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Regional Flood Frequency Analysis in the West Coast of Peninsular Malaysia using the L-Moments Approach

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Abstract

In this paper, the L-moments approach is used to establish the regional flood frequency relationships for annual maximum flow data of 18 autographic gauging stations located in the 10 main river basins, namely, Perai, Kerian, Perak, Bernam, Selangor, Kelang, Langat, Linggi, Melaka, and Kesang. The aim of this study is to examine the homogeneity of the study area as well as to identify and establish the statistical distribution for the annual maximum flow data. The peak flow data are screened for consistency using the discordancy measure, and the homogeneity of the region is tested using the heterogeneity measure proposed by Hosking and Wallis. The choice of the suitable distribution for the peak flow data is based on the L-moment ratio diagram and the $\left|Z_i^{dist}\right|$ *statistic criteria. Five distribution functions are used, i.e., generalized logistic (GLO), generalized extreme value (GEV), generalized normal (GNO), Pearson type 3 (PE3), and generalized Pareto (GPA) distribution. Generalized logistic distribution is identified as the robust distribution for this study. Regional flood frequency relationship is derived for gauged catchments for the study area using the GLO distribution. A relation between catchment size and mean annual peak flow is also developed to be used together with the regional growth curve derived from the gauged catchments for the estimation of design floods of ungauged catchments. Results showed that the variance between observed and estimated is less than 30 % which is the differences range of peak flow for Sg. Kampar is 27.61 m3/s for 50 ARI. Based on the findings, it can be suggested that the regional flood frequency analysis using L-moments approach would be able to serve reasonably well in determining design flood in the study area.*

Keywords: L-Moments, Regional Flood Frequency, GLO Distribution, Annual Maximum Flow

1. Introduction

The use of recorded peak flow data for frequency analysis allows the prediction of the magnitude of a flood event with a specific probability of occurrence. Frequency-based floods, also known as design floods, are used to determine the size of hydraulic structures, such as culverts, bridges, and flood control structures. However, because not all the basins are gauged, the estimation of design flood at an ungauged site becomes important. This is because most of the projects are proposed and built at locations where there are no gauging stations. Therefore, there is a need to estimate the design floods of an ungauged basin based on a regional flood frequency method [1]. The approach of the regional frequency analysis utilizes data from several sites to estimate the frequency distribution of observed data at each site [2,3]. Thus, the concept of regionalization is to supplement the time-limited sampling record by incorporating spatial randomness using data from different sites in a region [4]. Regional relationship can be established by fitting the statistical distribution to the sample flood data. Many methods have been used for this purpose, including method of moments, maximum likelihood, probability weighted moments, graphical method, least squares, maximum entropy, and so on.

Regional frequency analysis is based on the concept of regional homogeneity, which assumes that the standardized variate has the same distribution at several sites in the selected region, and that data from a region can be combined to produce a single regional or flood frequency, which is applicable anywhere in the region after an appropriate scaling [3,5]. By implementing this approach, any event can be estimated for sites where there are unavailable gauge data [6]. In nearly all practical situations, a regional method can be more efficient than the application of an at-site analysis [7]. This view is also shared by Hosking and Wallis who state that a "*well conducted regional frequency analysis will yield quantile estimates accurate enough to be useful in many realistic application*." [3].

Recently, Hosking and Wallis developed the L-moments approach for regional frequency analysis [2,3]. These techniques are widely used in regional flood studies, such as those from the United States [8], New Zealand and Australia [9], Southern Africa [10], India [11,12], Malaysia [13], Turkey [1], China [14], Iran [15], and Tunisia [16]. In this study, we use the L-moments approach for the regional flood study using peak flow data of the selected catchments in the west coast of Peninsular Malaysia.

2. The L-moments approach

Hosking and Wallis found that some linear combinations of probability weighted moments, which they termed "L-moments," can be considered as measures of probability distributions that, in turn, form a basis for the estimation of these distributions [3]. The L –moment statistics are similar to the conventional moments, but can be estimated by the linear combinations of the elements of an ordered sample. The L-moments approach has advantages over conventional moments because it can characterize a wider range of distributions. The L –moments do not raise data to powers of 2, 3, and 4 as required for variance, skewness, and kurtosis. Moreover, these provide better parameter estimates for data that contain outlying values. The L-moment ratio estimators of location, scale, and shape are almost unbiased irrespective of the probability distribution from which the observations arise. These estimators, such as L-coefficient of variation, L-skewness and L-kurtosis, exhibit lower bias than conventional product moment ratios, particularly for highly skewed samples. The L-coefficient of variation and L-skewness do not have bounds that depend on the sample size, as do the ordinary product moment ratio estimators of coefficient of variation and skewness. The diagrams of the L-moment ratio are particularly efficient in identifying the distributional properties of highly skewed sample data.

