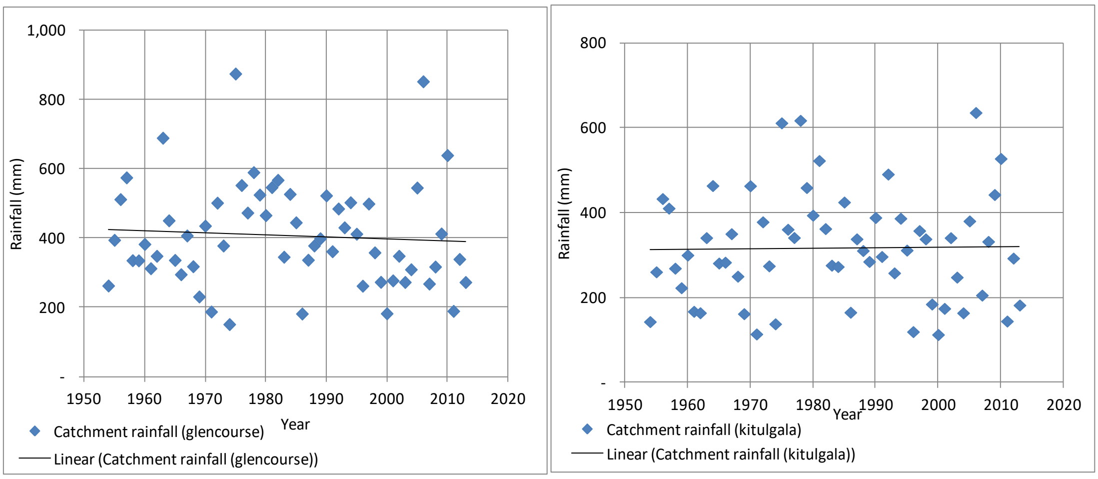


Figure C-0-72 November trends in catchment rainfall

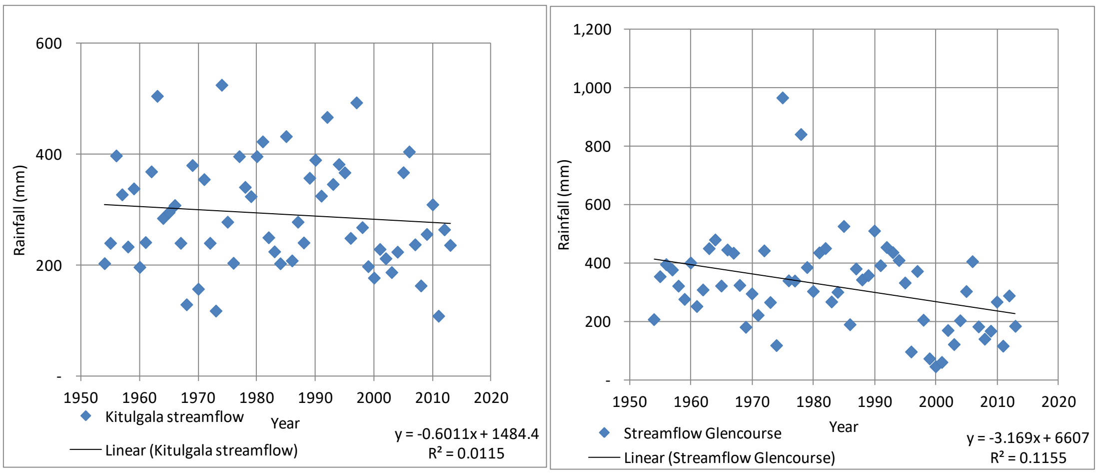


Figure C-0-73 November trends in streamflow

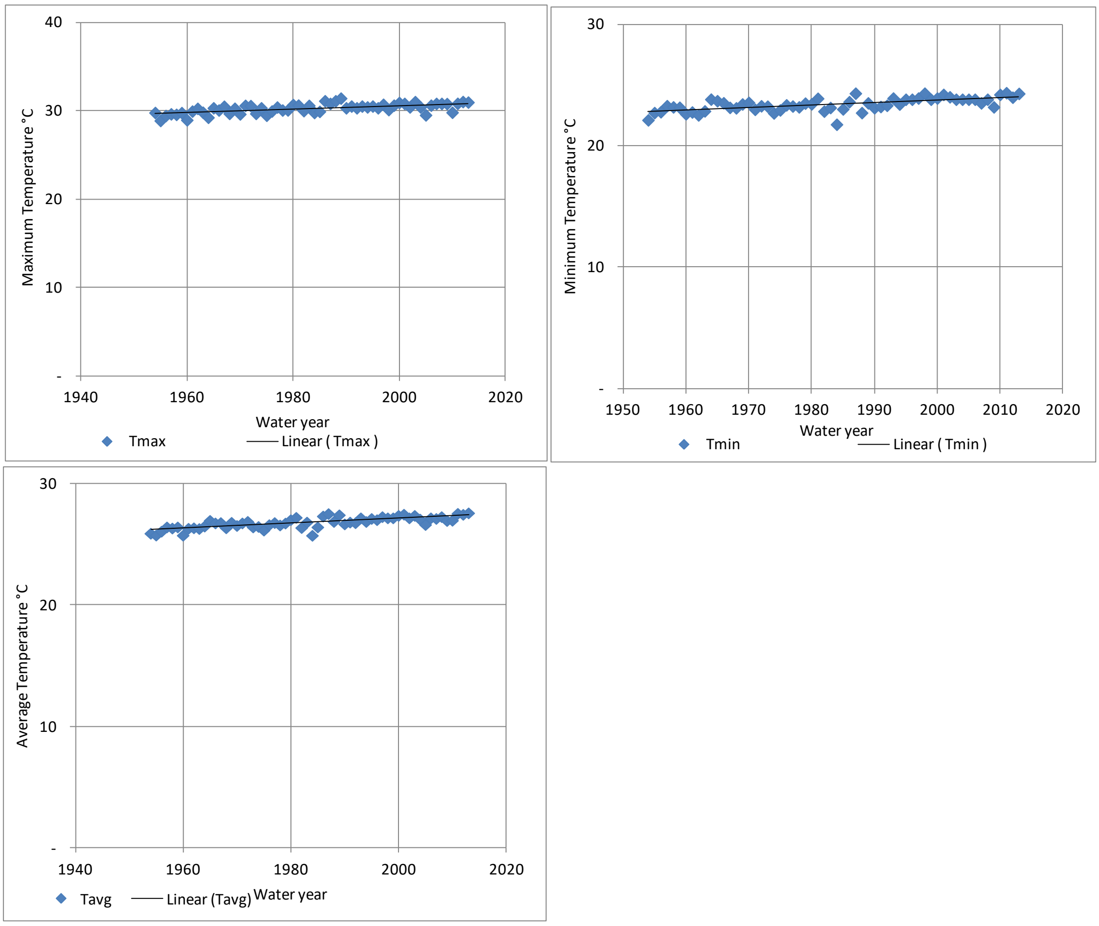


Figure C-0-74 November trends in temperature

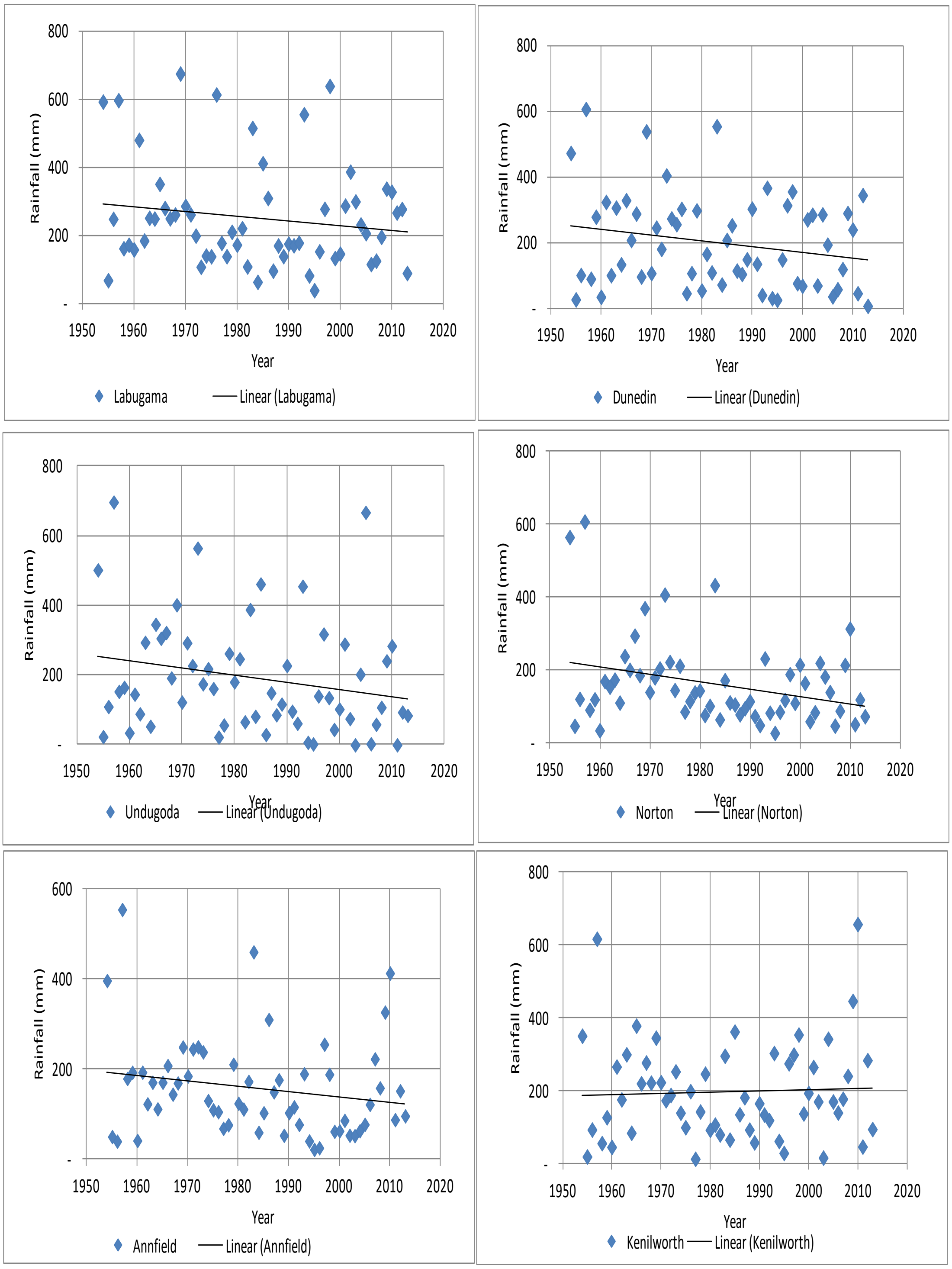


Figure C-0-75 December Trends in point rainfall stations

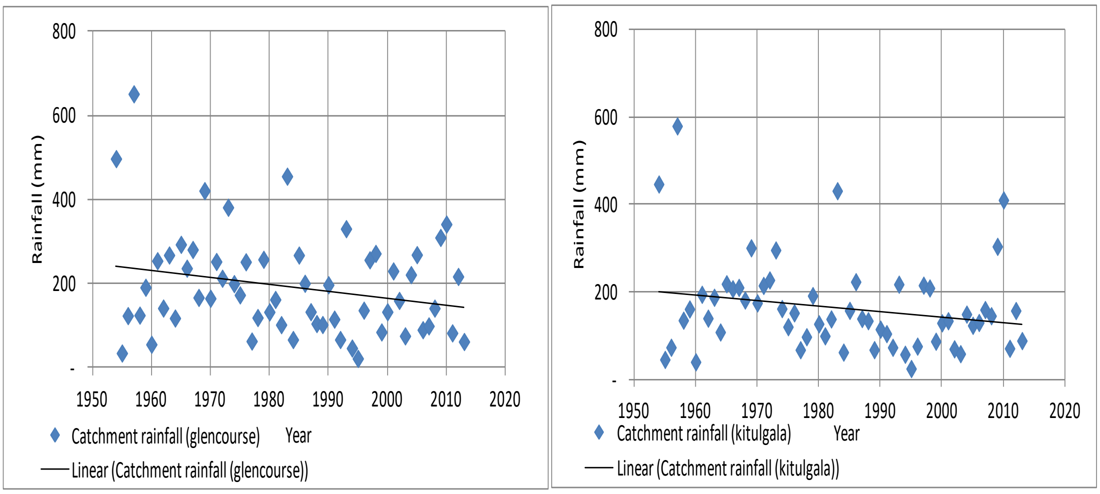


Figure C-0-76 December Trends in catchment rainfall

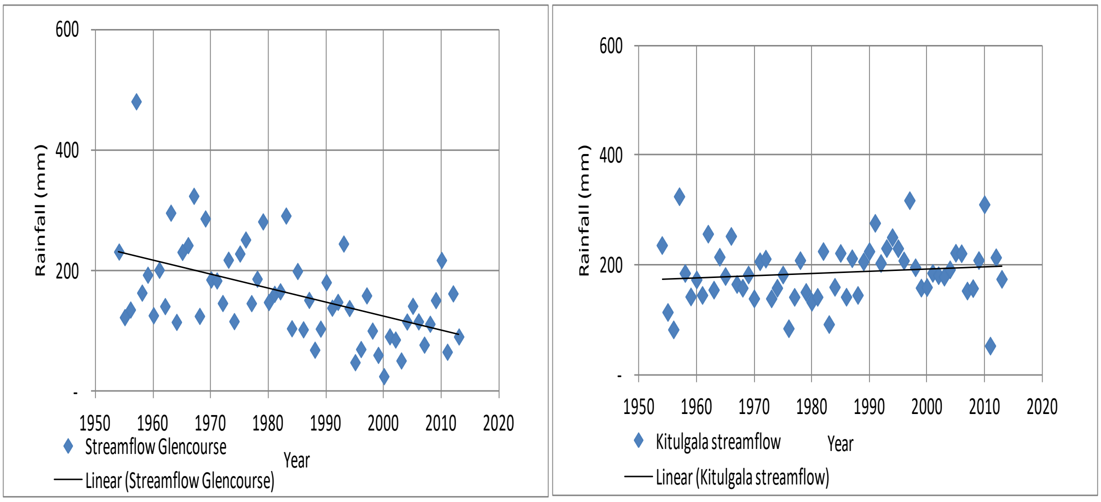


Figure C-0-77 December Trends in streamflow

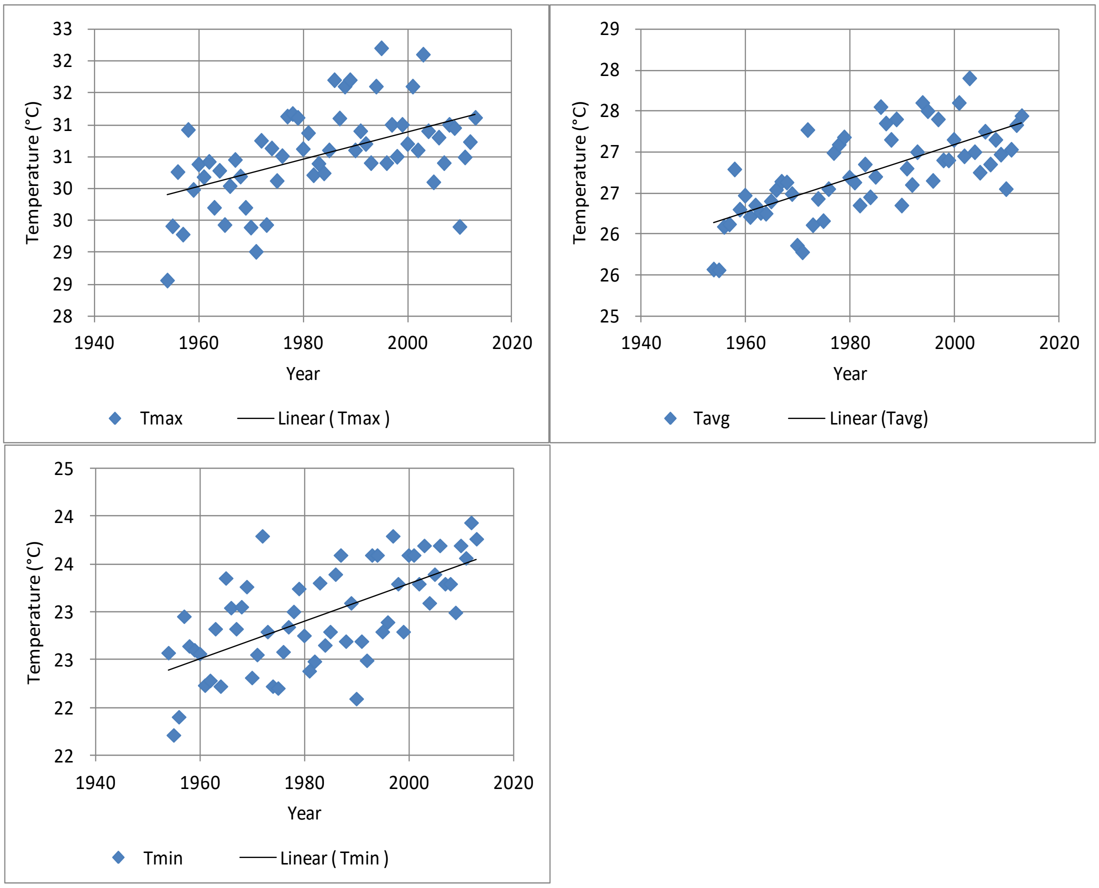


Figure C-0-78 December Trends in temperature

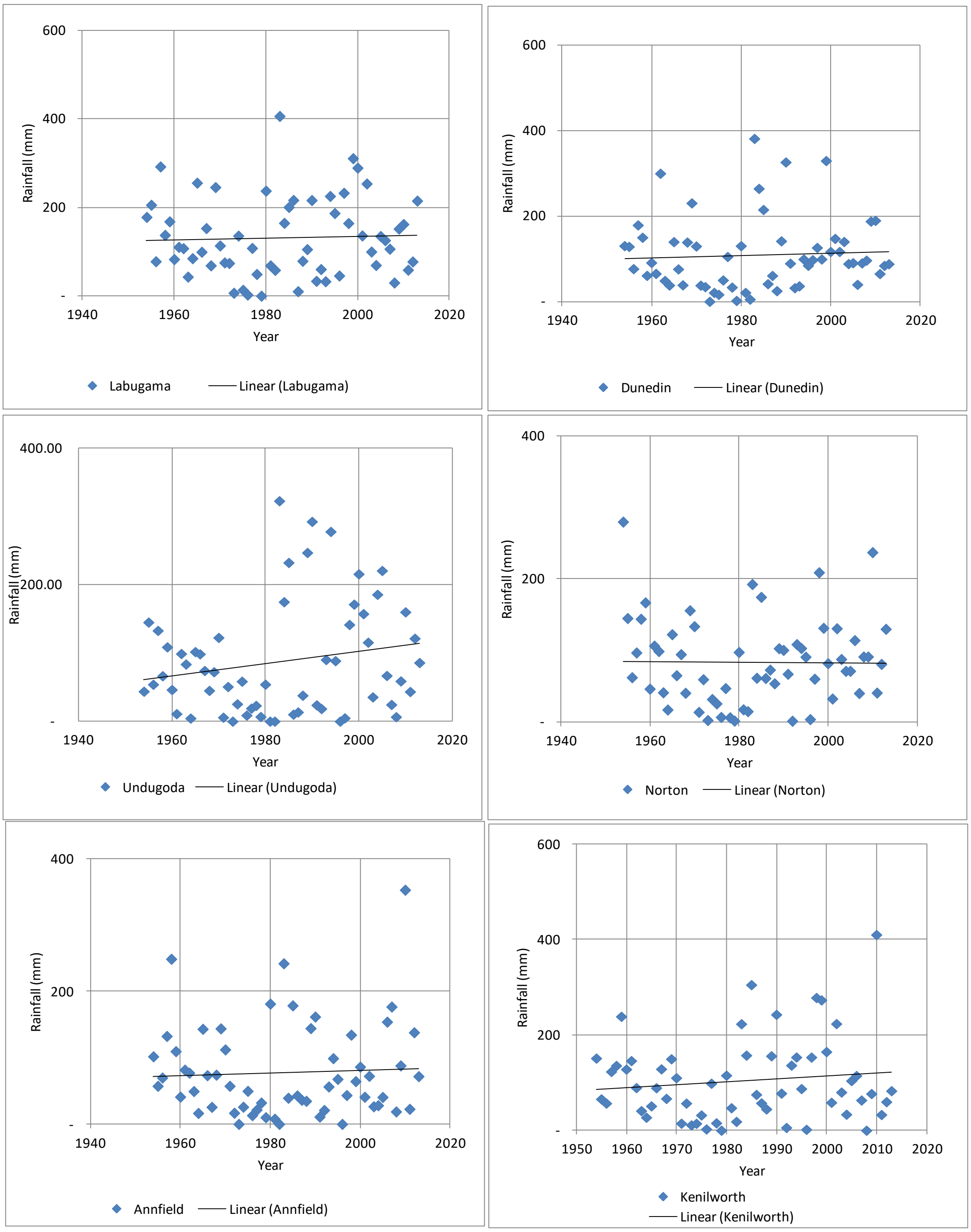


Figure C-0-79 January Trends at point rainfall stations

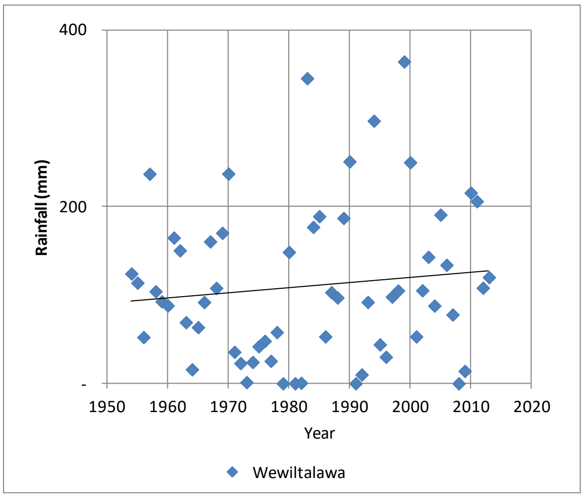


Figure C-0-80 January Trends at point rainfall stations

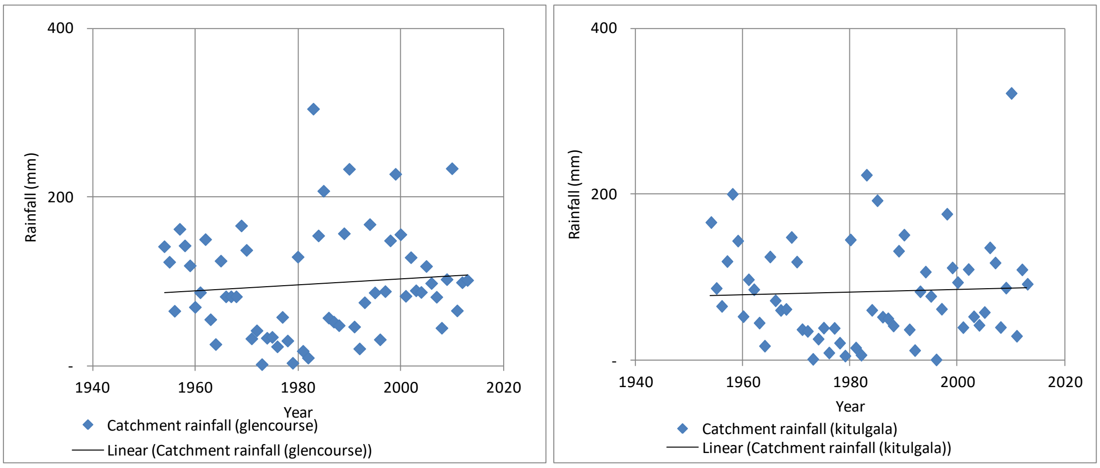


Figure C-0-81 January Trends

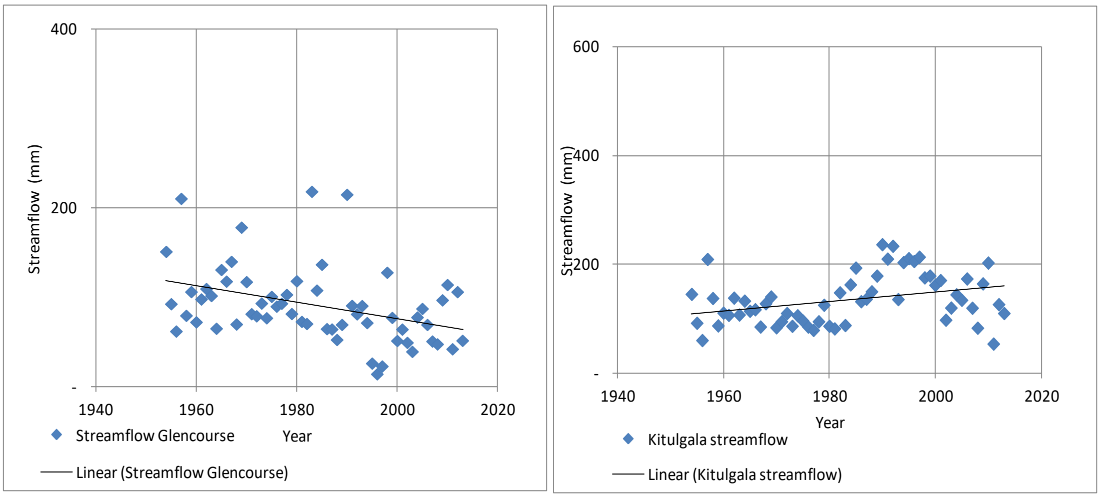


Figure C-0-82 January Trends in streamflow

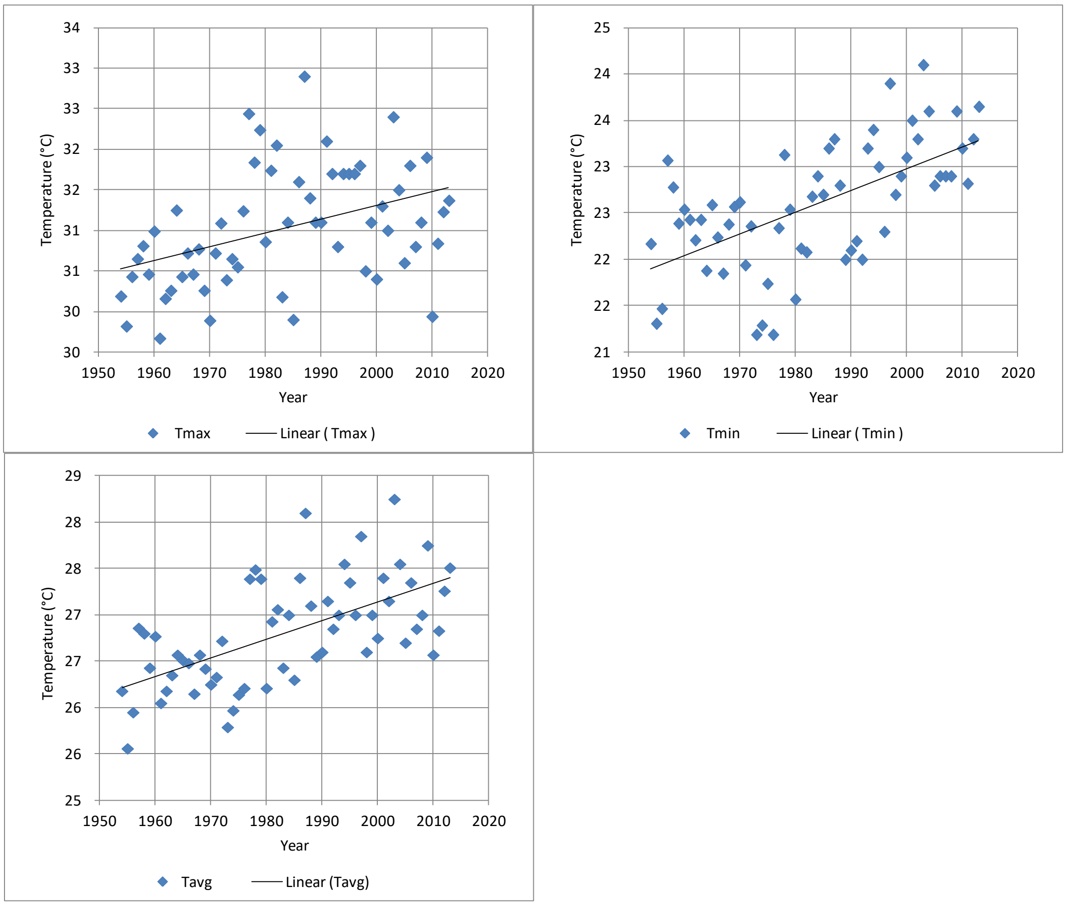


Figure C-0-83 January Trends in Temperature

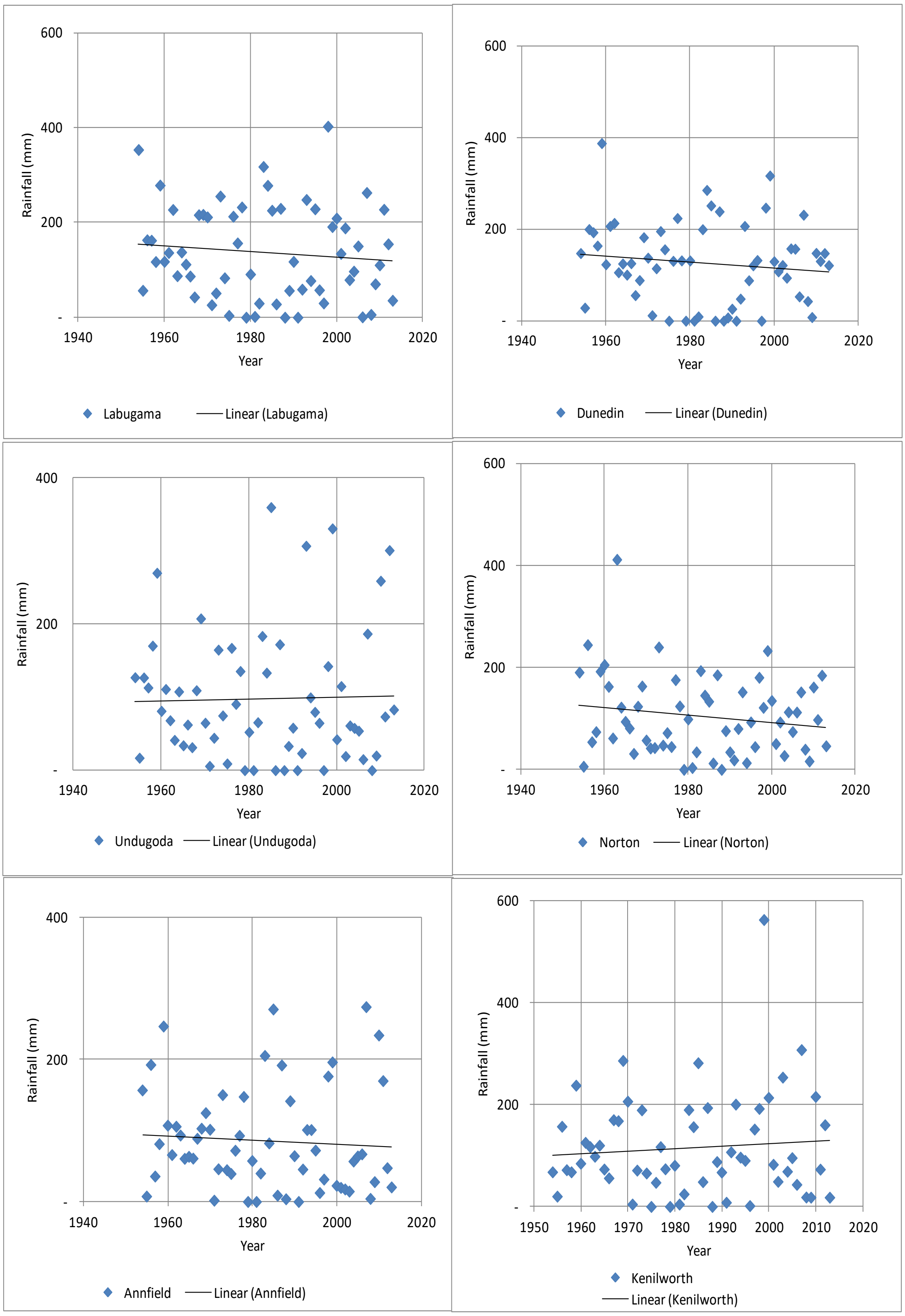


Figure C-0-84 February Trends in point rainfall station

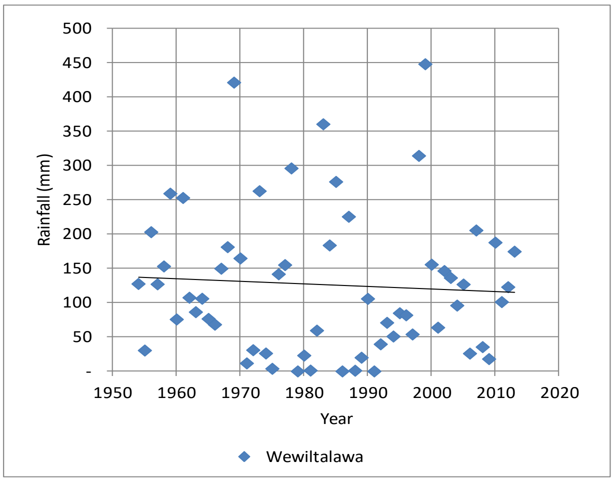
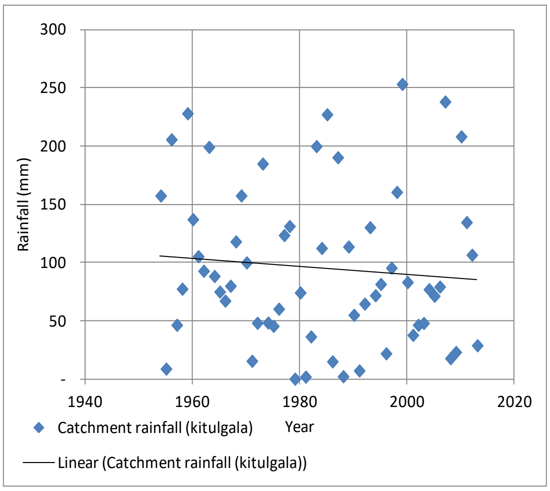


