Rainfall Characteristics in a Tropical Montane Cloud Forest, Gunung Alab, Crocker Range Park, Sabah, Malaysia

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ABSTRACT Generally, the tropical montane cloud forest (TMCF) has known to be the headwater for rivers which are the vital source of freshwater for the downstream user. Though one of the important information for freshwater management is the rainfall characteristics, for TMCF catchment it is still less explored in Sabah. This paper investigates the temporal pattern and variability of rainfall in Gunung Alab experimental catchment (GAEC) in the Crocker Range Park (CRP), Sabah, Malaysia. The analyses were based on rainfall observation data obtained in January 2006 to December 2018. As a comparison, similar analyses were also conducted to the rainfall observation data from a meteorological station in the west coast area of Sabah referred in this study as the coastal area of Kota Kinabalu (CAKK). The average annual rainfall for the 13 years data was 3527.1 mm and 2824.8 mm in GAEC and CAKK, respectively. The yearly average rain days in GAEC was 223 days and in CAKK was 157.1 days. Both stations received maximum monthly rainfall during the inter-monsoon season which generally occurred in April - May and September - October. In general, GAEC experienced low intensity of rains in long-duration whereas, CAKK experienced more extreme rainfall (average 2.4 ± 1.9 day yr^{-1}) compared to GAEC (0.3 ± 0.9 days yr^{-1}). Based on the set of rainfall data, total rainfall of 129.4 mm day^{-1} and 224.6 mm day^{-1} can be expected to be equal or exceeded once in 26 years at a probability of 3.85%, in GAEC and CAKK, respectively. In GAEC, one, two, five and ten years of recurrence interval, the expected maximum daily rainfall was estimated at 65.2 mm day^{-1}, 80.7 mm day^{-1}, 99.9 mm day^{-1}, and 114.1 mm day^{-1}. Whereas, in CAKK, the one, two, five and ten years of recurrence interval of maximum rainfall can be expected at 77.2 mm day^{-1}, 136 mm day^{-1}, 168.5 mm day^{-1} and 196.7 mm day^{-1}, respectively. The El Niño episodes reduce 10.5 % - 18 % and 2.7% - 27.9% of annual rainfall from the long-term average in GAEC and CAKK. These findings give insight into the potential capacity of GAEC as headwater catchment and reflect the sensitivity of the local rainfall distribution influenced by natural phenomenon namely, the El Niño-Southern Oscillation (ENSO) within the observation period.

KEYWORDS: Rainfall, Rainfall pattern, Rainfall variability, Tropical montane cloud forest, El Niño
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INTRODUCTION

Total rainfall and rainfall characteristics such as the timing, duration and intensity are among the most commonly reported and analysed meteorological data in related literature (Chen & Chen, 2003; Suhaila *et al*., 2010; Begueŕia *et al*., 2018). Such analyses are essential to define the meteorological characteristics of an area, which will then be utilised in other environmental investigations, whether as part of the studies or as the site description. In forest ecology-related research, the local rainfall profile of an area is known to affect the ecohydrological processes. In such studies, rainfall information is the first step to understanding most hydrological-related processes in a forested ecosystem. Among others, Kermavnar & Vilhar (2017) and Zheng *et al*. (2018) assessed the partitioning of rainfall in urban and natural forest settings. Rainfall characteristics have been found to influence soil moisture availability as well as soil erosion (Angulo-Martínez & Beguería, 2009; de Assunção Montenegro *et al*., 2018). In the meantime, rainfall data is the primary variable in streamflow estimation and modelling by Littlewood *et al.* (2010), Gomyo *et al*., (2011) and Zhang *et* *al.* (2019). In his study, Jamaludin *et al.* (2010) provided several examples of investigations associated with increasing and decreasing trend of rainfall in some parts of the world.

