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SPATIAL AND TEMPORAL ASSESSMENT OF DROUGHT SUSCEPTIBLE AREAS IN MALAYSIA

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By

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SPATIAL AND TEMPORAL ASSESSMENT OF DROUGHT SUSCEPTIBLE AREAS IN MALAYSIA

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Faculty : Environmental Studies

Extreme events associated with climate leave Malaysia in a devastating state, which caused economic losses in the agricultural and social aspects. Upon these kinds of events, this study aims to assess the spatial distribution of areas that are prone to face drought occurrence by conjoining the meteorological and agricultural drought assessment using Standardized Precipitation Index (SPI) and Normalized Differentiation Vegetation Index (NDVI) respectively. By application of a data reduction method, the rainfall patterns of spatial and temporal rainfall distribution was defined in Malaysia. The assessment employed 180 rainfall stations in Malaysia for 35 years, from 1980 to 2014, along with 16-day composite satellite imagery, from 2001 to 2014, in order to identify spatial and temporal pattern of drought conditions in Malaysia. The meteorological drought detection employed different time lapses, and a 3-month lag was found to be the most suitable combination with the NDVI for agricultural drought detection. An interpolation method was applied for the spatial presentation of the results, and Southwest Peninsular Malaysia has demonstrated a high consistency of drought occurrence in the past. There were occurrences of severe drought along the north coast area, while Sabah and Sarawak recorded only small areas of severely dry events. During the assessment, it was also observed that SPI share strong resemblance to the dry value recorded by the oceanic indices. This strongly supports the theory that Peninsular Malaysia was highly affected by the ocean's activities, since Malaysia itself is situated between two oceans. The combination of SPI and NDVI indicates that there are large areas in Peninsular Malaysia that are highly susceptible to events of water deficit, especially along the northwest coast area, starting from the northern peninsular, to the southern part. The middle of Peninsular Malaysia also recorded low to moderately susceptible to drought occurrence, and there are formations of high susceptibility areas in the southeast coast area. Sabah and Sarawak, however, record low numbers of areas that are susceptible, and more than half of Borneo Island is considered to as unsusceptible to drought occurrence. In a nutshell, the use of SPI and NDVI

independently helps to project the historical drought events that have occurred previously, and this historical data is useful in predicting future occurrence, since most climatic events are recurrent, and have distinctive patterns that can be investigated using past events.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENILAIAN RUANG DAN MASA UNTUK PENDEDAHAN KAWASAN KEMARAU DI MALAYSIA

Oleh

MELAWANI BINTI OTHMAN

April 2018

Pengerusi : Zulfa Hanan Ash'aari, PhD
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Kejadian ekstrem melibatkan iklim telah meletakkan Malaysia dalam keadaan yang membinasakan menyebabkan kerugian ekonomi dalam aspek pertanian dan sosial. Disebabkan kejadian yang sedemikian, kajian ini mensasarkan untuk menilai pengagihan ruang bagi kawasan yang terdedah menghadapi kemarau dengan menggabungkan penilaian kemarau meteorologi menggunakan Indeks Piawaian Kerpasan (SPI) dan kemarau pertanian yang di ukur menggunakan Indeks Menormalkan Perbezaan Vegetasi (NDVI). Dengan menggunakan aplikasi pengurangan data, corak taburan hujan secara ruang dan temporal di Semenanjung Malaysia dan Borneo Malaysia dapat dikenal pasti. Penilaian ini menggunakan data sepanjang 35 tahun dari 180 stesen hujan di Malaysia dari tahun 1980 hingga 2014 bersama-sama data penderian jarak jauh komposit 16-hari dari tahun 2001 hingga 2014. Pengesanan kemarau meteorologi diuji menggunakan sela masa yang berbeza dan didapati bahawa lag masa 3 bulan mempunyai kesesuaian yang paling tinggi untuk digabungkan dengan NDVI. Kaedah interpolasi juga turut digunakan untuk membentangkan keputusan analisa ruang dan didapati kawasan barat daya Semenanjung Malaysia menunjukkan berlakunya kejadian kemarau pada masa lalu dengan konsistensi yang tinggi. Di sepanjang kawasan pantai di utara, berlakunya kejadian kemarau yang teruk, manakala Sabah dan Sarawak, hanya merekodkan kawasan kecil menghadapi keadaan kering yang teruk. Semasa penilaian, didapati bahawa SPI mempunyai persamaan yang tinggi dengan bacaan yang direkodkan oleh indeks lautan. Secara teori, ianya disebabkan oleh posisi Semenanjung Malaysia yang terletak di antara dua lautan menjadikan iklimnya sangat dipengaruhi oleh aktiviti laut. Kombinasi penggunaan SPI dan NDVI menunjukan bahawa terdapatnya banyak kawasan di Semenanjung Malaysia yang sangat terdedah kepada kejadian kekurangan air, terutamanya disepanjang kawasan pantai barat laut, bermula dari utara ke selatan. Kawasan ditengah-tengah Semenanjung Malaysia turut merekodkan risiko rendah ke sederhana dan terdapat pembentukan kawasan berisiko tinggi di kawasan pantai di selatan timur. Walaubagaimanapun, Sabah dan Sarawak

kurang terdedah dan lebih dari separuh kawasan di Borneo Malaysia tidak berisiko menghadapi kemarau. Kesimpulannya, penggunaan SPI dan NDVI secara individu membantu dalam menggambarkan kejadian kemarau pada masa silam dan penggunaan data ini bermanfaat dalam membuat jangkaan masa depan kerana ke-banyakan peristiwa iklim adalah berulang dan mempunyai corak yang tersendiri yang boleh dikaji menggunakan maklumat sedia ada.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

DID	Department of Irrigation and Drainage Malaysia
EQSOI	Equatorial Southern Oscillation Index
GIS	Geographic Information System
IADA	Integrated Agriculture Development Area
MADA	Muda Agricultural Development Authority
MMD	Malaysian Meteorological Department
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
NEM	North East Monsoon
PCA	Principal Component Analysis
PDSI	Palmer Drought Severity Index
SPI	Standardized Precipitation Index
SWM	South West Monsoon
WMO	World Meteorological Organization

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Drought can be considered as a slow, creeping recurrent event happened globally and Malaysia have been place in precarious position before due to extreme water deficit needed whether for essential needs, daily used or for the agricultural purposes. Drought risk or susceptible conditions are result of region's exposure to natural occurring hazard and the extent of its vulnerability increase along the period of water shortage. There may have been confusion in differentiating between drought and heat waves where their differences can be define by its timescales where heat waves occur around a week times while drought may last month or even up to a year (Chang & Wallace, 1987) .