Figure C-0-85 February Trends in point rainfall station



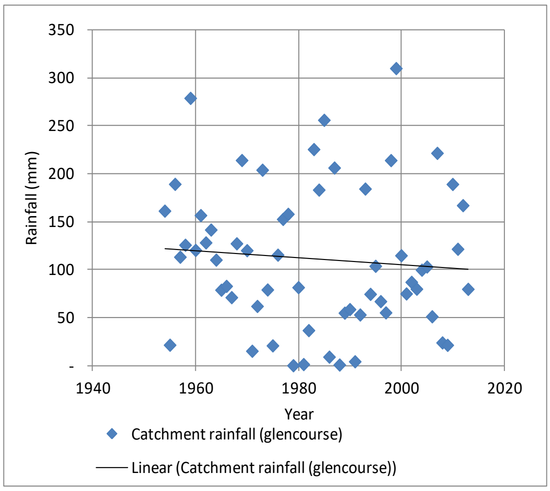
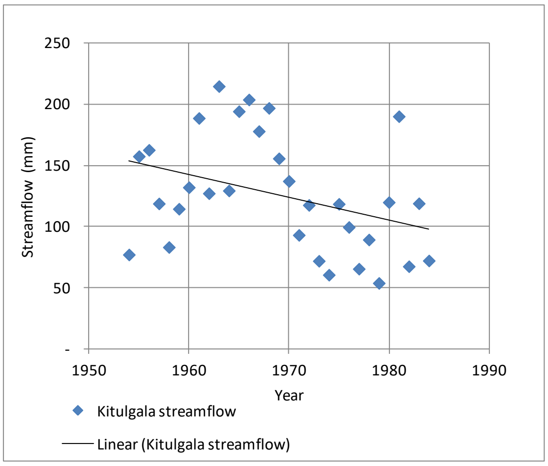


Figure C-0-86 February Trends in catchment rainfall station



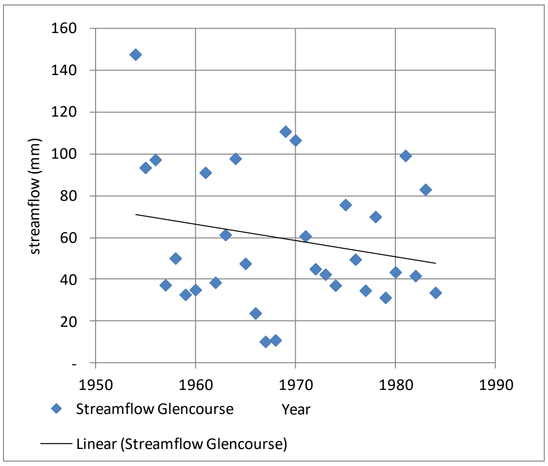


Figure C-0-87 February Trends in streamflow

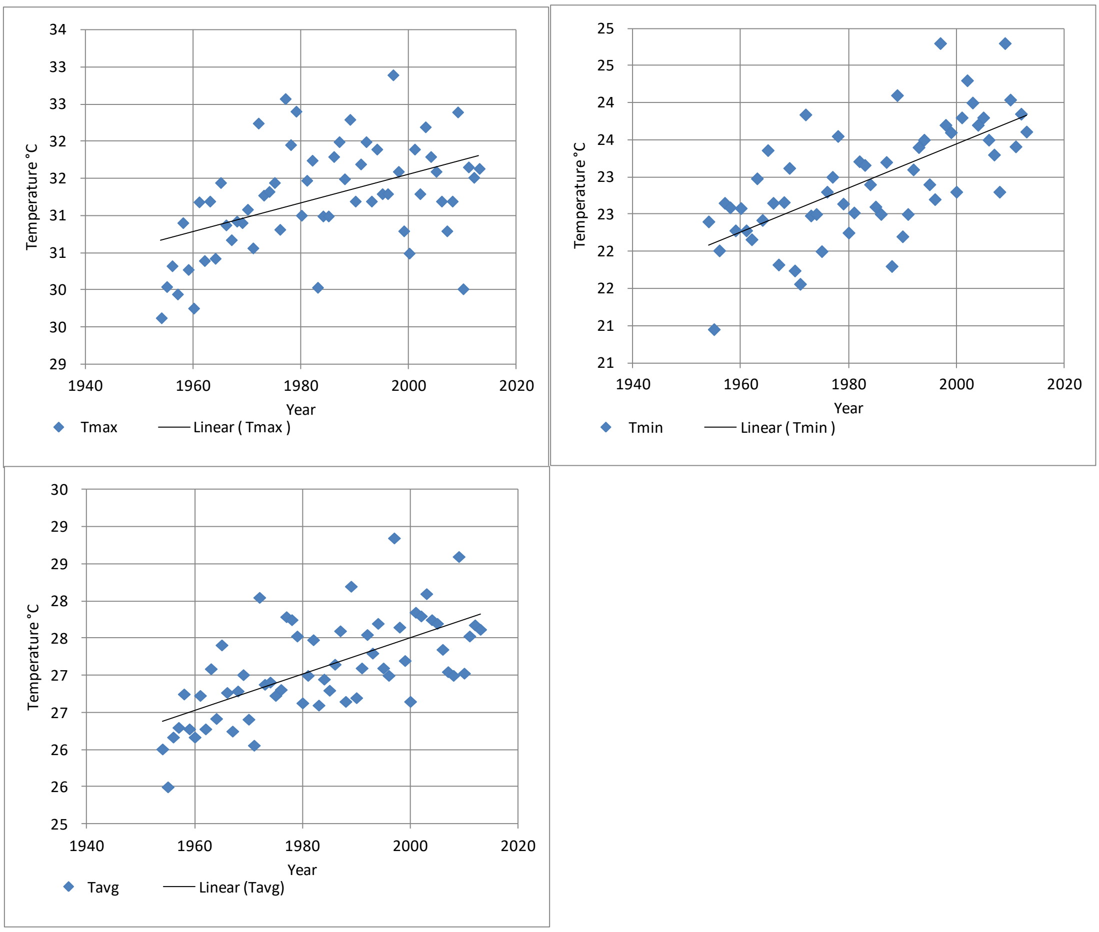


Figure C-0-88 February Trends in temperature

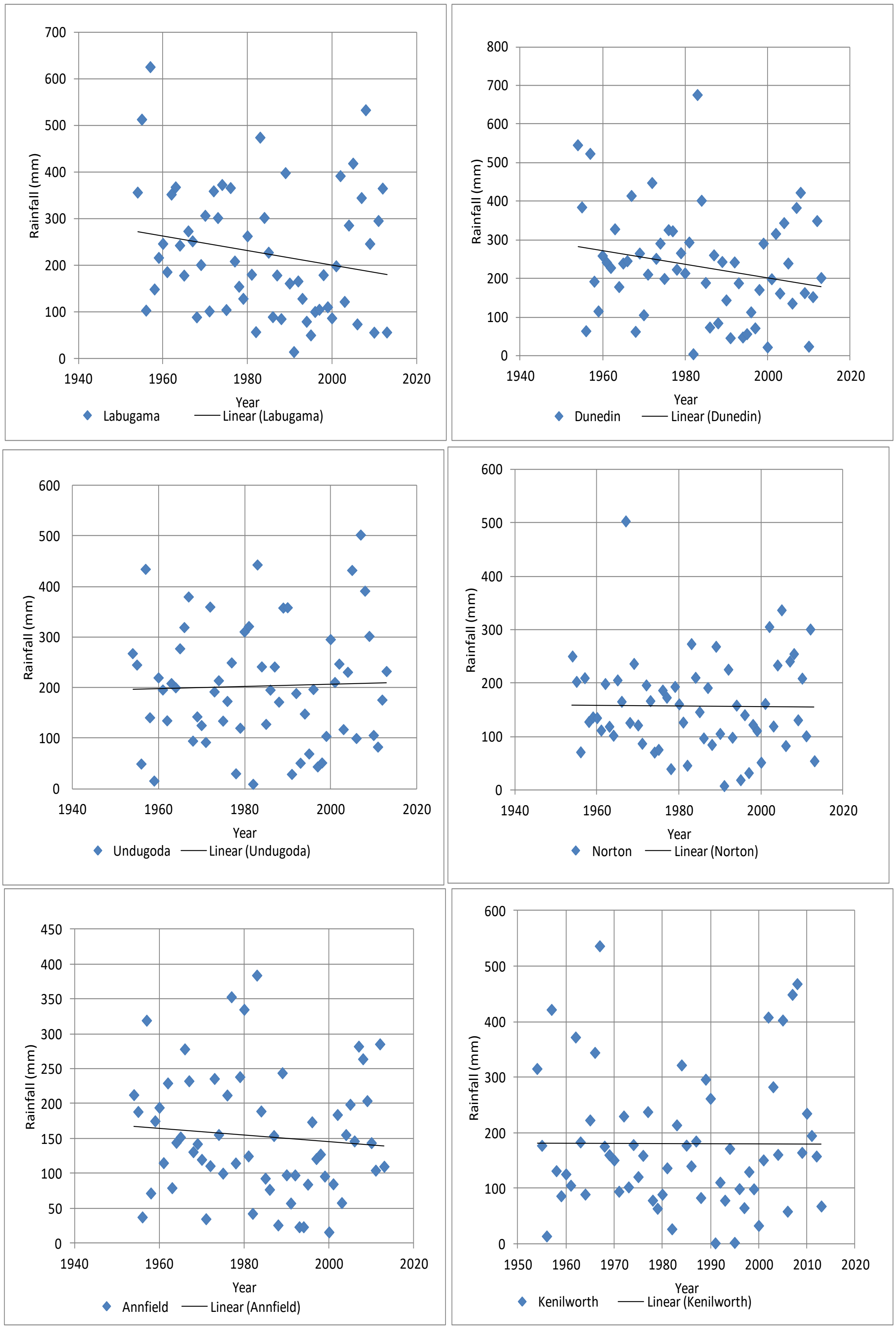


Figure C-0-89 March Trends in point rainfall

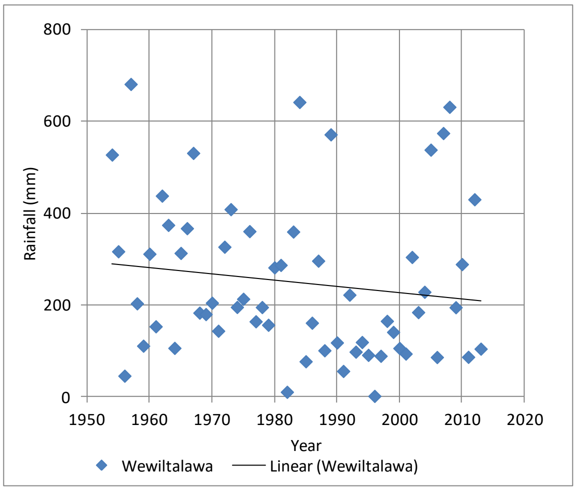
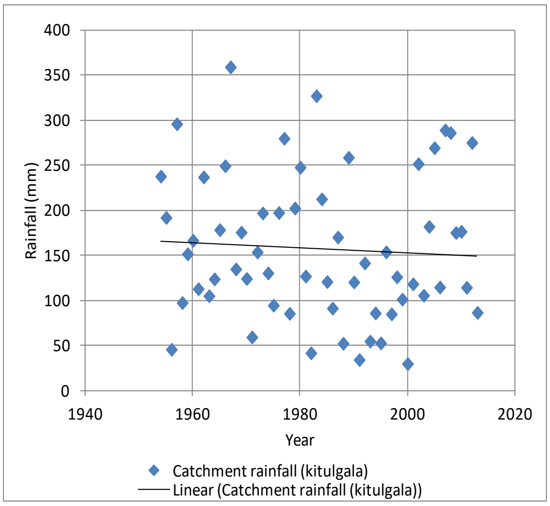


Figure C-0-90 March Trends in point rainfall



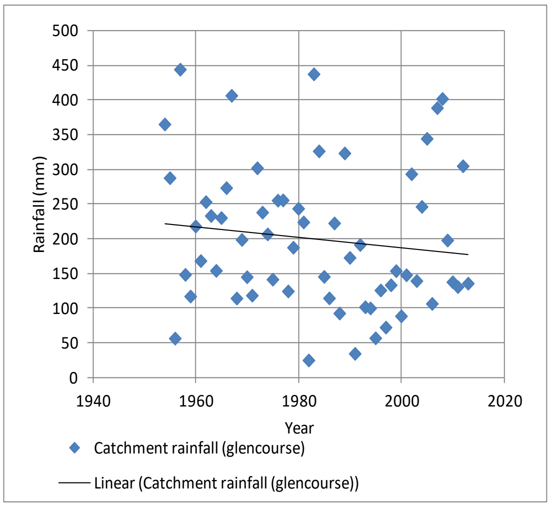
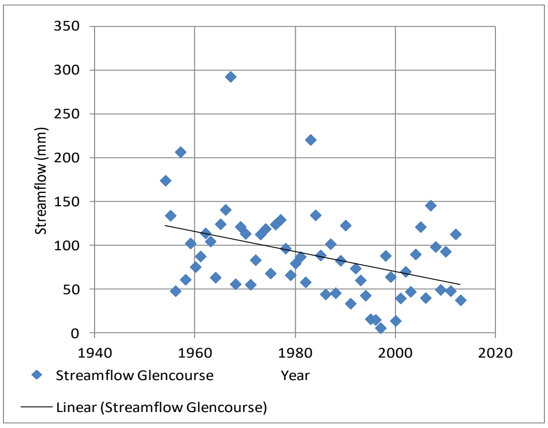


Figure C-0-91 March Trends in catchment rainfall



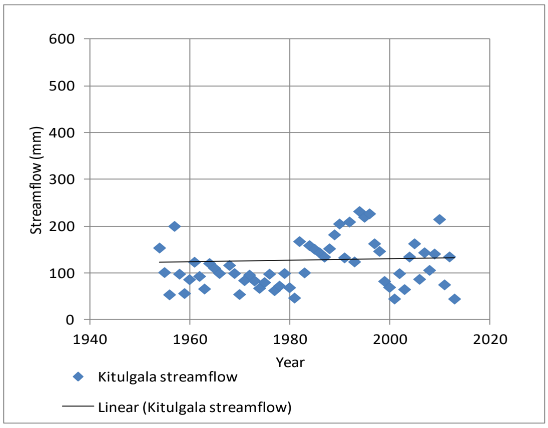
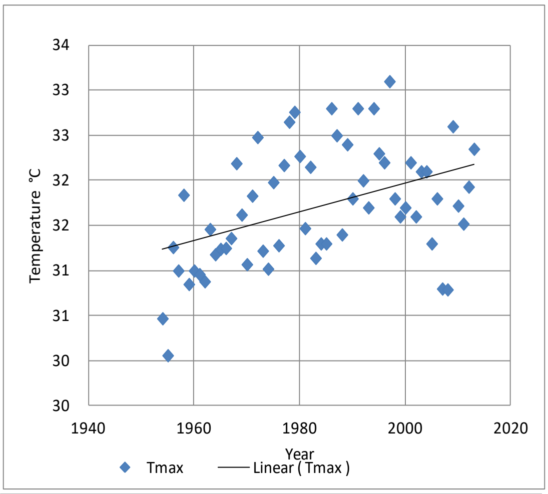
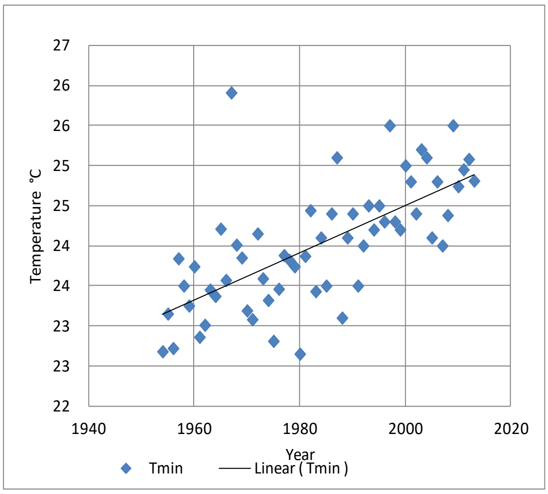


Figure C-0-92 March Trends in streamflow





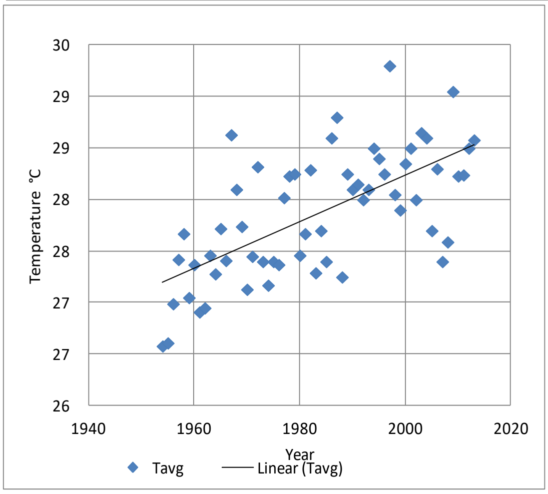


Figure C-0-93 March Trends in Temperature

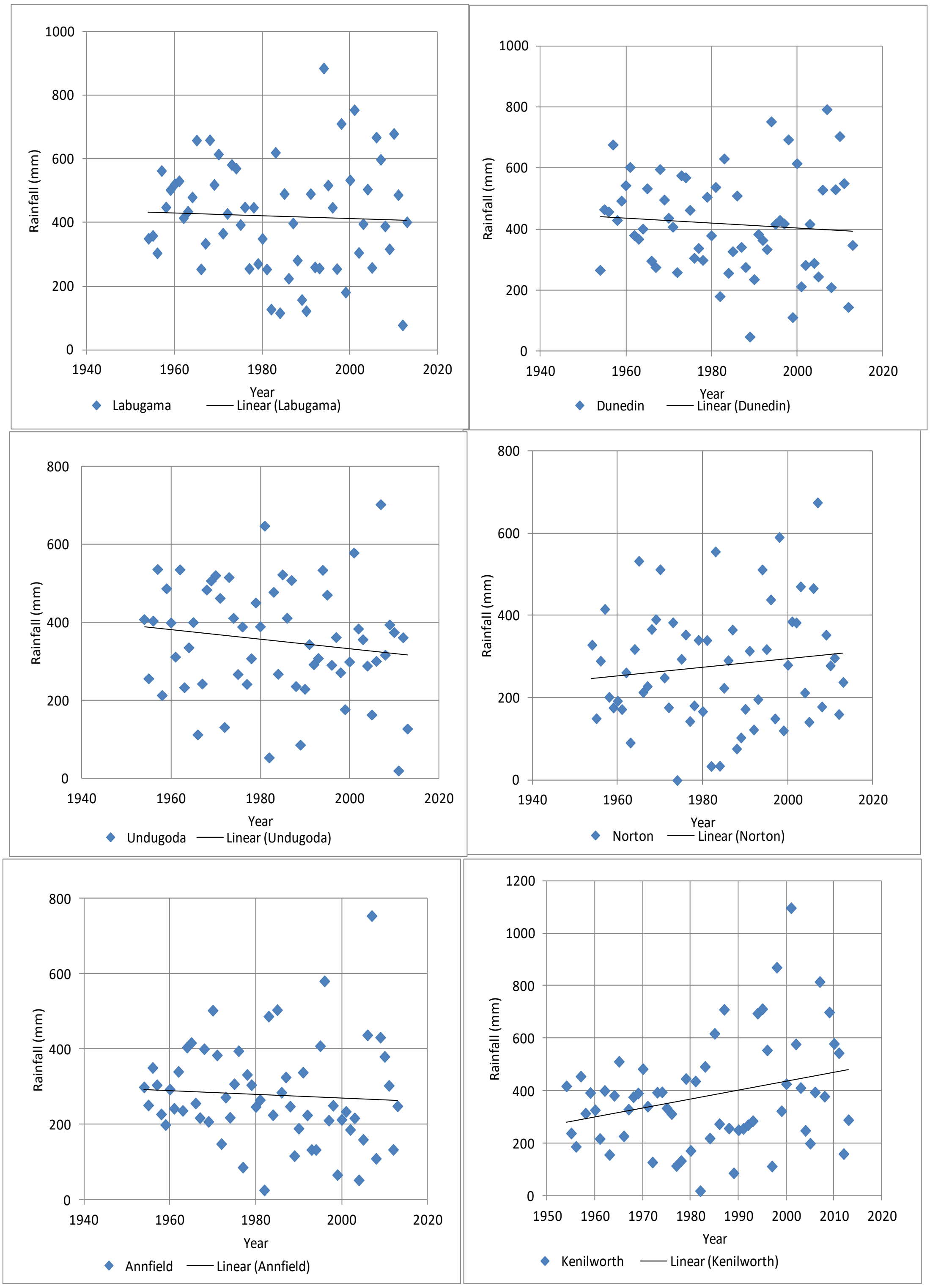


Figure C-0-94 April Trends in Point rainfall station

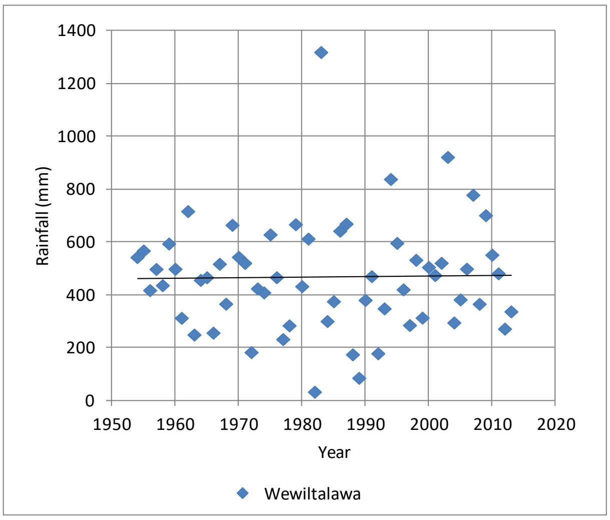
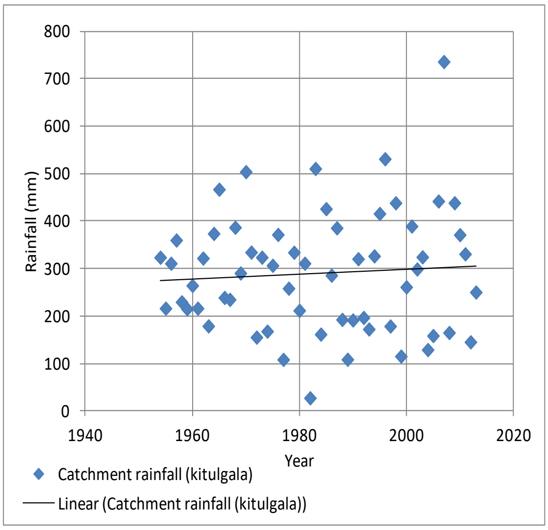


Figure C-0-95 April Trends in Point rainfall station



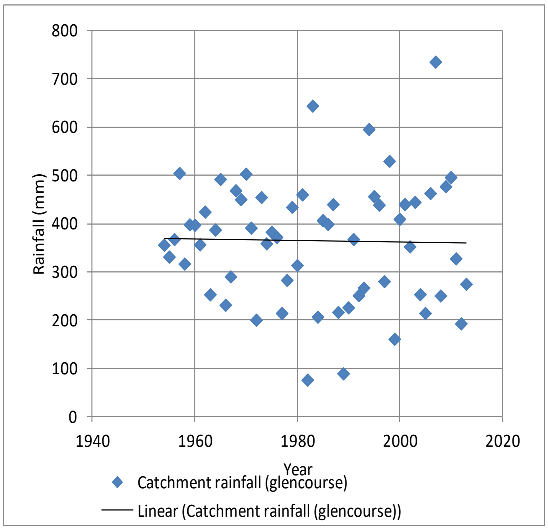
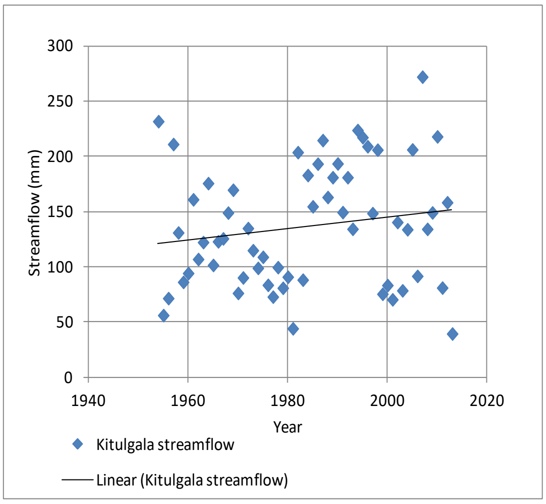