3. L-moments analysis

L-moment estimators are linear combinations of the observations. These techniques provide an alternative way of describing the shape of the probability distributions. The L-moments are derived by modifying the function of probability weighted moments (PWMs) of Greenwood [17]. Probability weighted moments are defined as

$$\beta_r = E[XF_X(x)^r] \tag{1}$$

Where is the rth order PWM and $F_X(x)$ is the cumulative distribution function (cdf) of X. For the ordered statistics of $x_{j:n}$, the unbiased estimator of the probability weighted moments is given by:

$$b_r = \frac{1}{n}\sum_{j=r+1}^{n}\frac{(j-1)(j-2)\ldots(j-r)}{(n-1)(n-2)\ldots(n-r)}x_{j:n} \tag{2}$$

where n is the sample size and by letting $x_{1:n} \leq x_{2:n} \leq \cdots \leq x_{n:n}$ be the ordered sample $r = 0, 1, 2, 3, \ldots.,$

The sample L-moments are defined as:

$$l_1 = b_0 \tag{3}$$

$$l_2 = 2b_1 - b_0 \tag{4}$$

$$l_3 = 6b_2 - 6b_1 + b_0 \tag{5}$$

$$l_4 = 20b_3 - 30b_2 + 12b_1 - b_0 \tag{6}$$

Hosking and Wallis (1997) defined the L-Moment ratios as:

L - coefficient of variation, L-CV $t = l_2/l_1$ (7)

L - coefficient of skewness, L-CS $t_3 = l_3/l_2$, and (8)

L - coefficient of kurtosis, L-CK $t_4 = l_4/l_2$ (9)

4. Application of L-moments

Hosking and Wallis suggested four steps in the application of L–moments for regional flood frequency analysis [3]. These are as follows: (1) screening the data by calculating the discordancy measure, D_i, which is used to identify unusual sites; (2) identifying regional homogeneity using the heterogeneity measure, H; (3) choosing a regional frequency distribution by means of the goodness of fit test, or the Z_i^{dist} measure, which decides whether or not the distribution is an adequate fit for the data; and (4) estimating the regional floods using the selected distribution.

4.1. Discordancy measure test

The objective of this test is to check the consistency of data used for regional analysis. The screening of the data can be carried out using the L-moment-based discordancy measure *D*$_i$, as proposed by Hosking and Wallis [18]. Let $\mu_i = \left[t^i \;\; t_3^i \;\; t_4^i\right]^{\mathrm{T}}$ be a vector containing the $t,\ t_3\ and\ t_4$ values for site i, with a total of n sites, where the superscript T denotes the transposition of a vector or matrix. By letting

$$\bar{\mu} = n^{-1}\sum_{i=1}^{n}\mu_i \tag{10}$$

be the unweighted group average and define the matrix of sums of squares and cross-products as:

$$\mathrm{A} = \sum_{i=1}^{n}(\mu_i - \bar{\mu})(\mu_i - \bar{\mu})^{\mathrm{T}}. \tag{11}$$

The discordancy measure for site i is given by:

$$D_i = \frac{1}{3}n(\mu_i - \bar{\mu})^{\mathrm{T}}A^{-1}(\mu_i - \bar{\mu}). \tag{12}$$

Sites with large values of *D*$_i$ indicate that there may be data errors for these sites, and further investigations may be required.

Hosking and Wallis have found that there is no fixed number that can be considered to be a “large” value. They also suggested some critical values for the discordance test that are dependent on the number of sites in the study area (as shown in Table 1). The possibility of a large *D*$_i$ value of a site may be

an error in the data of the site, or the station may probably belong to another region or no region at all.