A well prepared region with knowledge on drought severity, its onset and offsets along with its return period will have least losses compared to a region or country that have none of the information. Drought occurrence is unavoidable, however, the preparation and mitigation measure taken will reduce the damages and even decrease mortality rate due to drought impacts. Drought had also been defined as a long period with no rain, especially during planting season where the concern of drought impact was focused on the agriculture aspect (American Heritage Dictionary, 1976). This was justified by the losses that a country have to face due to late planting season, damage of crops due to water insufficiency and in extreme cases, death of livestock. A prolonged drought may lead to diminishing water storage either on surface or underground and disruption in nutrient or ion exchange in soil that result in decrease yield production. The chain of effect will continue on to the losses on economically and socially. Drought is also a natural phenomenon that have to be observed and studied since it is a part of the climate system and its recurrence is inevitable (Wilhite, 2016). The existing weather system on a particular location play huge role in the characteristic of drought and in order to understand the drought event in Malaysia, current climate and weather trend of Malaysia have be studied.

Previously, in the event of extended dry period, the authorities in Malaysia resort to the last solution which is the cloud seeding in the affected area (Bernama, 2016a; Chan, 2016). Cloud seeding provide the highest chances of rainfall by encouraging the cloud formation so that precipitation will happen (Bernama, 2016b, 2016c). However, cloud seeding only provide solution that come with expensive cost averaging over RM80, 000 per operation (Jalil, 2016). Further studies on the characteristic of drought in Malaysia is crucially needed since the drought warning based on the El-Niño circulation was estimated to hit Malaysia on many occasion in the future and may cause drastic decrease in rainfall that could affect water management system in such a way it could bring problems to the economic activities (Daud et al., 2002).

1.1.1 Climate in Malaysia

Prevailing weather conditions that occur in an area over a long period of time is what constitute as climate and it is hardly change over time. Climate differs around the world depending on complex interaction between many factors such as latitude, altitude of the land, sun's angle on an area, winds, ocean currents and many other related factors. Climates can be classified into Polar Regions, tundra, deserts, needle leaf or broadleaf forest, temperate rainforest, temperate grassland, Mediterranean, savannah, dry woodland, tropical rainforest and wetland with each of them tied to its on characteristic such as, the temperature variation, precipitations type and amount received and other factor that later on affect its variation of flora and fauna on that particular area. Malaysia is a temperate rainforest due to its location on the equator line which received direct sunlight all year round and its position in between the Indian and Pacific Ocean where ocean variability play a big role on its weather system (Tangang et al., 2012).

Located by the equator, weather system in Malaysia were mainly governed by monsoon season occur on bi-yearly basis which are the Northeast Monsoon (NEM) from November to February and Southwest Monsoon (SWM) that occur from May to August with transitional period in between the two main monsoon seasons (Suhaila & Jemain, 2007; Deni et al., 2010; Zin et al., 2010; Tangang et al., 2012). During the NEM, wind velocity can reach 20km/h with heavy rainfall especially in the east coast and south peninsular area (Zin et al., 2010; Mohtar et al., 2014;). NEM was also dominated by northeast wind that cross over the South China Sea. Southwest monsoon influenced by southwest winds that have weaker wind speed than northeast monsoon and dry season are more likely to happen during these monsoon period. Transitional period between the southwest and northeast monsoon is known as inter-monsoon period. The wind speed exceed 10 knots with variable direction is the characteristic associated with this period (Kang & Yusof, 2012). The inter-monsoon period occur during April and October yearly. There have also been reports on Sudden peak of temperature that last for few days and was classified as heat waves with sudden death due to heatstroke that occur in Malaysia in 2016 (Agencies, 2016; Bernama, 2016d). Frequent changes have been detected in Malaysia's climate with sudden temperature peak or sudden heavy downpours resulting in extreme event that cause massive impact and due to insufficient preparation. Malaysia face many losses, especially in finance due to clean up cost and compensation paid back to the society.

Malaysian Meteorological Department (MMD) in the early 2014 have issued a warning on the effect of El-Niño that will be felt in Peninsular Malaysia at the end of year 2014 and early 2015 (Bernama, 2014). Meanwhile, the AccuWeather Global Weather Center report that higher than the usual average temperature will occur in the middle of 2017 in some areas of India and the Southeast Asia and even issued a warning of drought ("Meteologist warn of drought in Malaysia, Indonesia," 2017). The increased apprehension on drought event can help the society in making proper preparation, even so, false alarm of drought could also cause panic and distress over the community. The case of false prediction can be overcome by developing a comprehend drought study that resulting in higher accuracy warning system and prediction modelling. This will provide better information for the society especially those in affected fields such as farmer and town management authorities. The understanding on drought characteristic is still lacking and need to be studied further, however, its impact are widely known and experienced previously such as losses of crop, livestock and arable land that in extreme condition will lead to starvations which will ultimately ended with fatality. However, the planning implementation and mitigations measure have to be based on scientific studies done at regional and local scales and unfortunately, the information are lacking especially in the southeast Asia (Tangang et al., 2012).

With proper information based on scientific studies and research, accurate modelling and prediction can be used for future estimation. In doing so, well planned mitigation measure can be developed and this will reduced the damage face in the event of drought. Proper early warning systems will also help in securing food and water storage in preparation to face prolong drought. Good planning and preparation will reduce the cost and may even resulting in low mortality rate. For this to happen, baseline regional studies are needed in order to identify those susceptible area and base study will also help in highlighting the area for a more detailed studies in the future.

1.2 Problem Statement

In previous years, large-scale intensive droughts have been observed in Malaysia leading to huge economic losses (Nakagawa et al., 2000; Ichie et al., 2004; Yusof, 2012). The Star/Asia News Network reported that in March 2016, paddy planting season in drought affected states was delayed due to water shortage and absence of rainfall resulting in huge losses to the farmers. Furthermore, based on Paddy Production Survey Report MALAYSIA (2003-2012), MADA estimated losses due to the off-season were around RM4-RM6 million, while, the estimated loss for KADA off-season caused by droughts were around RM5.5 - RM8.2 million. Studies and research on the onset and duration of a drought event can minimized or even prevent us from facing these huge losses. Immediate attention in drought prediction are needed since there was a prediction of Asia being hit by drought in year 2020s' based from projection made by the UK-based Centre for Low Carbon Futures that found out, compared to 1990-2005, increased event of severe drought in 2020s' which will primarily occur due to the water deficit (Padma & Jiao, 2012).