Figure C-0-96 April Trends in catchment rainfall station



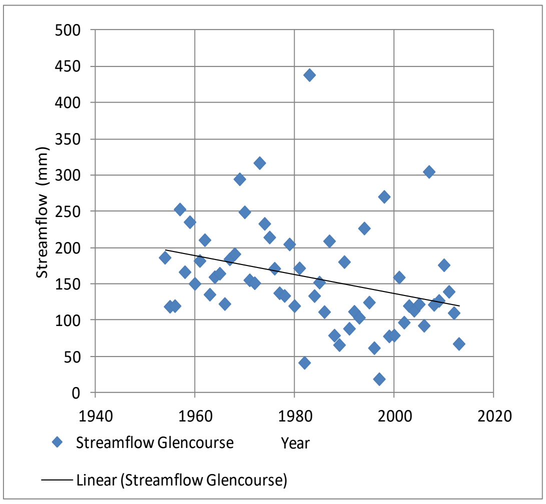


Figure C-0-97 April Trends in streamflow

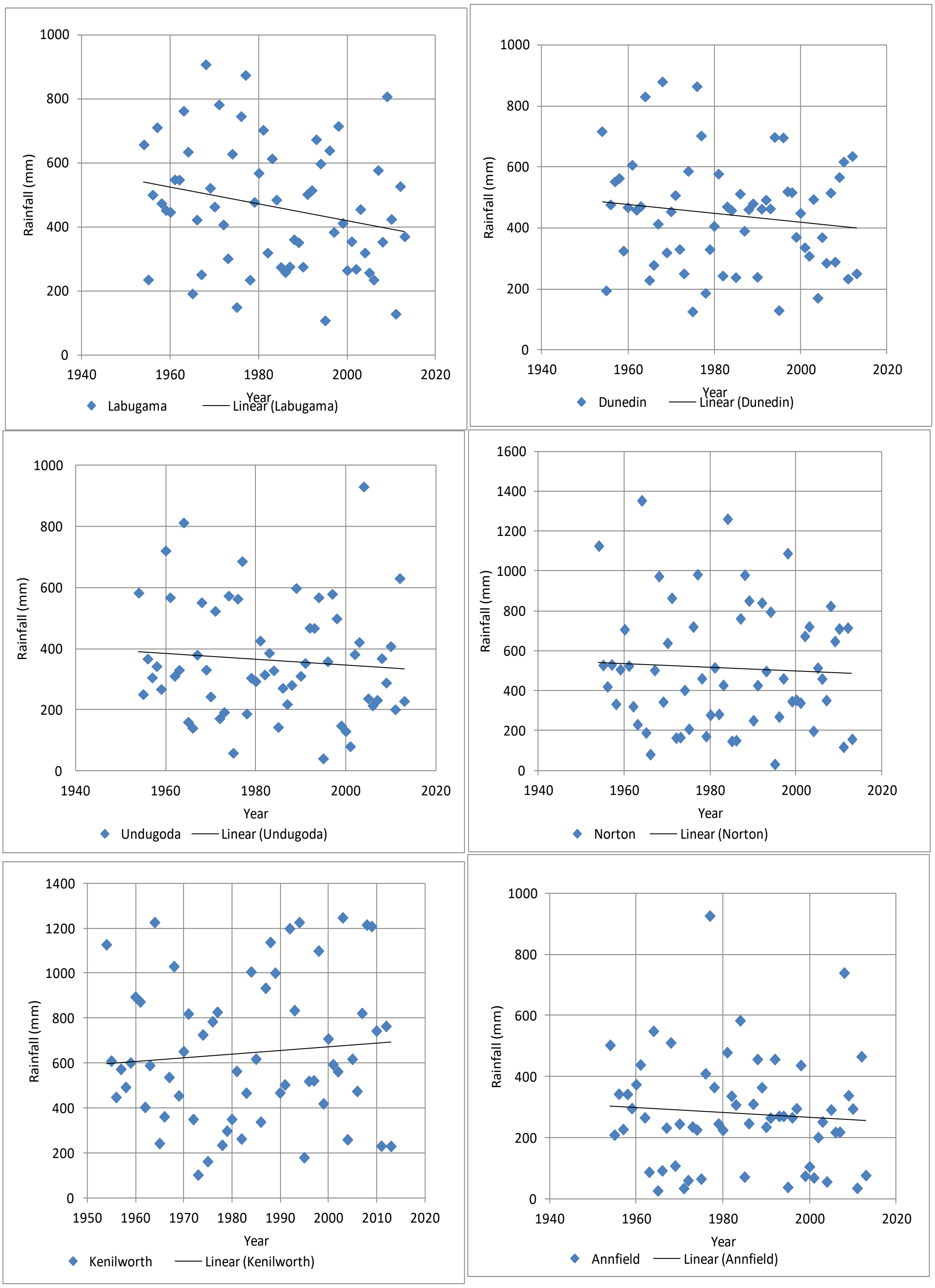


Figure B7: May trend

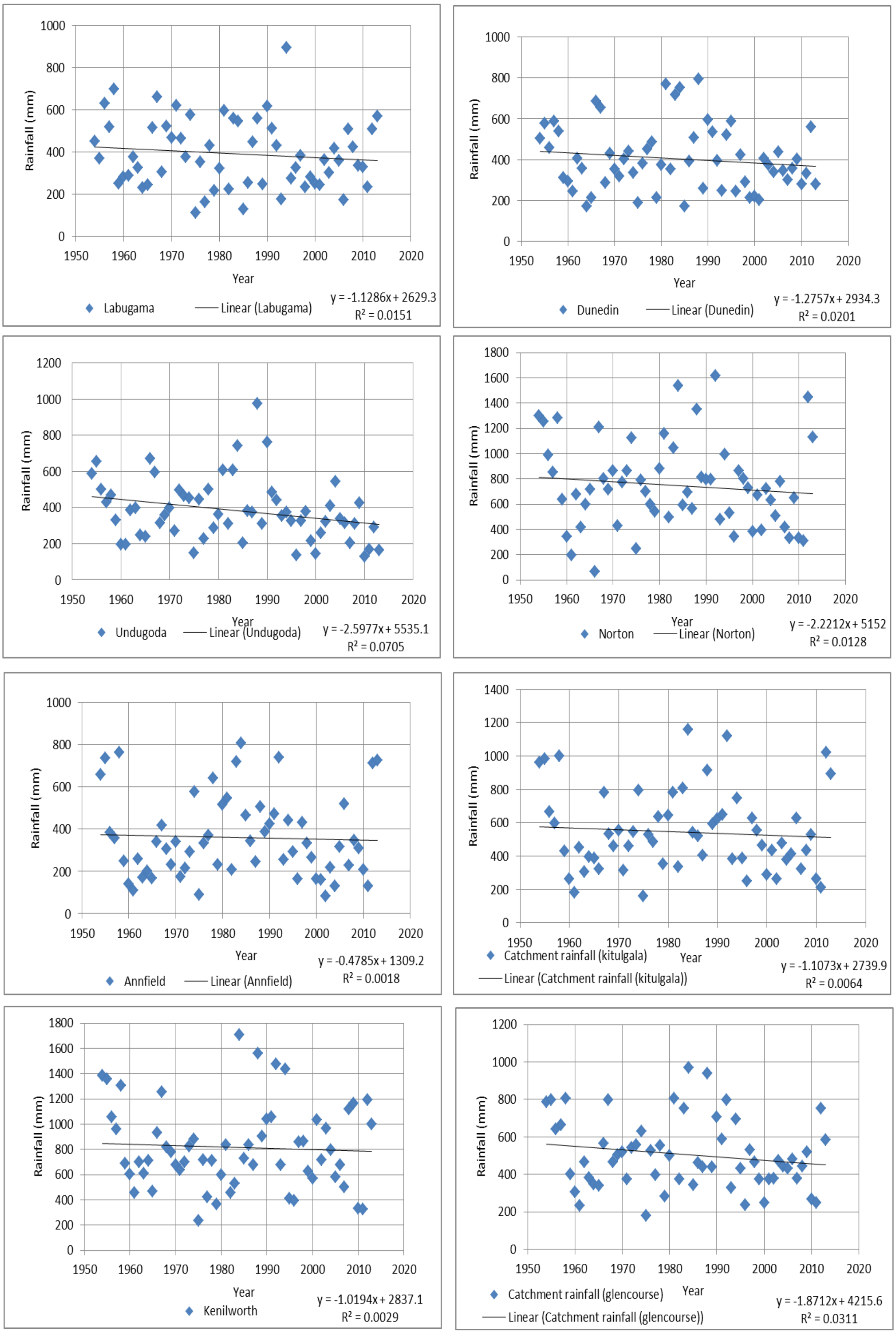


Figure C-0-98 May Trends in point rainfall stations

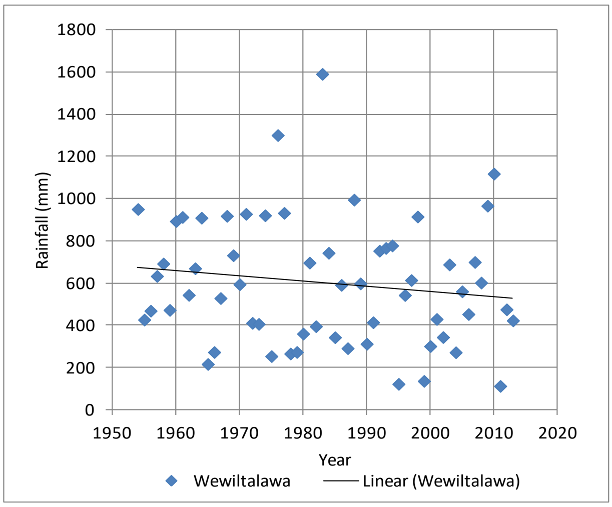
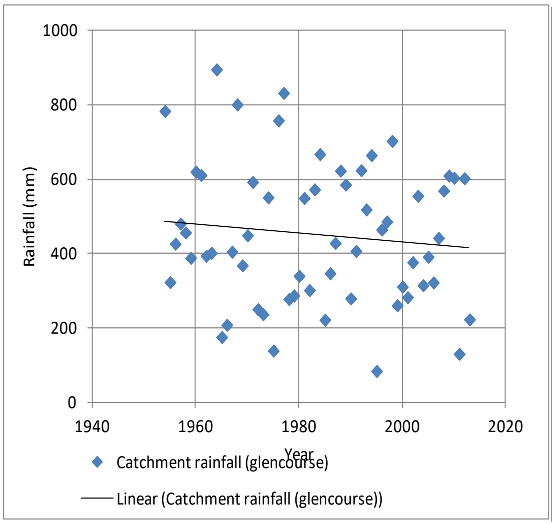


Figure C-0-99 May Trends in point rainfall stations



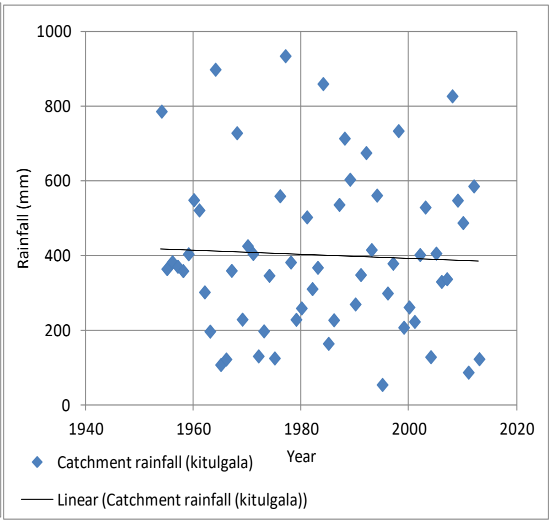
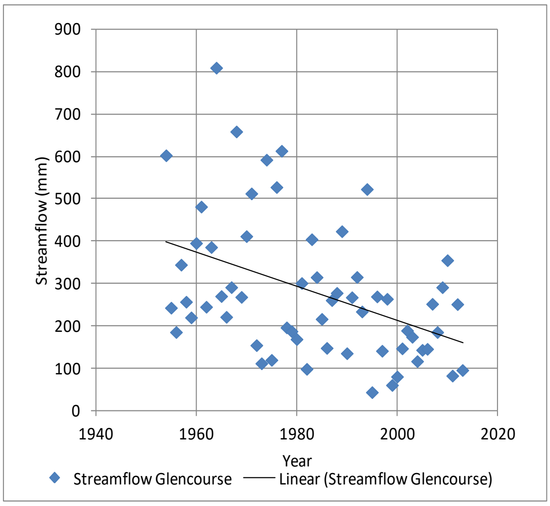


Figure C-0-100 May Trends in catchment rainfall



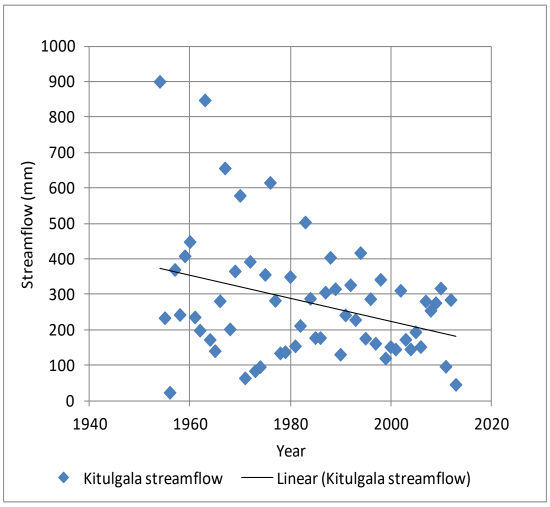


Figure C-0-101 May Trends in streamflow

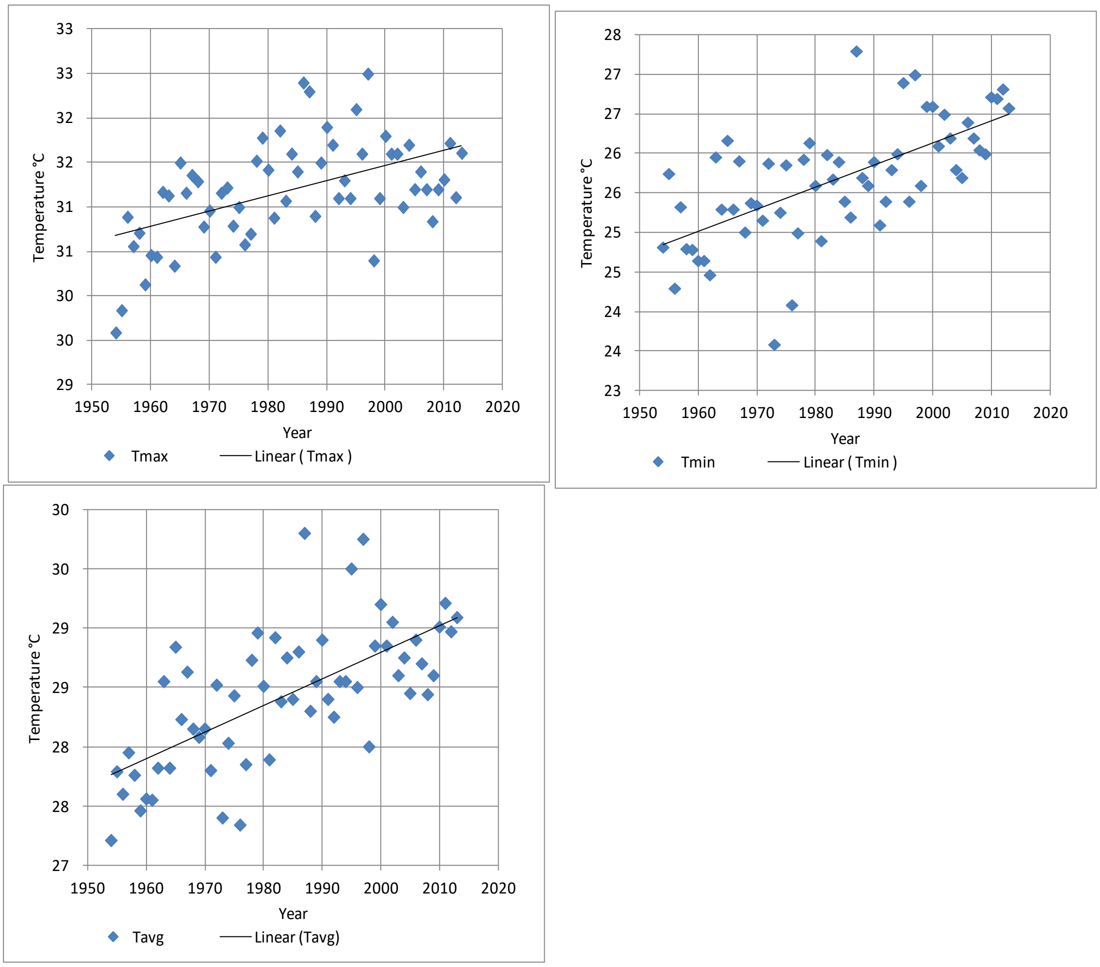


Figure C-0-102 May Trends in temperature

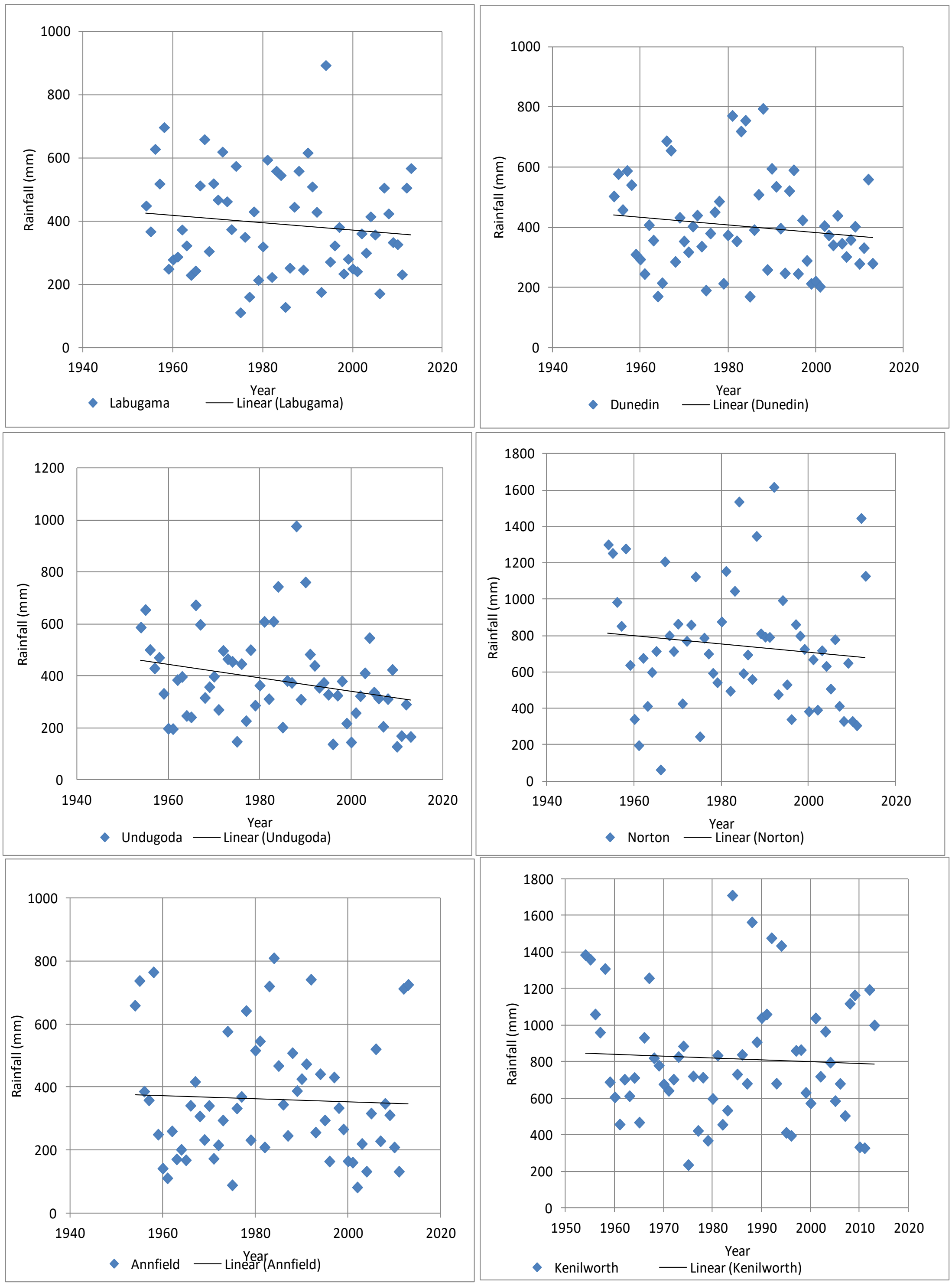


Figure C-0-103 June Trends in point rainfall station

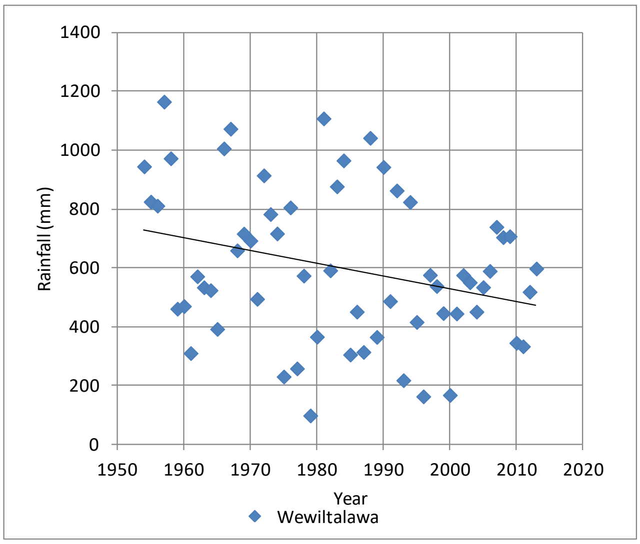
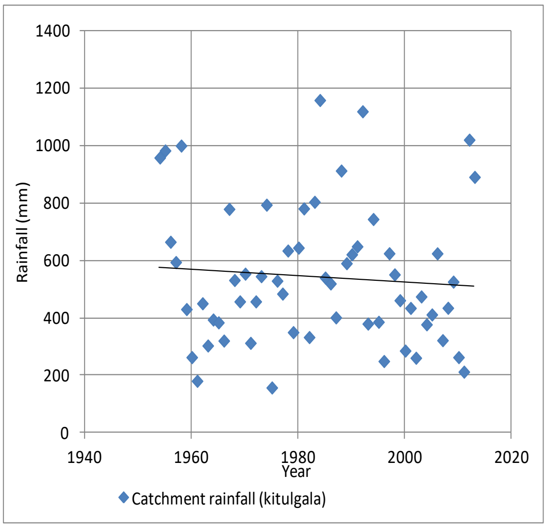


Figure C-0-104 June Trends in point rainfall station



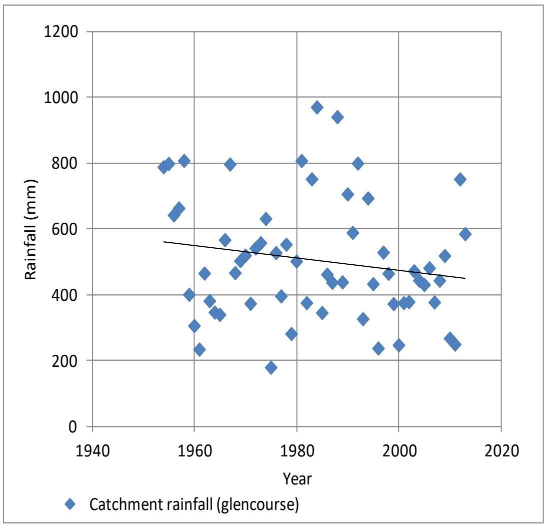
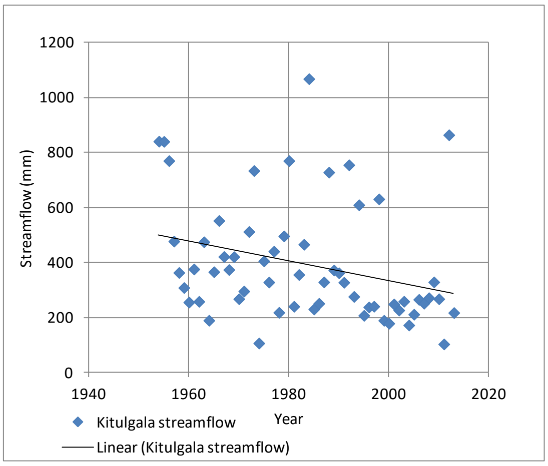


Figure C-0-105 June Trends in catchment rainfall



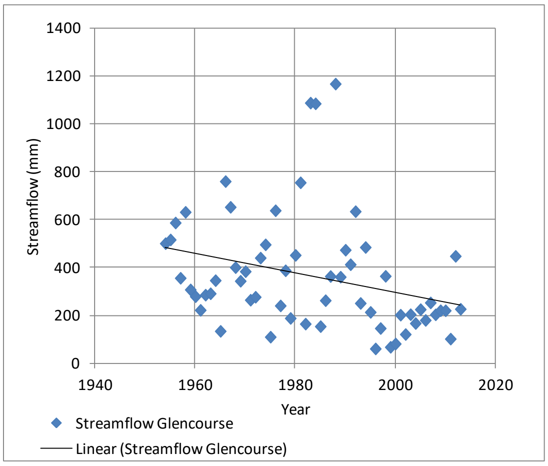


Figure C-0-106 June Trends in streamflow

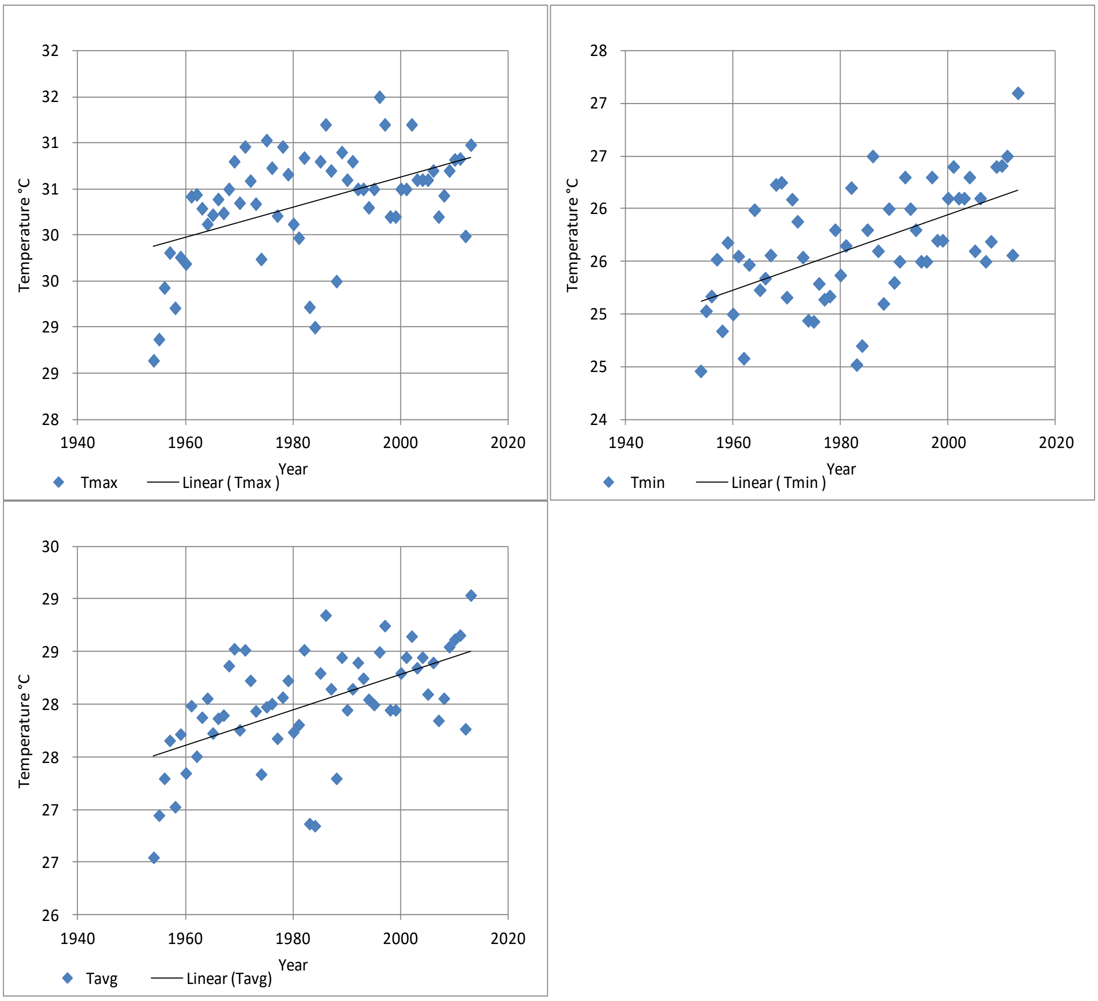


Figure C-0-107 June Trends in temperature

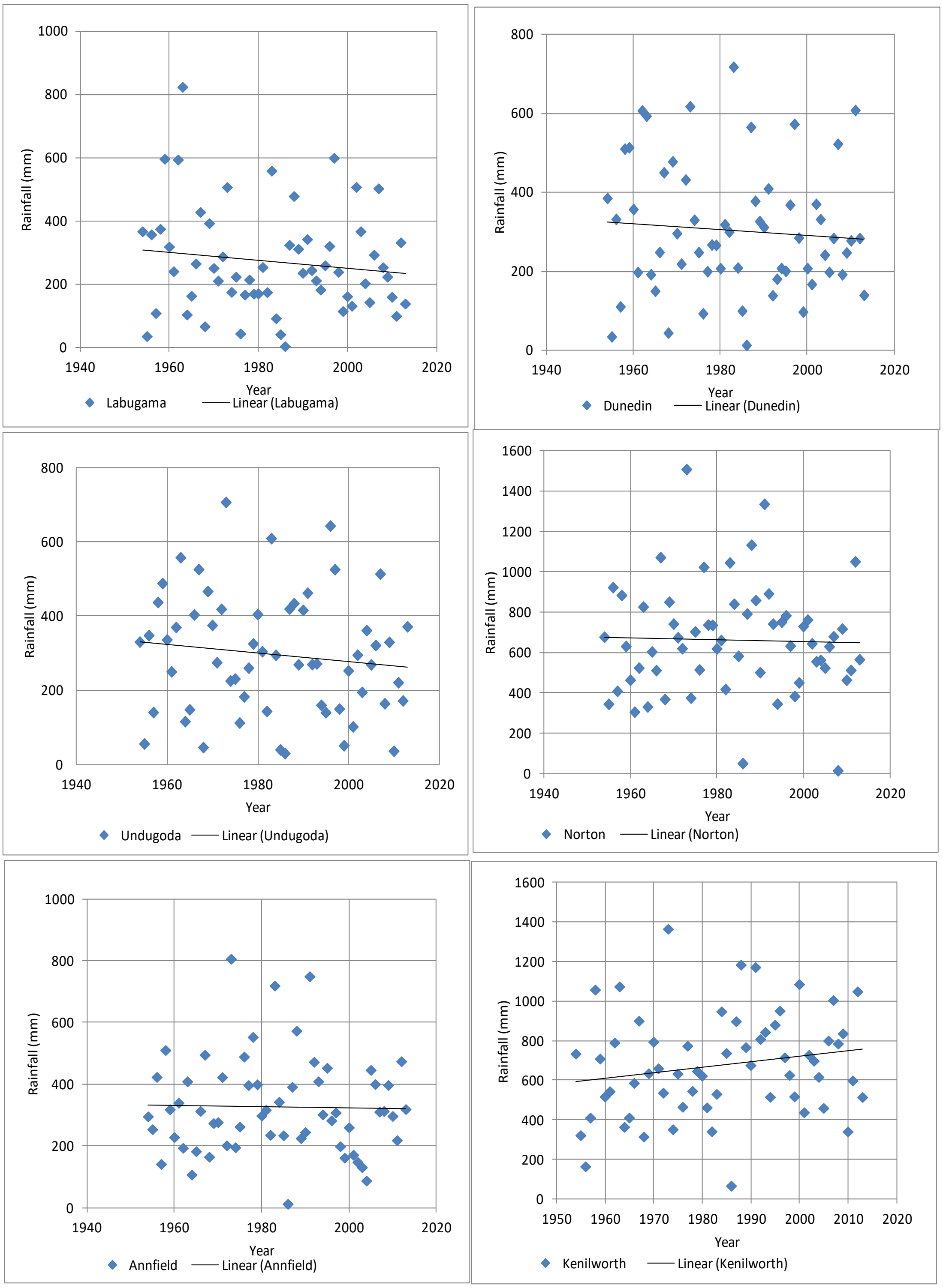


Figure C-0-108 July Trends in point rainfall

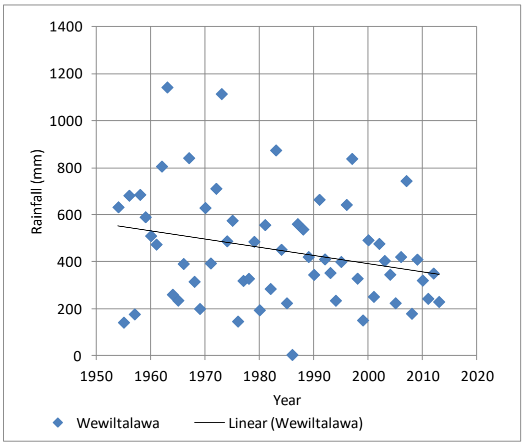
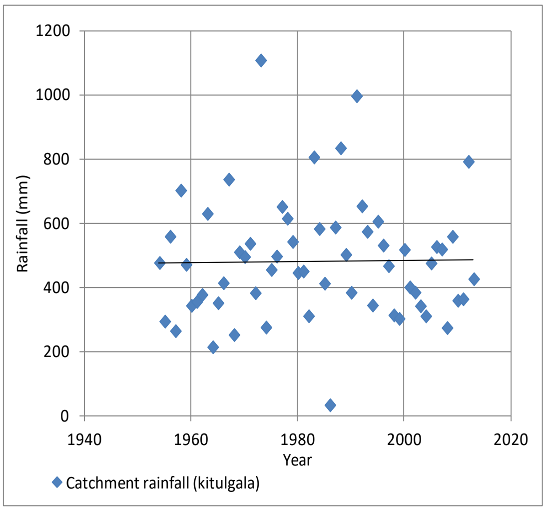


