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CLIMATE CHANGE ASSESSMENT ON RAINFALL AND TEMPERATURE IN CAMERON HIGHLANDS, MALAYSIA, USING REGIONAL CLIMATE DOWNSCALING METHOD

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Abstract: Series of massive flood disasters which occurred in Malaysia's highlands region has raised the concern of local community to water resources planning and management. Well-determined of climate change model on rainfall and temperature can be an important component on water resources management strategy to mitigate the disaster impacts. Cameron Highlands has been selected as the study area to conduct a climate change projection (1980-2069). Downscaled regional climate model (RCM) was used to project Cameron Highlands' temperature and precipitation. Bias correction was applied on the simulated model to remove common projection model errors. Based on the RCM outcomes, the maximum, minimum and mean temperatures showed an ascendant tendency with rate of 3.8°, 1.8° and 2.8°C in 100 years' time. The annual precipitation indicated a rise in rainfall amount of 2.32 mm per year (23.2 mm per 10 years or 231.8 mm per 100 years, respectively). Both precipitation and temperature parameters showed a positive gradient which means there would be heavier rainfall and increment in the average temperature in Cameron Highlands. These changes bring drastic impacts especially to water resources such as water shortage during the dry season in local farms and tea plantation estates and massive flooding that occurred during the rainy season. Further study was also identified to develop an integrated decision-making support system based on climate projection scenario that important enhancing policy development process.

Keywords: Climate change, water resources management, regional climate model, Cameron Highlands

1. INTRODUCTION

Climate warming is an undeniable global issue. It is a change in the statistical distribution of weather patterns when that change lasts for an extended period of time. Since the 1950s, many of the climate changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen (IPCC, 2014). Long term trend atmospheric analysis i.e. rainfall, temperature and evapotranspiration have been conducted as proxies for detecting climate changes, for example, assessment of regional climate change in Western Jilin China by Zhang et al., (2017); global rainfall patterns analysis by Dore Mohammed (2005); South Africa's temperature trend analysis by Warburton et al., (2005), Kruger & Shongwe (2004) and New et al., (2006); temperature, rainfall and streamflow by Warburton & Schulze (2005); evaporation (and soil moisture) by Malisawa & Rautenbach (2012). Climate change happened largely due to the observed increases in anthropogenic activities especially the release of greenhouse gases through the combustion of fossil fuels (coal, oil and natural gas), agriculture and land clearing (Hardy, 2003). Carbon dioxide (CO_2) and other greenhouse gases can be retained in the atmosphere for the next few hundred years after they are released. Rising of carbon dioxide, methane (CH_4) and nitrous oxide (NO_x) concentrations are warming the global atmosphere. Global warming is closely associated with other climate changes and impacts, including rising seas, thinning ice, increased extremes – floods and drought, surges in wildfires and ocean acidification.

Climate change brings serious impacts to human and natural systems. To understand well of the causes, mechanisms, and consequences of climate change, a regional climate model (RCM) can be used to predict future climate projection (Samuel et al., 2014). This allows more effective adaptations and mitigations from stakeholders taken to encounter climate change. Regional climate models are useful tools for analysis of climate in greater details in terms of representations of the atmosphere, land and surface and generate weather (Moufouma-Okia & Jones, 2009). One of the primary advantages of these models is that they can be used to provide local information, which can be most needed in many climate change impact applications.

Roosmale et al., (2009) finds that the use of high-resolution regional climate models to examine the hydrological impacts of climate change has grown significantly in recent years due to the improved representation of the local climate. The higher resolution of RCMs as compared to GCMs is able to realistically simulate regional climate features (Fowler et al., 2007) such as extreme events, orographic precipitation, and regional scale climate anomalies, or non-linear effects. IPCC (2000) suggests two main scenario families that describe climate change projections namely A1 Scenario Family and B1 Scenario Family. These two scenario families have different characteristics. The A1 scenario family assumes the high development in our earth including the economy and global population, and energy needs being met by a balance of fossil fuels and alternative technologies. A1B (a subset of the A1 family) lies near the high end of the spectrum for future greenhouse gas emissions, particularly through mid-century. A1B projects a future where technology is shared between developed and developing nations in order to reduce regional economic disparities. The B1 scenario family lies near the lower limit of projected changes in greenhouse gas emissions. The B1 scenario assumes global population growth peaks by mid-century and then declines, a rapid economic shift towards service and information economies, and the introduction of clean and resource-efficient technologies.