Concerning the study area, tropical montane cloud forest (TMCF) comprises only 1.4% of tropical forest worldwide (Scatena *et al.*, 2010), which translates to approximately 2.7% of the total tropical forests area in Asia. About 23% of TMCF in Malaysia have been lost or degraded from its original span of 2.7 million ha (Peh *et al.*, 2011). Despite being a small proportion of tropical forests, they are recognised as crucial components in watershed management and risk mitigation, as well as biodiversity and food security (Hostettler, 2002). In Borneo, hydro-meteorological characteristics and processes in TMCF are still relatively less explored compared to that in lowland tropical forests. One of the earlier works carried out by Bruijnzeel *et al.* (1993) in eastern Sabah, emphasized the role of TMCF on water balance and hydrochemistry. While a study in a small catchment in the Kinabalu Park focusing on water balance was conducted by Gomyo *et al*. (2011). Studies on the geological background (Tongkul *et al.*, 2006), as well as those highlighting the importance of TMCF on biodiversity (Latiff *et al.*, 2002; Repin *et al.*, 2012; Kappes, 2013; Suleiman *et al.*, 2017), were subsequently conducted, but those that seek to understand hydrological processes remain scarce. Meanwhile, TMCF has long been recognised as headwaters to downstream rivers, making them significant in providing clean water for domestic, agricultural, or industrial use.

This paper primarily discussed the rainfall characteristics in Gunung Alab, Crocker Range Park (CRP). It aims to provide insights on the temporal rainfall characteristics in the area under study, which may serve as baseline data for management purposes as well as to support ecological and eco-hydrological related studies. The discussion also includes the variation of rainfall distribution observed during the recognised El Niño-Southern Oscillation (ENSO) event within the study period. Having long-term related meteorological data (i.e., rainfall) is vital as a reference to understand changing trends, if any, and for prediction of expected/potential ecosystem impacts or deterioration. Previous studies identified cases of changes in rainfall patterns, more frequent drought incidents, and dry spell intensification associated with El Niño phenomenon (Walsh & Newberry, 1999; Wen & Sidik, 2000; Gomyo *et al*., 2011; *Susilo et al*., 2013). Known to be a vulnerable ecosystem, it is anticipated that montane cloud forest would be very much affected under current climate change scenario as mentioned in previous works (Foster, 2001; Diaz *et al*., 2003; Bruijnzeel *et al*., 2011). Some of the adverse impacts may include drier condition (Crausbay *et al*., 2014), alteration rate of fog interception (Bruijnzeel *et al*., 2011; Los *et al*., 2019), growth and survival of certain plant species (Aiba and Kitayama, 2002; Diaz *et al*., 2003) as well as modification of hydrological processes (Bruijnzeel *et al*., 2011). Comparison of rainfall data observed at the nearby coastal area are also included in this paper, with the intention to gain more understanding in the spatial differences of the amount and profile of rainfall in both Gunung Alab and the representative station situated at a much lower altitude.

GENERAL STUDY SITE DESCRIPTION

The research was carried out in the southwestern part of the Crocker Range in Sabah, Malaysian Borneo (5°49’18.8’’N, 116°20’28.4”E) as shown in Figure 1. At approximately 1,900 m a.s.l, Gunung Alab consists of tropical montane forest that is high in faunal species diversity as well as possessing a complex floristic composition (Latiff et al., 2002; Repin et al., 2012; Suleiman et al., 2017). For most parts, forests adjacent to the road leading to the catchments had been logged and cleared for village settlements, but Gunung Alab itself remained as undisturbed primary forests (Sabah Parks, 2006). In 1984 the Crocker range area was gazetted as a state park because of its importance as headwater catchments for significant rivers in the west coast and interior parts of Sabah (Sabah parks, 2006).

Since Gunung Alab itself is a headwater catchment, conservation of the area is crucial for maintaining stream water quality and flow stability for utilization by downstream users, especially those involved in agricultural activities.