Table 1: Critical values of *D*$_i$ for the discordance test [3]

Number of sites	5	6	7	8	9	10	11	12	13	14	≥15
Critical Value	1.333	1.648	1.917	2.140	2.329	2.491	2.632	2.757	2.869	2.971	3.000

4.2. Test of regional homogeneity

Hosking and Wallis have also developed a homogeneity test, which allows us to assess whether or not a group of sites are reasonably homogeneous. The measure (H) compares the inter-site variations in the sample L-moments for a group of sites with what would be expected of a homogeneous region. The inter-site variation of the L-moment ratio is measured as the standard deviation (V) of the at-site L-coefficient of variation (L-CV), which is proportionally weighted to the record length at each site. In this work, simulations were used to establish what would be expected of a homogeneous region. About 500 data regions were generated based on the regional weighted average statistics using the four parameter distributions, such as the Kappa distribution. The inter-site variation of each generated region was calculated, and the mean (μ_v) and standard deviation (σ_v) of the computed inter-site variation were obtained. The heterogeneity measure (H) can be derived as:

$$H = \frac{V - \mu_v}{\sigma_v} \tag{13}$$

The region is declared acceptably homogeneous if $H < 1$. The region is possibly heterogeneous if $1 \leq H \leq 2$; otherwise, if $H > 2$, the region is definitely heterogeneous.

Hosking and Wallis suggested that if the region tested is not acceptably homogeneous, some redefinition of the region can be considered. The region can be subdivided into two or more regions; some sites can be removed from the region, or the sites can be reassigned to different regions.

4.3. Goodness of fit test in indentify parent distribution

Comparing the moments of the distribution to the average moment statistics from the regional data is one way of choosing the suitable frequency distribution for a homogeneous region. This is achieved by seeing the match between the L-kurtosis and L-skewness of the fitted distribution as well as the regional average L-skewness and L-kurtosis of the observed data. The goodness of fit measure, Z_i^{dist}, is defined as:

$$Z_i^{dist} = \frac{\tau_1^R - \tau_i^{dist}}{\sigma_i^{dist}} \tag{14}$$

Where τ_i^R is the weighted regional average of L-moment statistics, and *i*. τ_i^{dist} and σ_i^{dist} are simulated regional average and standard deviation of L-moment statistics, respectively, for the given distribution.

A given distribution is declared as an adequate fit if the goodness of fit measure, Z_i^{dist}, is sufficiently close to zero. For a confident limit of 90%, an acceptable criterion is that the goodness of fit measure should be less than or equal to 1.64.

4.4. Computer program for method of L-moments

All of the processes have been programmed by Hosking which comprise the lmoments: version 3.04 based on Fortran -77 routines. In this study, the subroutines were combined under the program and were then compiled and adapted into an executable form in this study [18].

5 Application

5.1 Data set and the study area

Figure 1 shows the general layout of the main river basins and locations of the 18 gauging stations in the west coast of Peninsular Malaysia. The main range crossing the study area divides the Peninsular Malaysia into the east and west coasts. The upper reaches of the basins are generally steep, whereas the middle reaches comprise cleared, undulating lands cultivated with rubber and palm oil. The two types of monsoons which influence the climate of Peninsular Malaysia are the southwest monsoon and the northeast monsoon which occur in the months of May to August and November to February respectively. Meanwhile, the first and second inter monsoon periods occur in the months of March to April and September to October respectively. The mean annual rainfall for the west coast region is higher than east coast region. Wong et.al indicates the mean annual rainfall for west coast and east coast is about 2311 and 3124 mm for each respective region [19]. The large variations of mean annual rainfall for west and east regions were influenced by the monsoon seasons. The northeast monsoon exists from South China Sea and landed to east coast region with heavy rainfall. The rainfall were reduced before entering the west coast region due to Titiwangsa mountain range. Meanwhile, the southwest monsoon was not generating heavy rainfall at west coast region when a large portion of rainfall was sheltered by the Sumatra mountainous range and the Straits of Malacca [19]. However, west coast region was facing convective storms which usually fall in the afternoon over short durations of rainfall. The convective storm has been associated with the occurrence of major flash floods in many urban areas. The monsoon seasons normally contribute major percentage of the total annual rainfall and most of significant floods occurred during this seasons. But, floods at study area can occur in any month of the year. The main rivers of the study area are mostly gauged, with most of them located at middle to upper part of the river basin. However, most of the river tributaries were ungauged and the distribution of the rainfall stations were scattered especially in the upper part of the river basins. As shown in Table 2, streamflow data for the study area range from 8 to 50 years records. Some gauge stations were closed or shifted to other locations due to the river improvement work or the changes of catchments characteristics such as dam construction; channelization or the effect of landuse activities.