Figure C-0-109 July Trends in point rainfall



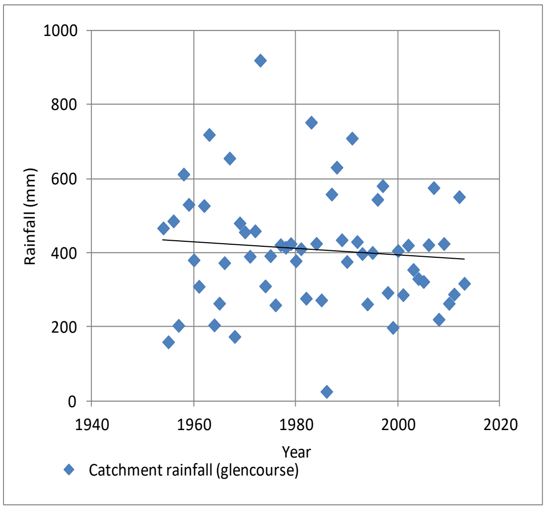
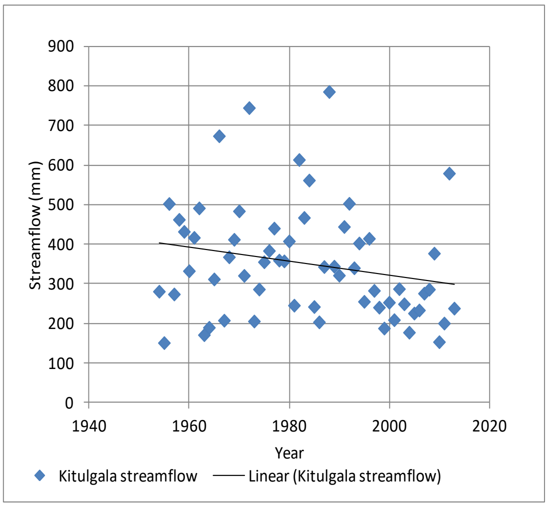


Figure C-0-110 July Trends in catchment rainfall



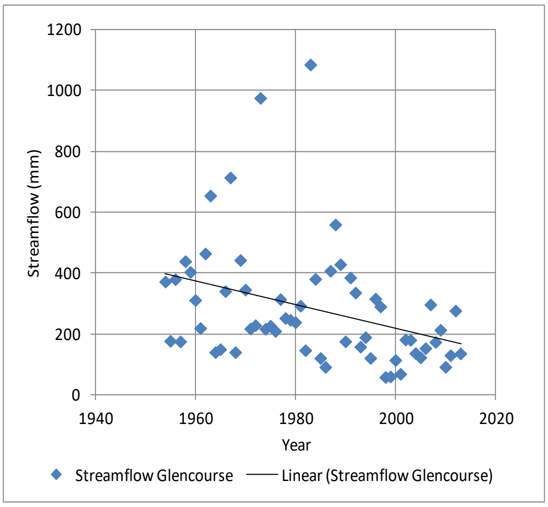


Figure C-0-111 July Trends in streamflow

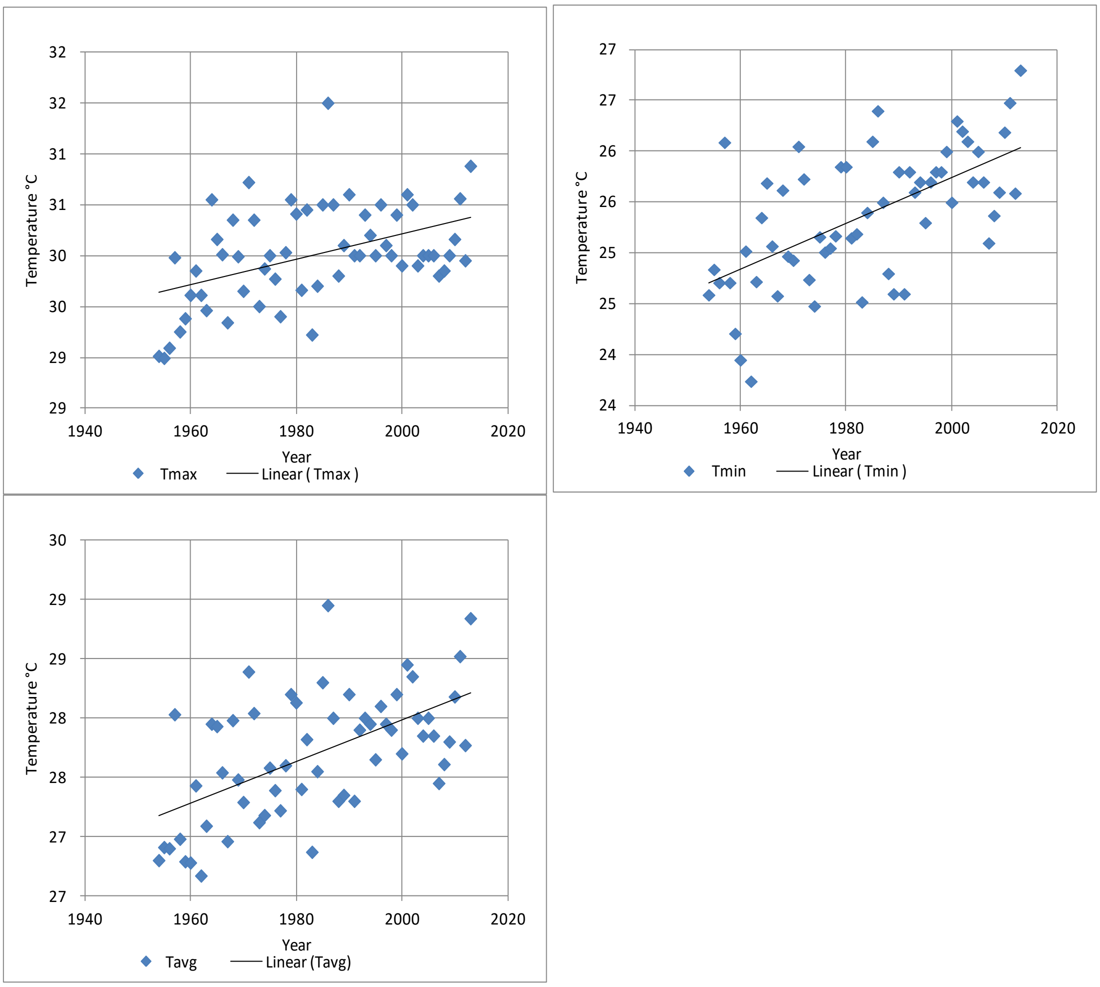


Figure C-0-112 July Trends in Temperature

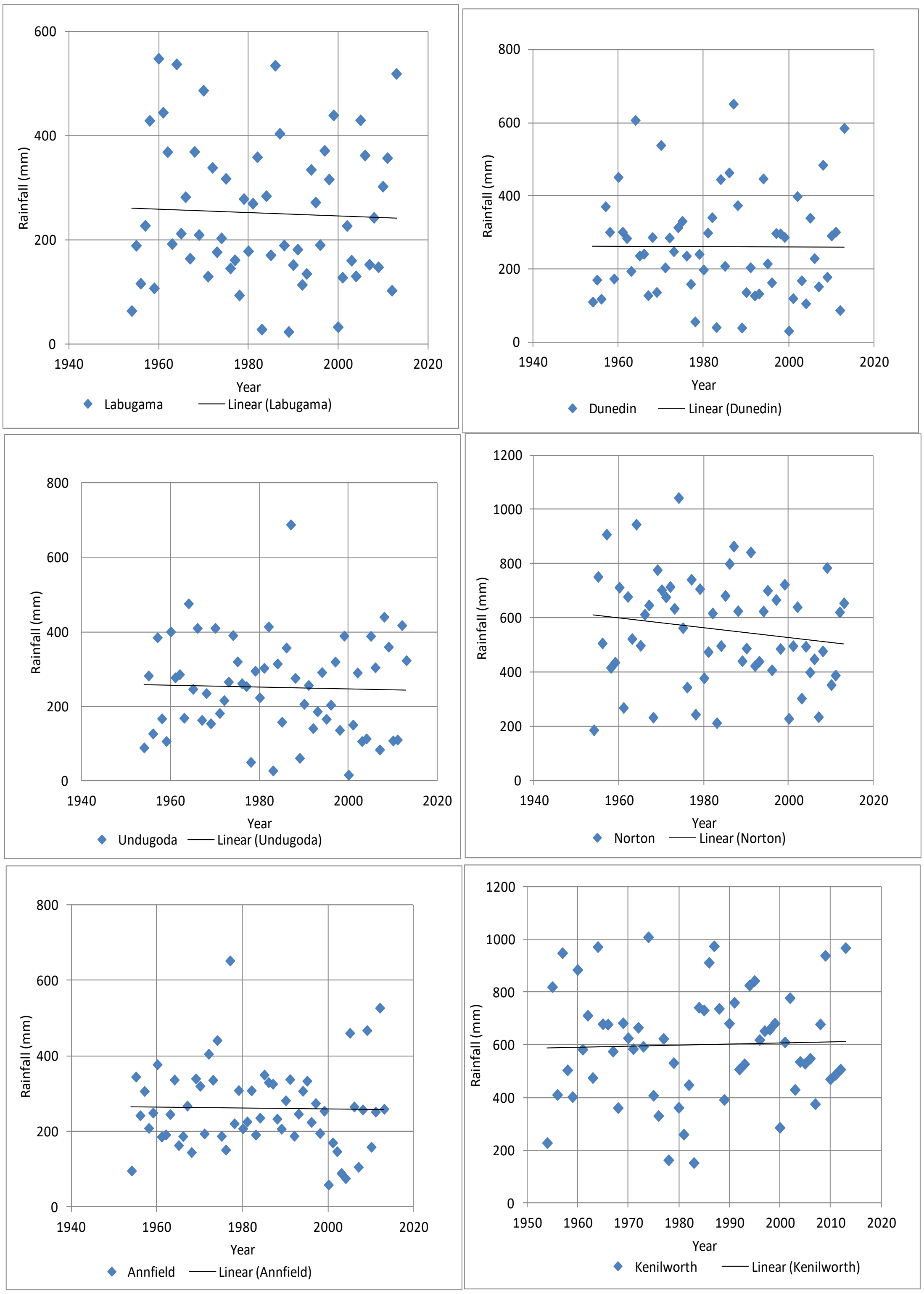


Figure C-0-113 August trend in point rainfall

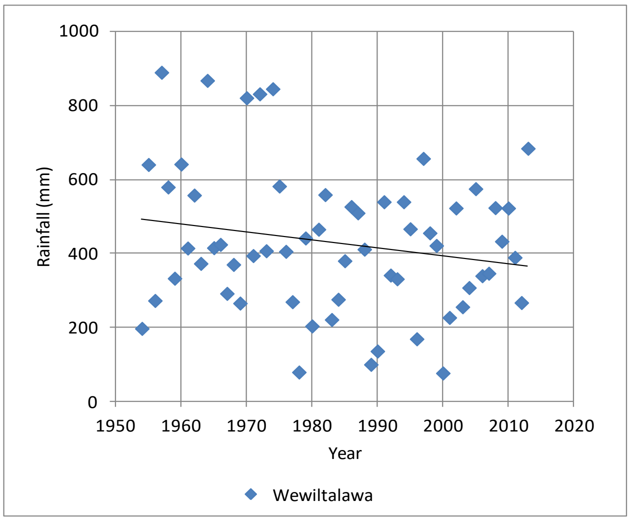
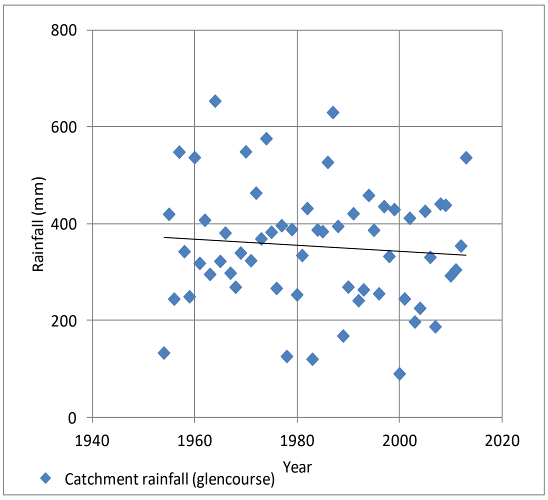


Figure C-0-114 August trend in point rainfall



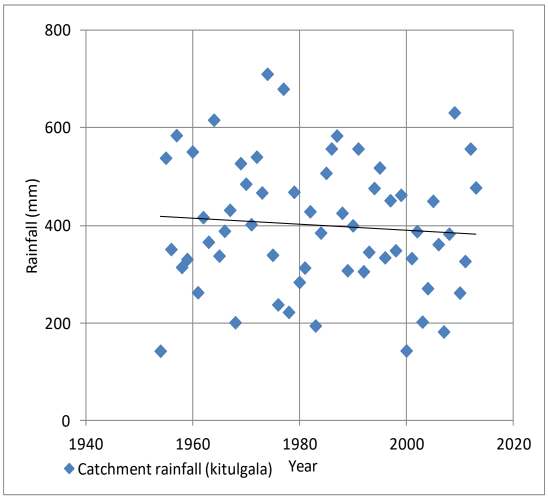
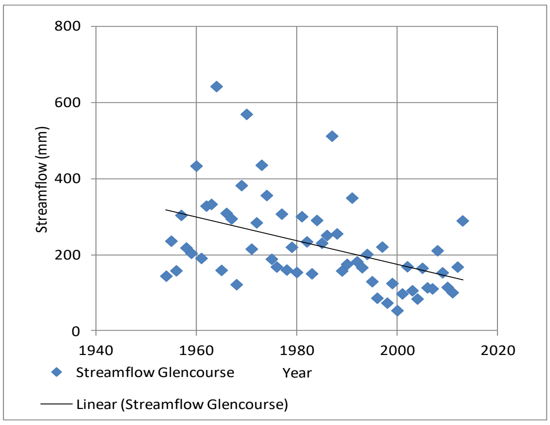


Figure C-0-115 August trend in catchment rainfall



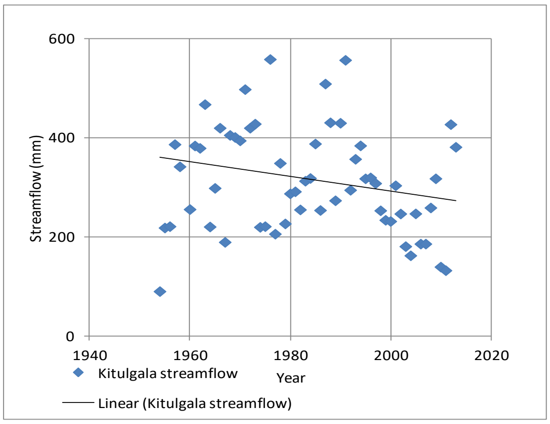


Figure C-0-116 August trend in streamflow

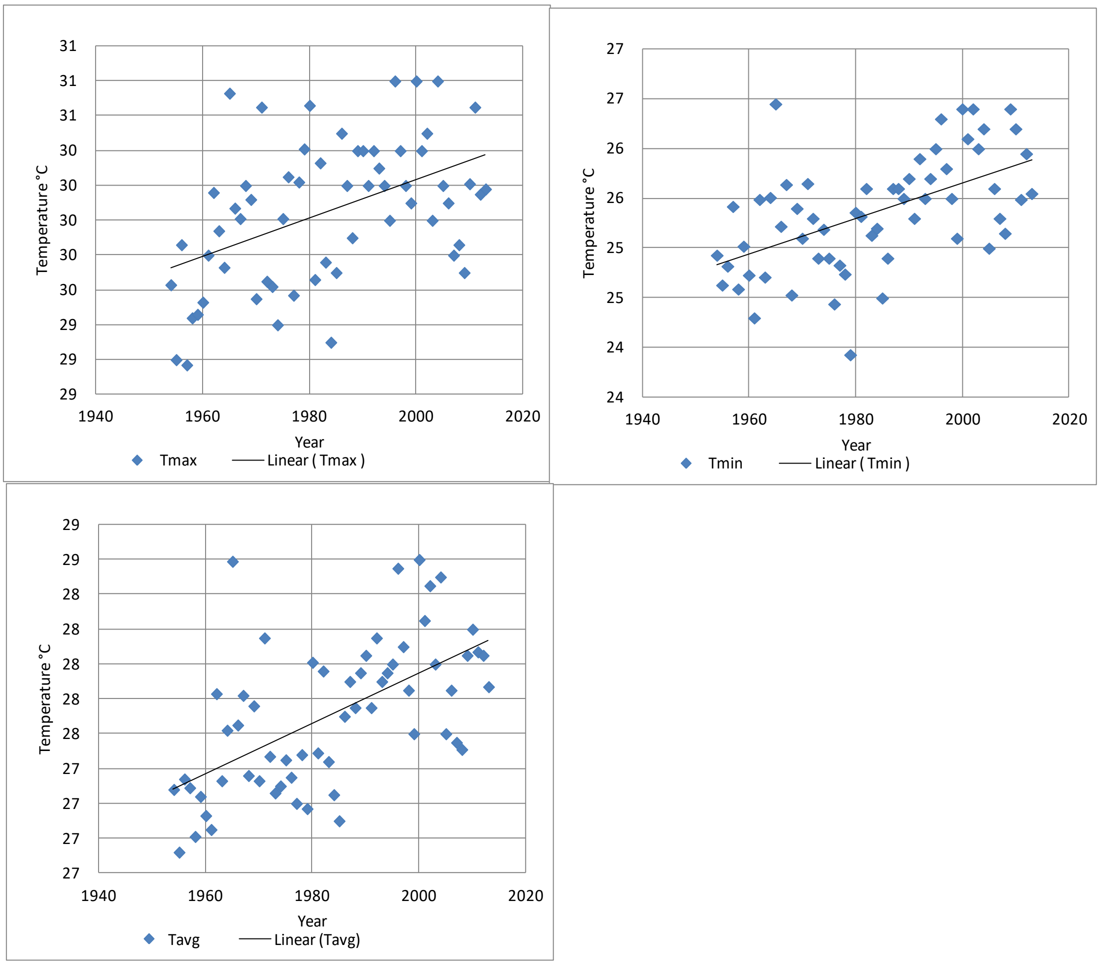


Figure C-0-117 August trend in temperature

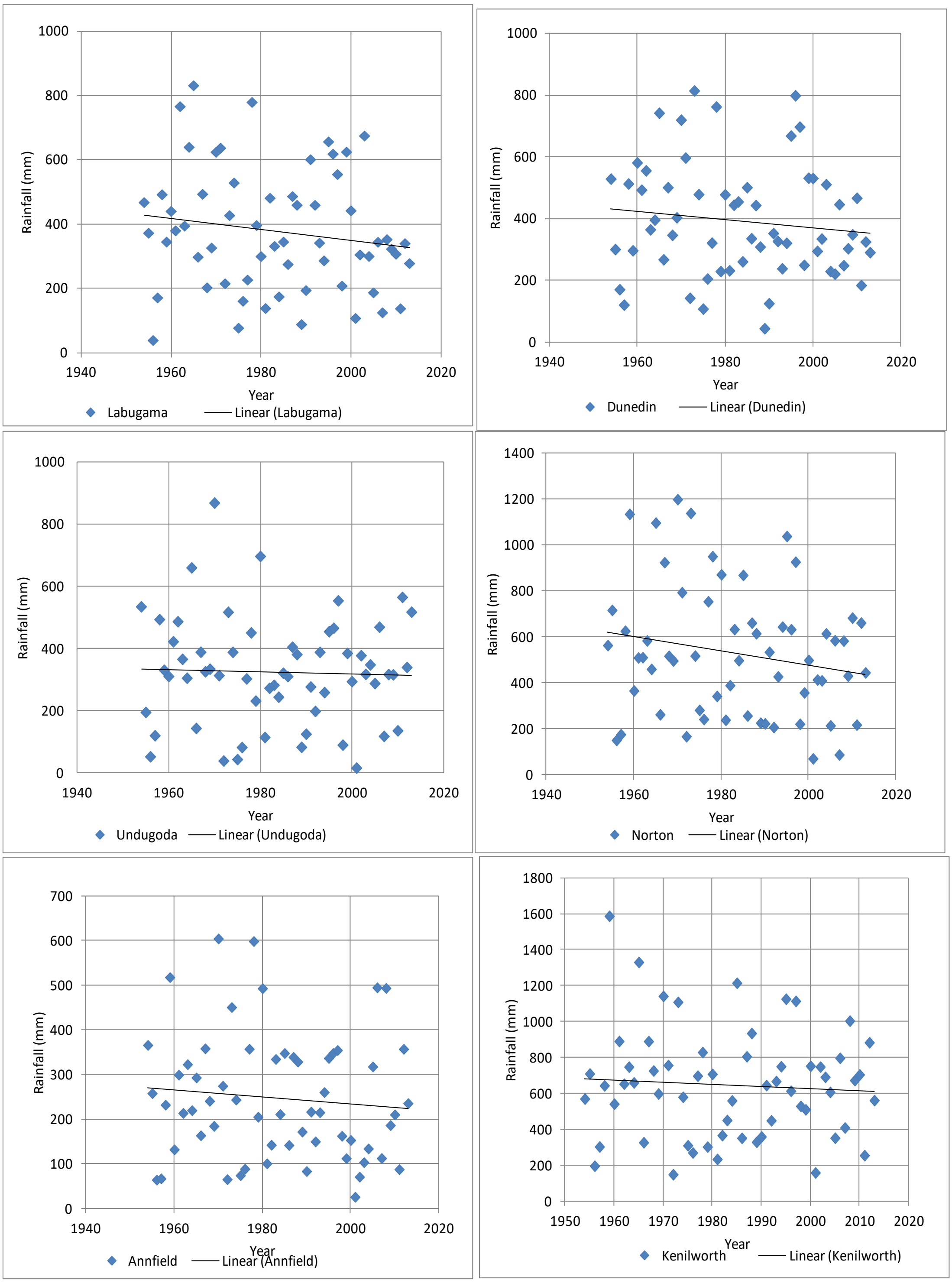


Figure C-0-118 September Trends in point rainfall

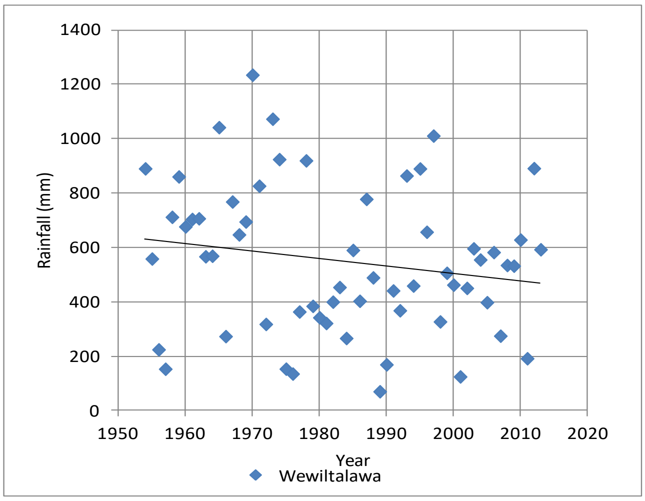
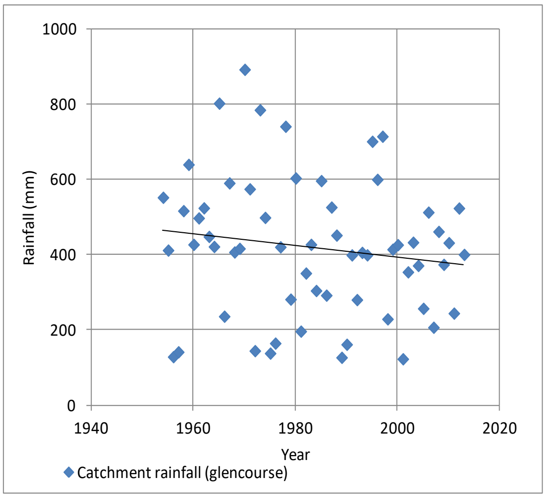


Figure C-0-119 September Trends in point rainfall



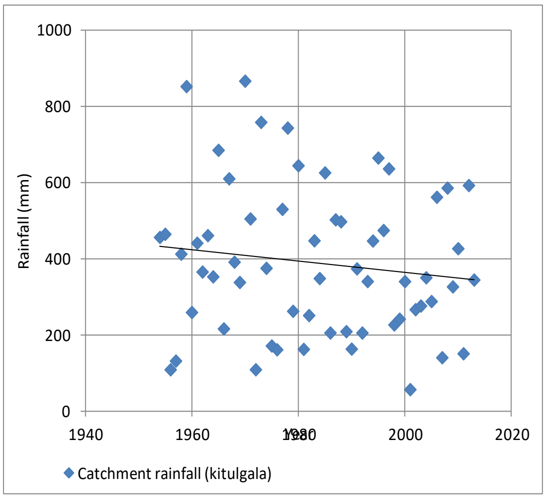
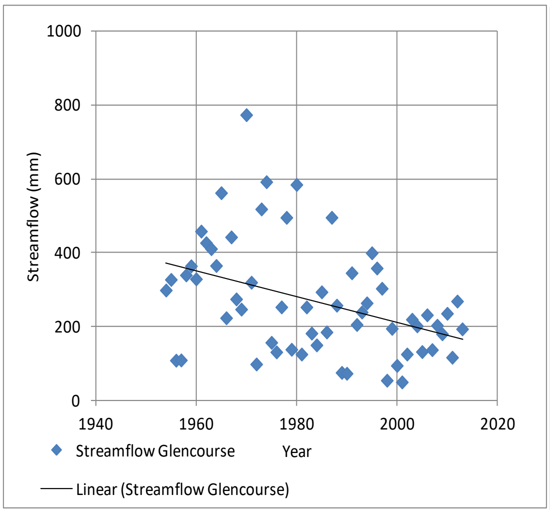


