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A Regional Frequency Analysis of Annual Maximum Rainfall in Terengganu using the Index Rainfall and L-moments Approaches

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Abstract. In data scarce regions, regionalization provides a means for estimating hydrological extremes. In this study, regional pooling of 1-, 3-, 5- and 10-day annual maximum rainfall from 1948 to 2013 at 32 stations across Terengganu, Malaysia is used in a standard regional frequency analysis using the well-known L-moments approach. The objectives of this study are (1) to estimate extreme rainfall in Terengganu, Malaysia using regional pooling of frequency analysis, (2) to establish a well-designed and accurate procedures of analysis of rainfall extremes in Terengganu using the regional frequency approach and (3) to improve the understanding of spatial rainfall characteristics as a main cause for design and planning practices in flood control. Cluster analysis is performed to determine the homogeneity of rainfall regions based on at-site characteristics. The cluster analysis has identified four rainfall regions based on homogeneity and heterogeneity tests using Monte Carlo simulations with regional average L-moment ratios fitted to the Kappa distribution. On the basis of the accuracy of the derived index rainfall quantiles, the regional rainfall frequency approach is found to be acceptable and had smaller uncertainty as compared to at-site estimates.

Keywords: Regional Frequency Analysis; L-moments; Index Rainfall; Cluster Analysis

INTRODUCTION

The occurrence of extreme events such as floods, rainfall and droughts are among the most disastrous consequences for human society. The estimation of the magnitudes and frequencies are of great importance for hydrological purpose, engineering practice for water resources and also for reservoirs design and management for weather-related emergencies.

The estimation on how often a specific rainfall extreme event will occur or how large the rare events with return period (T) of above 50 or 100 years is often the main interest [1, 2]. This might be achieved through at-site or regional rainfall frequency analysis. The main objective of regional frequency analysis (RFA) is to establish a relationship between rainfall amount and the return period [3]. Various statistical methods are used to study the spatial characterization of extreme events, including the at-site frequency analysis and RFA. Past rainfall regionalization are studied in Malaysia, including [4, 5, 6]. There are very few studies on extreme rainfall events in Malaysia with specifically concentrate in Terengganu which our focus study in this analysis has been conducted. To our best knowledge, the RFA approach used in this study, with the most up to date data available, is the first of its kind for rainfall extremes in East Coast of Malaysia. Therefore, the objectives of this study are (1) to estimate extreme rainfall in Terengganu, Malaysia using regional pooling of frequency analysis, (2) to establish a well-designed and systematic procedures of analysis of rainfall extremes in Terengganu using the regional frequency approach and (3) to improve the understanding of spatial rainfall characteristics as a main cause for design and planning practices in flood control. In this study, a regional frequency analysis approach based on L-moments [7] is used with an extreme value distribution. This involves the regional pooling of 1-, 3-, 5- and 10-day (AMS1, AMS3, AMS5 and AMS10) of annual maximum for each of the homogeneous region.

STUDY AREA AND DATA

In this study, 32 rain gauge stations, with an average record length of 48 years in Terengganu are considered. The data consist of daily rainfall amount from 1948 to 2013. The analysis used data from sites that satisfied the following criteria: record length at least 20 years, not more than 10% values missing, and no more than 12 consecutive months of data missing. The data are obtained from the Department of Irrigation and Drainage, Ampang, Kuala Lumpur. Those years are chosen based on the completeness and longest available period of the rainfall data. The details of the location, latitude (^0S), longitude (^0E) and elevation (meter) of each station are displayed in TABLE 1.

TABLE(1). Station name in Terengganu with the latitude (Lat), longitude (Long) and the elevation (Elev).