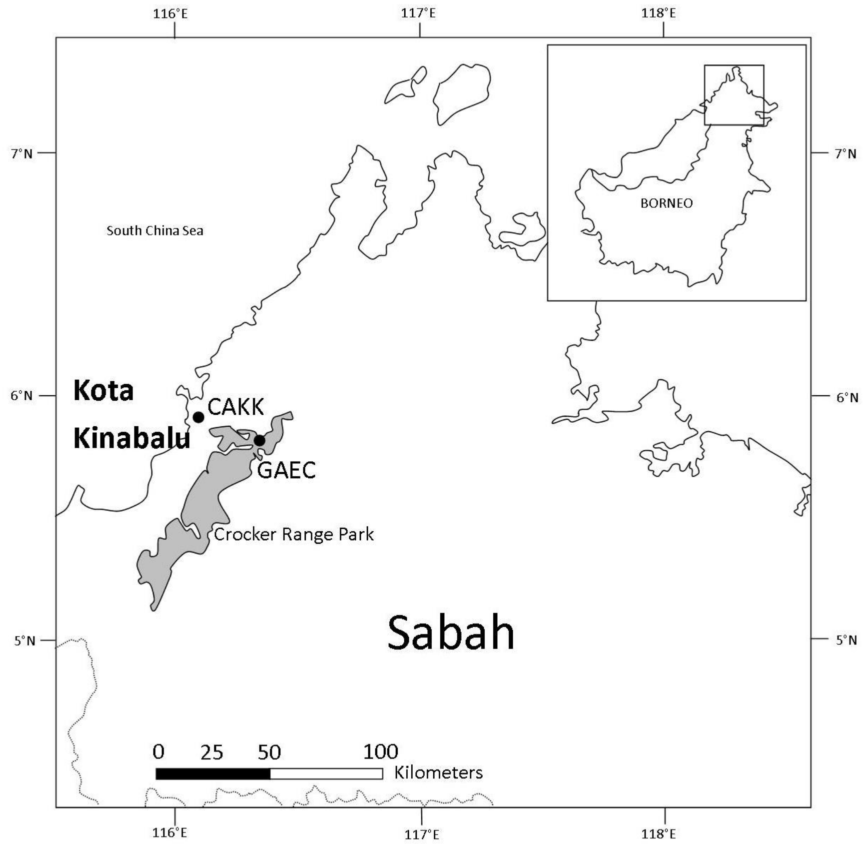

Figure 1. Location of weather station in Gunung Alab (GAEC) and Kota Kinabalu (CAKK).

METHODOLOGY

Gunung Alab daily rainfall records (2006 to 2018) were obtained from two meteorological stations. The first station is managed by the Sabah Drainage and Irrigation Department (DID) located at 5°48′46.3′′N, 116°20′18.2″E, whilst the second station is a result of a collaborative effort between Universiti Malaysia Sabah (UMS), Sabah Parks and The University of Tokyo. Universiti Malaysia Sabah was given the responsibility to manage and maintain data collection and the related equipments installed in the station. The latter is located northeast (approximately 1.8 km) from the first station.

In this paper, the first station is the primary data resource since the rainfall monitoring at the second station only started in middle of August 2010. Rainfall data from both stations were highly correlated (98%) and uniformly distributed, therefore the arithmetic average method was employed to calculate the average rainfall from both stations where necessary (i.e. missing data). Coastal area rainfall data recorded near the Kota Kinabalu International Airport (34.5 km northwest of Gunung Alab; 5°55′58.5′′N, 116°2′50.6″E) were obtained from the Malaysian Meteorological Department (MMD) to be compared with Gunung Alab rainfall observation data. The El Niño events, including their intensities, were obtained based on information available from the United States National Oceanic Atmospheric Administration (NOAA). El Niño can be categorized as weak (0.5 ℃ – 0.9 ℃), moderate (1.0℃ – 1.4℃) and strong (1.5℃ – 1.9℃) (NOAA)(https://ggweather.com/enso/oni.htm).

In addition to the time series investigation, total rainfall (annual and monthly) and temporal variation (seasonal and inter-annual) were computed and analyzed. Probability exceedance and return period were calculated for the annual maximum daily rainfall. Return period 'T' was computed using the Weibull's formula as given below:

$$T = 1/ P \quad (1)$$

The probability of exceedance of rainfall values is the reciprocal of the return period

$$P = [M/ (N + 1)] \times 100 \quad (2)$$

where P is the probability of each event in percentage, M is the order number of each event when the data are arranged in decreasing order; N is the total number of events in the data series

RESULTS AND DISCUSSIONS

Annual rainfall

Annual rainfall from 13 consecutive years is shown in Figure 2. In Gunung Alab (GAEC), the total annual rainfall ranged from a recorded-maximum of 4323.4 mm in 2014 to a minimum of 2878 in the year of 2009, while the standard deviation is 549.4 mm. In the coastal area Kota Kinabalu (CAKK) station, annual rainfall ranged from a recorded-maximum of 3399 mm in 2010 to a minimum of 2036.8 mm in 2015.