Table 2: Characteristics of the gauging stations

Site	DID Gage ID Number	Gage Name	Years of Record (autographic)	Catchment Area (km^2)	Mean Annual Peak Flow (m^{3}s^{-1})
1	5405421	Sg. Kulim at Ara Kuda	47	130	53.43
2	5206432	Sg. Selama at Selama	46	631	164.27
3	4511468	Sg. Raia at Keramat Pulai	20	190	44.48
4	4311464	Sg. Kampar at Kg. Lanjut	27	446	84.89
5	4012401	Sg. Bidor at Malayan Tin Bhd	20	210	106.93
6	3913458	Sg. Sungkai at Sungkai	48	289	79.54
7	3814416	Sg. Slim at Slim River	42	455	92.28
8	3615412	Sg. Bernam at Tg. Malim	49	186	92.63
9	3516422	Sg. Selangor at Rasa	38	322	102.61
10	3414421	Sg. Selangor at Rantau Panjang	40	1450	209.80
11	3216439	Sg. Batu at Kg. Sg. Tua	11	56	30.49
12	3217401	Sg. Gombak at Dam Site	8	85	27.26
13	3118445	Sg. Lui at Kg. Lui	45	68	21.43
14	2918501	Sg. Semenyih at Rinching	35	236	33.65
15	2816441	Sg. Langat at Dengkil	49	1248	202.01
16	2519421	Sg. Linggi at Sua Betong	50	527	98.30
17	2322413	Sg. Melaka at Pantai Belimbing	48	387	60.95
18	2224432	Sg. Kesang at Chin - Chin	50	172	16.97

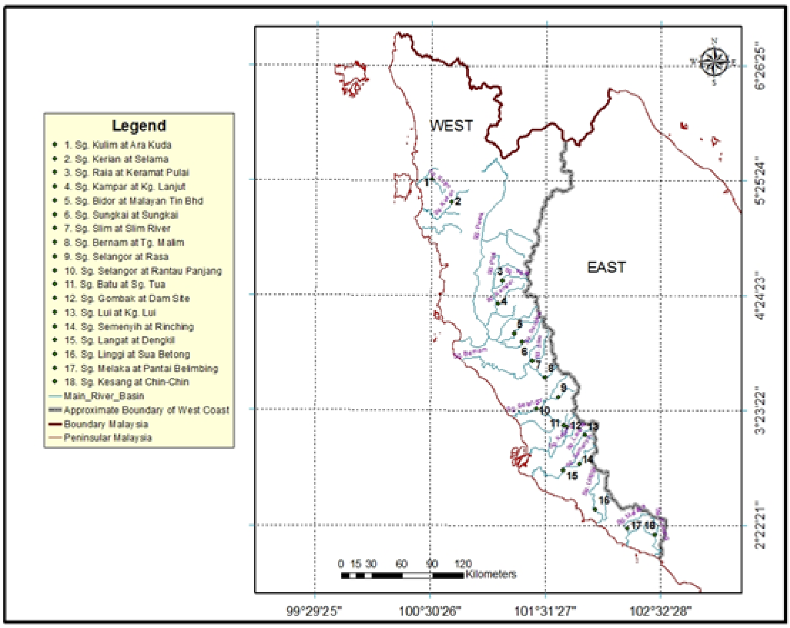

Figure 1: The study area located at the west coast of Peninsular Malaysia

5.2. Analysis

The following frequency distributions were used to carry out the regional frequency analysis for the study area, namely, generalized logistic (GLO), generalized extreme value (GEV), generalized normal (GNO), Pearson Type III (PE3), generalized Pareto (GPA), Kappa (KAP), and Wakeby (WAK). Screening of the data, testing of homogeneity, and test of goodness of fit were all carried out using the methods of Hosking and Wallis as described above.