In this study, A1B projection scenario is adopted to project rainfall and temperature changes for the next 30 years in Cameron Highlands, Malaysia. A1B portrays a rapid economic and population growth in the future world (Tayebiyan et al., 2015). Examples of A1B scenario can be found in Hamdi et al., (2015) and Cannaby et al., (2014). Both studies perform their simulations under present day conditions and a potential future climate scenario, based on the IPCC A1B greenhouse gas emission scenario which a balance across all sources. Background of the study area, model and dataset used are discussed in Section 2 and 3. Observed and simulated temperature and rainfall using RCM in Cameron Highlands is discussed in Section 4.

2. BACKGROUND OF STUDY AREA

Cameron Highlands has been selected as the study area in order to conduct a climate change projection. Situated in the northwest of Pahang state of Peninsular Malaysia (Fig. 1), Cameron Highlands (4°28'N 101°23'E) has a total area of 710 km^2 (Fortuin, 2006). The average elevation is approximately 1180 m and the highest peak is Mount Brinchang at 2032 m (CHDC, 2016). Thus, the temperature of Cameron Highlands is significantly lower than Malaysia's lowlands due to its high altitude.

Meteorological Station Cameron Highlands has recorded a temperature ranged from 15.0 °C to 25.4 °C with an average temperature of 19.4 °C by MMD (2014). The highest number of rain days in a month is 23 days recorded by Meteorological Station Cameron Highlands (MMD, 2014). Besides, the mean monthly rainfall is 95.8 mm with the maximum of 365.1 mm and minimum of 8.9 mm (MMD, 2009).

On 22nd and 23rd October 2013, a mud flood happened when excess water was released from the Sultan Abu Bakar Dam in Ringlet following continuous heavy rain. Three people died and about 80 houses were swept away (Kaur, 2013). On 5th and 6th November 2014, another mud flood took place in Cameron Highlands. More than 20 houses in Ringlet town, Ringlet new village, Kampung Ulu Merah Ringlet and Bertam Valley are submerged in knee-deep flood waters. Total three people were killed in this disaster which caused by heavy downpour.

Shallow (1956) published the earliest sets of soil erosion data followed by Baharuddin et al., (1996) 40 years later. It was clearly shown that vegetable cultivation generated the most amount of sediment compared to tea plantation and forest where the soil erosion was measured in the form of sediment in rivers (tonne per hectare per year, t/ha/y). Since Cameron Highlands practice very intensive farming and agriculture activities, with addition to rainy season of torrential rainfall and flowing water, erosion and runoff are relatively high, making the river bank even shallower. The combination of flash flood and mudslide happened. Hence, this study involved the analysis of extreme events by adopting regional climate model that took place in Cameron Highlands.