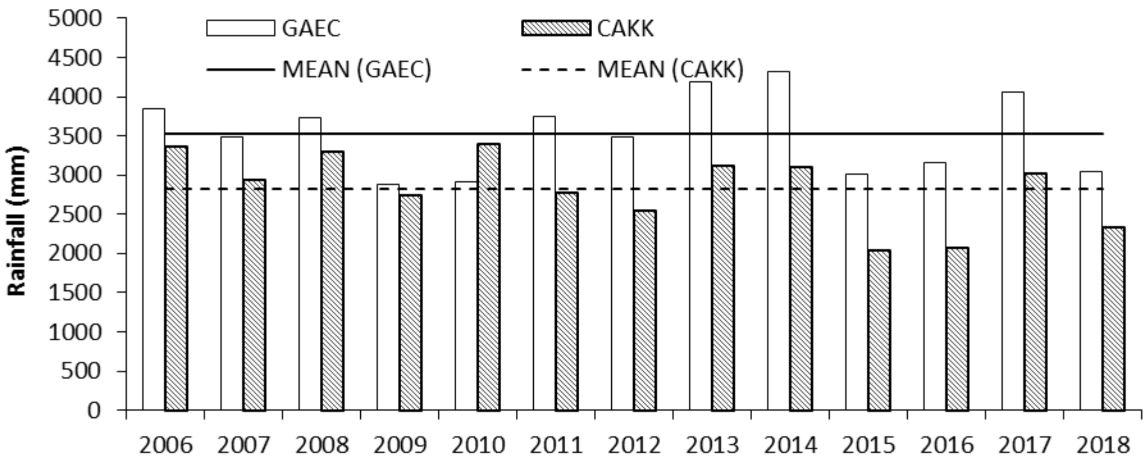

Figure 2. Annual rainfall from 2006 to 2018 in GAEC and CAKK.

The mean annual rainfall at GAEC for 2006−2018 was 3527.1 mm. Throughout this period, five years (2009, 2010, 2015, 2016, and 2018) received 300-650 mm less rainfall than the 13-year average – 2015 and 2016 being an El Niño year. As 2014 experienced a La Niña episode, annual precipitation was 4323.4 mm, which is 796.3 mm above the 13-year average - making it the wettest year throughout the data logging period. At the coast (CAKK), the mean annual rainfall was 2824.8 mm, while in 2015 and 2016, annual rainfall was 788 mm and 755.4 mm below the 13-year average. The wettest-recorded year in CAKK is 2010, where the yearly rainfall is 574.mm above the 13-year average.

Monthly rainfall

The number of rain days (a rainy day is defined as a day with more than 1 mm of precipitation) in a month is correlated to the mean monthly rainfall (Figure 3). The highest monthly rainfall in GAEC was in October (396.1 mm) and May (380.1 mm) corresponding to 20.8 and 22.1 rain days in each of those months; whereas in CAKK the highest monthly rainfall was recorded in October (357.9 mm) and September (301.3 mm) corresponding to 17.6 and 15 rain days respectively. Though both stations were affected by the inter-monsoon periods, GAEC seems to be more affected than CAKK that shows significant spatial variability of rainfall distribution. The month with the lowest number of rainy days is in February with 13.3 and 7.7 days, corresponding to 194 and 109 mm in GAEC and CAKK, respectively. In a relatively dry year (2015−2016) throughout the study period, the lowest number of rain days in GAEC was observed in March 2016 (2 days), whereas that in CAKK was in February 2015 (0 days).