Conventional method of drought studies always include site sampling and estimation based on small time lapse due to insufficient data, expensive cost and extensive time needed before a proper estimation can be made. There is also the fact that tradition assessments assimilate rainfall, soil moisture or water supply information without highlighting the local spatial details. In addition, drought indices used are usually localized and only valid for certain particular location (Brown et al., 2002) which can be enhanced by integrating spatial estimation technique in overcoming this weakness. The spatial interpolation technique will provide estimation of the environmental variables at the inaccessible site by using the data obtained from point observation (Li & Heap, 2011). The combination of site data collection and the spatial estimation method may provide better estimation and increase accuracy level.

Global drought studies have been done widely in order to understand the drought phenomenon, however, it is very critical to understand the local scale event due to its heterogeneity in the spatial and temporal variability of the hydrology and meteorology complex relationship (Mishra & Singh, 2010). It is also acknowledged that among natural hazards, drought can cause extensive damage that affect significant number of people (Wilhite, 1993). Large area studied will benefit large people in general, however, since drought are closely affected by the local climate condition, generalizing it for benefit or large area might reduce the accuracy of the result obtained. The condition might be over or underestimated due to over generalization. This factor have been considered and due to that, this studies will focus only on the Malaysia itself in order to understand its event al local level before it can be extrapolated further.

Objective

The main objective of this study is to identify areas in Malaysia that are susceptible to face drought condition by assessing the meteorological and agricultural condition. Meanwhile, the specific objectives of this study are as follow:

1. To identify spatial and temporal pattern of meteorological drought based on the data of 35 years.
2. To identify agricultural drought susceptible area through vegetation health response towards water deficit.
3. To assess drought susceptible area in Malaysia by using the combination of meteorological and agricultural drought risk area.

1.3 Significance of Study

The expected outcomes will generate visualization of drought susceptible area in Malaysia along with its temporal pattern for the last 35 years which can be used as base information to further analyse and estimate probable damage in the future. The outcomes will also provide critical information for risk management, mitigation measures and as base information for further studies in minimizing damage due to drought event. The main advantage of using GIS for drought assessment is that it not only generates a spatial visualization of information of hazard but also provide information for the area that was not covered due to location of the rainfall stations that was sparsely distributed.

The application of geospatial analysis provides a better opportunity in assessing the drought occurrence and provides researchers with extra information on the case studied. The remotely sensed images from satellites and aircrafts are often the only source that can provide this information for large areas at acceptable costs (Wipulanusat et al., 2009) and even though the remote sensing application is little challenging for Malaysia due to high cloud formations along the equator line, it is still consider as a better solution compared to the conventional method. There are many information provided by the remotely sensed imagery that can be utilized in many different aspect that come with less cost and less time consumed. The main significance of this study is to provide information of drought in Malaysia and there are two fundamental requirement in reinforcing mitigation measure which are; 1) drought risk assessment quantifying the area with high potential of facing hazard and the vulnerability of the different regions which will be highlighted for easier target by the authorities in the event of drought threat and 2) real-time information concerns the development of drought conditions and providing forecasts of the likely evolution of the drought (Vicente-serrano et al., 2012). The real-time information was provided using long historical data in order to increase its accuracy and this will improve current understanding on drought phenomenon in Malaysia. The information obtained from this study will assist the policy maker in identifying susceptible area to drought and provide solution that can minimize the damage face by the society.

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APPENDICES

APPENDIX

Table 15 : Summary of missing values replacement using linear interpolation method

Result Variables

	Result Variable	N of Replaced Missing Values	Case Number of Non-Missing Values		N of Valid Cases	Creating Function
			First	Last		
1	Sabah1_1	1	61	420	360	LINT(Sabah1)
2	Sabah2_1	6	61	420	360	LINT(Sabah2)
3	Sabah3_1	5	61	420	360	LINT(Sabah3)
4	Sabah4_1	0[a]	61	420	360	LINT(Sabah4)
5	Sabah5_1	8	61	420	360	LINT(Sabah5)
6	Sabah6_1	5	61	420	360	LINT(Sabah6)
7	Sabah7_1	0[a]	61	420	360	LINT(Sabah7)
8	Sabah8_1	0[a]	61	420	360	LINT(Sabah8)
9	Sabah9_1	6	61	420	360	LINT(Sabah9)
10	Sabah10_1	2	61	420	360	LINT(Sabah10)
11	Sabah11_1	0[a]	61	420	360	LINT(Sabah11)
12	Sabah12_1	2	61	420	360	LINT(Sabah12)
13	Sabah13_1	0[a]	61	420	360	LINT(Sabah13)
14	Sabah14_1	0[a]	61	420	360	LINT(Sabah14)
15	Sabah15_1	1	61	420	360	LINT(Sabah15)
16	Sabah16_1	0[a]	61	420	360	LINT(Sabah16)
17	Sabah17_1	4	61	419	359	LINT(Sabah17)
18	Sabah18_1	0[a]	61	407	347	LINT(Sabah18)
19	Sabah19_1	3	61	420	360	LINT(Sabah19)
20	Sabah20_1	1	61	420	360	LINT(Sabah20)
21	Sabah21_1	0[a]	61	420	360	LINT(Sabah21)
22	Sabah22_1	0[a]	61	419	359	LINT(Sabah22)
23	Sabah23_1	0[a]	61	419	359	LINT(Sabah23)
24	Sarawak2_1	14	1	420	420	LINT(Sarawak2)
25	Sarawak5_1	10	1	420	420	LINT(Sarawak5)
26	Sarawak6_1	1	1	420	420	LINT(Sarawak6)
27	Sarawak7_1	18	1	420	420	LINT(Sarawak7)
28	Sarawak8_1	10	1	420	420	LINT(Sarawak8)
29	Sarawak9_1	16	1	420	420	LINT(Sarawak9)
30	Sarawak10_1	2	1	420	420	LINT(Sarawak10)
31	Sarawak11_1	7	5	420	416	LINT(Sarawak11)
32	Sarawak12_1	20	1	420	420	LINT(Sarawak12)
33	Sarawak13_1	5	1	420	420	LINT(Sarawak13)
34	Sarawak14_1	4	1	420	420	LINT(Sarawak14)
35	Sarawak16_1	12	1	420	420	LINT(Sarawak16)
36	Sarawak17_1	1	1	420	420	LINT(Sarawak17)
37	Sarawak20_1	10	4	420	417	LINT(Sarawak20)
38	Sarawak22_1	4	1	420	420	LINT(Sarawak22)
39	Sarawak26_1	19	1	420	420	LINT(Sarawak26)
40	Sarawak27_1	34	2	420	419	LINT(Sarawak27)
41	Sarawak28_1	19	1	420	420	LINT(Sarawak28)
42	Sarawak30_1	10	1	420	420	LINT(Sarawak30)
43	Sarawak32_1	0[a]	1	420	420	LINT(Sarawak32)