Num	Station Name	Lat (^0S)	Long (^0E)	Elev (m)	Num	Station Name	Lat (^0S)	Long (^0E)	Elev (m)
V1	Hulu Jabor	3.92	103.31	85	V17	Rumah Pam Paya Rapat	5.17	102.90	66
V2	Kg. Ban Ho	4.13	103.18	26	V18	Sek. Men. Bkt. Sawa	5.19	103.10	36
V3	Jambatan Air putih	4.27	103.20	93	V19	Sek. Keb. Kuala Telemong	5.20	103.03	57
V4	Sek. Keb. Pasir Gajah	4.24	103.30	27	V20	Rumah Pam Pulau Musang	5.29	103.10	33
V5	JPS Kemaman	4.23	103.42	70	V21	Sek. Keb. Marang	5.21	103.21	68
V6	Jambatan Tebak	4.38	103.26	63	V22	Kg. Sg. Tong	5.36	102.89	56
V7	Sek. Keb. Kijal	4.33	103.49	35	V23	Sek. Keb. Kg. Gemuroh	5.35	103.01	96
V8	Sek. Men. Keb. Badrul Alam Shah	4.43	103.45	33	V24	Setor JPS Kuala Terengganu	5.32	103.13	29
V9	Jambatan Penarik	4.60	102.82	85	V25	Kg. Keruak	5.48	102.49	66
V10	Bandar Al Muktafi Billah Shah	4.61	103.20	80	V26	Kg. Batu Hampai	5.45	102.82	47
V11	Pusat Kesihatan Paka	4.64	103.44	23	V27	Klinik Chalok Barat	5.41	102.82	67
V12	Sek. Men. Sultan Omar	4.76	103.42	43	V28	Kg. Padang Maras	5.43	103.04	50
V13	Rumah Pam Delong	4.82	103.31	86	V29	Ibu Bekalan Setiu	5.56	102.77	19
V14	Kg. Embong Sekayu	4.95	102.97	67	V30	Kg. Merang	5.53	102.95	30
V15	Ldg. Koko Jerangau	4.98	103.16	70	V31	Institut Pertanian Besut	5.64	102.62	92
V16	Sg. Gawi	5.14	102.84	89	V32	Sek. Keb. Kg. Tembila	5.74	102.61	33

METHODOLOGY

This section presents the regionalisation procedure applied. The estimation of rainfall amount can be achieved by two most common methods that are based on annual maximum (AM) series approach and peak-over-threshold (POT) series approach. AM approach considers extracting the maximum rainfall recorded each year during a specific duration, meanwhile the POT approach is extracting rainfall series above a predefined threshold [8]. The dilemma arises on choosing between these two methods. The POT approach consists of more than one extreme value for each year, therefore this method improves the sampling of extreme events [9]. On the other hand, the AM series only consider one value of extreme each year resulting only a small number of rainfall peaks considered. Unfortunately, however, the treatment of missing data in the POT approach is demanding and determining which peaks to exclude during the same rainfall event can be very time consuming, so the AM series approach was adopted in the first instance [10].

Data screening

Frequency analysis requires that the at-site data are independent (without serial correlation and trends) and identically distributed (i.i.d.).The Mann–Kendall (M–K) method [11, 12] is applied in this study to check whether there are trends in the hydrological series. This method is a nonparametric test, with the advantage of not requiring the data to conform to any particular distribution and its low sensitivity to outliers [13].

Regional rainfall frequency analysis

The L-moments (LMOM) algorithm [7] and the index-flood procedure [14] are used for the RFA. LMOM is a linear combination of Probability Weighted Moments (PWMs) [15, 16] are considered over other conventional moments in certain aspects. The main advantages of LMOM are that they are being linear functions of the data; suffer less from the effect of sampling variability; more robust to outliers in the data and enable more secure inferences to be made from small samples about an underlying probability distribution and are usually computationally more tractable than maximum likelihood. The regional frequency analysis method used in this study is based on the methods proposed by [7]. The five steps in the analysis procedure are summarized as follows: screening data using the discordancy measure test; identification of homogeneous regions; regional heterogeneity test; selection of the best fit of the distribution; and regional quantile estimations of extreme rainfall amount.