Figure C-0-120 September Trends in catchment rainfall



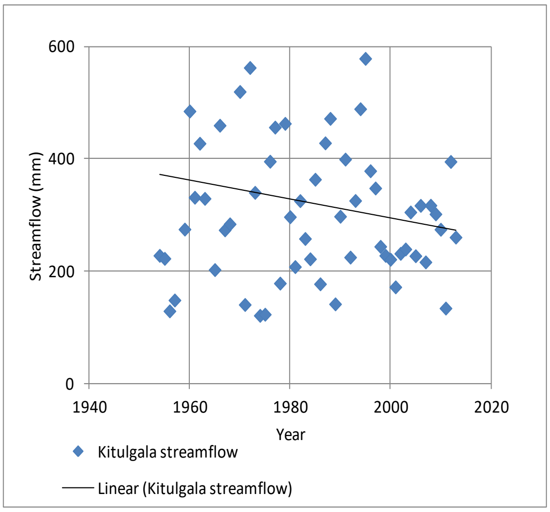


Figure C-0-121 September Trends in streamflow

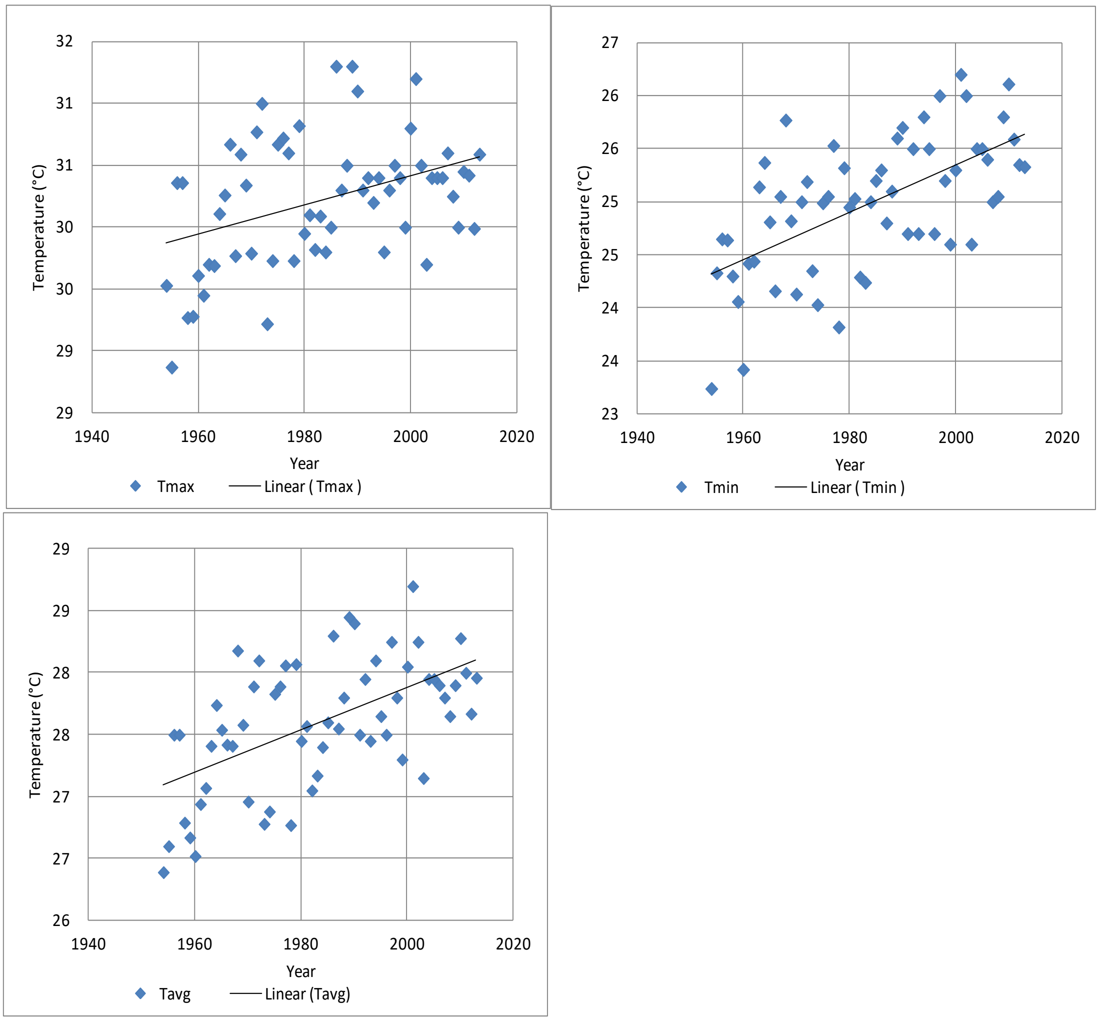


Figure C-0-122 September Trends in Temperature

Annual trends from 1954 to 2015

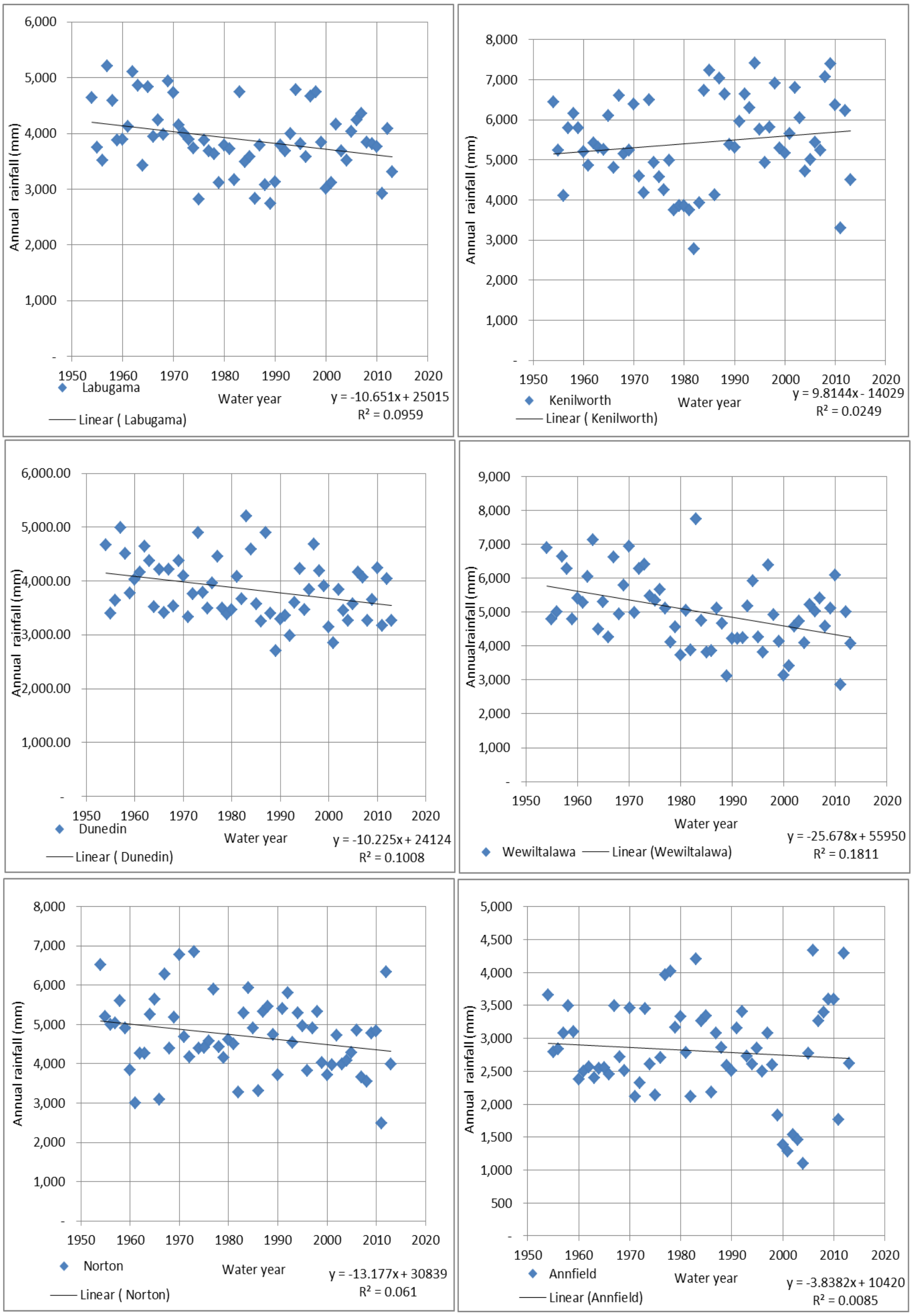


Figure C-0-123 Annual Trends

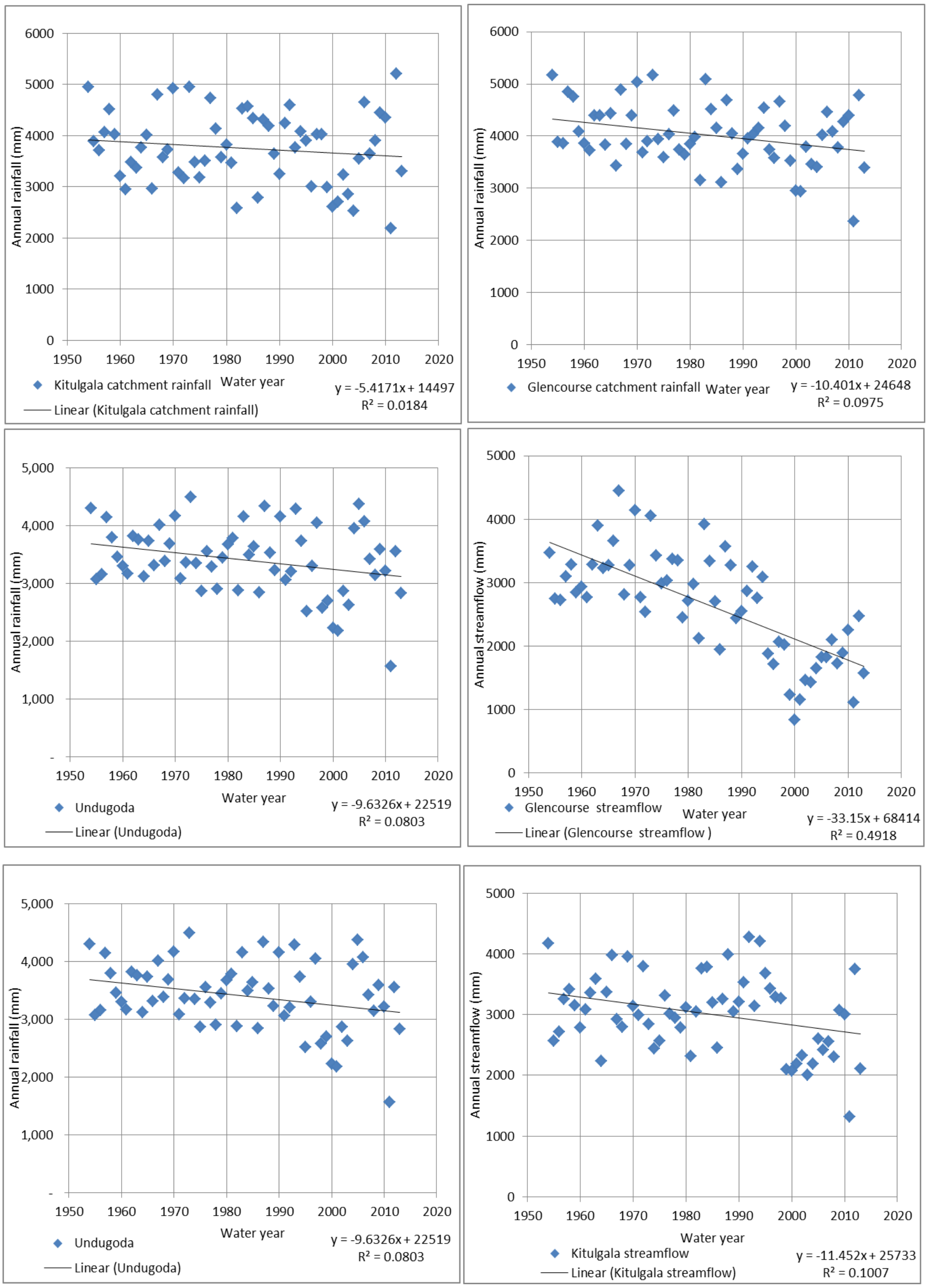


Figure C-0-124 Annual Trends

Seasonal Trends (Maha and Yala)

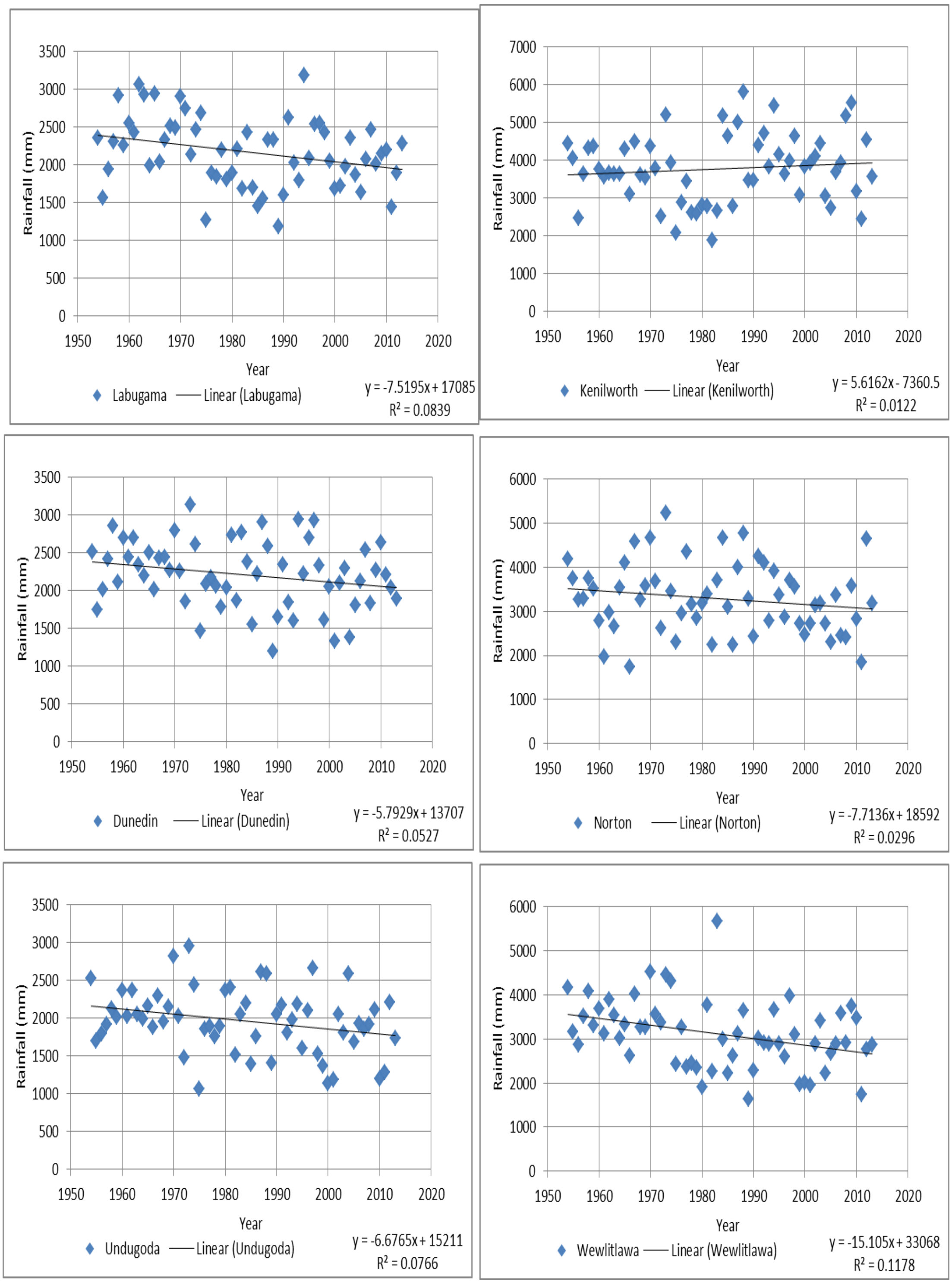


Figure C-0-125 Yala Trends

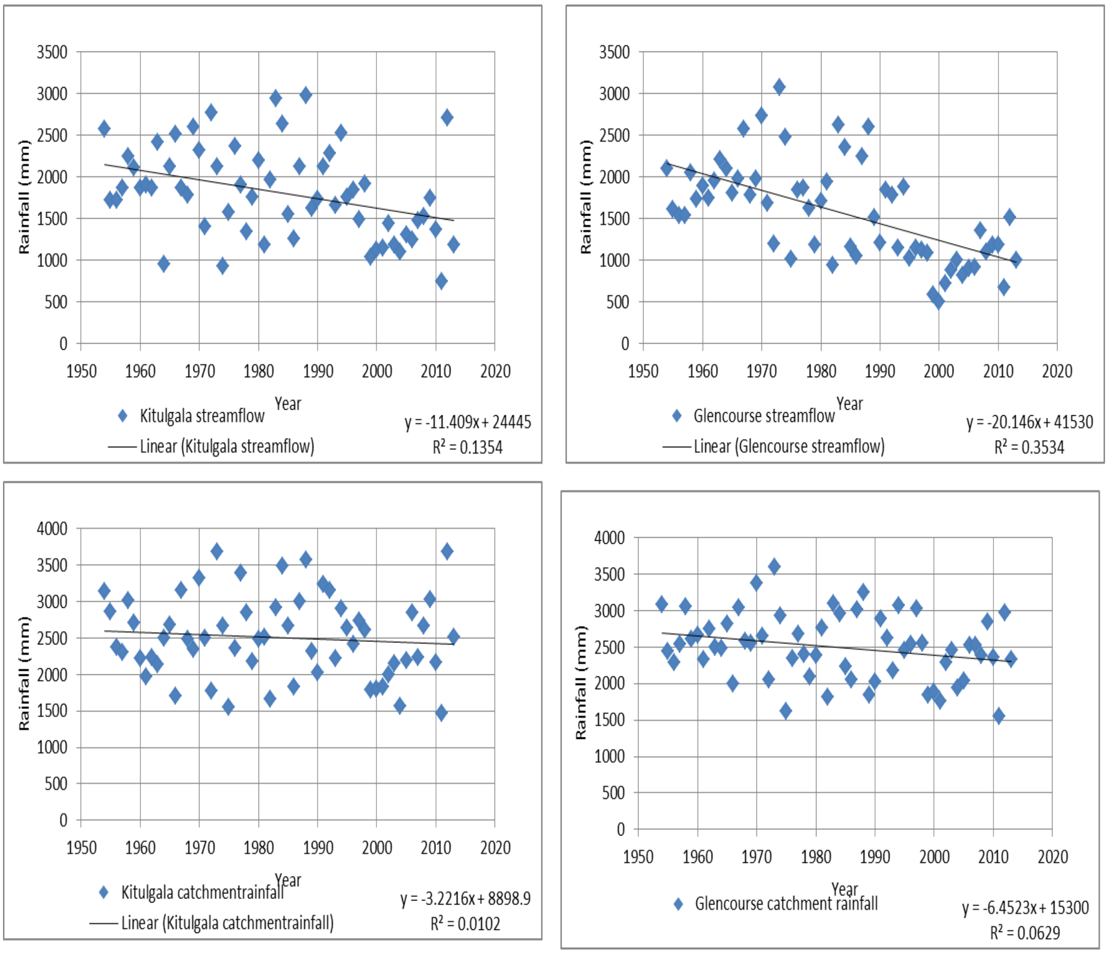


Figure C-0-126 Yala Trends

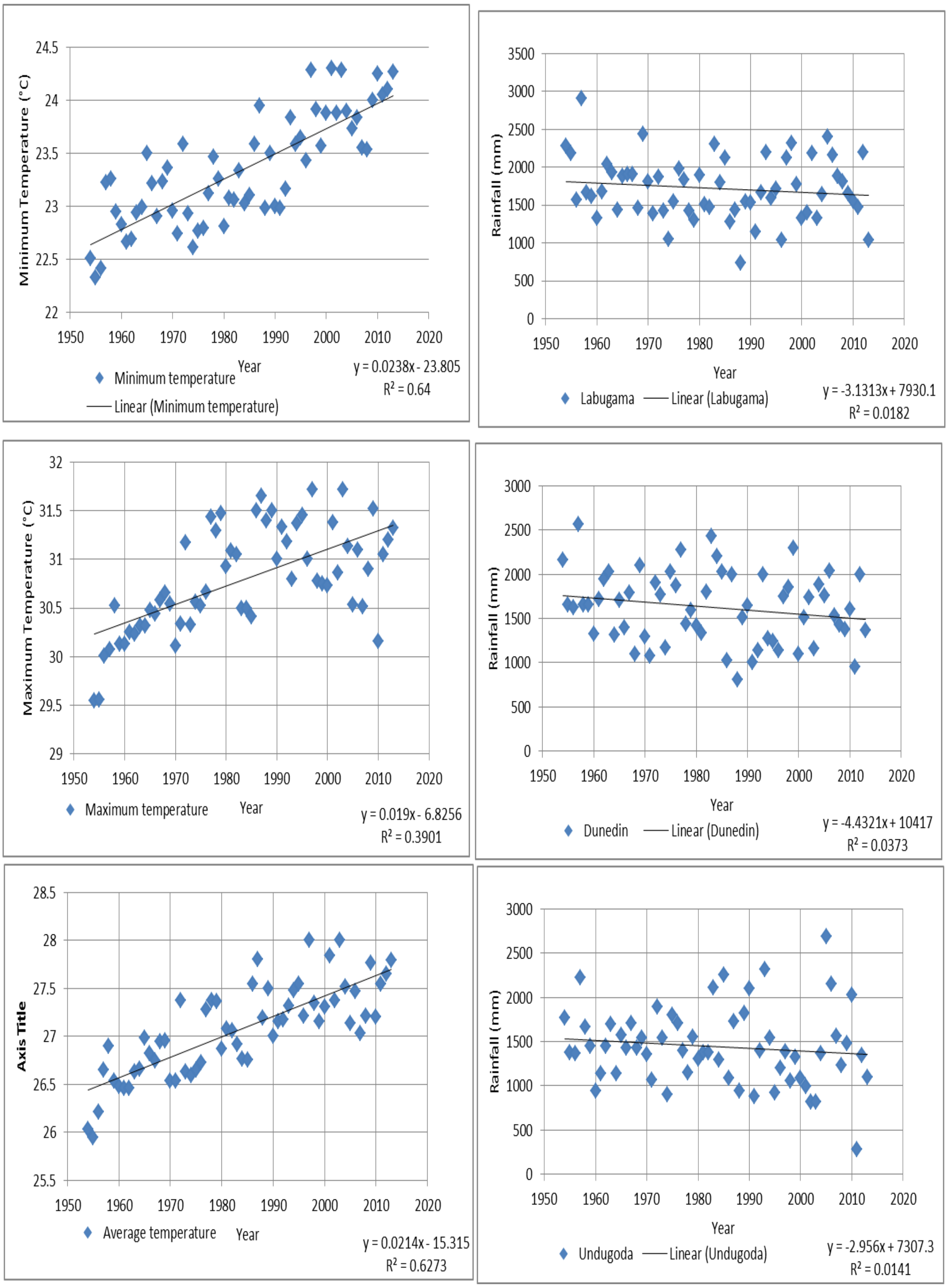


Figure C-0-127 Maha Trends

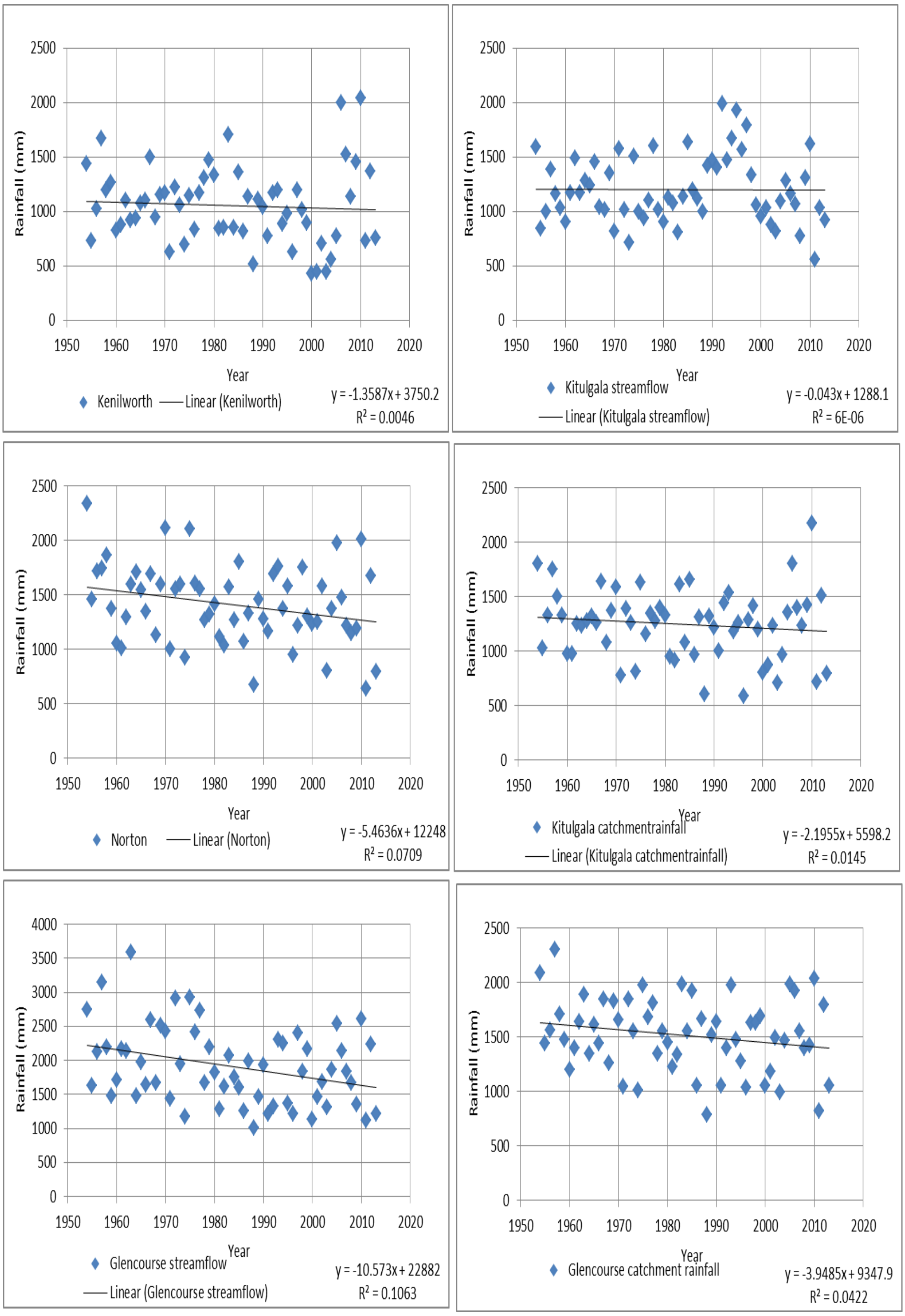
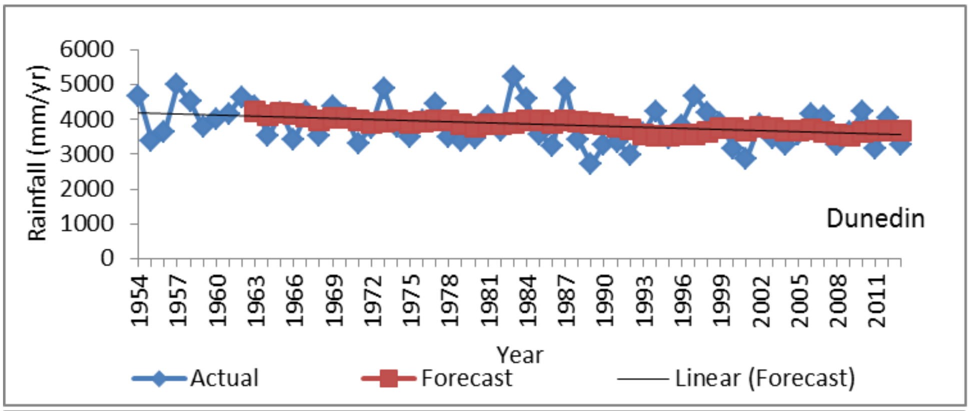
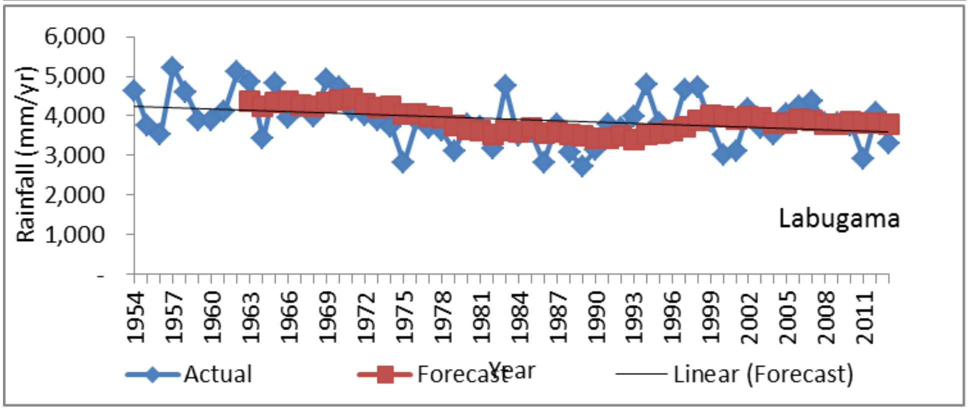
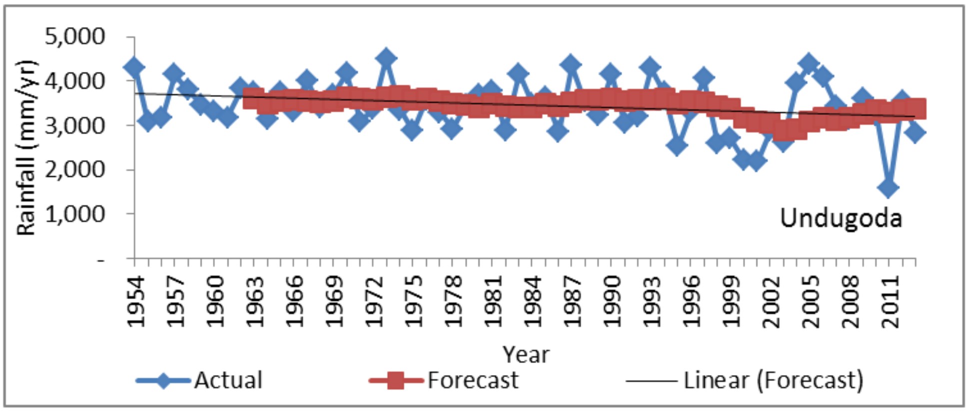


Figure C-0-128 Maha Trends

Appendix D Moving Average Trends







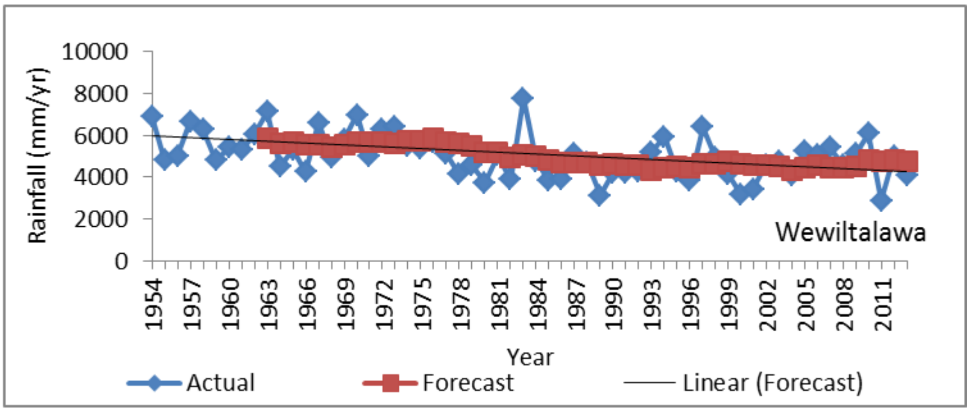


Figure D -0-1 10 Year Annual Moving Average Trends (Point Rainfall)

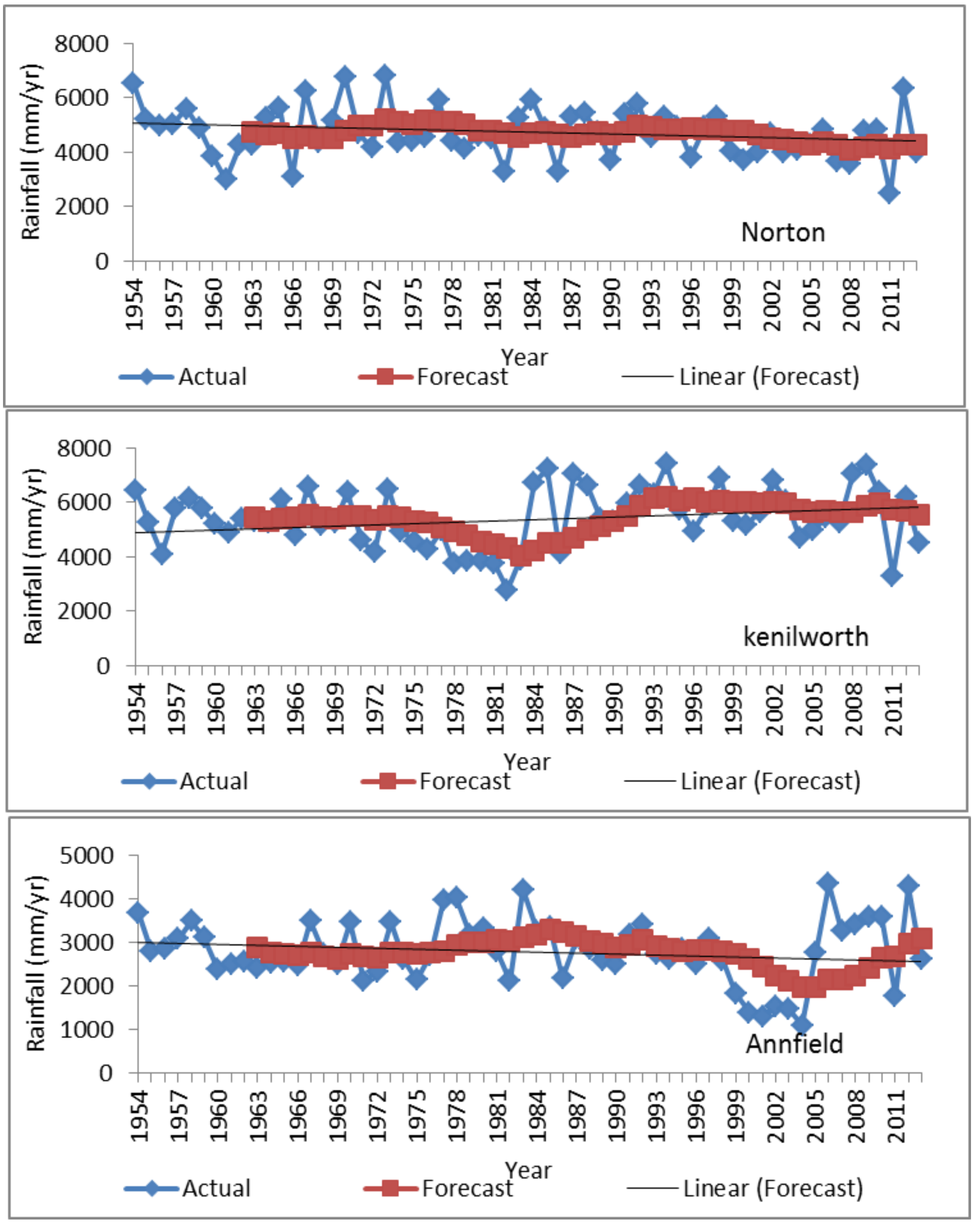
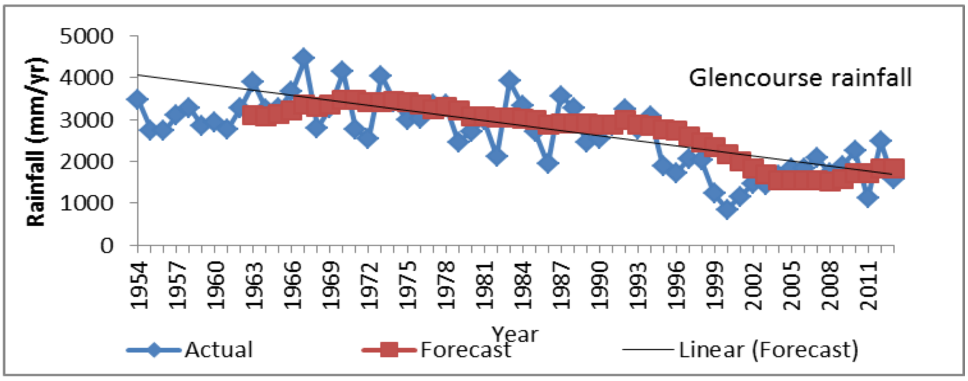


Figure D-0-2 10 Year Annual Moving Average Trends (Point Rainfall)