5.2.1. Screening the data using the discordancy measure test: The values of discordancy measures for the 18 gauging stations were calculated, and they varied from 0.04 to 2.62 (refer Table 3). Given that these are less than the critical value of 3.00 for 18 sites, the data for all the 18 sites may be considered appropriate for regional frequency analysis. Figure 2 shows the plot of the 18 sites, and the discordant sites are viewed based on L-CV and L-CS. It can be seen that four sites, namely, Raia, Kampar, Gombak and Lui, are located far from the other 14 sites. Therefore, four simulations were used to check the discordancy D_i, where each simulation had a different group of sites. Simulations 1, 2, 3, and 4 consist of 18, 16, 15 and 14 sites, respectively. The selection of sites for each group was based on the D_i value for prior simulations. Any site which had a higher D_i value was excluded. Table 3 shows the results of L-moments ratios and discordancy measure for the study area.

Table 3: L-moment ratios and discordancy statistic, D_i for annual peak flow in the west coast of Peninsular Malaysia catchment for various simulations

DID Gage ID Number	*t*	t_3	t_4	D_i (sim 1)	D_i (sim 2)	D_i (sim 3)	D_i (sim 4)
5405421	0.2883	0.4646	0.4093	1.16	1.33	1.24	1.27
5206432	0.2057	0.2790	0.1709	1.05	1.33	1.23	1.30
4511468	0.1400	0.0180	0.0894	1.05	1.38	1.97	-
4311464	0.1959	- 0.0024	0.2231	2.34	-	-	-
4012401	0.2278	0.2023	0.0889	1.10	1.21	1.14	1.19
3913458	0.2760	0.1825	0.1350	0.41	0.42	0.38	0.36
3814416	0.2604	0.4352	0.4227	1.36	1.41	1.45	1.35
3615412	0.3040	0.2800	0.1384	0.77	0.78	0.99	0.97
3516422	0.2666	0.0739	0.1399	1.10	1.80	1.78	1.83
3414421	0.1471	0.1707	0.2280	0.77	0.90	1.63	2.64
3216439	0.2472	0.2439	0.2027	0.04	0.01	0.00	0.04
3217401	0.1073	0.0851	0.2628	1.75	2.25	-	-
3118445	0.4406	0.4869	0.3685	2.62	-	-	-
2918501	0.2689	0.1520	0.1972	0.51	1.08	1.09	1.08
2816441	0.3168	0.2306	0.1333	0.77	0.87	0.99	0.95
2519421	0.2728	0.3890	0.3016	0.40	0.42	0.38	0.36
2322413	0.2767	0.2946	0.2083	0.15	0.16	0.15	0.13
2224432	0.2678	0.4153	0.3302	0.62	0.63	0.57	0.54