(i) Screening of Data Using Discordancy Measure Test

The discordancy measure, D_i in terms of the L-moments is used to identify if the data are appropriate for the analysis and to screen for erroneous of the data within the identified homogeneous region. Let $\mathbf{u_i} = \left[t^{(i)} t_3^{(i)} t_4^{(i)} \right]^T$ be a vector containing the L-moment ratios. The discordancy measure for site i is:

$$D_i = \frac{1}{3} N (\mathbf{u_i} - \bar{\mathbf{u}})^T \mathbf{A}^{-1} (\mathbf{u_i} - \bar{\mathbf{u}}) \quad (1)$$

$$\bar{\mathbf{u}} = N^{-1} \sum_{i=1}^{N} \mathbf{u_i} \quad (2)$$

$$\mathbf{A} = \sum_{i=1}^{N} (\mathbf{u_i} - \bar{\mathbf{u}})(\mathbf{u_i} - \bar{\mathbf{u}})^T \quad (3)$$

where N is the number of stations, $\bar{\mathbf{u}}$ be the group average, $\mathbf{A}$ is the sample covariance matrix and N is the number of sites in the group. $D_i \geq 3$ indicates that the station in homogeneous region are considered to be discordant from the remaining of the regional data [7].

(ii) Identification of Homogeneous Regions using Cluster Analysis

Ward's clustering method is chosen for determination of homogeneous regions in regional frequency analysis based on most commonly used approach. The physical characteristics such as the area, longitude, latitude, and the elevations of selected stations in the basin are used. Reasonable numbers of clusters are 3 and 4. However, subjective adjustments are necessary in all cases to improve the geographical and climatologically coherence of regions and to avoid heterogeneity. A region is considered 'acceptably homogenous' if $H < 1$; 'possibly heterogeneous' if $1 \leq H < 2$; and 'definitely heterogeneous' if $H \geq 2$.

(iii) Identification of the best-fit distribution

In general regional frequency analysis a single frequency distribution is fitted to the data from several sites and the aim is therefore not to identify a 'true' distribution but to find a distribution that will yield more accurate quantile estimates for each site. Firstly, in this study, six applied distributions are selected, and fitted to the homogeneous regions; generalized logistic (GLO), generalized extreme-value (GEV), generalized normal (GNO), Pearson type-3 (PE3), generalized pareto (GPA) and Wakeby (WAK) distributions. The Wakeby distribution offers the best distribution in case if the choice of the candidate distribution is inconclusive as it is more robust [7].

(iv) Estimation of distribution parameters using L-moments

In the L-moments approach, the three parameters (location, scale and shape) for each probability distribution in the regional rainfall frequency analysis are obtained by the regional average of the L-moment and L-moment ratios.

(v) Derivation of regional rainfall quantiles

The index rainfall method is first introduced by [14] and is used to obtain extreme rainfall quantiles of the best-fit frequency distribution. The quantile estimates $Q(F)$ is calculated by $Q_i(F) = l_1 q(F)$ with F is the non-exceedance probability, q is the quantile function (growth curve) and l_1 is the index rainfall value. In this study, the mean (μ_i) extreme rainfall amount is used as the index rainfall, which is the site-specific scale factor. The accuracy and uncertainty of the estimated rainfall quantiles are evaluated using Monte Carlo simulations. The root mean square error (RMSE) of the estimated quantiles is used as the criterion to assess the accuracy of the frequency analysis [1].

All the procedures in this study used the R package free statistical software. The LmomRFA package [7] is useful for the regional frequency analysis using L-moment approach.

RESULTS AND DISCUSSION

Trend analysis of extreme precipitation

The Mann Kendall test is performed to examine the trend of rainfall extreme for AMS1, AMS3, AMS5 and AMS10 in the region of Terengganu. The result indicates that most of the stations show significant trend probably due to the reason that the trend are more localized and not regionally consistent for evidence of climate change.