44	Sarawak33_1	4	1	420	420	LINT(Sarawak33)
45	Sarawak36_1	34	1	420	420	LINT(Sarawak36)
46	Sarawak37_1	2	1	420	420	LINT(Sarawak37)
47	Sarawak40_1	41	1	420	420	LINT(Sarawak40)
48	Sarawak44_1	13	3	420	418	LINT(Sarawak44)
49	Sarawak46_1	1	1	420	420	LINT(Sarawak46)
50	Sarawak50_1	51	11	420	410	LINT(Sarawak50)
51	Sarawak51_1	14	1	420	420	LINT(Sarawak51)
52	Sarawak55_1	5	1	420	420	LINT(Sarawak55)
53	Sarawak56_1	30	1	420	420	LINT(Sarawak56)
54	Sarawak57_1	8	1	420	420	LINT(Sarawak57)
55	Sarawak59_1	31	11	420	410	LINT(Sarawak59)
56	Sarawak60_1	16	11	420	410	LINT(Sarawak60)
57	Sarawak62_1	13	1	420	420	LINT(Sarawak62)
58	Sarawak65_1	8	2	420	419	LINT(Sarawak65)
59	Sarawak68_1	6	8	420	413	LINT(Sarawak68)
60	Sarawak69_1	31	1	420	420	LINT(Sarawak69)
61	Sarawak73_1	36	6	420	415	LINT(Sarawak73)
62	Sarawak77_1	18	7	420	414	LINT(Sarawak77)
63	Sarawak79_1	19	1	420	420	LINT(Sarawak79)
64	Sarawak80_1	28	7	420	414	LINT(Sarawak80)
65	Sarawak82_1	5	1	420	420	LINT(Sarawak82)
66	Sarawak83_1	32	1	420	420	LINT(Sarawak83)
67	Sarawak85_1	0[a]	1	420	420	LINT(Sarawak85)
68	Sarawak89_1	4	1	420	420	LINT(Sarawak89)
69	Sarawak91_1	5	1	420	420	LINT(Sarawak91)
70	Sarawak92_1	2	11	420	410	LINT(Sarawak92)
71	Terengganu3_1	9	1	420	420	LINT(Terengganu3)
72	Terengganu6_1	17	1	420	420	LINT(Terengganu6)
73	Terengganu7_1	7	1	420	420	LINT(Terengganu7)
74	Terengganu8_1	2	1	420	420	LINT(Terengganu8)
75	Terengganu11_1	2	1	420	420	LINT(Terengganu11)
76	Terengganu14_1	28	1	420	420	LINT(Terengganu14)
77	Terengganu18_1	18	1	420	420	LINT(Terengganu18)
78	Terengganu22_1	11	1	420	420	LINT(Terengganu22)
79	Terengganu24_1	39	1	420	420	LINT(Terengganu24)
80	Terengganu29_1	14	1	420	420	LINT(Terengganu29)
81	Terengganu30_1	51	1	420	420	LINT(Terengganu30)
82	Perlis1_1	16	38	420	383	LINT(Perlis1)
83	Perlis2_1	11	1	420	420	LINT(Perlis2)
84	Perlis3_1	9	1	420	420	LINT(Perlis3)

a. The input variable contains no embedded missing values or the number of valid cases is less than 2. No missing cases are replaced.

Principal Component Analysis

Peninsular Malaysia

Table 16 : Suitability test for data reduction

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.949
Bartlett's Test of Sphericity	Approx. Chi-Square	31739.746
	df	4950
	Sig.	.000

Table 17 : Scree plot method to decide numbers of component retained

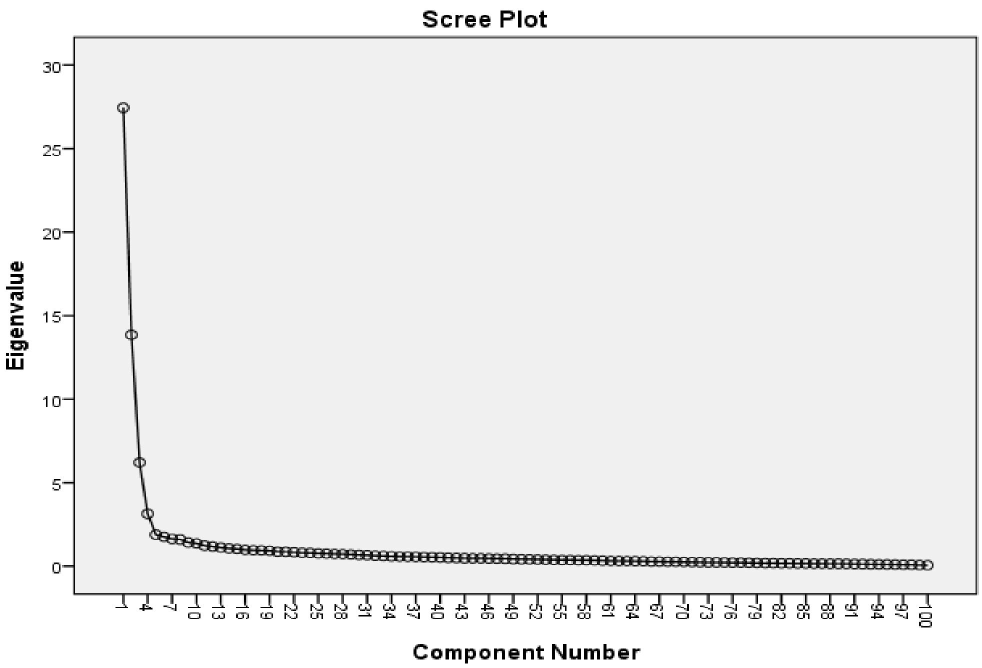

Table 18 : Component retained from PCA

Component Matrix[a]