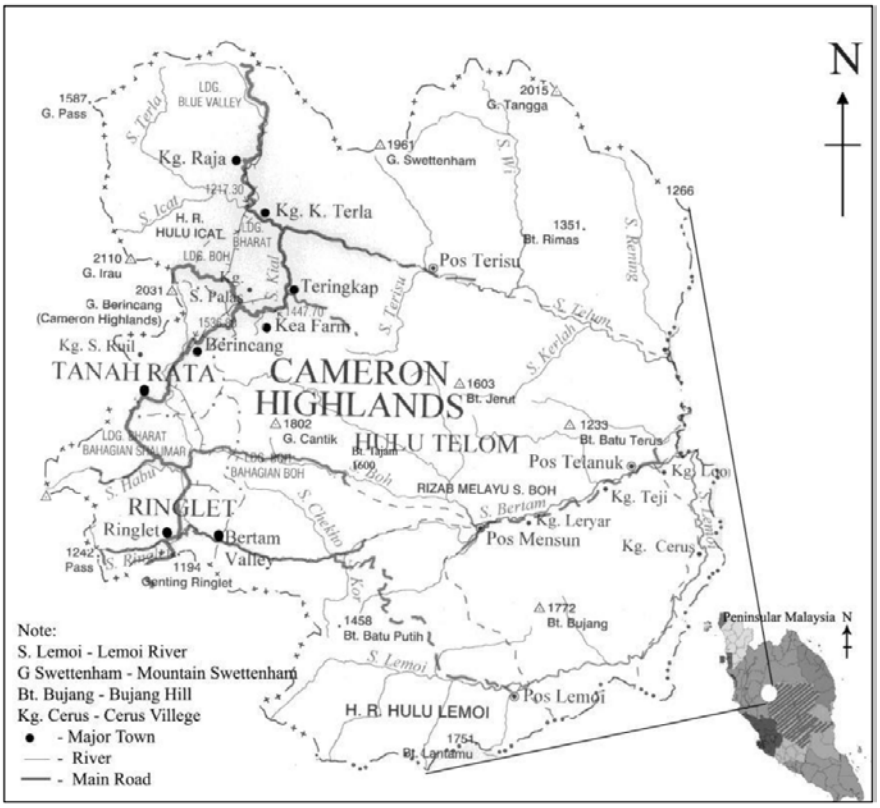

Figure 1. Location of Cameron Highlands in Peninsular Malaysia (Sources: CHDC, 2016; JUPEM, 2002)

3. DOWNSCALED REGIONAL CLIMATE MODEL (RCM) ANALYSIS

The regional climate model applied in the present study was the fifth-generation atmospheric general circulation model (ECHAM5). This model was developed at the Max Planck Institute for Meteorology (MPIM; Roeckner et al., 2003). It was the latest version in a series of ECHAM models which evolved from the spectral weather prediction model of the European Centre for Medium Range Weather Forecasts (ECMWF; Simmons et al., 1989). ECHAM5 was flexible compared to its predecessors (Roeckner et al., 2003). Tests had been carried out by Roeckner et al., (2003) on various platforms.

The RCM data was obtained from START (System for Analysis, Research and Training) Regional Centre, Chulalongkorn University, Thailand. The climatic data was downscaled to 25 km resolution using Regional Climate Model software. For both precipitation and temperature, mean and median were calculated on a yearly basis. Hence, RCM projection was conducted for a reference period of the year 1980 to 2069 in Cameron Highlands. The projections scenario in this study is based on scenario A1B which projected a future where economic growth is sustained and technology is shared between developed and developing countries in order to reduce regional economic disparities. Two key climate parameters that were being projected namely precipitation (in mm) and temperature (in °C).

The average and the median were two different measures of central tendency and could often give two very different stories about the data, especially when the data set contained outliers. An outlier represented a clerical error and markedly affected the mean while the median was not influenced by outliers (Rumsey, 2011). The median was a more appropriate measure of central tendency to describe if there were several outliers. In order to minimise unnecessary errors, both mean and median were taken as the measures of central tendency in this study.

Results from RCM are first analysed. Bias correction of climate model outputs is done after that before their use in assessment studies because climate models are not perfectly simulated. Past actual records of daily maximum and minimum temperature and daily rainfall amount data from Malaysian Meteorological Department (MMD) were regarded as the basis for analysis. Bias correction factors are derived for period 1983 – 2014 and applied to 1980 – 2069. The purpose was to remove common systematic model errors. The bias correction applied in this study was proposed by Terink et al., (2010). The bias correction is applied for precipitation and temperature. The corrected precipitation P' was obtained as:

$$P' = \left(\frac{\bar{P}_{sim}}{\bar{P}_{obs}}\right) \times P \quad 1)$$

Where:

P' = corrected precipitation

$\bar{P}_{sim}$ = mean uncorrected simulated precipitation

$\bar{P}_{obs}$ = mean observed precipitation

P = uncorrected simulated precipitation

Each daily temperature value T is transformed to a corrected T' using:

$$T' = \bar{T}_{obs} + \frac{\sigma(T_{obs})}{\sigma(T_{sim})} (T_{sim} - \bar{T}_{obs}) + (\bar{T}_{obs} - \bar{T}_{sim}) \quad 2)$$

Where:

T' = corrected temperature

$\bar{T}_{obs}$ = mean observed temperature

$\sigma(T_{obs})$ = standard deviation of observed temperature

$\sigma(T_{sim})$ = standard deviation of uncorrected simulated temperature

T_{sim} = uncorrected simulated temperature

$\bar{T}_{sim}$ = mean uncorrected simulated temperature

4. RESULTS AND DISCUSSION

4.1. Temperature

Global increases in temperature along with the increase of greenhouse gases in the atmosphere. The global average surface temperature has been risen 0.6 °C to 0.9 °C between 1906 and 2005 (Karen, 2015). The rate of temperature increase had nearly doubled in the last 50 years. Temperature plays an important role in form of living and non-living things include water resources.

The maximum, minimum and mean temperature from the year 1980-2069 has been projected for the chosen study area. Figure 2 shows the results of simulated maximum, minimum and mean temperature from the year 1980-2069 in Cameron Highland. Three equations correspondingly which are y = 0.0421x – 59.715 for maximum, y = 0.0249x – 30.786 for minimum and y = 0.0315x – 41.109 for mean. This model shows that in the next 100 years, the maximum, minimum and mean temperatures are expected to rise 4.2°, 2.5° and 3.2 °C respectively.

Figure 3 shows the observed maximum, minimum and mean temperatures that are on different slopes. Tierce the equations y = 0.0282x – 33.99, y = 0.0113x − 7.176 and y = 0.0197x – 20.583 have a smaller gradient where the maximum, minimum and mean temperatures are estimated to increase 2.8°, 1.1° and 2.0 °C respectively in 100 years' time. This complies with the observation on the field where local people commented on the "warmer days, less cold days/nights" statement.

In order to remove common systematic model errors, bias correction has been applied to the simulated data. Figure 4 shows the outcomes of corrected maximum, minimum and mean temperature. The corrected equations are: y = 0.0383x – 54.178, y = 0.0283x – 38.62 and y = 0.0182x – 23.061.

Thus, the maximum, minimum and mean temperatures are estimated to rise around 3.8°, 1.8° and 2.8 °C in 100 years' time. The rate of temperature rise after correction is slightly lower than simulated data. According to Stern (2006), the rate of temperature rise brings different levels of impacts.

Temperature rise increases evaporation and decreases runoff, but has been found to cause an increased rate of runoff (Azin et al., 2016). With an increase of 2°C, crop yields will drop by 5% – 10%.

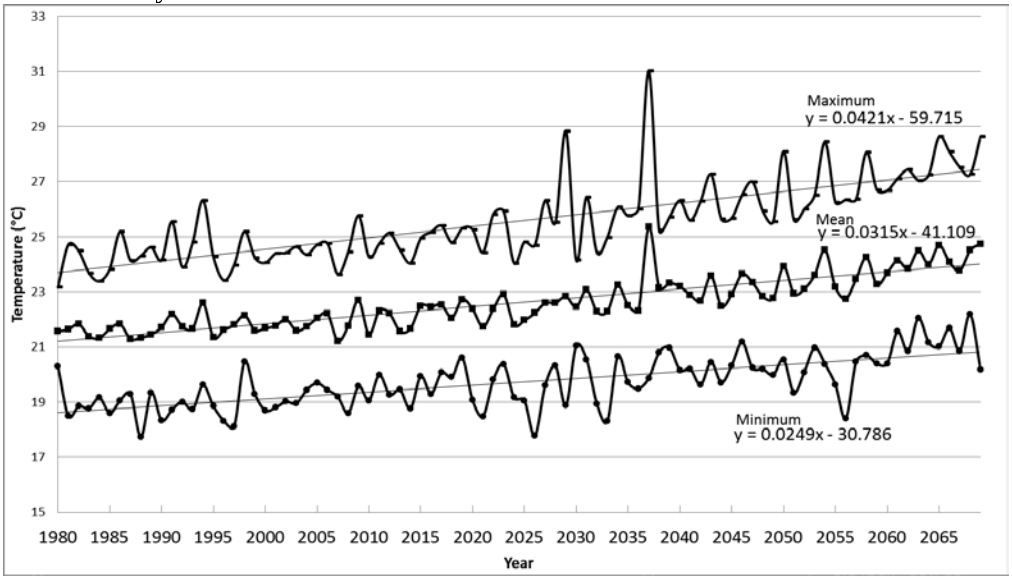

Figure 2. Simulated maximum, minimum and mean temperature from year 1980 – 2069 in Cameron Highlands