Regional rainfall frequency analysis based on L-moments

By treating the entire set of 32 stations as a single region, the heterogeneity statistic was evaluated as $H = 5.02$. The entire set is therefore is 'definitely heterogeneous' and the possibility of performing RFA with the entire set of stations being treated as a single region is rejected. A subdivision of set is needed. Four indicators including latitude, longitude, elevation and the mean annual rainfall amount are used to form homogeneous cluster via Ward's method. Referring to TABLE 2, the entire region is accordingly divided into four groups. The first group (G1) is located in central and south of Terengganu, containing ten stations. The second group (G2) is located in the southeast of Terengganu with six stations. The third group (G3) is located in northwest of Terengganu with ten stations. The last group (G4) is located in northeast of Terengganu with six stations.

The results for heterogeneity test for all four regions are presented in TABLE 2. For AMS1, AMS3, AMS5 and AMS10 most of the region passed the heterogeneity test with 'acceptably homogenous' except for those stations with (*) signs which is marked as 'possibly heterogeneous' but the discordancy measure D_i at all stations are smaller than the critical value, which indicates that all the stations pass the discordancy test and the extreme rainfall amount of the stations are accordant with the group in the region. Therefore, the four regions are reasonable to be treated as homogeneous region.

TABLE (2). Results of the discordancy test and the heterogeneity measure

Series	Region	Sites (Di)	Heterogeneity		
			H1	H2	H3
AMS1	G1	V1 (1.56), V3 (1.82), V4 (0.30), V6 (0.39), V9 (1.51), V10 (1.45), V13 (0.30), V16 (0.25), V23 (2.11), V31 (0.30).	0.92	1.69	1.19
	G2	V2 (1.44), V5 (1.46), V7 (0.86), V8 (0.42), V11 (0.36), V12 (1.46).	-0.46	0.27	0.52
	G3*	V14 (0.91), V15 (0.94), V17 (0.16), V19 (1.90), V21 (0.79), V22 (0.92), V25 (1.48), V26 (0.46), V27 (0.65), V28 (1.80).	1.56	0.73	0.93
	G4	V18 (1.63), V20 (1.58), V24 (0.20), V29 (0.10), V30 (1.57), V32 (0.91).	0.68	-0.52	-0.85
AMS3	G1*	V1 (2.10), V3 (1.69), V4 (0.42), V6 (0.98), V9 (1.04), V10 (1.34), V13 (1.16), V16 (0.11), V23 (0.65), V31 (0.51).	1.53	0.69	-0.13

	G2	V2 (1.59), V5 (1.23), V7 (0.30), V8 (0.37), V11 (1.12), V12 (1.40).	0.4	-0.74	-0.66
	G3*	V14 (1.86), V15 (0.89), V17 (1.47), V19 (1.15), V21 (0.54), V22 (1.35), V25 (0.56), V26 (0.03), V27 (0.17), V28 (1.97).	1.41	-0.06	-1.34
	G4	V18 (1.60), V20 (1.48), V24 (1.43), V29 (0.29), V30 (0.48), V32 (0.73).	0.58	0.72	0.37
AMS5	G1*	V1 (1.38), V3 (1.50), V4 (1.12), V6 (1.29), V9 (1.36), V10 (1.53), V13 (1.58), V16 (0.11), V23 (0.01), V31 (0.11).	1.42	0.52	0.18
	G2	V2 (1.35), V5 (1.12), V7 (1.18), V8 (0.28), V11 (0.41), V12 (1.67).	0.5	0	-0.72
	G3	V14 (1.79), V15 (1.20), V17 (0.17), V19 (1.27), V21 (0.09), V22 (1.01), V25 (1.02), V26 (1.07), V27 (0.55), V28 (1.84).	0.84	-0.31	-0.86
	G4	V18 (1.65), V20 (0.90), V24 (0.51), V29 (0.35), V30 (1.59), V32 (1.00).	-0.44	-0.25	-0.56
AMS10	G1	V1 (1.30), V3 (1.62), V4 (1.38), V6 (1.00), V9 (1.31), V10 (0.88), V13 (1.35), V16 (0.45), V23 (0.48), V31 (0.23).	0.14	-0.72	-0.89
	G2	V2 (1.55), V5 (0.56), V7 (1.22), V8 (0.17), V11 (1.51), V12 (0.99).	0.27	-1.19	-1.54
	G3	V14 (1.79), V15 (1.12), V17 (0.87), V19 (1.50), V21 (0.66), V22 (0.74), V25 (0.32), V26 (0.70), V27 (0.80), V28 (1.49).	-0.04	-0.92	-0.73
	G4	V18 (1.62), V20 (0.68), V24 (0.48), V29 (0.51), V30 (0.84), V32 (0.87).	-0.26	1.33	1.26