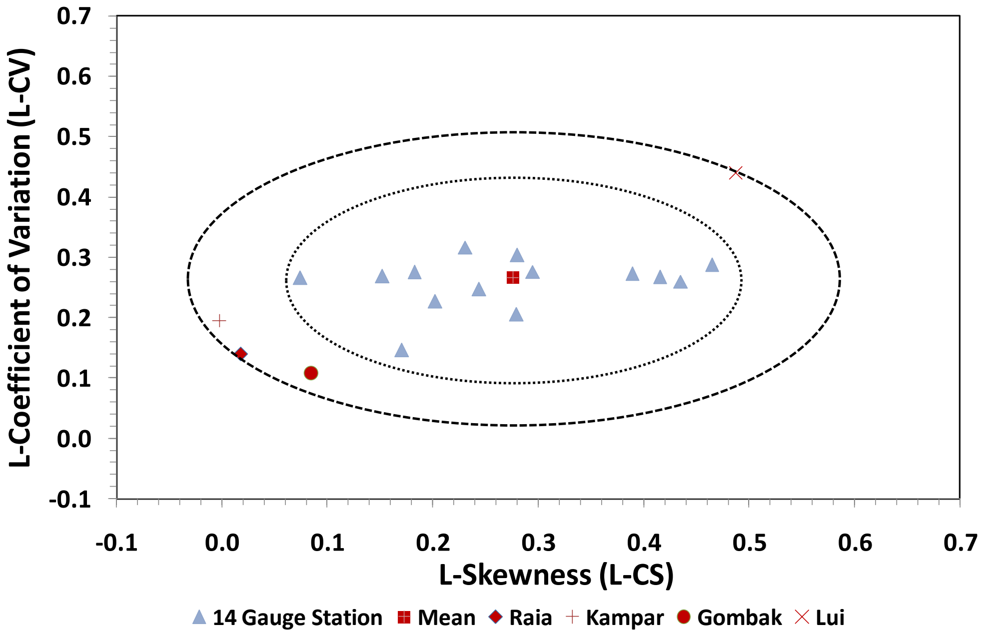

Figure 2: Sketch for discordancy for the 18 sites

5.2.2. Regional homogeneity test: The homogeneity measures for each group of the sites, which were determined from the discordance measure test *D_i*, were computed using 500 simulations. Table 4 shows the values for each simulation. H_1, which is normally used to measure the heterogeneity of a region, is greater than 2 for Simulation 1, between 1 and 2 for Simulations 2 and 3, and less than 1 for Simulation 4. Therefore, Simulation 4 gives the best result for H_1, H_2, and H_3 with values of 0.54, 1.14 and 1.18, respectively. This means the results from Simulation 4 shows the set of 14 stations can be considered acceptably homogeneous and not required to divide region.

The annual maximum peak flow data of these 14 stations were also used for developing the required regional frequency relationships for the study area.

5.2.3. Adopted regional frequency distribution: For the L-moments approach in flood frequency analysis, the L-moment ratio diagram and the Z_i^{dist} -statistics can be used as the criteria for identifying the robust probability distribution for the study area. The regional average values of L-skewness and L-kurtosis were found to be 0.2841 and 0.2296, respectively, for the study area.

Figure 3 shows the L-moment ratio diagram for the study area. It can be seen that the GLO distribution fits the data of the region. The Z_i^{dist}test for four simulations using three parameter distributions is given in Table 4. The Z_i^{dist} statistics test shows that the GLO distribution is acceptable for all simulation tests. The values were found to be -0.97, -0.35, -0.26 and -0.31, which were lower than the critical value of 1.64. Meanwhile, these values can be considered acceptable results for GEV distribution in Simulations 2, 3, and 4. However, the GLO distribution is the most appropriate distribution to be used for further analysis in the study area. Table 5 shows the regional parameters for GLO distribution.

Table 4: Heterogeneity measure H_i and Z_i^{dist}statistic for each simulation

Homogeneity Test	Simulation 1	Simulation 2	Simulation 3	Simulation 4
H_1	3.13	1.48	1.27	0.54
H_2	2.31	1.64	1.63	1.14
H_3	21.82	1.36	1.44	1.18
Goodness of Fit Test, Z_i^{Dist}				
GLO	-0.97	-0.35	-0.26	-0.31
GEV	-2.18	-1.55	-1.49	-1.45
GNO	-2.94	-2.27	-2.25	-2.23
PE3	-4.26	-3.53	-3.57	-3.56
GPA	-5.33	-4.64	-4.66	-4.45

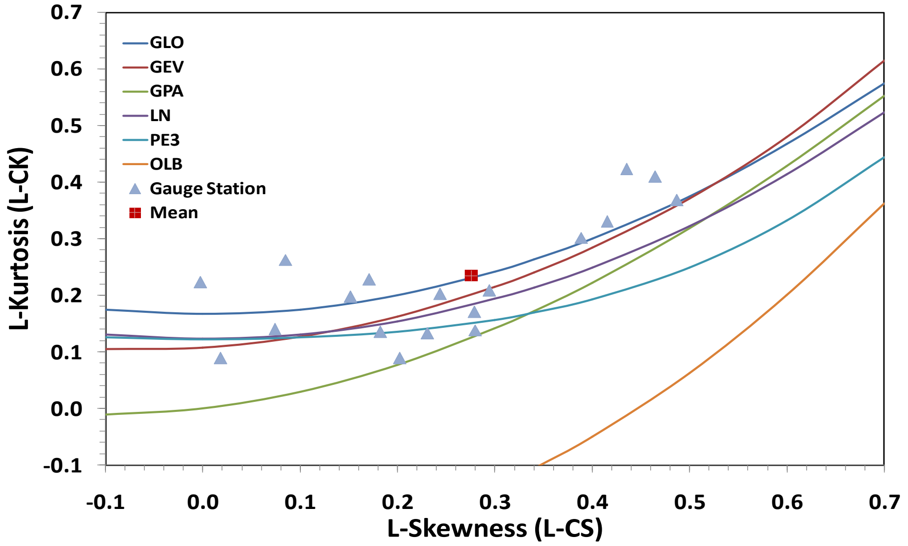

Figure 3: L-moment ratio diagram of the 18 sites in the west coast of Peninsular Malaysia catchment.