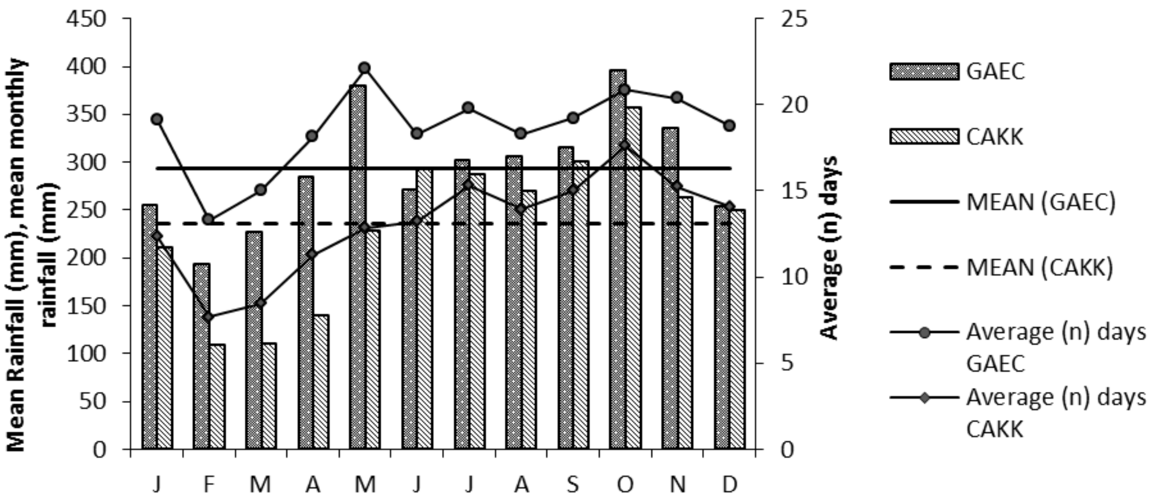

Figure 3. Average monthly variation of rainfall at GAEC and CAKK from 2006-2018

The calculated mean monthly rainfall was 293.9 and 235.4 mm in GAEC and CAKK, respectively. In GAEC, monthly rainfall exceeded the monthly mean from May until November, whereas in CAKK, the monthly mean was exceeded from July till December. In GAEC, two months had less than 10% (29.39 mm) of the mean monthly rainfall (Feb 2007, 15.5 mm; Feb 2010, 20.5 mm) whereas in CAKK five months had less than 10% (23.54 mm) of the monthly mean (Feb 2010, 0.4 mm; Feb 2015, 3 mm; Mar 2015, 15 mm; Jan 2016, 17.2 mm; Mar 2016, 15 mm).

February 2007 has seen a record-low rainfall in GAEC (15.5.mm) even though the El Niño event was recorded at weak intensity (0.5 ℃ – 0.9 ℃). The dry condition was also reflected in the low monthly rainfall at CAKK with 28.2 mm of rainfall in February 2007. Although drought extremes are generally enhanced during El Niño, the temporal and spatial distribution of rainfall in Malaysia is also determined by the monsoon cycles and local topography of the region (Tanggang *et al*.,2017; Salimun *et al*., 2014).

Frequency of daily rainfall

At GAEC, rain (≥ 1 mm) falls on an average of 223 days per year, which, is 29.6% higher than in CAKK (157.1 days) due to “orographic lifting” that is common in mountainous areas (Houze, 2012). The annual rainy days in GAEC range between 192 days (2016 and 2014) and 267 days (2017). Meanwhile, CAKK recorded annual rainy days between 123 days (2015) and 184 days (2011). Table 1 shows, the average numbers of days under different amount of rainfall or rainfall depth.

GAEC exhibits the meteorological characteristics of TMCF with frequent but small rain events and the presence of fog (i.e. horizontal precipitation). Usually, this condition is observed during early morning and afternoon. The presence of fog might be related to the ‘light shower’ occurring in the vicinity. Fog deposition could be a significant input to precipitation in the study area and would be a potential topic for future study. However, understanding cloud water interception involves more work and specific gages, as mentioned in Bruijnzeel *et al*. (2011). On average, GAEC has 152.1

days with ≤ 10 mm of rainfall per year, while in CAKK, the average number of days with ≤10 mm was 117.2 days per year. Days with rainfall of ≤ 10 mm is the most frequent, which contributed up to 57.9 % of the total number of rainy days.