	Component			
	1	2	3	4
Terengganu3	.674	-.508	-.272	-.211
Terengganu18	.674	-.528	-.269	-.186
Terengganu7	.657	-.479	-.301	-.231
Pahang26	.656	-.388	-.072	.092
Kelantan8	.654	-.390	-.358	-.111
Terengganu29	.646	-.368	-.180	-.301
Terengganu11	.645	-.546	-.185	-.112
Terengganu8	.645	-.432	-.257	-.252
Terengganu14	.643	-.482	-.132	-.212
Terengganu24	.642	-.449	-.276	-.180
Kelantan7	.637	-.306	-.248	.042
Kelantan15	.625	-.428	-.319	-.127
Terengganu6	.622	-.530	-.247	-.062
Pahang16	.620	-.114	.051	.194
Perak11	.619	.168	.276	-.187
Selangor20	.616	-.016	.227	-.041
Kelantan18	.602	-.367	-.222	-.067
Pahang10	.602	-.253	.177	.207
Kelantan3	.601	-.400	-.302	-.155
Terengganu22	.596	-.577	-.133	-.118
Kelantan12	.592	-.003	-.290	.155
Perlis2	.590	.318	-.390	.025
Pahang23	.589	.159	.189	-.007
Kelantan20	.588	-.332	-.370	-.184
Pahang25	.586	-.097	-.001	.014
Pahang21	.584	-.520	-.133	.025
Pahang33	.575	-.206	-.132	.127
Pahang27	.575	.040	.019	.176
Pahang17	.570	-.420	.023	.138
N.Sembilan1	.562	.092	.144	-.224
Pahang20	.558	.062	.312	-.041
Pahang36	.557	.151	-.005	-.055
Selangor3	.555	.001	.097	.030
Selangor1	.550	.007	.092	.067
Perak7	.549	.361	.090	-.104
Selangor17	.548	.425	.219	-.218
Selangor2	.546	.295	.303	-.170
Perak15	.544	.126	.341	-.122
Terengganu30	.543	-.462	-.231	-.223
Perak16	.538	.045	.405	-.139
Melaka1	.532	.246	.319	.066
Pahang4	.529	-.346	.336	.351
Perak12	.527	.474	-.086	-.113
Perak2	.526	.249	.062	.006
Pahang32	.525	.004	-.180	-.004
Selangor12	.517	.125	.337	-.151
Pahang3	.514	-.284	.184	.304
Perak8	.509	.349	.156	-.216
Pahang34	.508	.037	-.178	.046
Perak17	.506	.346	.351	-.193
Selangor18	.504	.427	.109	-.134

Johor11	.504	-.345	.219	.326
Johor2	.501	.045	.297	.203
N.Sembilan2	.500	-.019	.326	.016
Melaka2	.495	.245	.131	-.041
N.Sembilan4	.494	.348	.316	-.195
Johor12	.492	-.420	.080	.297
Selangor4	.491	.230	.377	-.289
Perak3	.487	.461	.120	-.092
Johor5	.484	-.026	.367	.244
Pahang8	.483	.045	.199	.108
Perak14	.482	.458	.073	-.056
Selangor19	.481	.264	.356	-.240
Pahang13	.480	.018	.190	.016
Johor7	.470	-.352	.063	.330
Perak10	.469	.335	.378	-.331
Johor1	.468	-.033	.344	.171
Kelantan4	.467	-.106	-.362	.059
Selangor14	.467	.054	.036	-.097
Pahang5	.466	-.431	.254	.267
Johor9	.465	-.156	.317	.410
Perak18	.459	.417	.070	-.100
Selangor8	.459	.356	.211	-.142
Johor6	.457	-.133	.219	.337
Johor13	.455	-.129	.345	.377
Pahang1	.452	-.333	.268	.302
Pahang31	.452	.079	.027	-.015
Perak13	.445	.241	.272	-.127
N.Sembilan3	.437	.138	.306	-.039
Pahang28	.436	-.036	-.111	.078
Perak9	.420	.401	-.171	.073
Kedah4	.431	.647	-.197	.079
Kedah2	.446	.614	-.181	.073
Johor17	.478	-.613	.077	.165
Kedah5	.471	.600	-.258	.064
Pahang15	.563	-.585	.024	.102
Penang5	.344	.581	-.386	.268
Penang2	.370	.578	-.370	.248
Kedah6	.293	.572	-.355	.147
Penang4	.383	.567	-.312	.207
Perlis3	.338	.551	-.409	.162
Kedah8	.470	.547	-.300	.084
Kedah9	.477	.546	-.267	.080
Kedah11	.472	.537	-.243	.032
Penang1	.383	.534	-.368	.255
Kedah10	.482	.526	-.265	.109
Perak6	.448	.516	-.294	.061
kedah1	.211	.514	-.381	.206
Perak4	.462	.503	.046	-.080
Perak5	.365	.373	-.053	-.087

Extraction Method: Principal Component Analysis.
a. 4 components extracted.

Borneo Malaysia

Table 19 : Suitability test for data reduction

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.939
Bartlett's Test of Sphericity	Approx. Chi-Square	18149.565
	df	2346
	Sig.	.000

Table 20 : Scree plot method to decide numbers of component retained

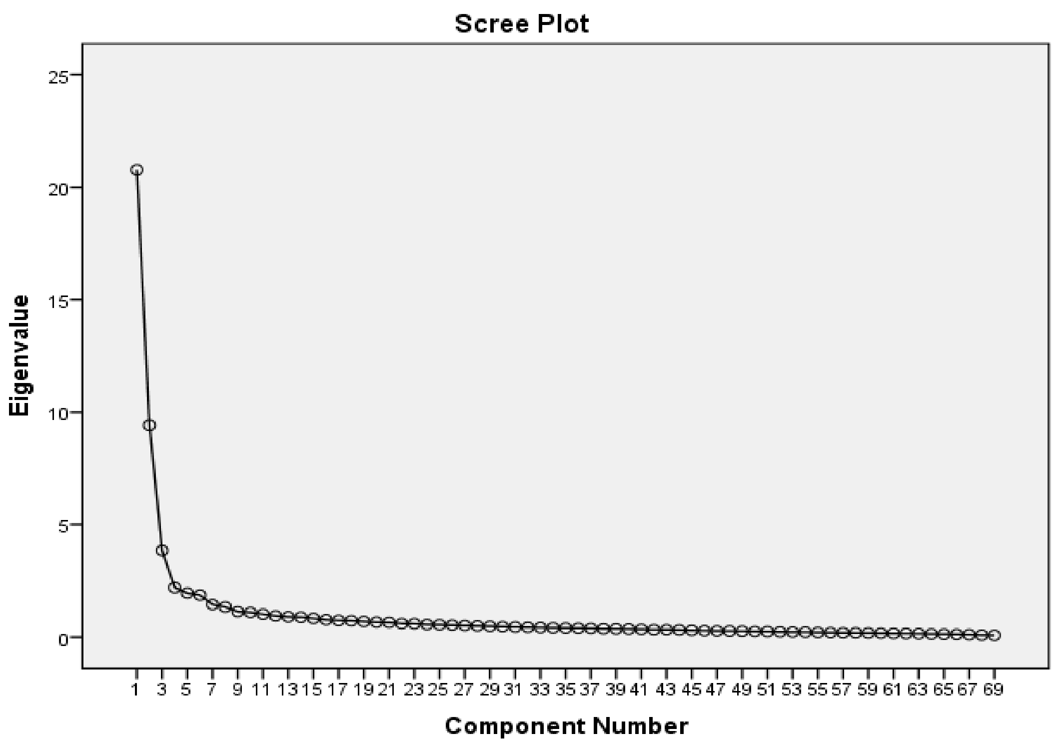

Table 21 : Component retained from PCA

Component Matrix[a]