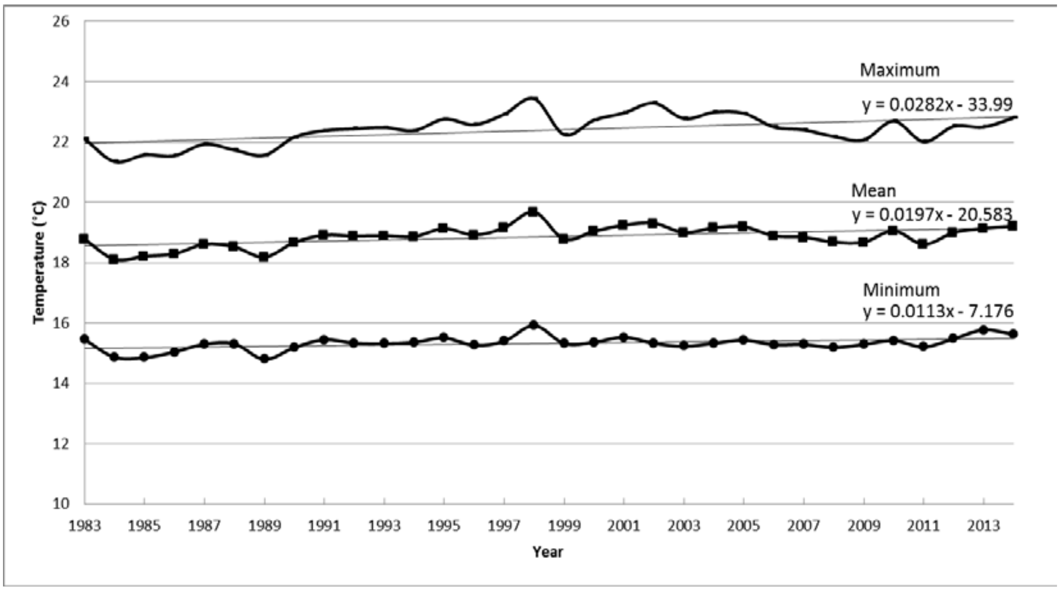

Figure 3. Observed maximum, minimum and mean temperature from year 1983 – 2014 in Cameron Highlands