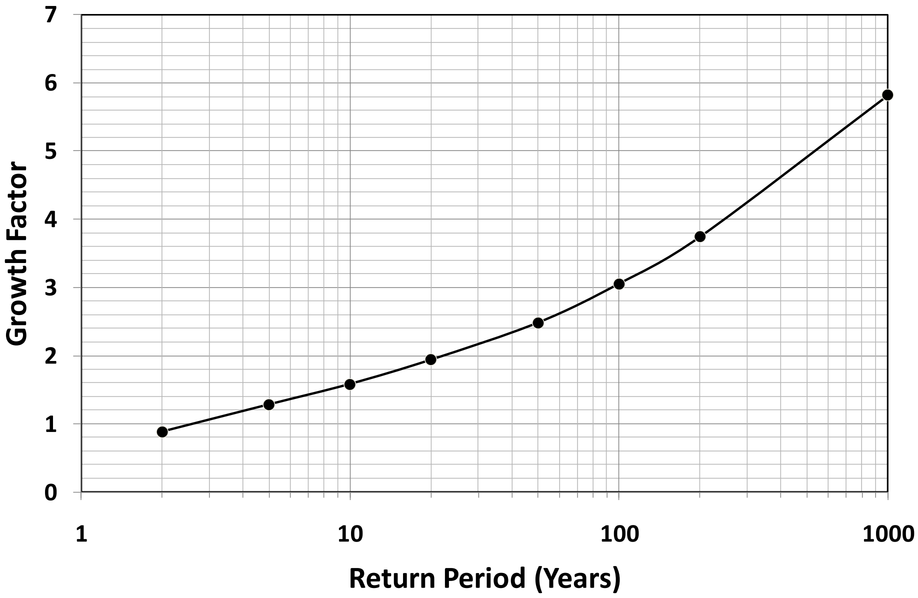

Figure 4: Regional growth curve for the study area

5.2.4. Regional flood frequency for gauged catchments: The regional flood frequency relationships for the GLO distribution can be used for estimating the floods of various return periods for the gauge catchments. The cumulative probability function for GLO is given by:

$$F(x) = \frac{1}{1+e^{-y}} \qquad (15)$$

and the quantile function is represented by:

$$x(F) = \xi + \frac{\alpha\left[1 - \left\{\frac{(1-F)}{F}\right\}^{\kappa}\right]}{\kappa} \qquad \kappa \neq 0$$

$$x(F) = \xi - \alpha\, log\{(1-F)/F\} \qquad \kappa = 0 \qquad (16)$$

where,

$$y = -\frac{1}{\kappa} log\left\{\frac{1-\kappa(x-\xi)}{\alpha}\right\} \qquad \kappa \neq 0$$

$$y = \frac{(x-\xi)}{\alpha} \qquad \kappa = 0 \qquad (17)$$

Above, ξ, α, κ are the location, scale and shape parameters.

Figure 4 shows the regional growth curve for the GLO distribution. Values of growth factor, $Q_T/\overline{Q}$ for GLO distribution are given in Table 6. The floods of various return periods can be estimated using the mean annual peak flow of a catchment and then multiplying these by the corresponding growth factors of Table 6.

Table 5: Regional parameters of GLO distribution for simulation 4

Parameter	ξ	α	κ
Gen. logistic	0.882	0.229	-0.284

Table 6: Growth factors for the study area using GLO distribution

Return Period in years	2	5	10	20	50	100	200	1000
Growth Factor	0.882	1.282	1.582	1.938	2.482	3.053	3.741	5.818

5.2.5. Regional flood estimation for ungauged catchments: The mean annual peak flow for ungauged sites in the study area cannot be calculated because there are no observed data. Therefore, a relationship between the mean annual peak flow values of gauged sites and the climatic and physical characteristics of the catchments is required for the estimation of the mean annual peak flow of ungauged sites. In this study, the use of the least-square method analysis for the mean annual flow and catchment area of the 14 sites in the log domain shows the following relationship:

$$Q_{mean} = 1.832A^{0.649}, \qquad (18)$$

Where A is the catchment area in square kilometers, and Q_{mean} is the mean annual peak flow. The coefficient of correlation is 0.778. Figure 5 shows that the above fitting is quite satisfactory. Compared with the other sites, there were two sites, namely, Semenyih and Kesang, that showed relatively lower values of mean annual peak flows in the catchment area. It may be caused by other factors that can influence the mean annual peak flow, such as catchment slope, types of soil, landuse and also the quality of observed data.