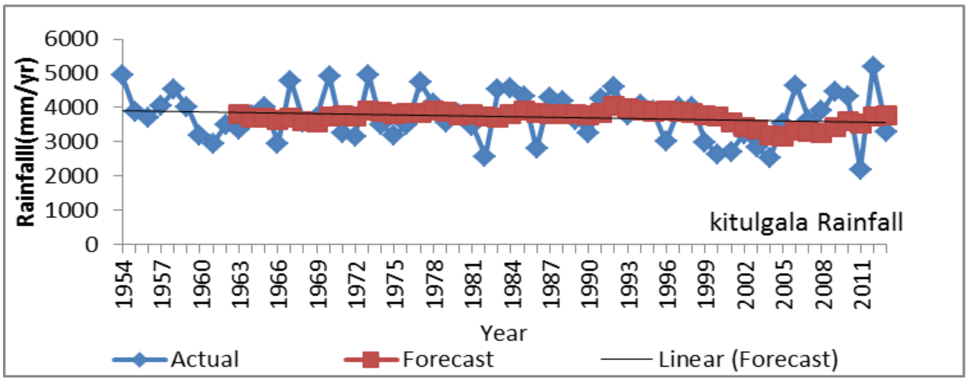
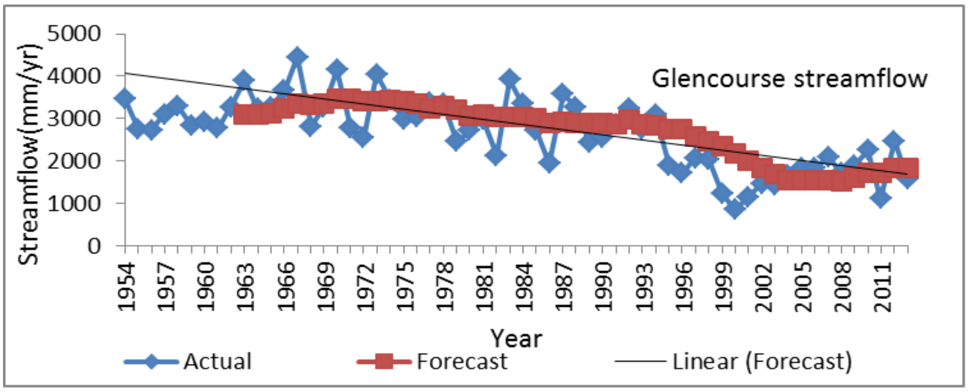


Figure D-0-3 Moving Average Trends (Catchment Rainfall)



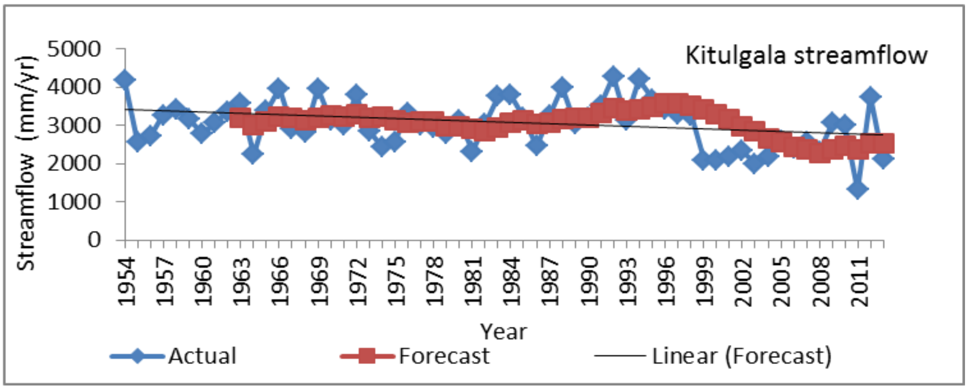


Figure D-0-4 10 Year Annual Moving Average Trends (Streamflow)

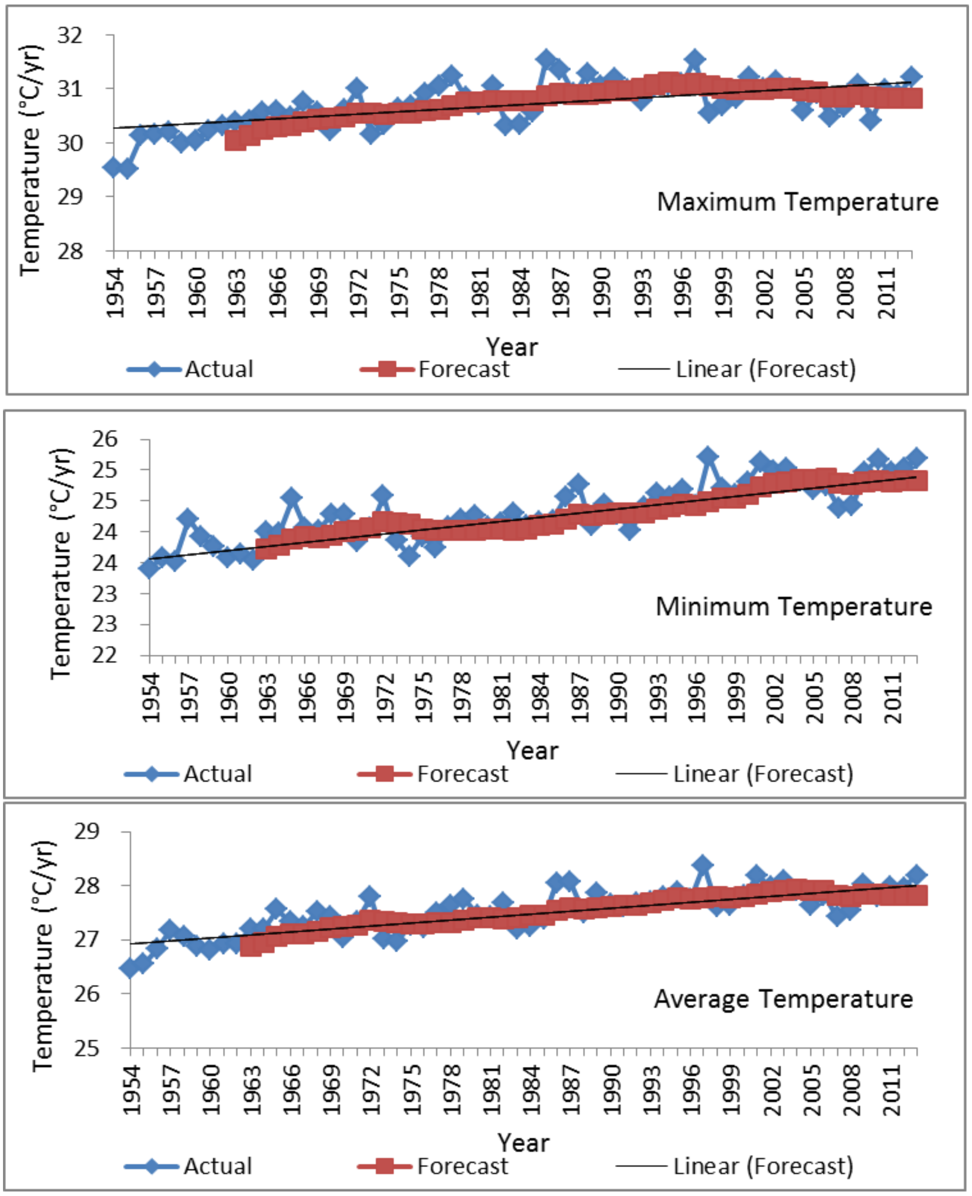


Figure D-0-5 10 Year Annual Moving Average Trends (Temperature)

Appendix E Base Period Trends

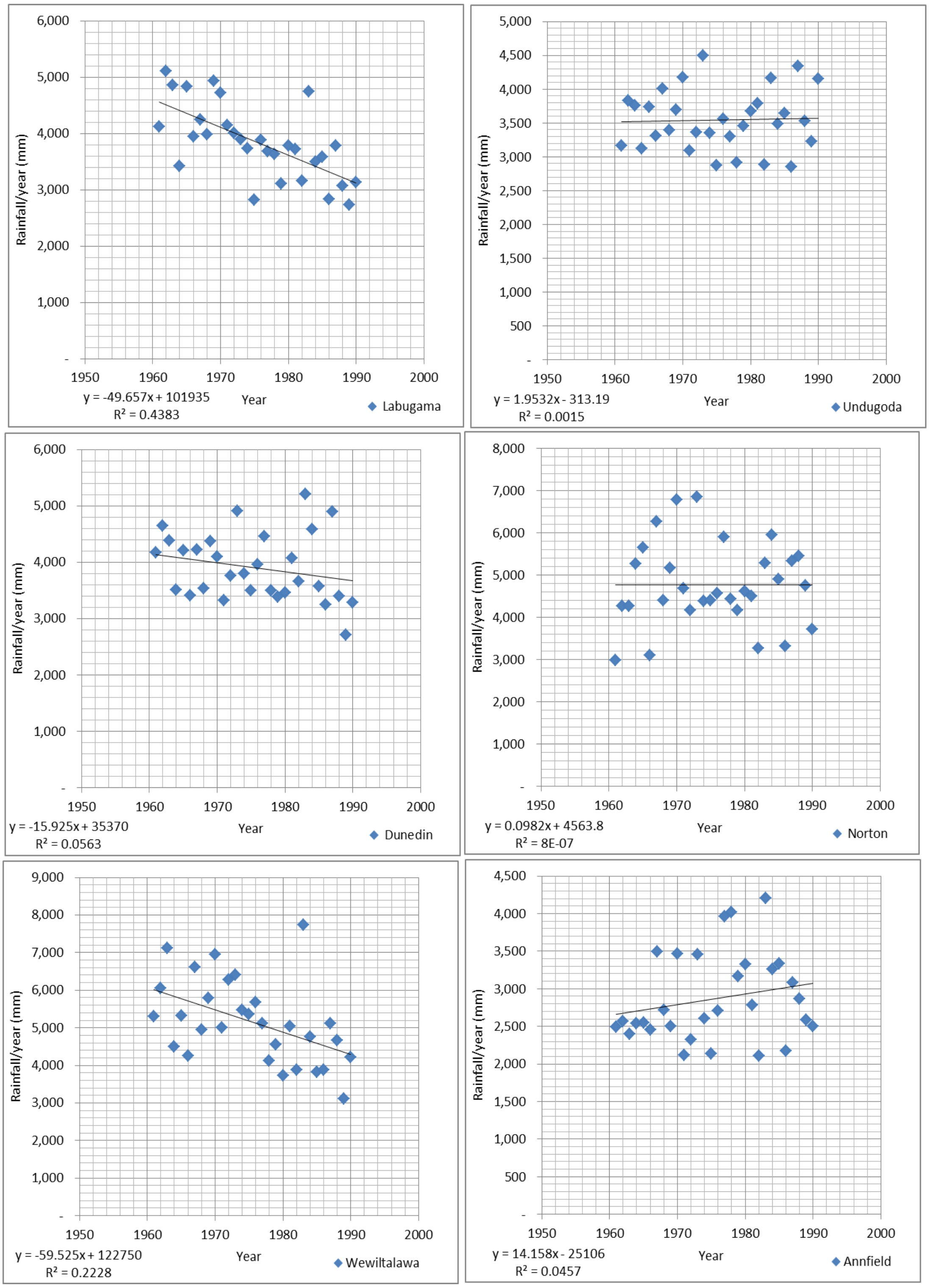


Figure E-0-1 Annual Rainfall Trends (1961-1990)

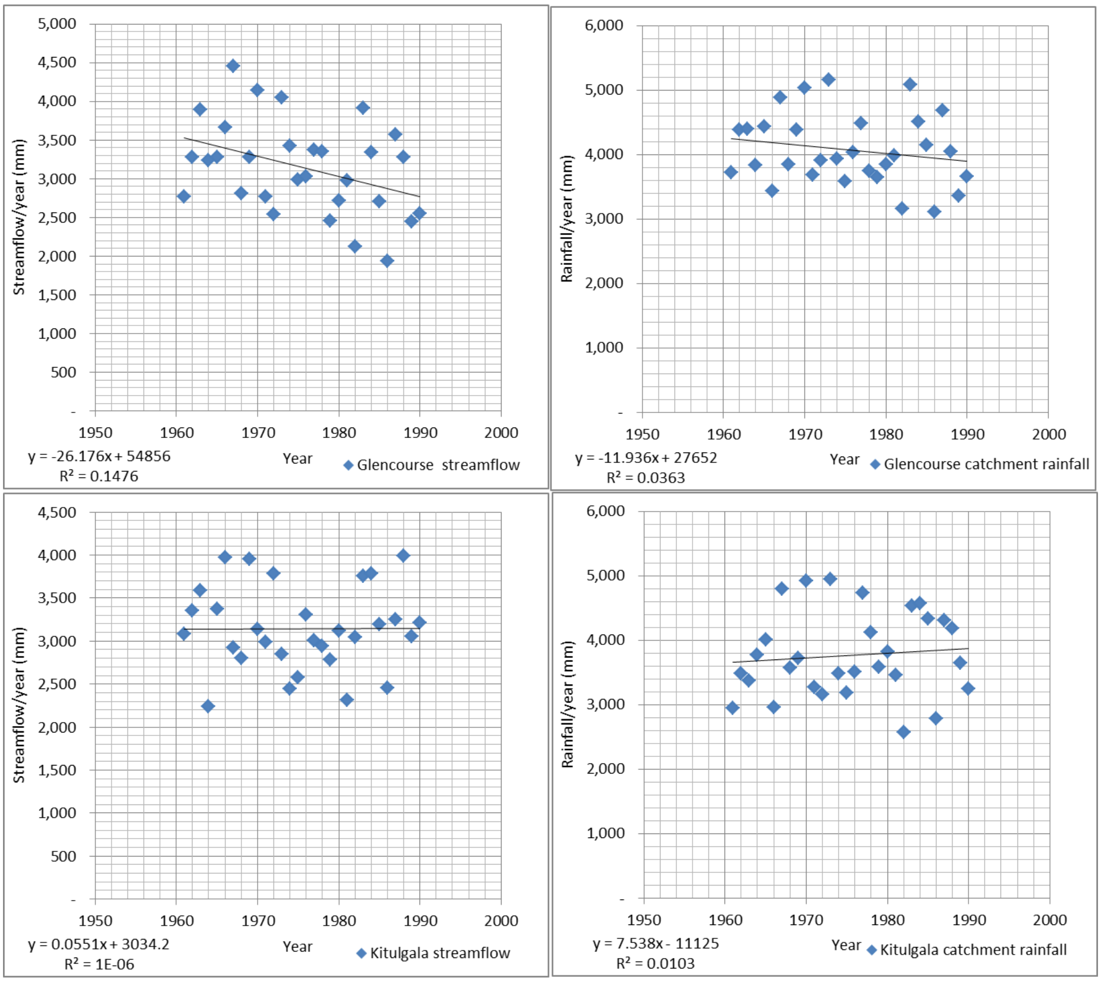


Figure E-0-2 Annual catchment rainfall and streamflow trends (1961-1990)

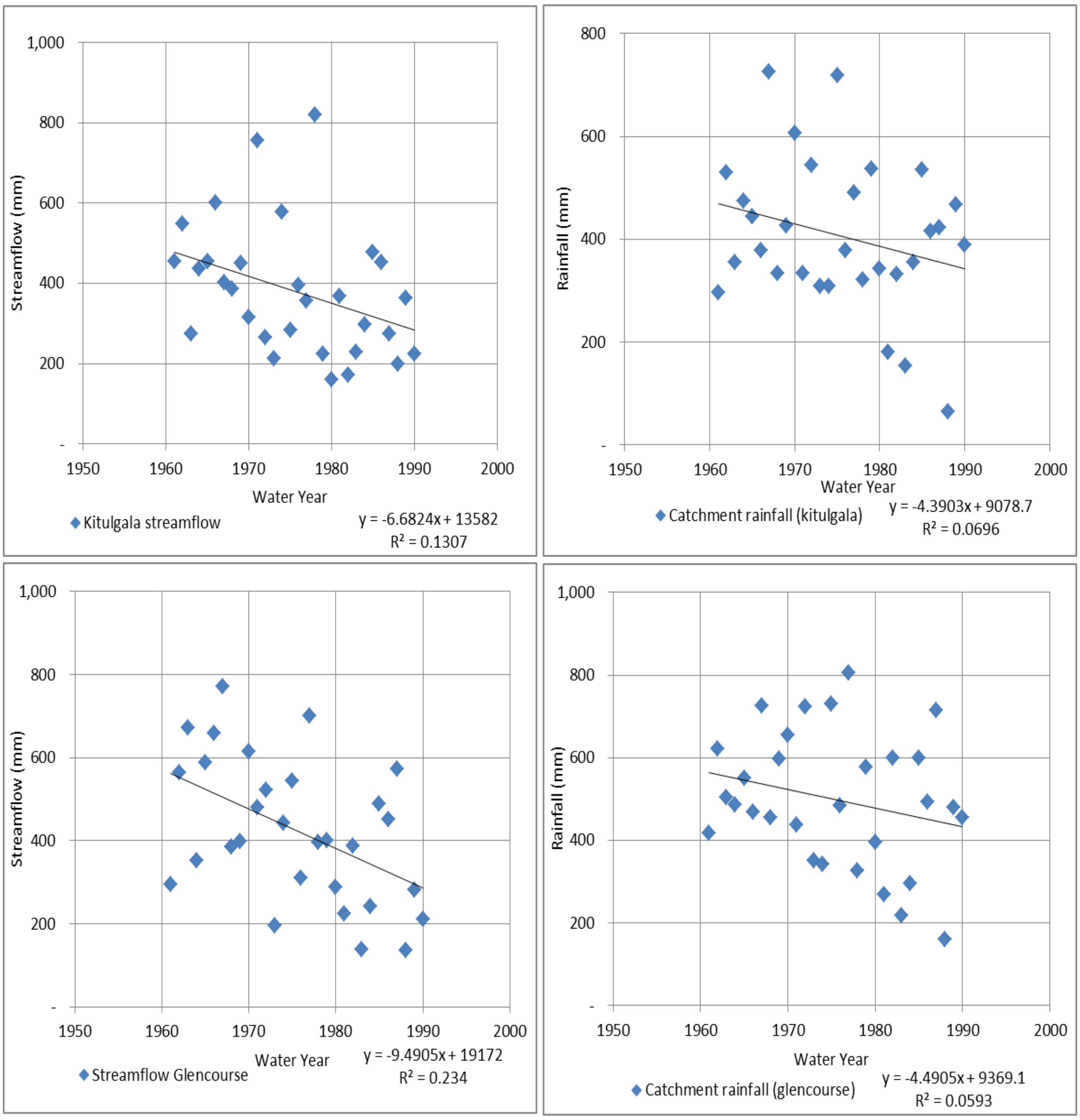


Figure E-0-3 October Catchment rainfall & streamflow trends (1961-1990)

Appendix F Trends (1983/84 – 2013/2014)