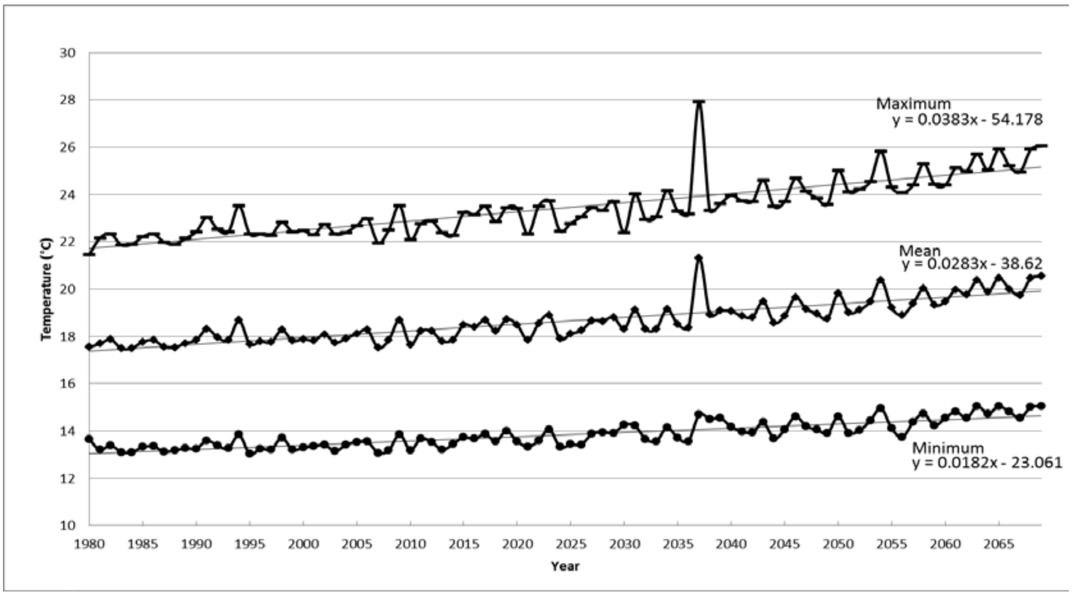

Figure 4. Corrected maximum, minimum and mean temperature from year 1980 – 2069 in Cameron Highlands

While with an increase of 3°C, increased floods event will occur. A total 4°C of temperature rise causes agricultural yields to drop 15% – 35%, that is a terrifying figure which eventually can lead to food shortage when over half of Malaysian vegetable demands are supplied by Cameron Highlands' farmers (Barrow et al., 2009).

Trenberth (1998) stated that an increase in heavy precipitation events should be a primary sign of climate change which caused by the increasing atmospheric greenhouse gases. Higher concentrations of greenhouse gases increase the downward current of infrared radiation which causes global heating at the surface. This heat not only acts to increase temperatures but also promotes evaporation which enhances the atmospheric moisture content. As a result, all weather systems that depend on the moisture availability are likely to bring intensified precipitation rates. The main reason for erratic rainfall in Cameron Highlands is climate change (Tayebiyan et al., 2015). Climate change is caused by the excessive greenhouse gases trapped heat energy in the atmosphere. Besides deforestation, installation of rain shelters for crops in Cameron Highlands as well contributes to the emission of greenhouse gases. Rain shelters reflected heat back into the surroundings, causing more extreme events and changing rainfall pattern.

4.2. Precipitation

Simulation outputs from regional climate model are used to develop the annual rainfall trend. Figure 5 shows the simulated annual rainfall from the year 1980 – 2069. The equation y = 2.5245x – 2498. It gives a positive gradient of 2.5245 with an increase in annual precipitation of 2.5 mm per year (25.2 mm in 10 years or 252.5 mm in 100 years).

The observed annual rainfall recorded from MMD climatic monitoring station in Cameron Highlands from 1984 to 2013 shows a positive gradient of 13.868 as in figure 6. The equation was found to be y = 13.868x – 24872. There is an increment of 13.9 mm of rainfall per year. This complies with the field observation where local people commented on the “more heavy rain events” statement.

Rainfall is common all year round in Cameron Highlands although the Northeast monsoon season is between November and February. The dry season is between February and April which has been shown in figure 7. January has the least rainfall of 117.53 mm while October is the wettest month with the most rainfall of 367.09 mm.

The corrected annual precipitation in figure 8 gives an equation of y = 2.3178x – 2293.6 with a slope of 2.3178. This positive slope indicates a rise in rainfall amount of 2.3 mm per year (23.2 mm per 10 years or 231.8 mm per 100 years). Increased temperature could lead to a more intense water cycle. The evaporation rates of soils and water plus the evapotranspiration from plants could increase. This may cause the increasing amount of precipitation in the study area.

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The evaporation rates of soils and water plus the evapotranspiration from plants could increase. This may cause the increasing amount of precipitation in the study area.

Extraordinary rainfall can increase floods in Cameron Highlands. This situation can become serious in addition to the excessive land clearing at hill slope in Cameron Highlands. According to Department of Irrigation and Drainage Cameron Highlands (2015), the number of massive flood disaster has been increased in recent years in Cameron Highlands which requires serious concern of government authorities. Nevertheless, the outcomes show that there may have increased of maximum precipitation significantly in coming 10 and 100 years. This probably adds a new dimension of challenges to sustainable development in Cameron Highlands.

5. CONCLUSIONS

This study was conducted to develop the climate projection scenario (1980 – 2069) in Cameron Highlands using regional climate model.