	Component			
	1	2	3	4
Sarawak17	.724	-.259	-.159	.088
Sarawak5	.722	-.337	-.185	.311
Sarawak10	.721	-.333	-.198	.147
Sarawak46	.718	-.215	-.069	-.087
Sarawak9	.685	-.256	-.178	.304
Sarawak55	.682	-.218	.028	.039
Sarawak68	.676	.170	-.124	-.192
Sarawak14	.675	-.420	-.126	.132
Sarawak7	.672	-.240	-.157	.186
Sarawak62	.663	-.216	.060	-.166
Sarawak82	.659	.250	-.078	-.188
Sarawak22	.643	-.155	-.210	.090
Sarawak79	.642	.220	-.060	-.188
Sabah23	.631	.115	.299	-.184
Sarawak2	.621	-.278	-.205	.240
Sarawak27	.620	-.407	.122	-.098
Sarawak28	.617	-.144	-.203	.067
Sarawak57	.615	-.007	-.233	-.056
Sarawak20	.615	-.481	-.008	.025
Sarawak89	.610	.401	-.084	-.134
Sarawak77	.610	.237	-.177	-.205
Sarawak73	.608	.219	-.078	-.188
Sarawak91	.608	.488	-.175	-.250
Sarawak65	.603	-.012	.044	-.263
Sarawak13	.602	-.424	-.081	.169
Sarawak33	.599	-.475	.195	-.097
Sabah16	.599	.288	.435	.054
Sarawak8	.593	-.354	-.213	.329
Sarawak16	.593	-.358	-.184	.186
Sarawak85	.590	.284	-.010	-.216
Sarawak83	.589	.414	-.128	-.002
Sarawak32	.589	-.441	.244	-.100
Sarawak69	.587	.145	-.130	-.170
Sarawak6	.583	-.447	-.118	.197
Sarawak26	.582	-.492	.104	-.059
Sarawak11	.573	-.191	-.309	.238
Sarawak80	.572	.370	-.019	-.200
Sarawak60	.566	-.036	.055	-.168
Sarawak40	.566	-.344	.090	-.090
Sarawak56	.565	.054	-.295	-.035
Sabah20	.547	.131	.545	.059
Sarawak92	.546	.424	-.119	-.202
Sarawak30	.545	-.407	.183	-.140
Sabah10	.504	.490	.036	.113
Sarawak59	.495	.212	-.241	.079
Sabah2	.471	.461	.003	-.090
Sarawak50	.442	.100	-.351	.089
Sarawak12	.384	-.119	-.243	.045
Sarawak36	.372	-.318	.261	-.246
Sabah21	.450	.702	-.015	.012
Sabah7	.384	.682	-.115	-.022

Sabah13	.265	.673	-.048	.190
Sabah15	.341	.661	-.082	.017
Sabah14	.271	.624	-.028	.052
Sabah19	.345	.595	.124	.218
Sabah22	.520	.590	.051	-.057
Sabah11	.407	.559	.092	.161
Sabah4	.336	.541	.036	.233
Sabah8	.478	.520	.036	.102
Sarawak37	.441	-.475	.218	-.231
Sarawak51	.404	-.448	.162	-.182
Sabah1	.149	.421	.012	.345
Sabah17	.395	-.083	.608	.142
Sabah9	.391	.056	.605	.161
Sabah12	.372	.293	.605	.251
Sabah6	.478	-.039	.545	.102
Sabah5	.226	.046	.473	.330
Sabah3	.410	.043	.471	.165
Sarawak44	.444	-.239	.189	-.444

Extraction Method: Principal Component Analysis.
a. 4 components extracted.

List of rainfall station used in this study

State	Site No.	Lat	y	Long	x
JOHOR	1437116	01 28 15	1.470833333	103 45 10	103.7527778
JOHOR	1534002	01 30 55	1.515277778	103 29 40	103.4944444
JOHOR	1636001	01 37 50	1.630555556	103 41 50	103.6972222
JOHOR	1732004	01 42 30	1.708333333	103 16 25	103.2736111
JOHOR	1737001	01 45 50	1.763888889	103 43 10	103.7194444
JOHOR	1839196	01 51 00	1.85	103 57 55	103.9652778
JOHOR	1931003	01 58 25	1.973611111	103 10 45	103.1791667
JOHOR	2231001	02 15 00	2.25	103 08 50	103.1472222
JOHOR	2232001	02 15 05	2.251388889	103 17 50	103.2972222
JOHOR	2235163	02 13 45	2.229166667	103 35 55	103.5986111
JOHOR	2237164	02 15 25	2.256944444	103 44 10	103.7361111
JOHOR	2330009	02 23 05	2.384722222	103 01 00	103.0166667
JOHOR	2636170	02 39 00	2.65	103 37 15	103.6208333
KEDAH	6397111	06 21.347	6.355783333	99 43.903	99.73171667
KEDAH	5507076	05 35 00	5.583333333	100 44 10	100.7361111
KEDAH	5704055	05 47 45	5.795833333	100 26 20	100.4388889
KEDAH	5806066	05 48 50	5.813888889	100 37 55	100.6319444
KEDAH	5808001	05 52 50	5.880555556	100 53 40	100.8944444
KEDAH	6103047	06 06 20	6.105555556	100 23 30	100.3916667
KEDAH	6108001	06 06 20	6.105555556	100 50 50	100.8472222
KEDAH	6206035	06 15 15	6.254166667	100 36 45	100.6152
KEDAH	6207032	06 14 25	6.240277778	100 46 20	100.7722222
KEDAH	6306031	06 20 35	6.343055556	100 41 25	100.6902778
KELANTAN	5820006	05 50 40	5.844444444	102 04 25	102.0736111
KELANTAN	5120025	05 08 45	5.145833333	102 02 55	102.0486111
KELANTAN	5320038	05 22 40	5.377777778	102 00 55	102.0152778
KELANTAN	5719001	05 46 50	5.780555556	101 58 05	101.9680556
KELANTAN	4819027	04 52 45	4.879166667	101 58 10	101.9694444
KELANTAN	5522047	05 31 55	5.531944444	102 12 10	102.2027778
KELANTAN	5322044	05 18 30	5.308333333	102 16 30	102.275
KELANTAN	5718002	05 46 30	5.775	101 53 20	101.8888889
KELANTAN	6019004	06 01 25	6.023611111	101 58 45	101.9791667
MELAKA	2224038	02 17 20	2.288888889	102 29 30	102.4916667
MELAKA	2321006	02 21 50	2.363888889	102 11 35	102.1930556
N. SEMBILAN	3020016	03 05 35	3.093055556	102 04 25	102.0736111
N. SEMBILAN	2725083	02 43 10	2.719444444	102 30 45	102.5125
N. SEMBILAN	2722002	02 45 20	2.755555556	102 15 50	102.2638889
N. SEMBILAN	2719001	02 44 15	2.7375	101 57 20	101.9555556
PERAK	5005003	05 00 50	5.013888889	100 32 45	100.5458333
PERAK	4908018	04 58 45	4.979166667	100 48 15	100.8041667