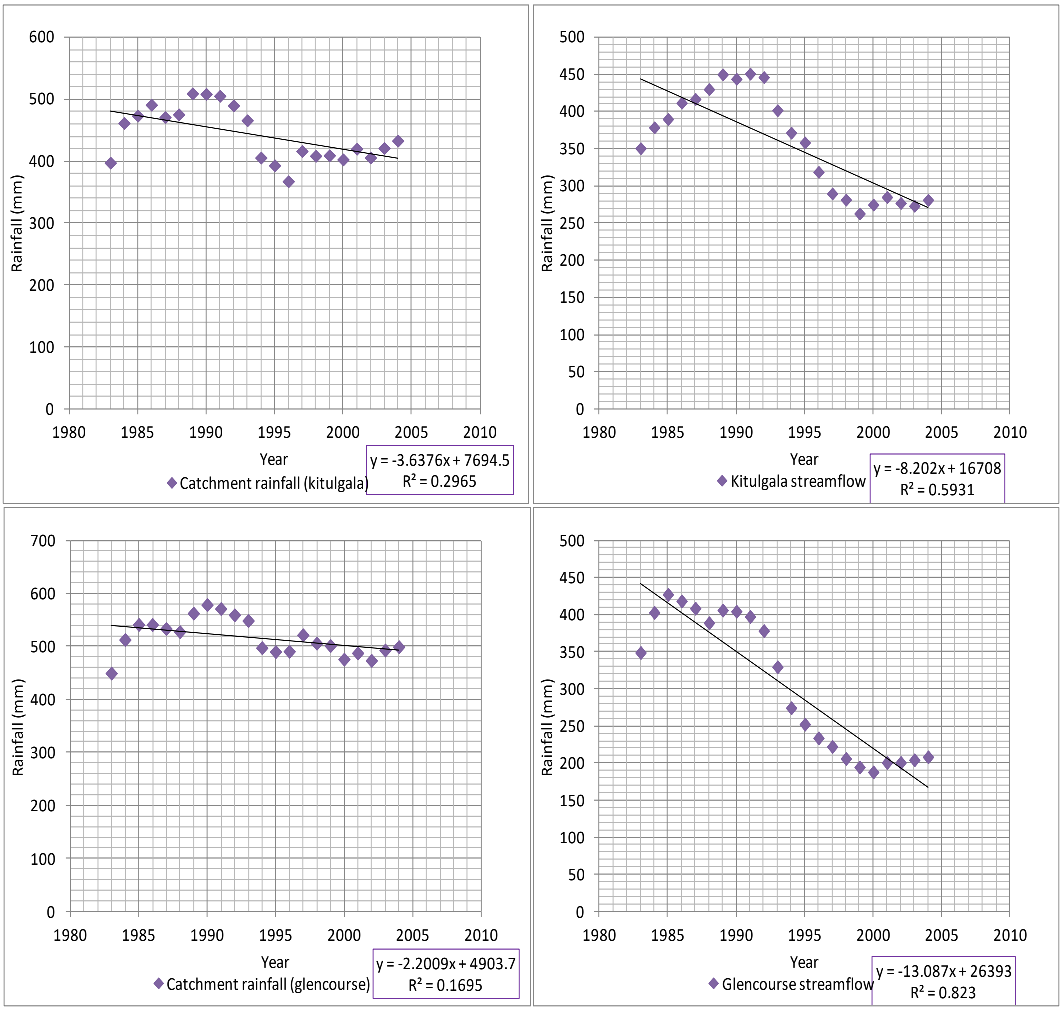


Figure F-0-1 October trends

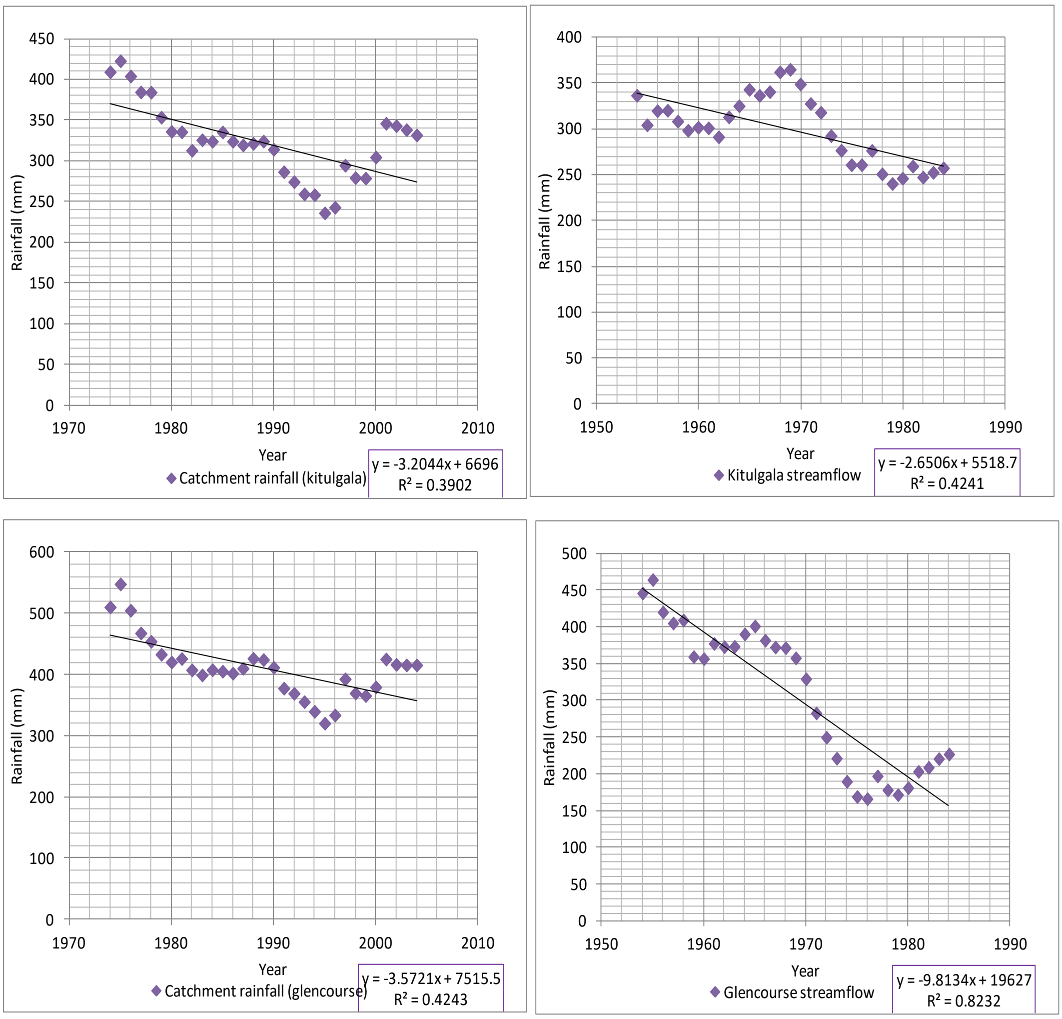


Figure F-0-2 November trends

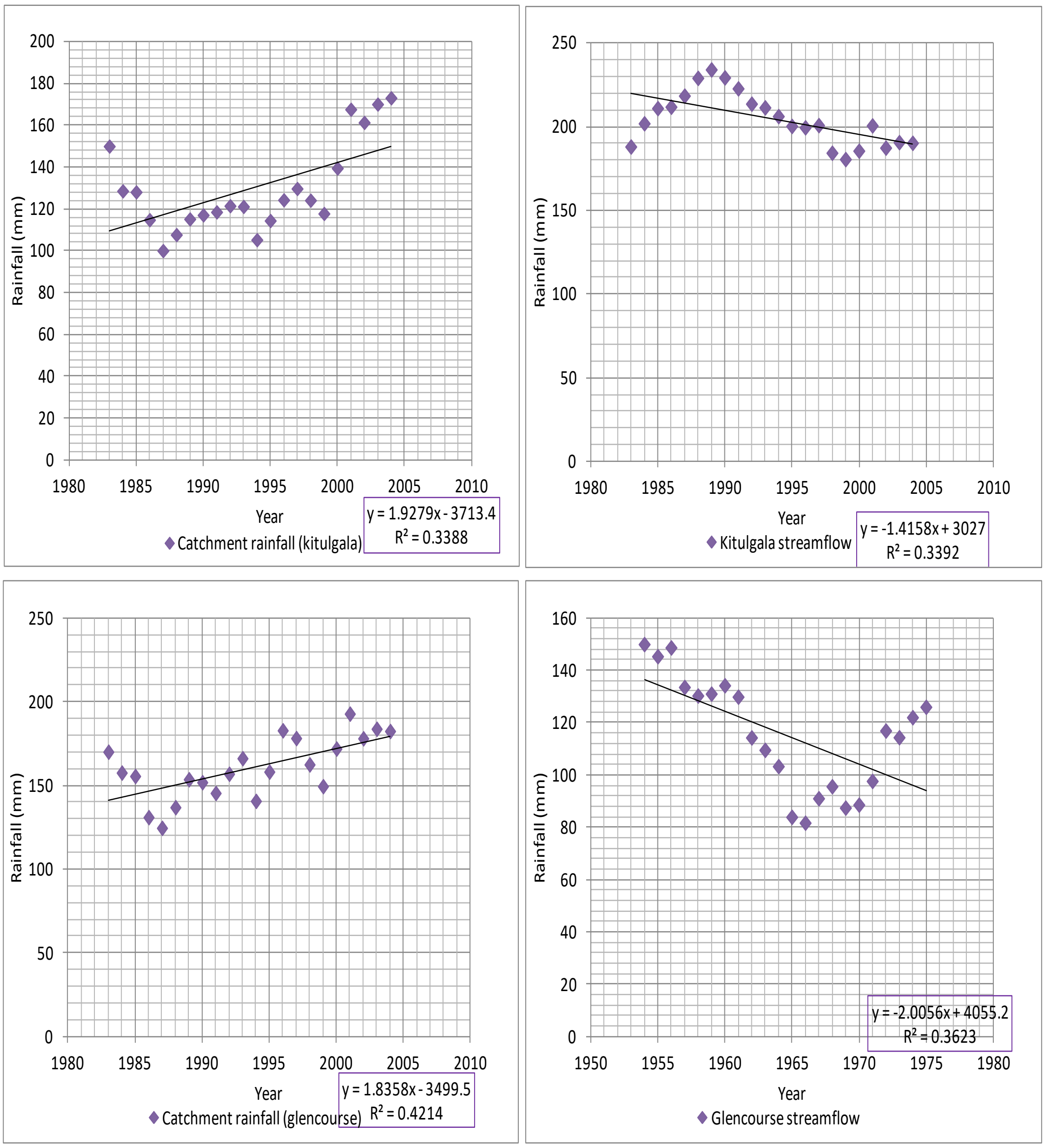


Figure F-0-3 December Rainfall trends

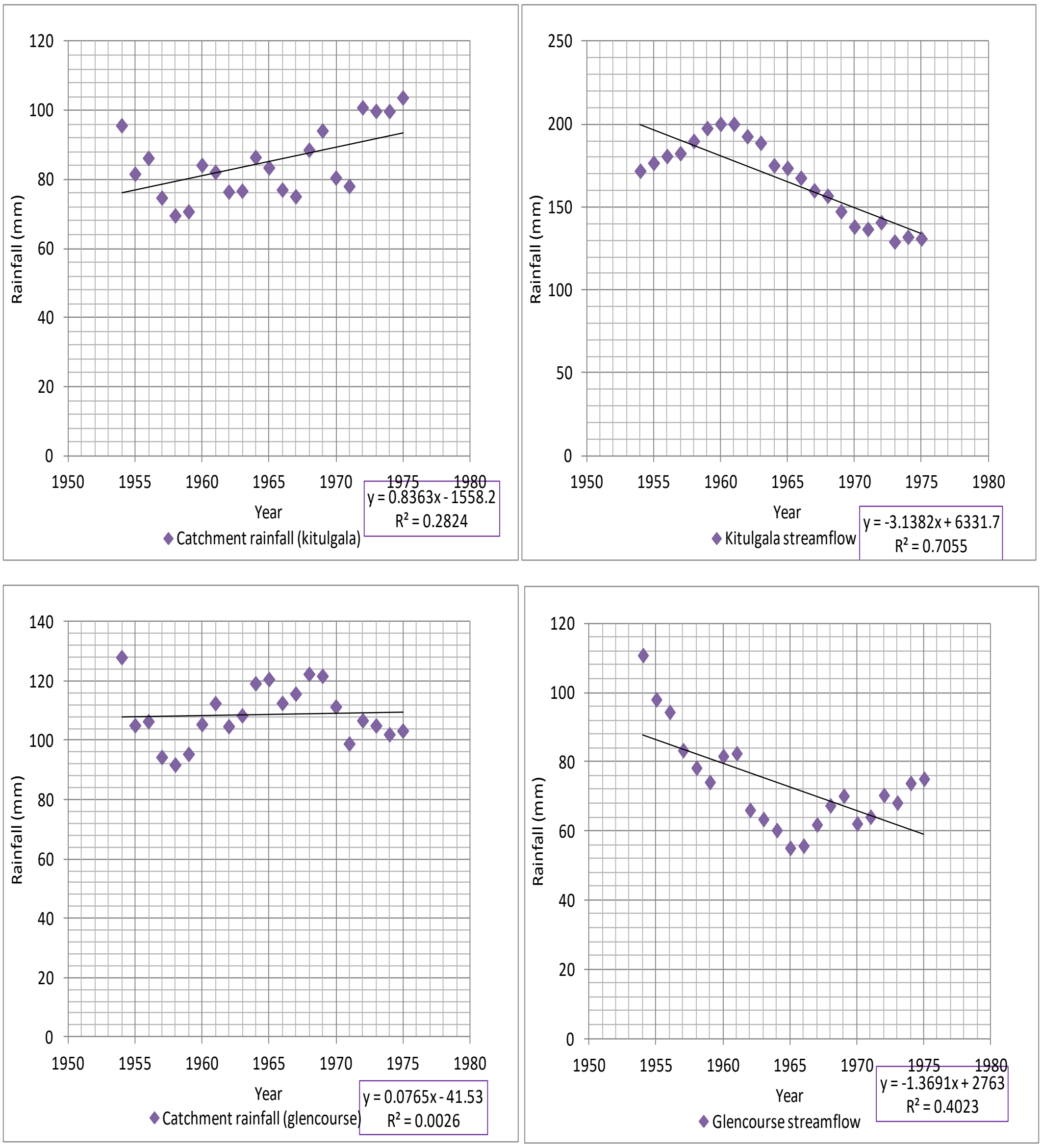


Figure F-0-4 January trends

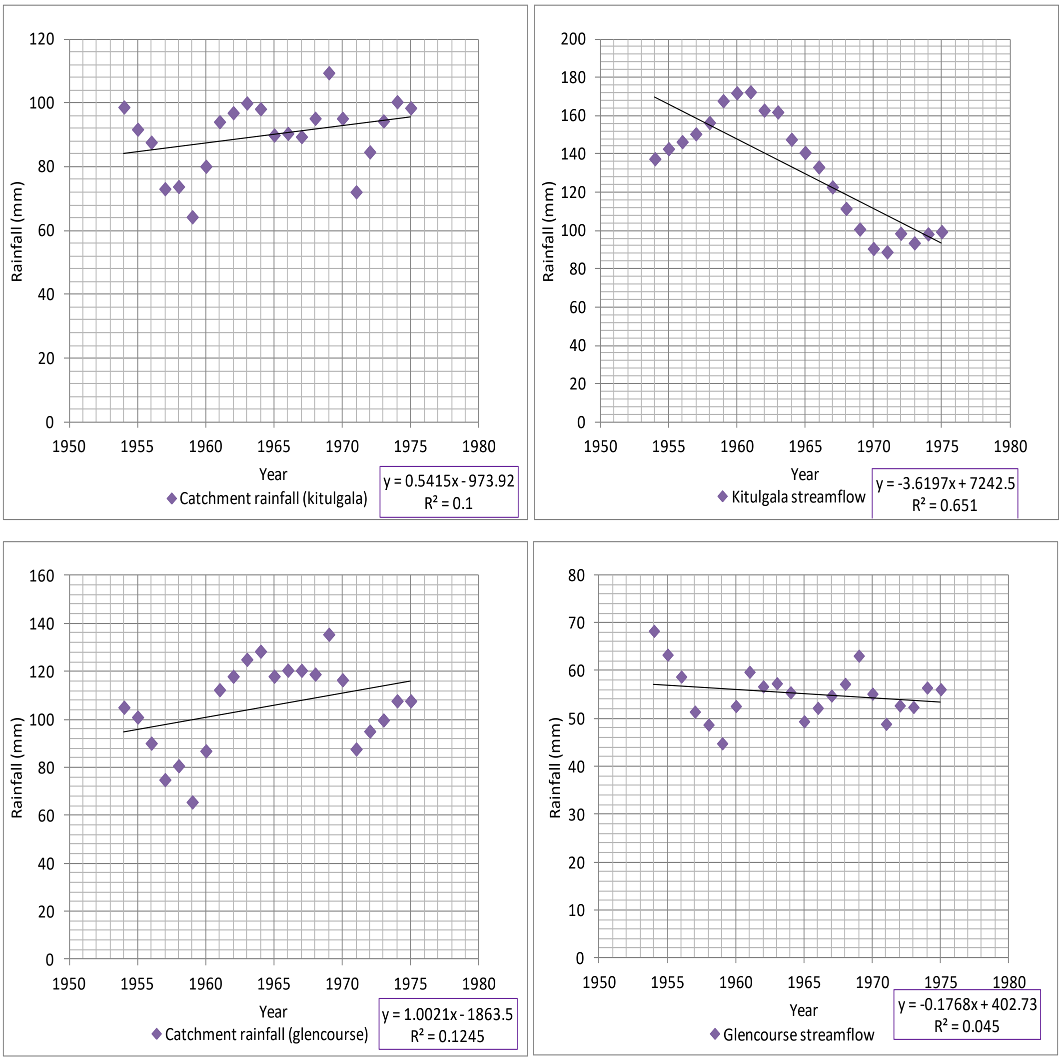


Figure F-0-5 February trends

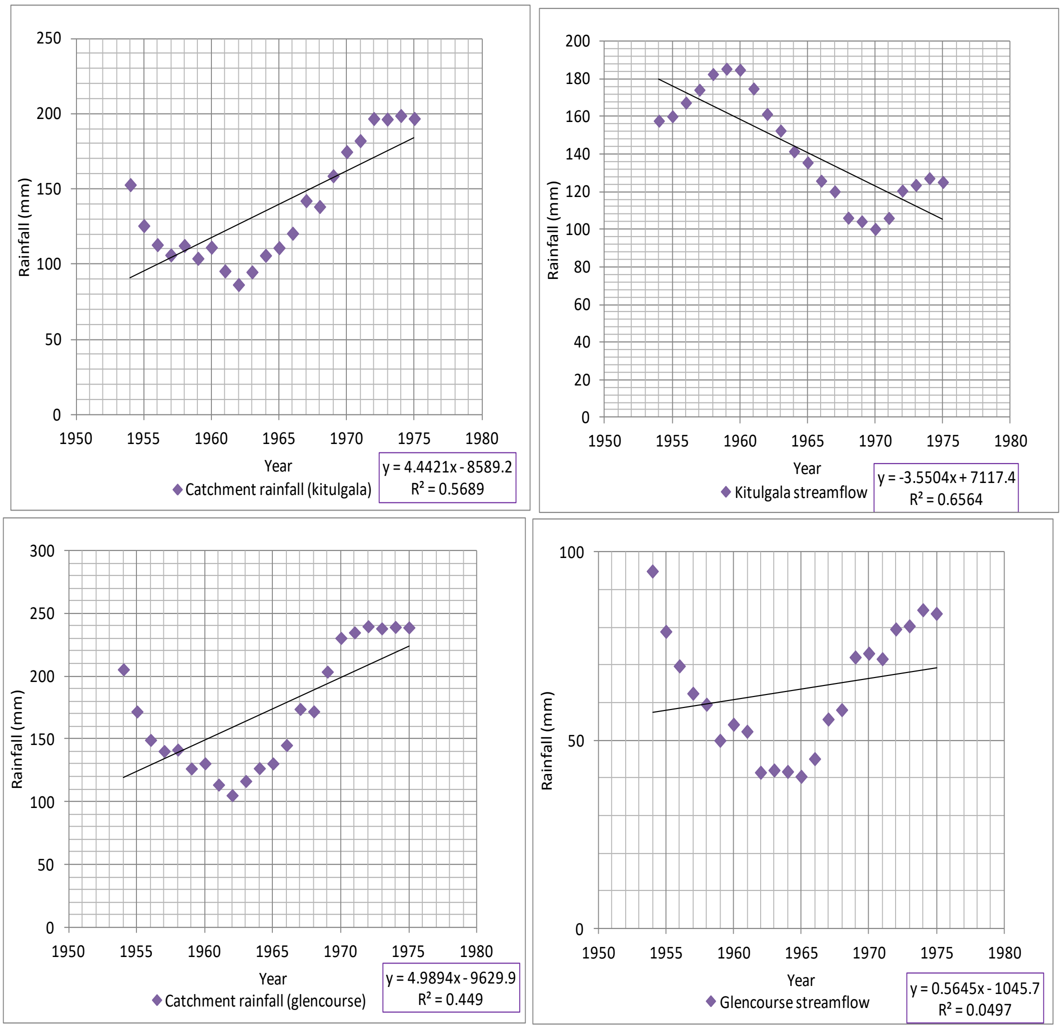


Figure F-0-6 March trends

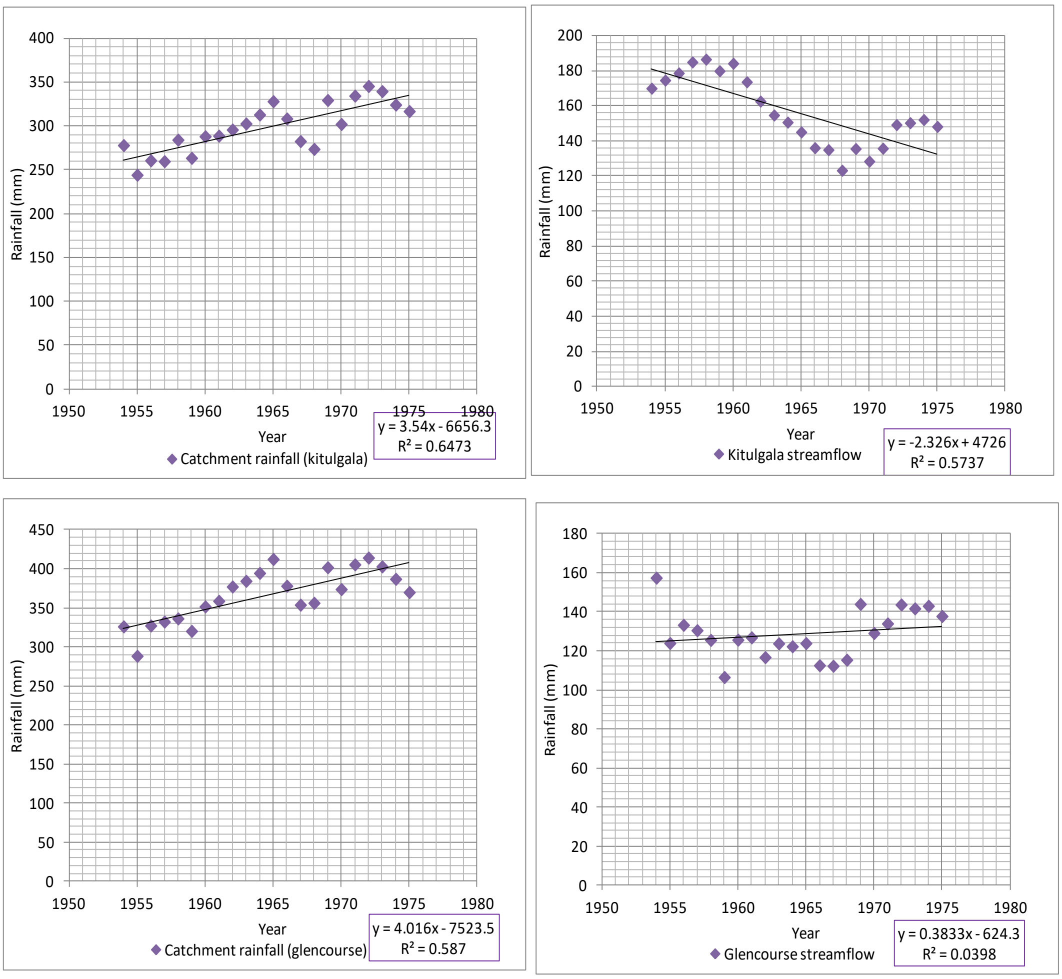


Figure F-0-7 April trends

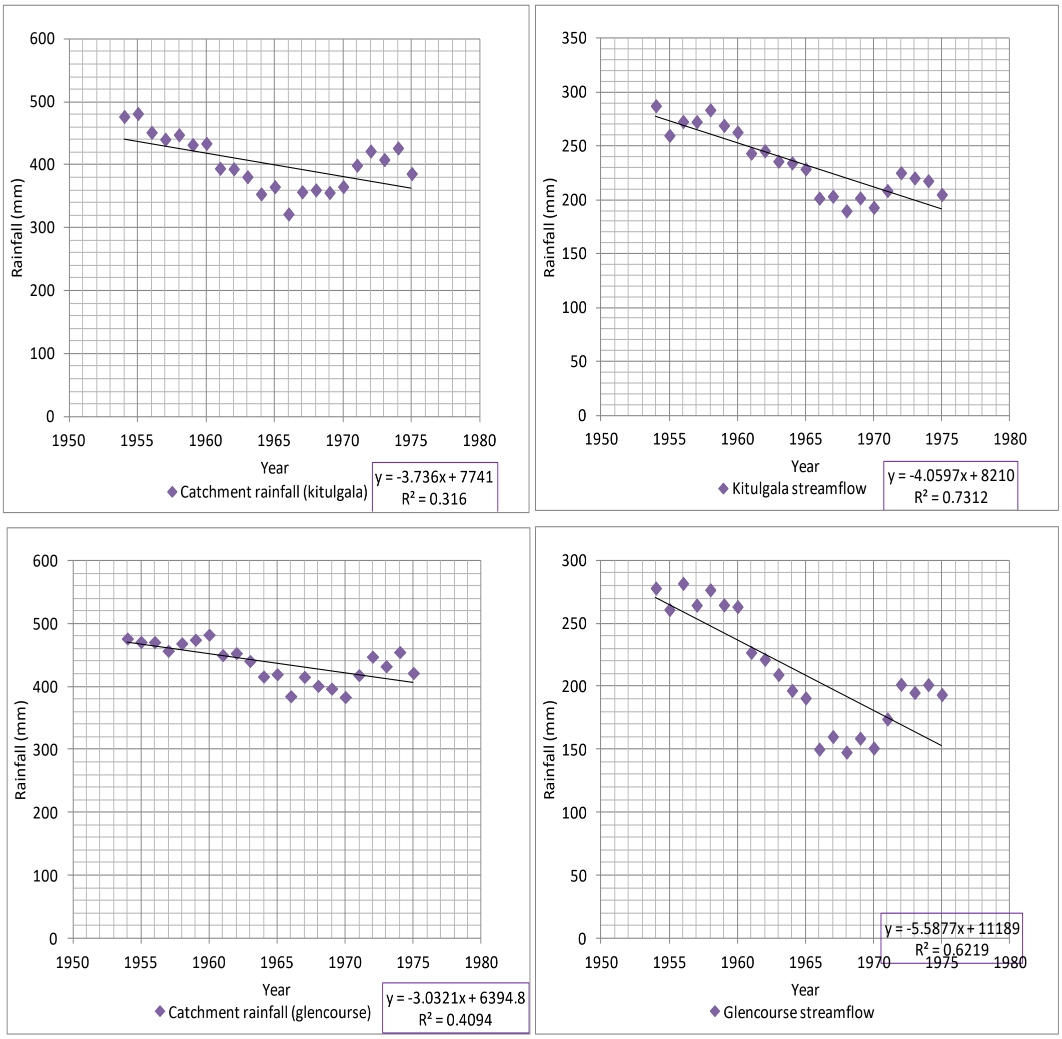


Figure F-0-8 May trends

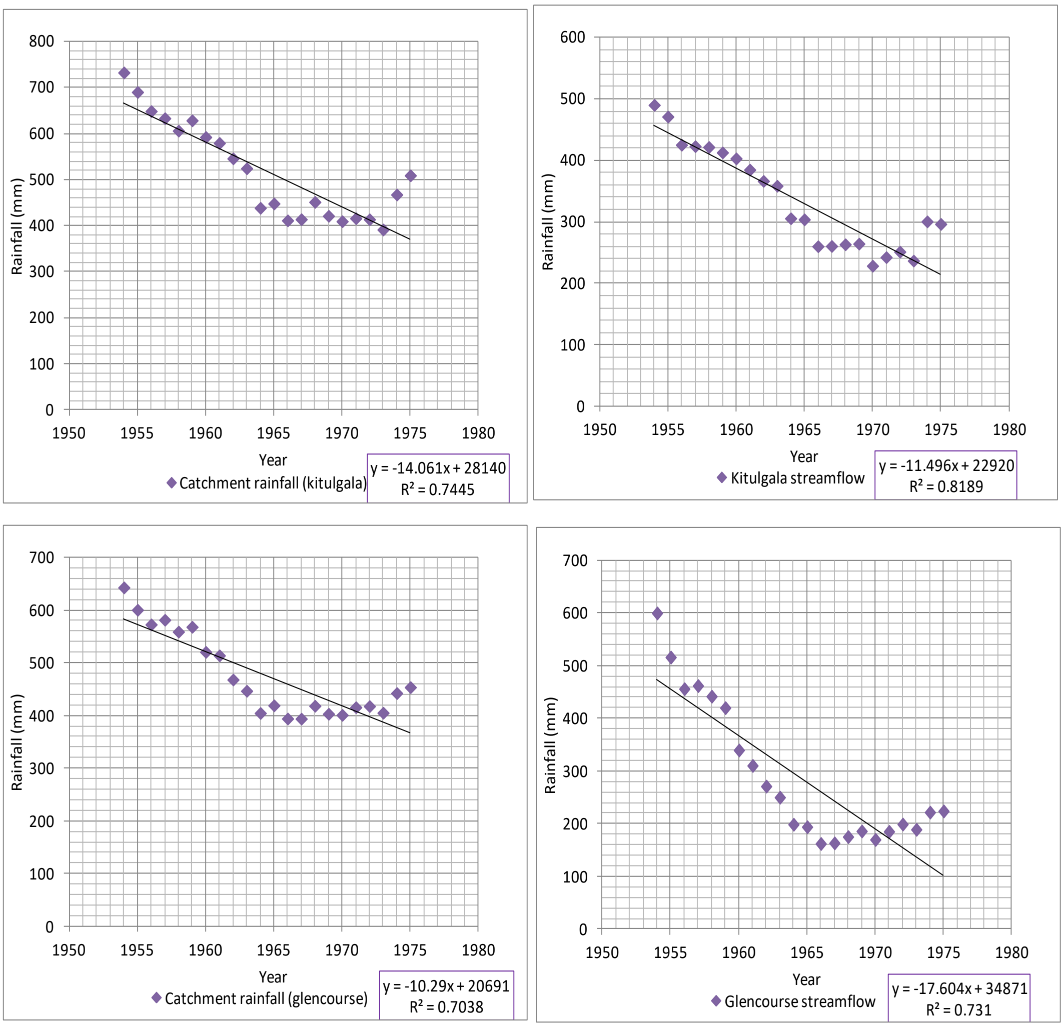


Figure F-0-9 June trends

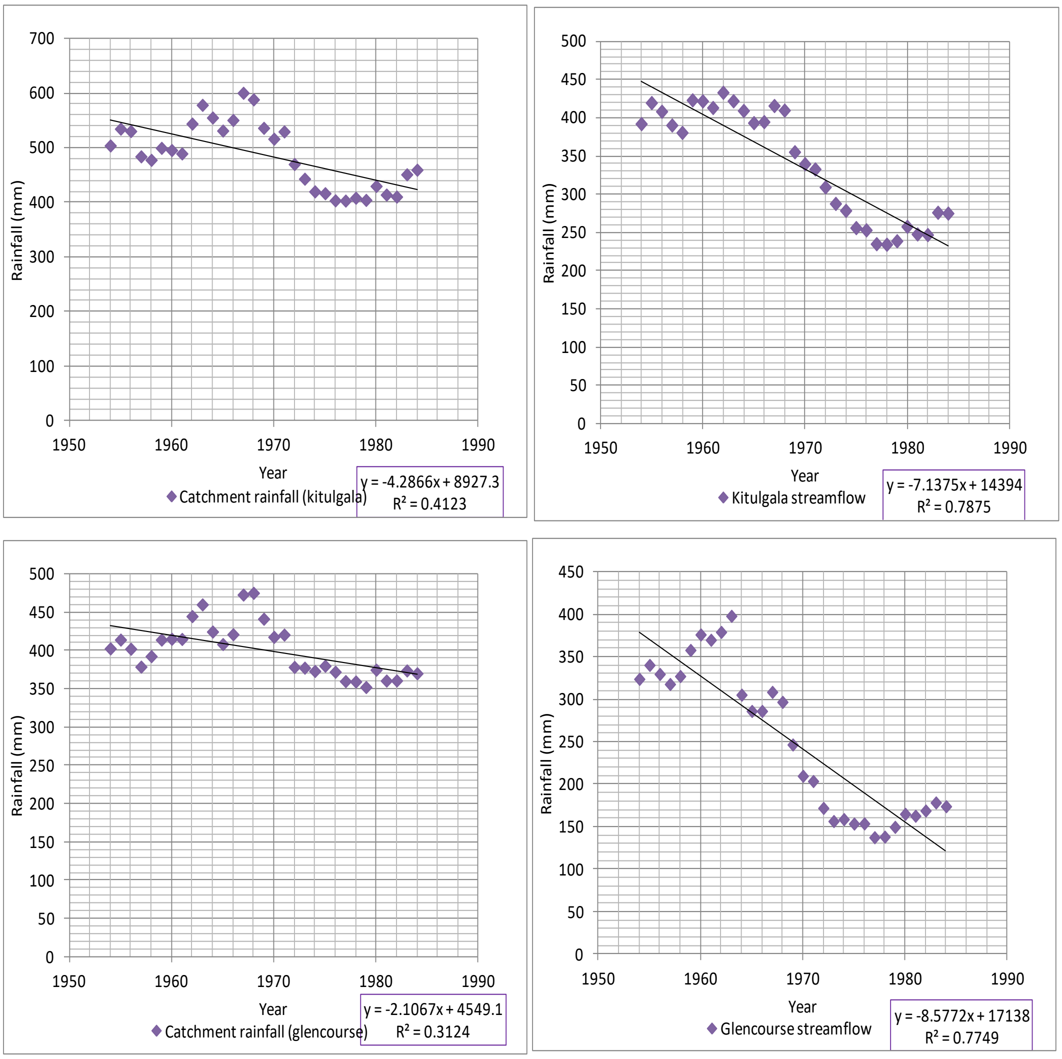


Figure F-0-10 July trends

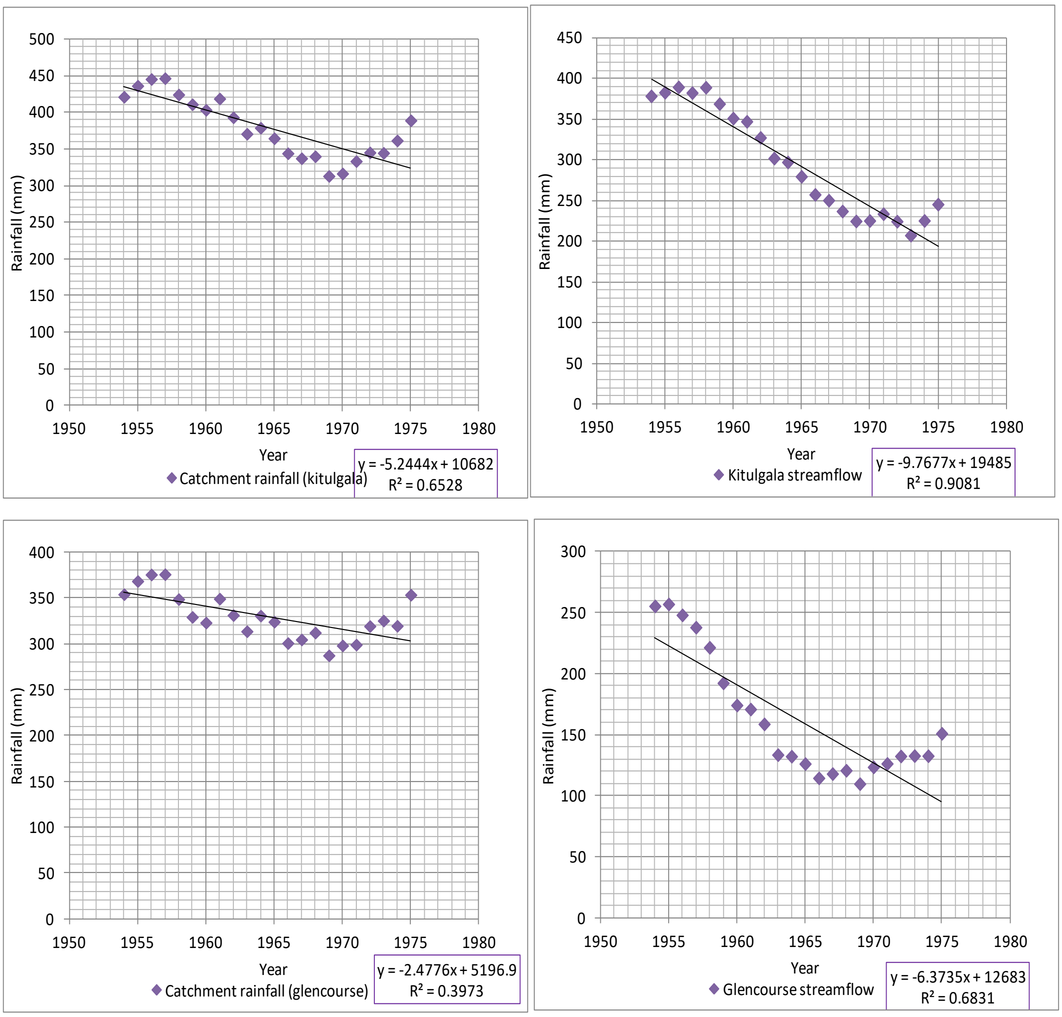


Figure F-0-11 August trends

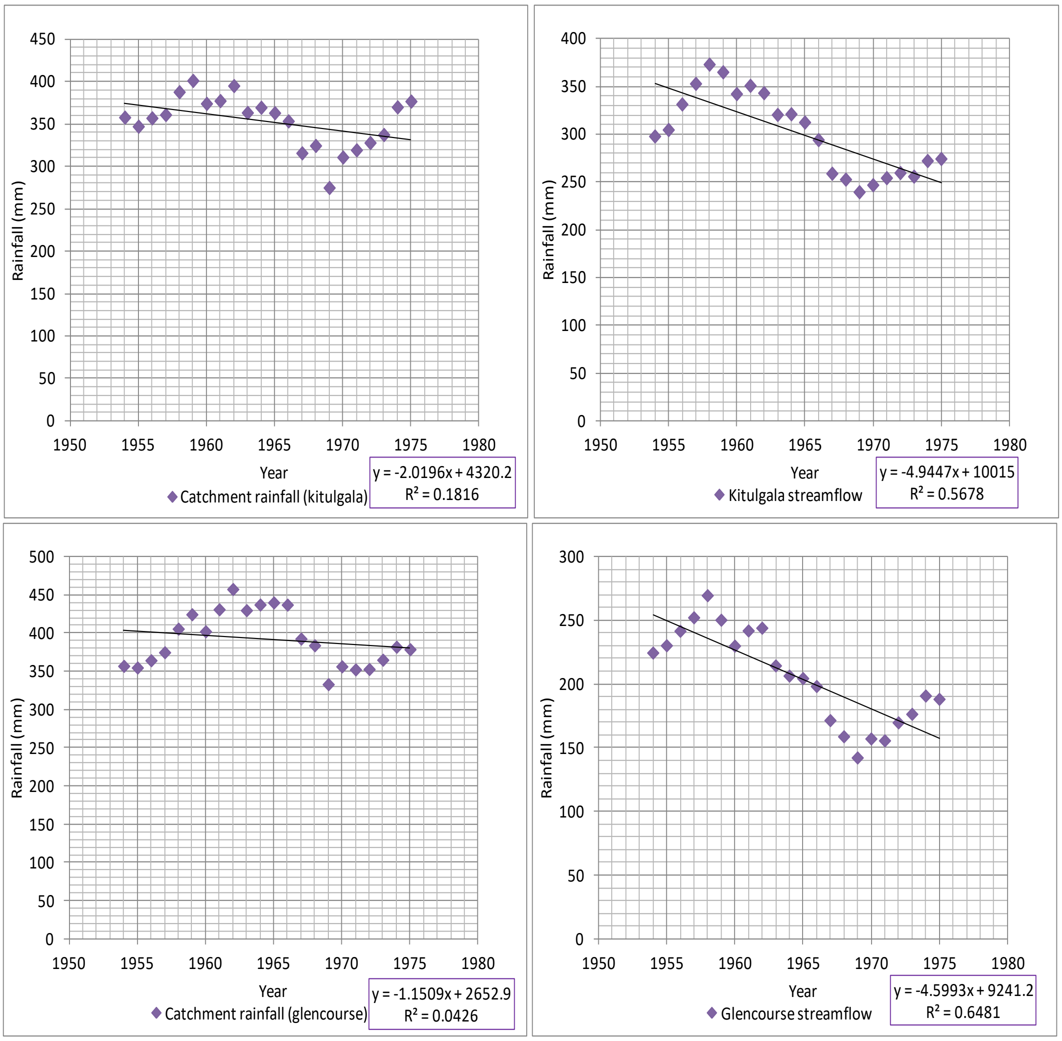


Figure F-0-12 September trends

Appendix G Correlation between Parameters

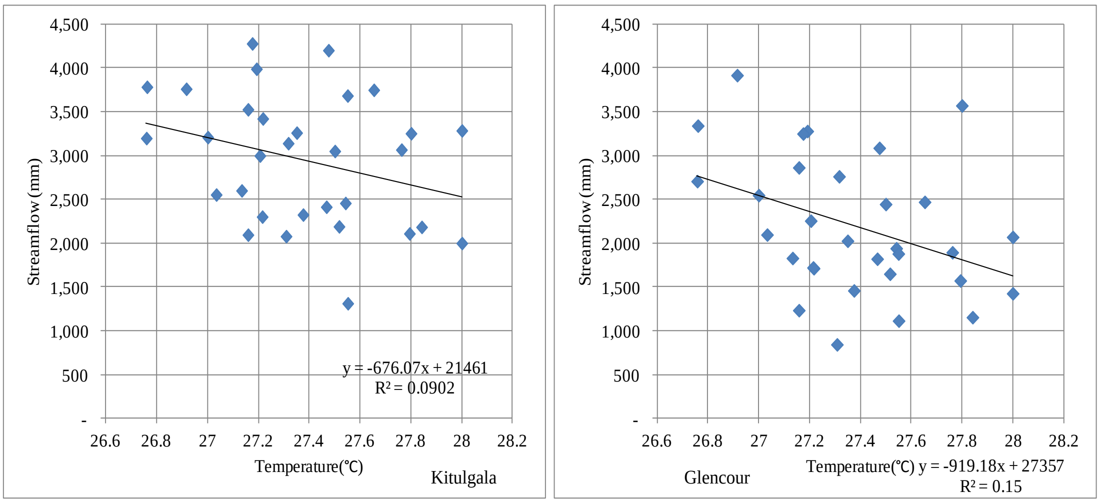


Figure G-0-1 Correlation (Annual Average Temperature and Streamflow)