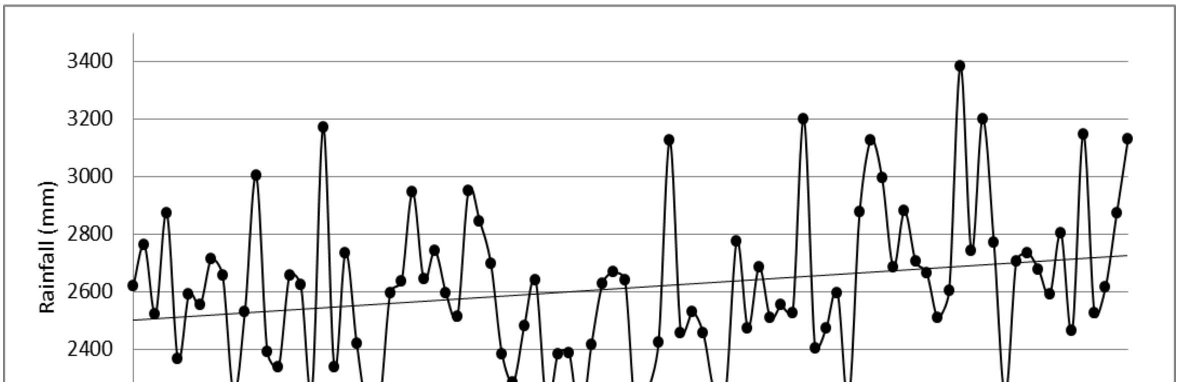

Figure 5. Simulated Annual Rainfall from year 1980 – 2069 in Cameron Highlands

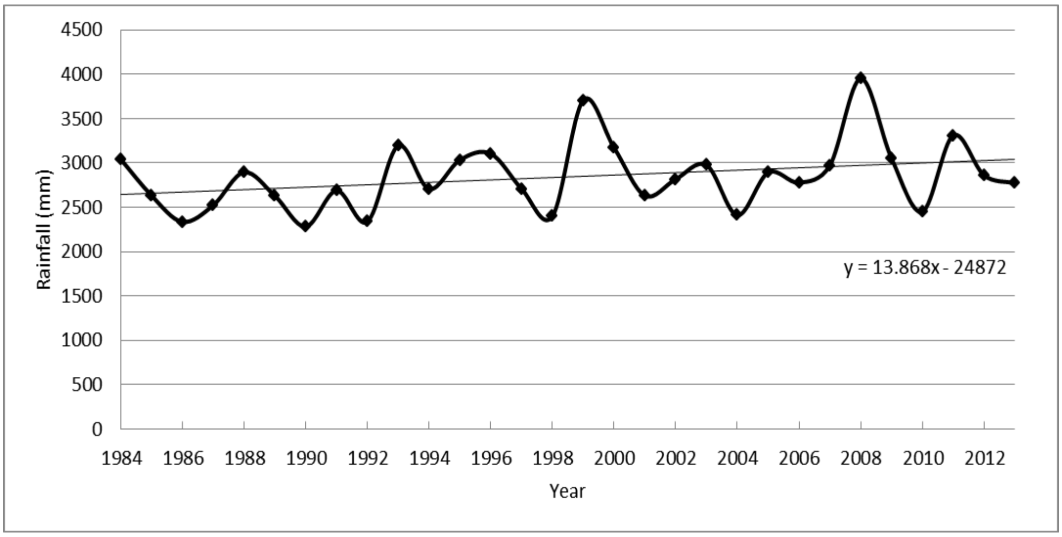

Figure 6. Observed Annual Rainfall from year 1984 – 2013 in Cameron Highlands

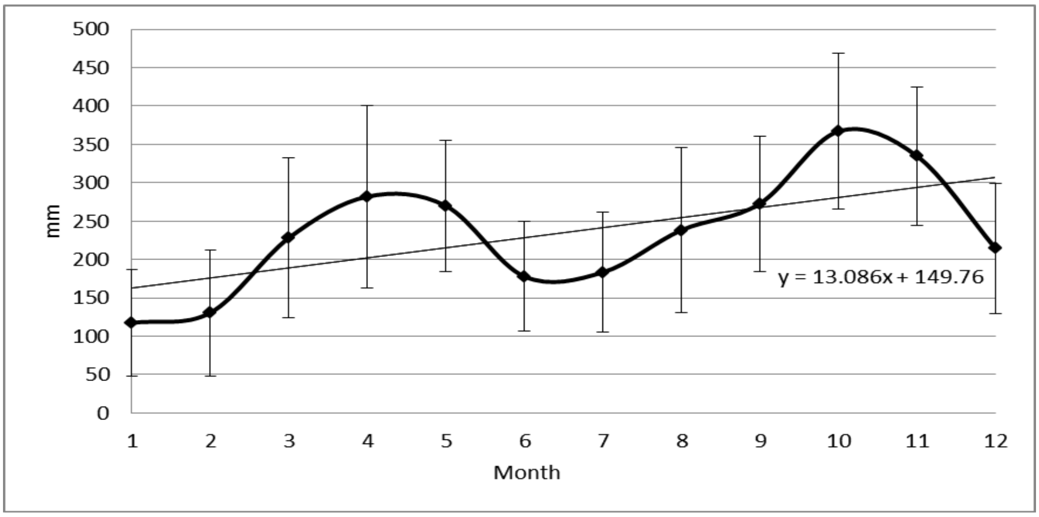

Figure 7. Average Observed Monthly Rainfall from year 1983 – 2014 in Cameron Highlands

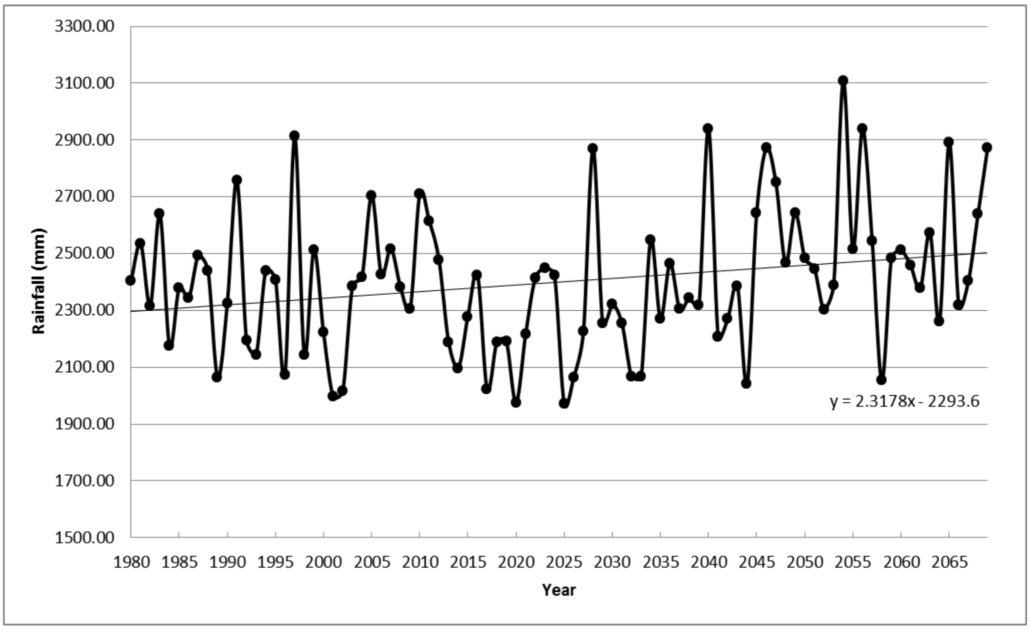

Figure 8. Corrected Annual Rainfall from year 1980 – 2069 in Cameron Highlands

In this study, the observed historical data from 1983 – 2014 was used to validate the model for the chosen site. The outcomes showed that the maximum, minimum and mean temperatures are estimated to rise 3.8°, 1.8° and 2.8 °C in 100 years' time.

The corrected annual precipitation indicates a rise in rainfall amount of 2.32 mm per year (23.2 mm per 10 years or 231.8 mm per 100 years). Both precipitation and temperature parameters showed a positive gradient which means there will be heavier rainfall and an increase in the average temperature in Cameron Highlands. These small changes can bring drastic impacts especially to water resources such as water shortage during the dry season in local farms and tea plantation estates; massive flooding that occurred during the rainy season. Further study is also identified to develop an integrated decision-making support system based on climate projection scenario that important enhancing policy development process.

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