PERAK	4811075	04 53 35	4.893055556	101 10 30	101.175
PERAK	4807016	04 51 45	4.8625	100 47 35	100.7930556
PERAK	5710061	05 42 30	5.708333333	101 00 00	101
PERAK	4511111	04 35 20	4.588888889	101 07 30	101.125
PERAK	4708084	04 46 30	4.775	100 53 40	100.8944444
PERAK	5411066	05 25 00	5.416666667	101 09 15	101.1541667
PERAK	4311001	04 18 20	4.305555556	101 09 20	101.1555556
PERAK	4409091	04 27 40	4.461111111	100 54 05	100.9013889
PERAK	5210069	05 17 55	5.298611111	101 03 30	101.0583333
PERAK	4012143	04 02 55	4.048611111	101 18 00	101.3
PERAK	5207001	05 13 00	5.216666667	100 42 05	100.7013889
PERAK	4209093	04 15 20	4.255555556	100 54 00	100.9
PERAK	4010001	04 01 00	4.016666667	101 02 10	101.0361111
PERAK	3615003	03 41 00	3.683333333	101 31 25	101.5236111
PERAK	4611001	04 40 50	4.680555556	101 10 10	101.1694444
PERLIS	6402008	06 28 30	6.475	100 14 50	100.2472222
PERLIS	6603002	06 39 25	6.656944444	100 18 35	100.3097222
PERLIS	6401002	06 26 45	6.445833333	100 11 15	100.1875
PAHANG	2630001	02 36 10	2.602777778	103 03 25	103.0569444
PAHANG	2634193	02 37 00	2.616666667	103 27 30	103.4583333
PAHANG	2828173	02 51 00	2.85	102 51 20	102.8555556
PAHANG	2829001	02 48 45	2.8125	102 56 15	102.9375
PAHANG	2831179	02 53 20	2.888888889	103 11 10	103.1861111
PAHANG	2924096	02 56 15	2.9375	102 25 08	102.4188889
PAHANG	3028001	03 01 15	3.018055556	102 49 55	102.8319444
PAHANG	3032167	03 01 00	3.016666667	103 11 55	103.1986111
PAHANG	3121143	03 10 30	3.175	102 11 50	102.1972222
PAHANG	3134165	03 08 15	3.1375	103 26 30	103.4416667
PAHANG	3228174	03 17 55	3.298611111	102 49 20	102.8222222
PAHANG	3231163	03 17 15	3.2875	103 11 20	103.1888889
PAHANG	3424081	03 26 20	3.438888889	102 25 35	102.4263889
PAHANG	3519125	03 30 45	3.5125	101 54 55	101.9152778
PAHANG	3533102	03 33 40	3.561111111	103 21 25	103.3569444
PAHANG	3628001	03 38 00	3.633333333	102 51 20	102.8555556
PAHANG	3818054	03 48 20	3.805555556	101 50 50	101.8472222
PAHANG	3833002	03 48 30	3.808333333	103 19 45	103.3291667
PAHANG	3924072	03 54 15	3.904166667	102 26 00	102.4333333
PAHANG	3930012	03 55 00	3.916666667	103 02 10	103.0361111
PAHANG	4019001	04 02 00	4.033333333	101 58 00	101.9666667
PAHANG	4023001	04 01 55	4.031944444	102 19 30	102.325
PAHANG	4127001	04 06 20	4.105555556	102 45 11	102.7530556
PAHANG	4219001	04 14 00	4.233333333	101 56 25	101.9402778

PAHANG	4223115	04 14 35	4.243055556	102 23 00	102.3833333
PAHANG	4227001	04 14 00	4.233333333	102 44 00	102.7333333
PAHANG	4324001	04 23 10	4.386111111	102 24 10	102.4027778
PAHANG	4513033	04 31 00	4.516666667	101 23 00	101.3833333
P. PINANG	5302003	05 23 45	5.395833333	100 15 55	100.2652778
P. PINANG	5402001	05 25 25	5.423611111	100 16 15	100.2708333
P. PINANG	5504035	05 32 05	5.534722222	100 25 50	100.4305556
P. PINANG	5402002	05 26 25	5.440277778	100 17 10	100.2861111
TERENGGANU	5428001	05 26 50	5.447222222	102 48 55	102.8152778
TERENGGANU	4131001	04 08 00	4.133333333	103 10 30	103.175
TERENGGANU	5626001	05 38 35	5.643055556	102 37 20	102.6222222
TERENGGANU	4631001	04 36 50	4.613888889	103 11 55	103.1986111
TERENGGANU	5428002	05 24 40	5.411111111	102 49 25	102.8236111
TERENGGANU	4734079	04 45 45	4.7625	103 25 10	103.4194444
TERENGGANU	4332001	04 22 40	4.377777778	103 15 45	103.2625
TERENGGANU	4832011	04 50 35	4.843055556	103 12 15	103.2041667
TERENGGANU	4234109	04 13 55	4.231944444	103 25 20	103.4222222
TERENGGANU	5029034	05 04 00	5.066666667	102 56 30	102.9416667
TERENGGANU	3933001	03 55 05	3.918055556	103 18 30	103.3083333
TERENGGANU	4930038	04 56 20	4.938888889	103 03 40	103.0611111
TERENGGANU	4529001	04 34 05	4.568055556	102 58 45	102.9791667
TERENGGANU	4929001	04 57 10	4.952777778	102 58 00	102.9666667
TERENGGANU	5128001	05 08 35	5.143055556	102 50 40	102.8444444
TERENGGANU	5328044	05 21 20	5.355555556	102 53 10	102.8861111
TERENGGANU	5331048	05 19 05	5.318055556	103 08 00	103.1333333
TERENGGANU	5426001	05 28 35	5.476388889	102 40 30	102.675
SELANGOR	2815001	02 49 35	2.826388889	101 32 30	101.5416667
SELANGOR	2818110	02 53 55.47	2.898741667	101 52 13.3	101.8703611
SELANGOR	2913001	02 55 50	2.930555556	101 23 35	101.3930556
SELANGOR	2917001	02 59 46	2.996111111	101 47 8.9	101.7858056
SELANGOR	3117070	03 09 18	3.155	101 44 54	101.7483333
SELANGOR	3118102	03 10 25	3.173611111	101 52 20	101.8722222
SELANGOR	3314001	03 22 08	3.368888889	101 24 43.9	101.4121944
SELANGOR	3411017	03 25 25	3.423611111	101 10 23.9	101.1733056
SELANGOR	3416002	03 26 18	3.438333333	101 39 41	101.6613889
SELANGOR	3516022	03 34 33	3.575833333	101 39 56	101.6655556
SELANGOR	3613004	03 41 53	3.698055556	101 20 60	101.35
SELANGOR	3710006	03 43 43	3.728611111	101 04 59.3	101.0831389
SABAH	4764002	04 42 10	4.702777778	116 28 55	116.4819444
SABAH	4959001	04 54 50	4.913888889	115 55 20	115.9222222
SABAH	5074001	05 04 55	5.081944444	117 26 30	117.4416667
SABAH	5163002	05 09 00	5.15	116 18 20	116.3055556