Table 1. Average numbers of days under different rainfall depth within year 2006–2018

		≤10 mm	> 10 mm	>25 mm	>50 mm	> 75 mm	> 100 mm
GAEC	Average	152.1	66.2	34.3	8.3	1.3	0.3
	S.D	16.0	7.4	8.5	3.9	1.2	0.9
CAKK	Average	117.2	36.9	21.2	9.2	2.9	2.4
	S.D	17.4	6.3	3.7	3.4	1.7	1.9

In GAEC, extreme rainfall (>100 mm day^{-1}) only occurred three times in 2014 and once in 2015. For eight years since 2006, no extreme events observed. CAKK, on the other hand, experienced more frequent heavy rainfall (average of 2.4 day yr^{-1}) compared to GAEC. In 2014, rainfall of >100 mm day^{-1} occurred seven times - three of them in October. In the case of CAKK, the highest daily rainfall was recorded in 12th June (224.6 mm day-1) and 25th June (220 mm day^{-1}). Within the study period, extreme rainfall usually occurred in May and sometimes in January (2009, 2014) and March (2007). The coastal area is subjected to the effects of the land-sea diurnal breeze circulation, which greatly influences the amount of precipitation (Zhu et al., 2017; Ng et al., 2019). In his paper, Walsh *et al.* (2013) mentioned that the orientation of coastlines and mountain ranges, the interaction between local land/sea as well as mountain/valley wind systems and the regional winds are known to contribute to the variation in rainfall in Sabah.

Rainfall intensity in GAEC

Rainfall intensity in GAEC (Station 2) was calculated using hourly data which was available from 2017 to 2018. For the calculation of rainfall intensity, the data observed by Universiti Malaysia Sabah in Gunung Alab was used because only daily rainfall data were available from the Sabah Drainage and Irrigation Department (DID). The same situation also applied to CAKK whereby only daily rainfall data was available.

Precipitation in the GAEC is of high intensity and short duration. According to rainfall intensity classification by the Malaysian Department of Irrigation and Drainage, rainfall intensity of less than 10 mm hr^{-1} is categorized as light rain, 11-30 mm hr^{-1} is moderate rain, 31-60 mm hr^{-1} is heavy rain and rainfall that is more than 60 mm hr^{-1} is very heavy rain. Figure 4 shows the variation of rainfall intensity with duration.

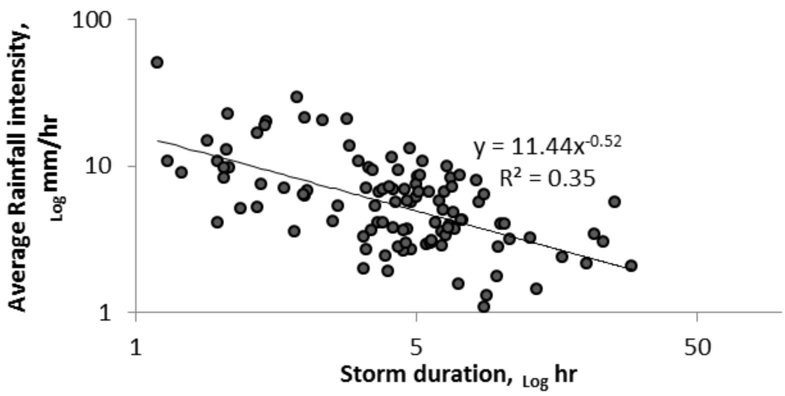

Figure 4. Variation in average rainfall intensity with storm duration in GAEC

In general, rainfall intensity in GAEC is inversely proportional to the storm period. Typically, this catchment experienced longer duration of low intensity rainfall and shorter duration of high intensity rainfall. The high amount of rainfall was typically due to prolonged orographic or relief precipitation with low intensity (Houze, 2012). The maximum 10 minutes rainfall intensity recorded was 123 mm hr^{-1} and 117 mm hr^{-1} in the month of April in 2017 and 2018 respectively. The longest duration of rainfall event identified occurred within 29.3 hours with an average intensity of 2.1 mm hr^{-1} (61 mm total rainfall).