TABLE (3). Results of the goodness of fit test

Series	Region	Acceptable distributions	Best distribution (min $Z_{crit}^{Dist} \le \lvert 1.64 \rvert$)	|Z| (best fit)	Min $\lvert \tau_{4(sample)} - \tau_{4(Dist)} \rvert$	DIST
AMS1	G1	GEV, GNO	GNO	0.06	0.0151	GNO
	G2	GEV, GNO, PE3	GNO	0.11	0.0048	GNO
	G3	GPA	GPA	1.93	0.0017	GPA
	G4	GNO, PE3	PE3	0.29	0.0087	PE3
AMS3	G1	GEV, GNO, PE3	GNO	0.05	0.0159	GNO
	G2	GEV, GNO, PE3	GNO	0.25	0.0049	GNO
	G3	GNO, PE3	PE3	0.01	0.0005	PE3
	G4	GEV, GNO, PE3	PE3	0.46	0.0042	PE3
AMS5	G1	GEV, GNO	GEV	0.23	0.0015	GEV
	G2	GEV, GNO, PE3	GEV	0.17	0.0034	GEV
	G3	GEV, GNO, PE3	GEV	0.11	0.0025	GEV
	G4	GLO, GEV, GNO, PE3	GEV	0.2	0.0008	GEV
AMS10	G1	GLO, GEV, GNO	GEV	0.39	0.0045	GEV
	G2	GLO, GEV, GNO, PE3	GEV	0.32	0.0075	GEV
	G3	GNO, PE3	PE3	0.14	0.0129	PE3
	G4	GLO, GEV, GNO, PE3	GEV	0.12	0.0101	GEV

Goodness of fit test results for candidate distributions of the four homogeneous regions are shown in TABLE 3. From TABLE 3, it can be seen that GEV distribution is the most acceptable distribution in most of the regions and GPA is the least acceptable distributions except for G3 in AMS1 only. The best distributions are the GNO (G1 and

G2 for AMS1 and AMS3), PE3 (G4 for AMS1 and AMS3, G3 for AMS3 and AMS10) and GEV (AMS5 and G1, G2 and G4 for AMS10). In another study, the L-moment ratio plots are used to further confirm that these distributions were indeed closest to the regional weighted L-moments means since the result is consistent with the result of the goodness of fit test.

TABLE 4 shows the location (ξ), scale (α) and shape (κ) parameters of the acceptable distributions as well as the five-parameter Wakeby distribution in each region.

TABLE (4). Regional parameter estimates for each sub-region

Series	Group	Distribution	Parameters				
			(ξ)	(α)	(κ)	(γ)	(δ)
AMS1	G1	GNO	0.857	0.424	-0.612		
		WAK	0.261	3.431	15.590	0.524	0.016
	G2	GNO	0.893	0.377	-0.528		
		WAK	0.399	1.115	5.743	0.437	-0.003
	G3	GPA	0.400	0.864	0.439		
		WAK	0.400	0.864	0.439	0.000	0.000
	G4	PE3	1.000	0.442	1.168		
		WAK	0.376	0.919	3.551	0.457	-0.083
AMS3	G1	GNO	0.887	0.401	-0.528		
		WAK	0.283	3.432	14.118	0.512	-0.044
	G2	GNO	0.909	0.375	-0.459		
		WAK	0.380	1.370	5.548	0.419	-0.020
	G3	PE3	1.000	0.443	1.218		
		WAK	0.346	1.610	7.927	0.545	-0.149
	G4	PE3	1.000	0.475	1.419		
		WAK	0.347	1.406	7.572	0.529	-0.082
AMS5	G1	GEV	0.774	0.334	-0.091		
		WAK	0.282	2.490	9.208	0.494	-0.043
	G2	GEV	0.798	0.311	-0.068		
		WAK	0.365	1.571	6.045	0.424	-0.030
	G3	GEV	0.795	0.331	-0.041		
		WAK	0.333	1.587	5.341	0.433	-0.039
	G4	GEV	0.767	0.336	-0.106		
		WAK	0.334	1.224	4.281	0.414	0.046
AMS10	G1	GEV	0.783	0.327	-0.082		
		WAK	0.295	2.361	7.920	0.446	-0.012
	G2	GEV	0.810	0.314	-0.026		
		WAK	0.387	1.228	3.178	0.294	0.081
	G3	PE3	1.000	0.428	1.094		
		WAK	0.344	1.586	6.867	0.529	-0.164
	G4	PE3	1.000	0.468	1.282		
		WAK	0.334	1.260	0.391	0.349	0.081