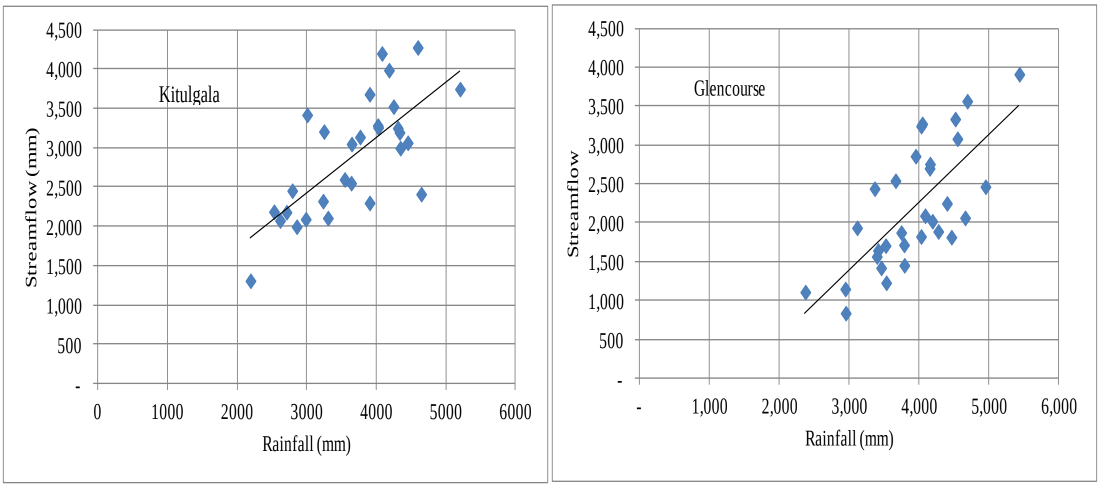


Figure G-0-2 Correlation (Average temperature and Rainfall)

Appendix H - Rainfall deficit and Dry months

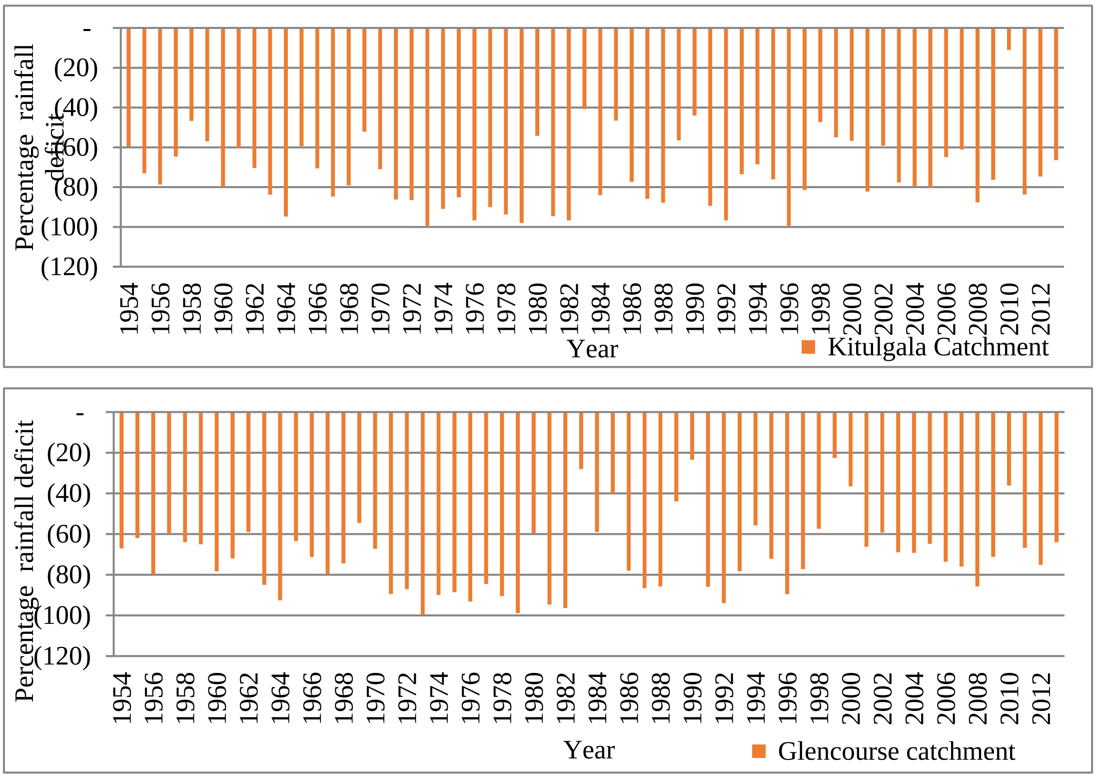


Figure H-0-1 Dryness of a month (January)

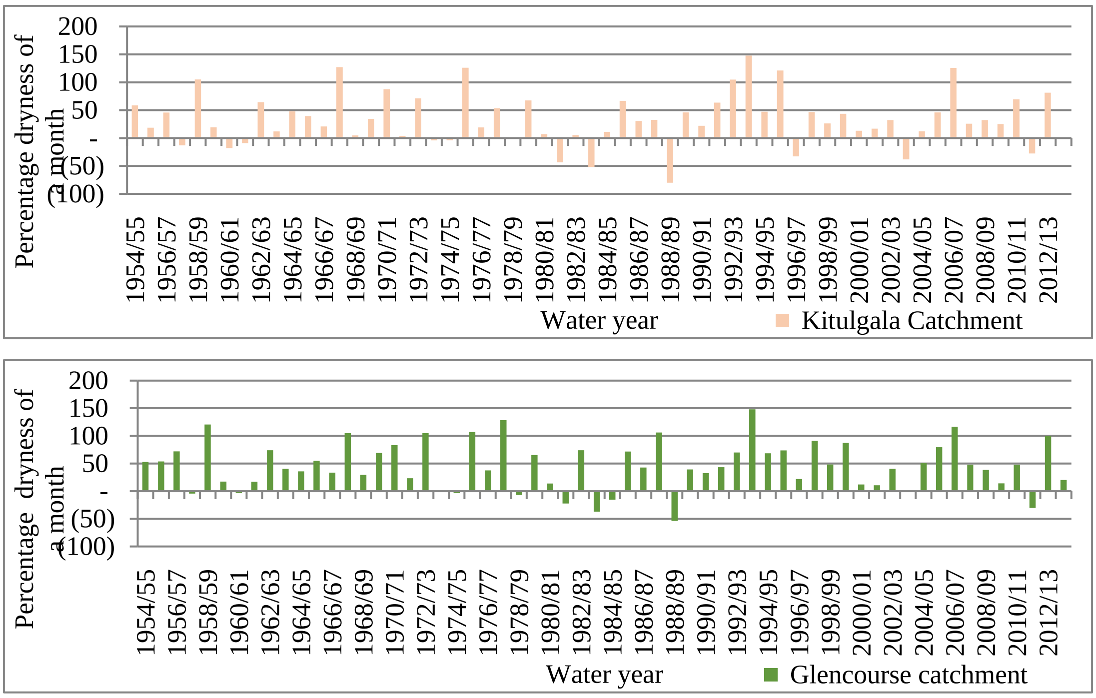


Figure H-0-2 Dryness of a month (February)

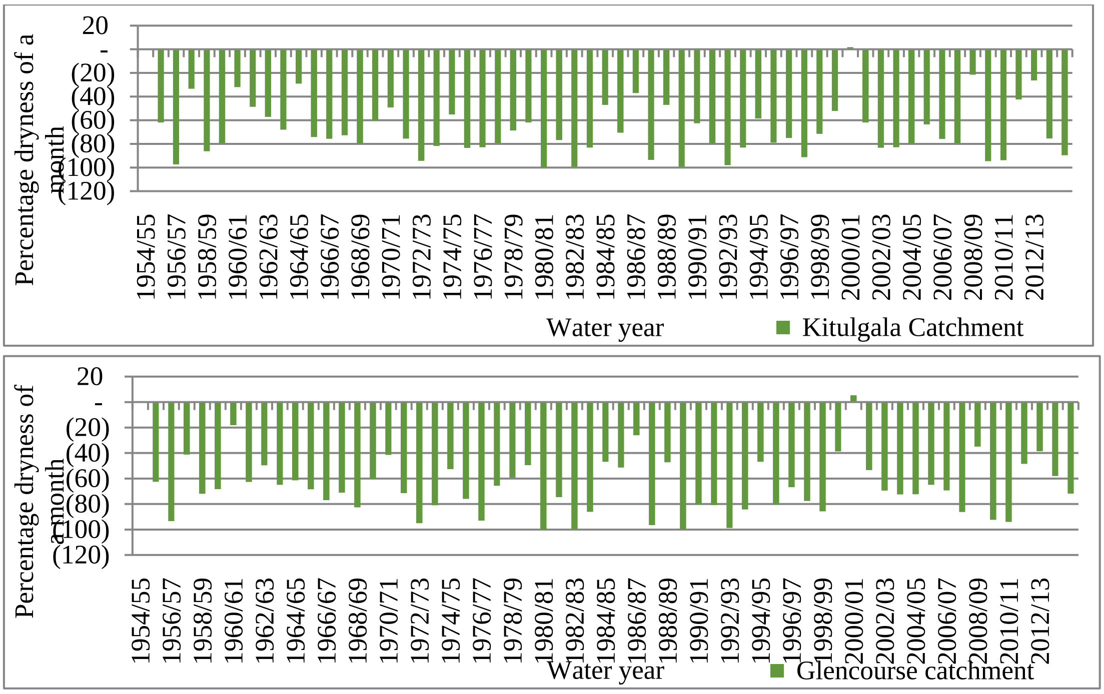


Figure H-0-3 Dryness of a month (March)

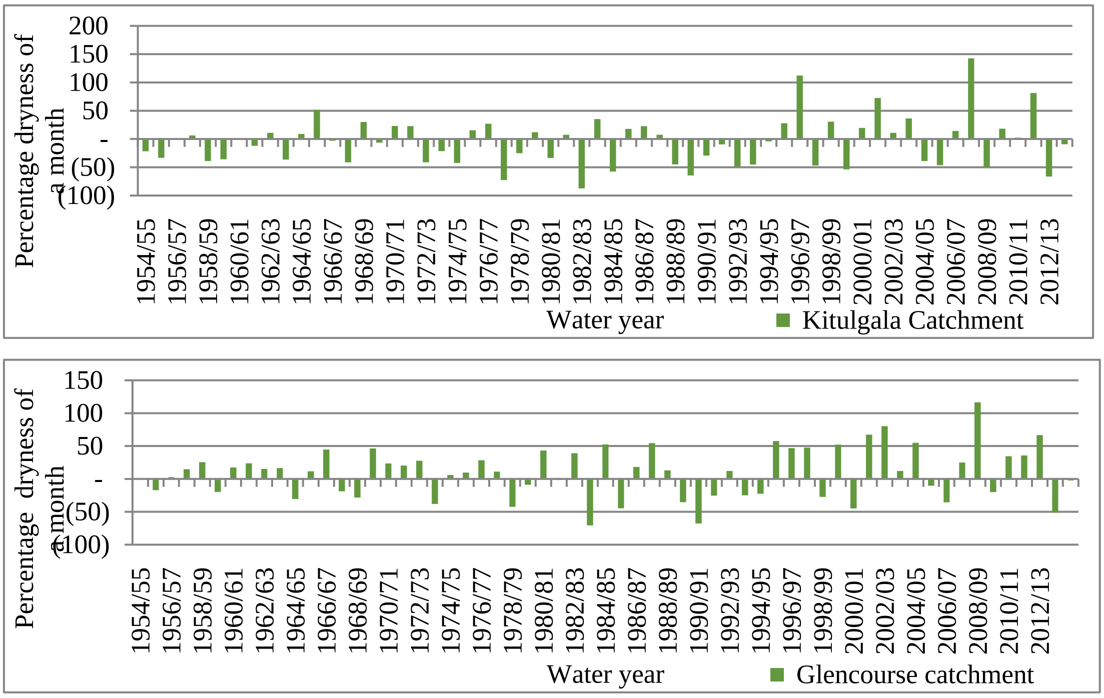


Figure H-0-4 Dryness of a month (April)

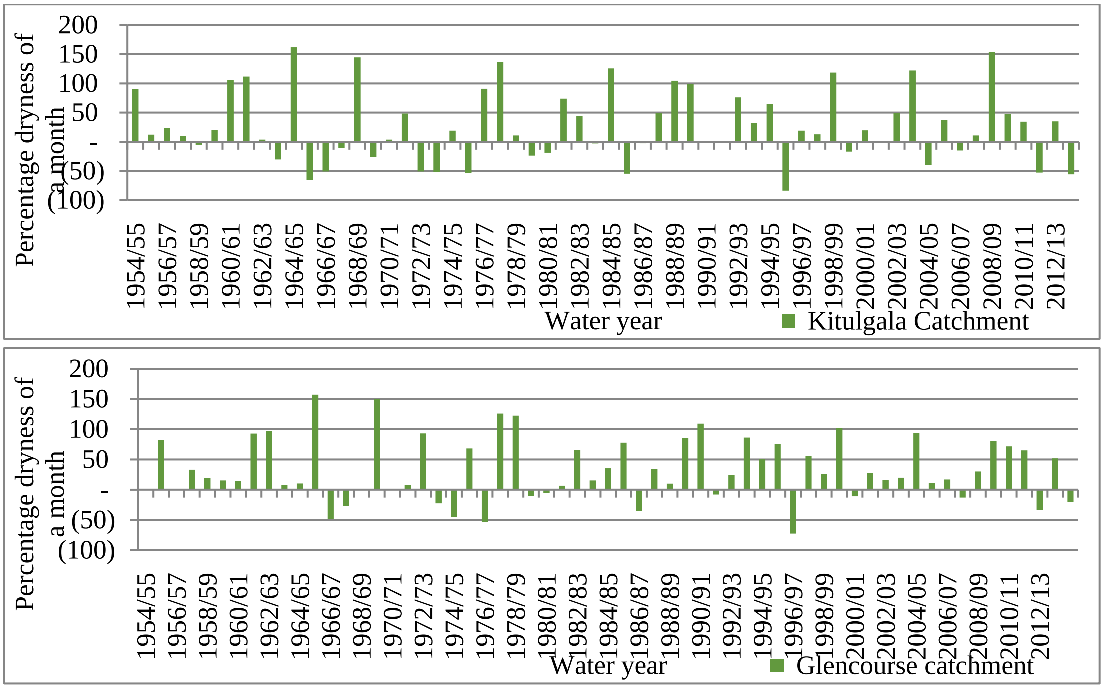


Figure H-0-5 Dryness of a month (May)

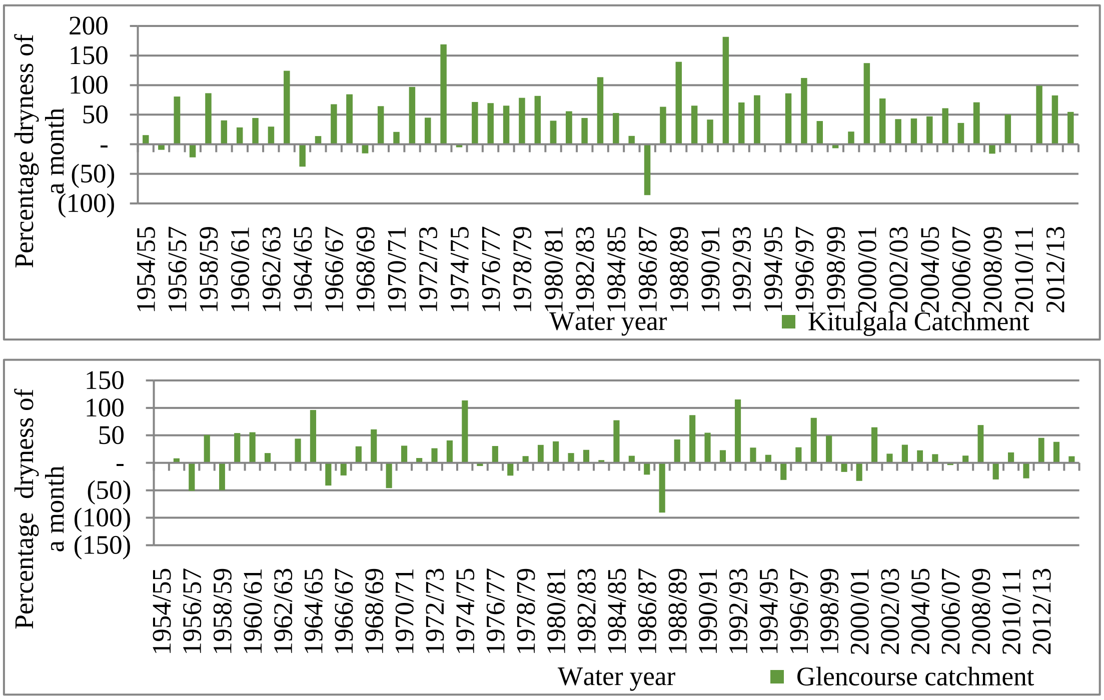


Figure H-0-6 Dryness of a month (June)

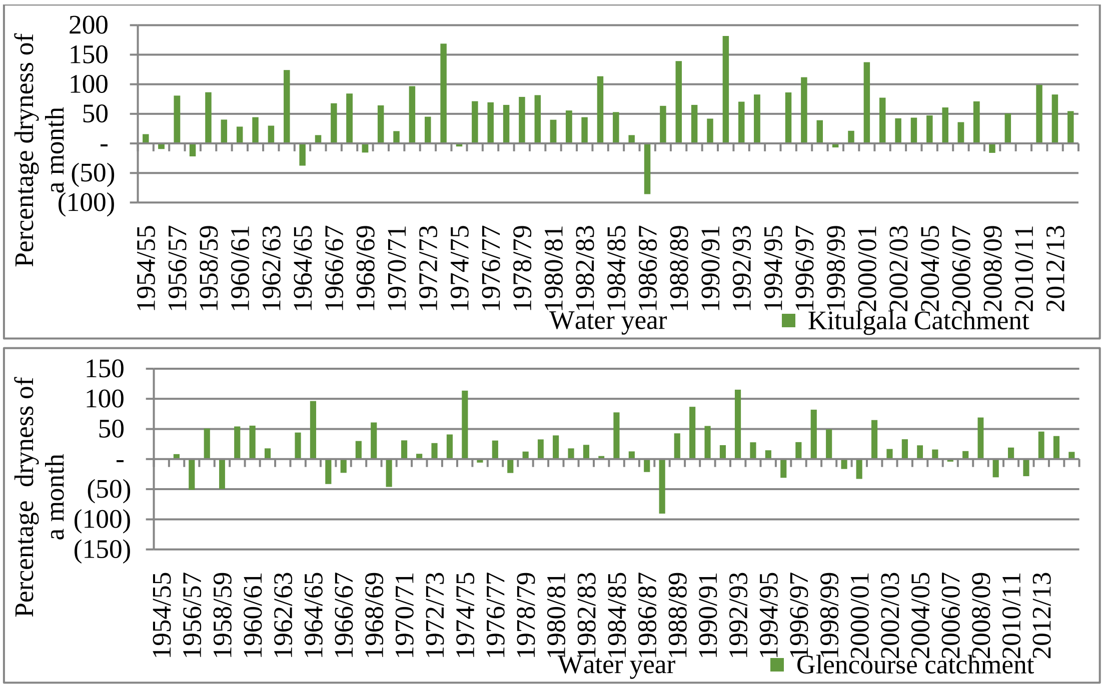


Figure H-0-7 Dryness of a month (July)

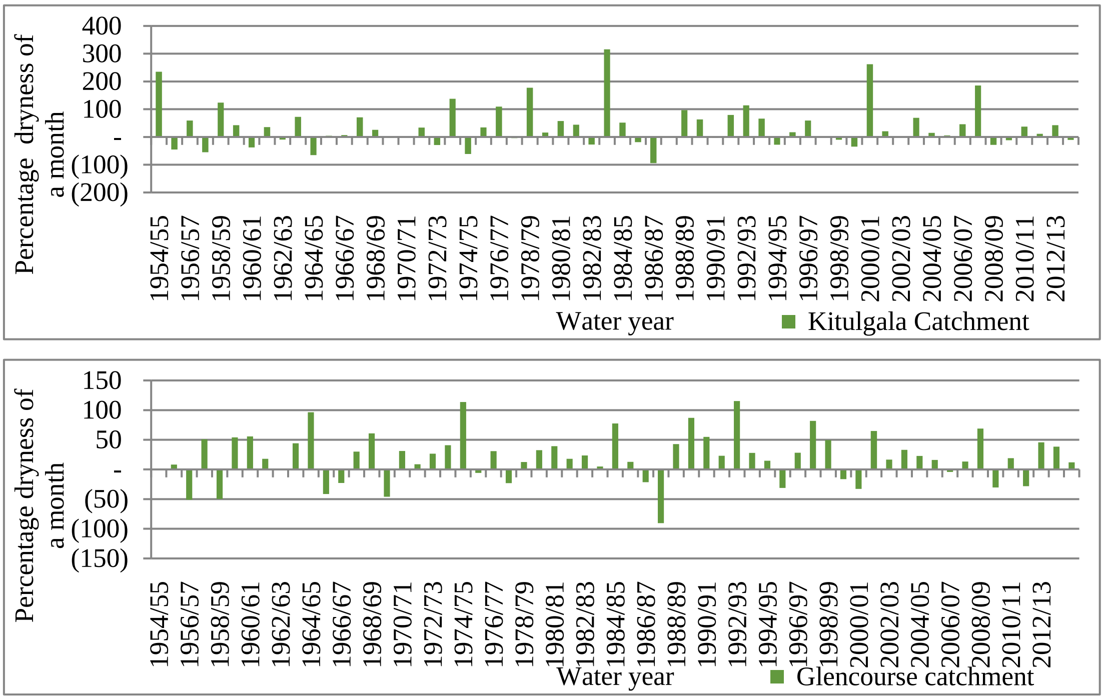


Figure H-0-8 Dryness of a month (August)

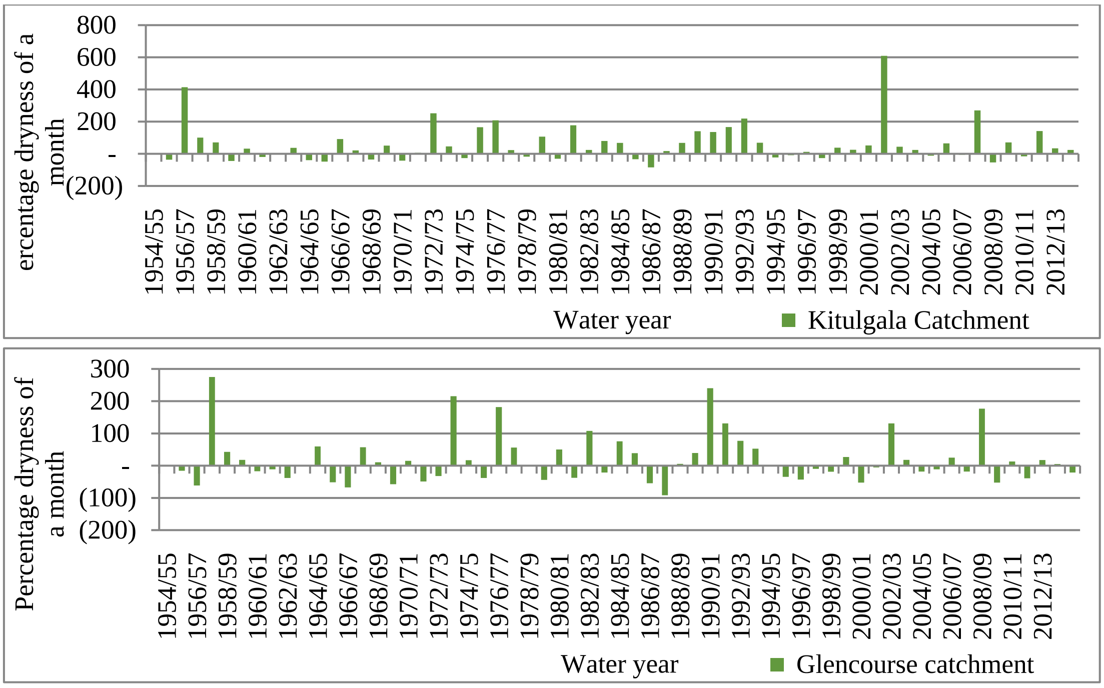


Figure H-0-9 Dryness of a month (September)

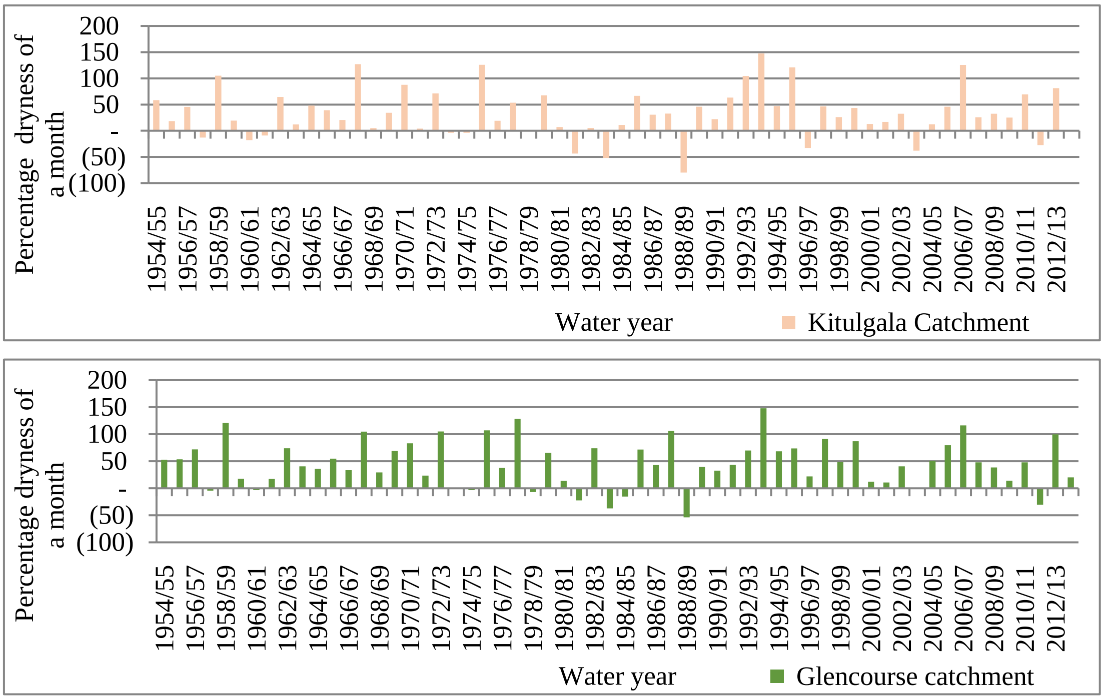


Figure H-0-10 Dryness of a month (October)

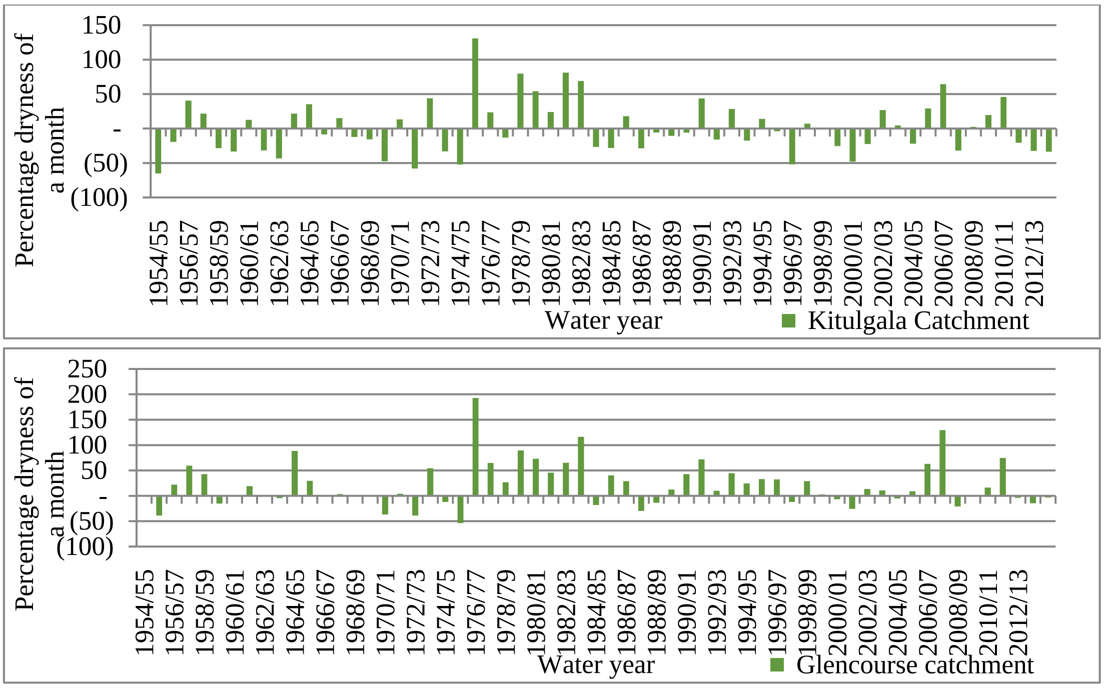


Figure H-0-11 Dryness of a month (November)

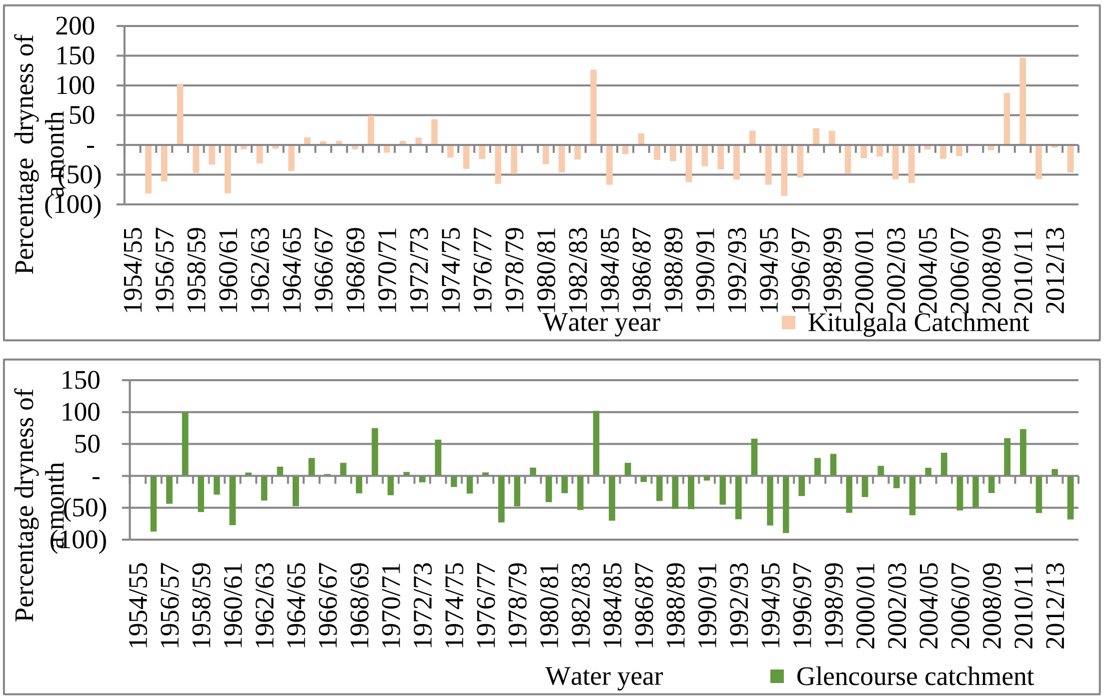


Figure H-0-12 Dryness of a month (December)

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.