Return period

The probability of exceedance explains the likelihood of recurrence of a specific daily rainfall in a given year. The annual maximum rainfall frequency curve for GAEC and CAKK is shown in Figure 5. Based on this data, daily rainfall of 129.4 mm is expected to occur once in 26 years in GAEC at a probability of 3.85%; whereas in CAKK, the estimated return period of the highest daily rainfall (224.6 mm) is 26 years, with a probability occurrence of 3.85%.

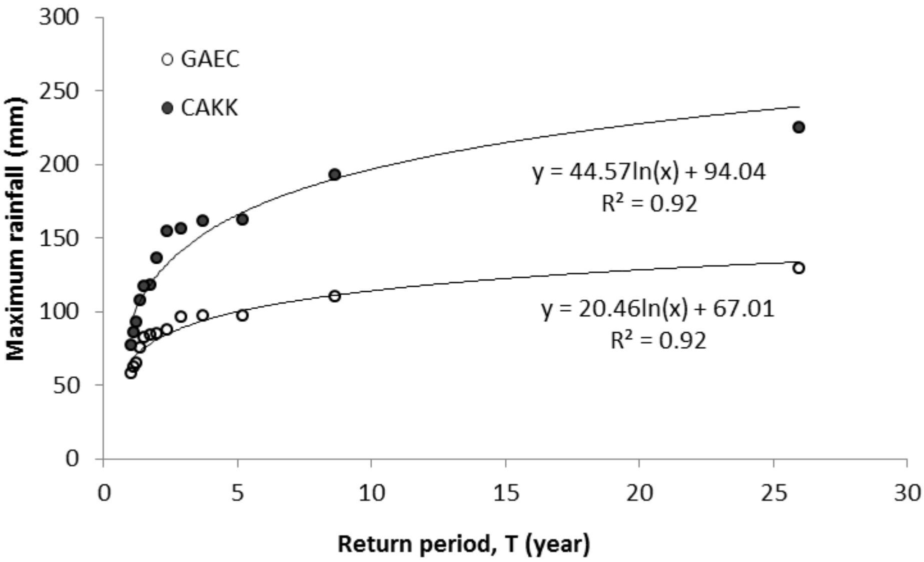

Figure 5. Probability analyses of annual rainfall for the period of 2006-2018.

The expected daily maximum rainfall at one, two, five and ten years recurrence intervals were estimated to be 65.2, 80.7, 99.9, and 114.1 mm day^{-1} respectively. In CAKK, the estimated daily maximum rainfalls for the same recurrence intervals were 77.2, 136, 168.5 and 196.7 mm day^{-1} respectively.

CONCLUSION

Gunung Alab (GAEC) exhibit varying rainfall characteristic. Daily falls mostly dominated by the morning and late afternoon short duration shower <10 mm. CAKK receives fewer rain days compared to GAEC, but more frequent heavy rainfall compared to GAEC.

The maximum monthly rainfall generally occurred during the monsoon transition (May and October). The annual rainfall pattern was also affected by the El Niño Southern Oscillation events which, resulted in a distinct climatic condition and decline in rainfall (especially in February and March) throughout the region/area. An El Niño episode in 2015−2016 reduced annual rainfall in GAEC by about 14.4% and 10.5% below the long-term average of annual rainfall, respectively. While, in CAKK, annual rainfall decreased by 27.9% and 26.7% in 2015 and 2016, respectively. The El

Niño episode in 2009−2010 reduces about 18% and 17.4% from the long-term average of rainfall in GAEC. There was also a 13.9 % reduction of rainfall recorded in GAEC in the year 2018. However, in CAKK the effects of El Niño were not apparent since the records showed only 2.7% reduction in annual rainfall in 2009 and 20.3% increase in rainfall in 2010 compared to the long-term average records. However, rainfall records in CAKK showed that there was a reduction of rainfall amount in 2012 and 2018 by 17.4 % and 10 %, respectively. The response of annual rainfall fluctuation to El Niño is lower in GAEC (more consistent) compared to in CAKK.

The distribution characteristics such as variability, persistence, frequency, and intensity of rainfall are essential for GAEC since the local community depend on rainfall for sustained livelihood in the mountain ecosystem. The runoff from the watershed relies very much on the rainfall distribution; therefore, this information is important to ensure the sufficiency of water supply to meet the future requirement in the nearby area.

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