A simulation result of the estimated regional quantiles, are analysed based on error bounds and are presented in TABLE 5. The results show that the RMSE values increase with the increase in the frequency of the AM series for all four regions, which indicates that the quantile estimates become less accurate when the return period is large. When the quantiles exceed 0.99 (return period exceed 100 years), the RMSE values are large and the estimations become unreliable. The accuracy and uncertainty analysis of quantiles estimations are then carried out and the regional and at site frequency analysis are compared for selected stations from four regions; G1: Sek. Keb. Pasir Gajah and Bandar Al-Muktafi Bilal Shah, G2: Sek. Men. Keb. Badrul Alam Shah and Sek. Men Sultan Omar, G3: Kg. Embong Sekayu and Ldg. Koko Jerangau and G4: Setor JPS Kuala Terengganu and Kg. Merang. The design rainfall estimates based on regional quantiles are compared with those derived from fitting the acceptable distribution based on at-site L-moment ratios. In every case, the RMSE of the regional estimator is lower than that of the at-site estimator, sometimes by a large amount where $T \geq 100$, except in the lower tail. In the lower tail, RMSE values of sites based estimates and regional based show not much difference.

TABLE (5). Regional quantiles, 90% error bounds and RMSE (%) values for the four homogeneous regions and their best distributions