SABAH	5269001	05 16 05	5.268055556	116 58 05	116.9680556
SABAH	5274001	05 13 20	5.222222222	117 29 10	117.4861111
SABAH	5357003	05 21 15	5.354166667	115 43 25	115.7236111
SABAH	5361002	05 20 45	5.345833333	116 09 40	116.1611111
SABAH	5372001	05 18 15	5.304166667	117 16 40	117.2777778
SABAH	5462001	05 28 35	5.476388889	116 16 00	116.2666667
SABAH	5663001	05 37 15	5.620833333	116 19 35	116.3263889
SABAH	5768001	05 42 40	5.711111111	116 51 35	116.8597222
SABAH	5862002	05 51 50	5.863888889	116 15 50	116.2638889
SABAH	5961002	05 59 45	5.995833333	116 06 55	116.1152778
SABAH	5961001	05 59 05	5.984722222	116 10 40	116.1777778
SABAH	5966001	05 56 50	5.947222222	116 39 40	116.6611111
SABAH	5973001	05 54 10	5.902777778	117 22 25	117.3736111
SABAH	6062001	06 03 45	6.0625	116 16 45	116.2791667
SABAH	6064001	06 02 00	6.033333333	116 28 00	116.4666667
SABAH	6168001	06 06 15	6.104166667	116 50 30	116.8416667
SABAH	6264001	06 15 50	6.263888889	116 27 10	116.4527778
SABAH	6365001	06 23 30	6.391666667	116 31 30	116.525
SABAH	6868001	06 53 20	6.888888889	116 50 35	116.8430556
SARAWAK	1003031	001 01 30	1.025	110 21 35	110.3597222
SARAWAK	1005079	001 03 50	1.063888889	110 35 35	110.5930556
SARAWAK	1005080	001 05 25	1.090277778	110 34 40	110.5777778
SARAWAK	1006028	001 05 10	1.086111111	110 37 50	110.6305556
SARAWAK	1006033	001 05 40	1.094444444	110 36 25	110.6069444
SARAWAK	1006037	001 03 15	1.054166667	110 37 00	110.6166667
SARAWAK	1007040	001 03 05	1.051388889	110 45 05	110.7513889
SARAWAK	1015001	001 01 10	1.019444444	111 33 15	111.5541667
SARAWAK	1018002	001 02 30	1.041666667	111 49 45	111.8291667
SARAWAK	1102019	001 09 45	1.1625	110 15 20	110.2555556
SARAWAK	1105027	001 09 35	1.159722222	110 34 00	110.5666667
SARAWAK	1105050	001 06 05	1.101388889	110 30 10	110.5027778
SARAWAK	1111008	001 08 15	1.1375	111 06 50	111.1138889
SARAWAK	1204024	001 16 35	1.276388889	110 25 00	110.4166667
SARAWAK	1214001	001 14 40	1.244444444	111 27 20	111.4555556
SARAWAK	1303014	001 23 25	1.390277778	110 19 25	110.3236111
SARAWAK	1306055	001 18 40	1.311111111	110 40 25	110.6736111
SARAWAK	1313006	001 18 05	1.301388889	111 23 20	111.3888889
SARAWAK	1401005	001 25 00	1.416666667	110 09 05	110.1513889
SARAWAK	1403001	001 28 55	1.481944444	110 20 15	110.3375
SARAWAK	1404049	001 26 30	1.441666667	110 29 30	110.4916667
SARAWAK	1502001	001 35 00	1.583333333	110 13 00	110.2166667
SARAWAK	1505081	001 32 55	1.598611111	110 31 40	110.5277778

SARAWAK	1509009	001 31 15	1.520833333	110 55 25	110.9236111
SARAWAK	1698007	001 40 20	1.672222222	109 51 30	109.8583333
SARAWAK	1713005	001 44 40	1.744444444	111 20 05	111.3347222
SARAWAK	1843001	001 52 15	1.870833333	114 19 00	114.3166667
SARAWAK	1897016	001 48 30	1.808333333	109 46 25	109.7736111
SARAWAK	2115008	002 07 40	2.127777778	111 15 05	111.2513889
SARAWAK	2141048	002 07 05	2.118055556	114 11 05	114.1847222
SARAWAK	2230143	002 16 10	2.269444444	113 05 25	113.0902778
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SARAWAK	2412001	002 25 15	2.420833333	111 40 25	111.6736111
SARAWAK	2514004	002 30 50	2.513888889	111 25 15	111.4208333
SARAWAK	2828025	002 52 35	2.876388889	112 50 50	112.8472222
SARAWAK	3132023	003 06 30	3.108333333	113 15 45	113.2625
SARAWAK	3137021	003 09 35	3.159722222	113 42 20	113.7055556
SARAWAK	3444018	003 29 05	3.484722222	114 25 35	114.4263889
SARAWAK	3744009	003 45 45	3.7625	114 24 15	114.4041667
SARAWAK	3842034	003 51 50	3.863888889	114 14 25	114.2402778
SARAWAK	4038006	004 03 22	4.056111111	113 50 41	113.8447222
SARAWAK	4143004	004 10 48	4.18	114 19 15	114.3208333
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SARAWAK	4548004	004 33 00	4.55	114 51 15	114.8541667
SARAWAK	4650023	004 41 15	4.6875	115 01 10	115.0194444
SARAWAK	4749001	004 44 40	4.744444444	114 59 50	114.9972222

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LIST OF PUBLICATIONS

Othman, M., Ash'aari, Z. H. & Mohamad, N. D., (2015). Long-term daily rainfall pattern recognition: Application of principal component analysis. In Procedia Environmental Sciences (30) 127-132. Elsevier (Presented at a conference)

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