Series	Region (Dist.)	*T*(years):	2	10	100	1000	Series	Region (Dist.)	*T*(years):	2	10	100	1000
		F:	0.5	0.9	0.99	0.999			*F*:	0.5	0.9	0.99	0.999
AMS1	G1	$\hat{q}(F)$	0.86	1.68	3.04	4.76	AMS5	G1	$\hat{q}(F)$	0.9	1.61	2.68	3.99
	(GNO)	RMSE(%)	0.02	0.04	0.23	0.58		(GEV)	RMSE(%)	0.02	0.04	0.22	0.62
		Lower	0.82	1.61	2.66	3.87			Lower	0.87	1.54	2.34	3.12
		Upper	0.9	1.75	3.44	5.78			Upper	0.93	1.67	3.01	4.9
	G2	$\hat{q}(F)$	0.89	1.58	2.62	3.83		G2	$\hat{q}(F)$	0.91	1.55	2.48	3.54
	(GNO)	RMSE(%)	0.02	0.04	0.23	0.55		(GEV)	RMSE(%)	0.02	0.04	0.22	0.6
		Lower	0.86	1.52	2.26	3.02			Lower	0.89	1.5	2.14	2.66
		Upper	0.93	1.66	2.96	4.64			Upper	0.95	1.62	2.81	4.43
	G3	$\hat{q}(F)$	0.92	1.65	2.11	2.27		G3	$\hat{q}(F)$	0.92	1.58	2.47	3.44
	(GPA)	RMSE(%)	0.01	0.03	0.11	0.17		(GEV)	RMSE(%)	0.02	0.04	0.18	0.46
		Lower	0.9	1.59	1.89	1.94			Lower	0.9	1.51	2.18	2.77
		Upper	0.94	1.7	2.25	2.47			Upper	0.94	1.63	2.72	4.08
	G4	$\hat{q}(F)$	0.92	1.59	2.38	3.11		G4	$\hat{q}(F)$	0.89	1.62	2.76	4.19
	(PE3)	RMSE(%)	0.02	0.05	0.15	0.27		(GEV)	RMSE(%)	0.02	0.04	0.27	0.8
		Lower	0.89	1.52	2.14	2.7			Lower	0.86	1.56	2.34	3.06
		Upper	0.95	1.66	2.61	3.51			Upper	0.93	1.69	3.17	5.35
AMS3	G1	$\hat{q}(F)$	0.89	1.62	2.72	4.01	AMS10	G1	$\hat{q}(F)$	0.9	1.59	2.61	3.81
	(GNO)	RMSE(%)	0.02	0.04	0.21	0.5		(GEV)	RMSE(%)	0.02	0.04	0.21	0.57
		Lower	0.86	1.55	2.39	3.28			Lower	0.88	1.53	2.27	3
		Upper	0.92	1.68	3.02	4.74			Upper	0.94	1.64	2.91	4.65
	G2	$\hat{q}(F)$	0.91	1.56	2.47	3.47		G2	$\hat{q}(F)$	0.93	1.54	2.35	3.19
	(GNO)	RMSE(%)	0.02	0.04	0.2	0.45		(GEV)	RMSE(%)	0.02	0.04	0.19	0.48
		Lower	0.88	1.5	2.16	2.79			Lower	0.9	1.48	2.05	2.46
		Upper	0.95	1.63	2.76	4.13			Upper	0.96	1.6	2.62	3.88
	G3	$\hat{q}(F)$	0.91	1.59	2.4	3.14		G3	$\hat{q}(F)$	0.92	1.57	2.32	3
	(PE3)	RMSE(%)	0.02	0.04	0.13	0.23		(GEV)	RMSE(%)	0.01	0.04	0.12	0.21
		Lower	0.89	1.52	2.17	2.76			Lower	0.9	1.51	2.1	2.64
		Upper	0.94	1.65	2.58	3.47			Upper	0.95	1.63	2.49	3.3
	G4	$\hat{q}(F)$	0.89	1.63	2.56	3.43		G4	$\hat{q}(F)$	0.9	1.63	2.5	3.31
	(PE3)	RMSE(%)	0.02	0.05	0.17	0.31		(GEV)	RMSE(%)	0.02	0.05	0.16	0.3
		Lower	0.86	1.56	2.29	2.95			Lower	0.88	1.55	2.24	2.86
		Upper	0.93	1.71	2.82	3.9			Upper	0.94	1.7	2.74	3.75

CONCLUSION

In this study, regional rainfall frequency analysis method based on the index rainfall and L-moment was carried out to estimate spatial distribution of extreme rainfall amount in Terengganu, Malaysia as well as the comparison with the at site frequency analysis. Terengganu region can be categorized into four sub-regions via Wards's hierarchical cluster analysis with the consideration of topographical factors and mean annual rainfall amount: G1 in central and south of Terengganu, G2 in the southeast of Terengganu region, G3 is located in northwest of Terengganu and the last group, G4 is located in northeast of Terengganu. The GEV, GNO, GLO, GPA and PE3 distributions are used to fit the extreme rainfall amount in different series of Terengganu sub-regions. The GEV distribution is found to be the most acceptable distribution in most of the regions and GPA is the least acceptable distributions except for G3 in AMS1 only. The best distributions are the GNO (G1 and G2 for AMS1 and AMS3), PE3 (G4 for AMS1 and AMS3, G3 for AMS3 and AMS10) and GEV (AMS5 and G1, G2 and G4 for AMS10). The accuracy measures for the estimated regional quantiles indicate that the quantile estimates become less accurate and uncertain when the return period is longer. When the return period exceeds 100 years, the RMSE is large and the estimations become unreliable. The quantile estimates from RFA are more accurate and less uncertain than those from at site frequency analysis, especially with longer return periods.

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