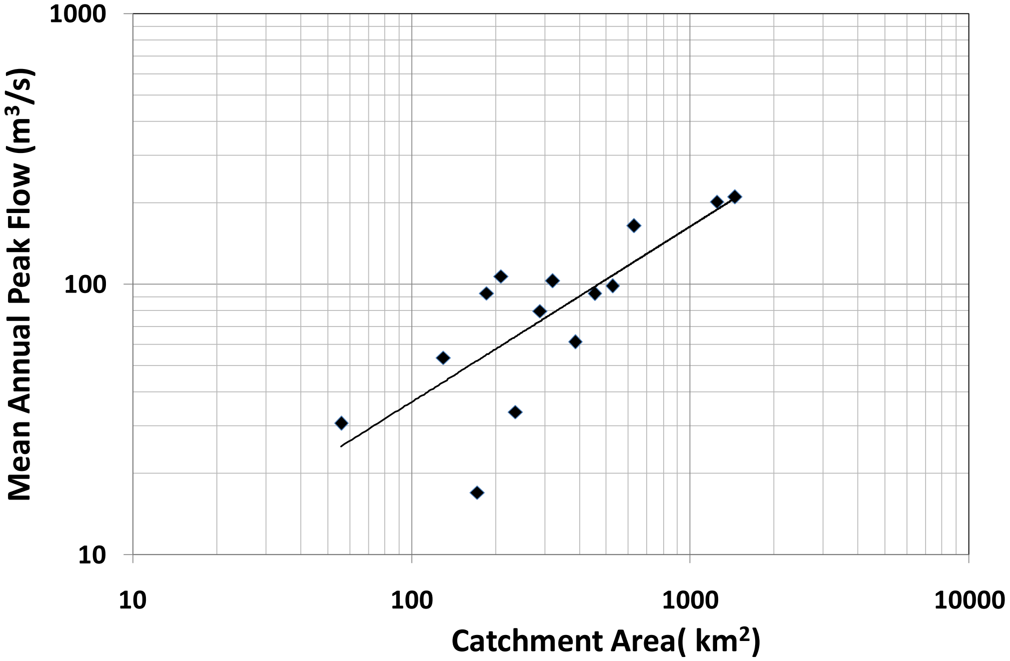

Figure 5: Relationship for catchment area and mean annual peak flow

To estimate the T-year flood of ungauged catchments, the mean annual peak flow of the catchments can be estimated from Eq.(18), as well as by using the growth curve developed for gauged catchments. This can be expressed as:

$$Q_T = C_T Q_{mean} , \tag{19}$$

where C_T is the growth factor, and Q_T is the T year peak flow.

To check the performance of the equation developed in Eq.(18), robustness tests were carried out as follows:

a) the design peak discharges via regional growth curve and mean peak flows were calculated using the average value from the observed data (noted as observed value); and
b) the design peak discharges were calculated using the regional growth curve and Eq.(18) for mean peak flows (noted as fitted value).

Four streamflow stations were used, including Raia, Kampar, Gombak, and Lui. These stations were selected in which the developing regional analysis was not used. These sites were also categorized as heterogeneous in this region. The results for observed and fitted design peak discharges are shown in Table 7 and Figure 6. The difference between the observed and fitted values was smaller for the low return periods, and gradually increased for higher return periods. The results also indicated that of the four sites, Kampar produced the most reliable values between the observed and fitted values, although this site gave a high D_i value during the test of discordance. Meanwhile, Fig. 6 shows the percentage difference of the design peak discharge of the four sites. Overall, Eq.(18) provides satisfactory results, which can be used in this region where the percentage difference for three sites is below 30%. This value is considered normally acceptable for regional estimation [20]. These results further support previous findings by Pilgrim which mentioned the difficulty to produce hydrological relationship in regional basis. [21]

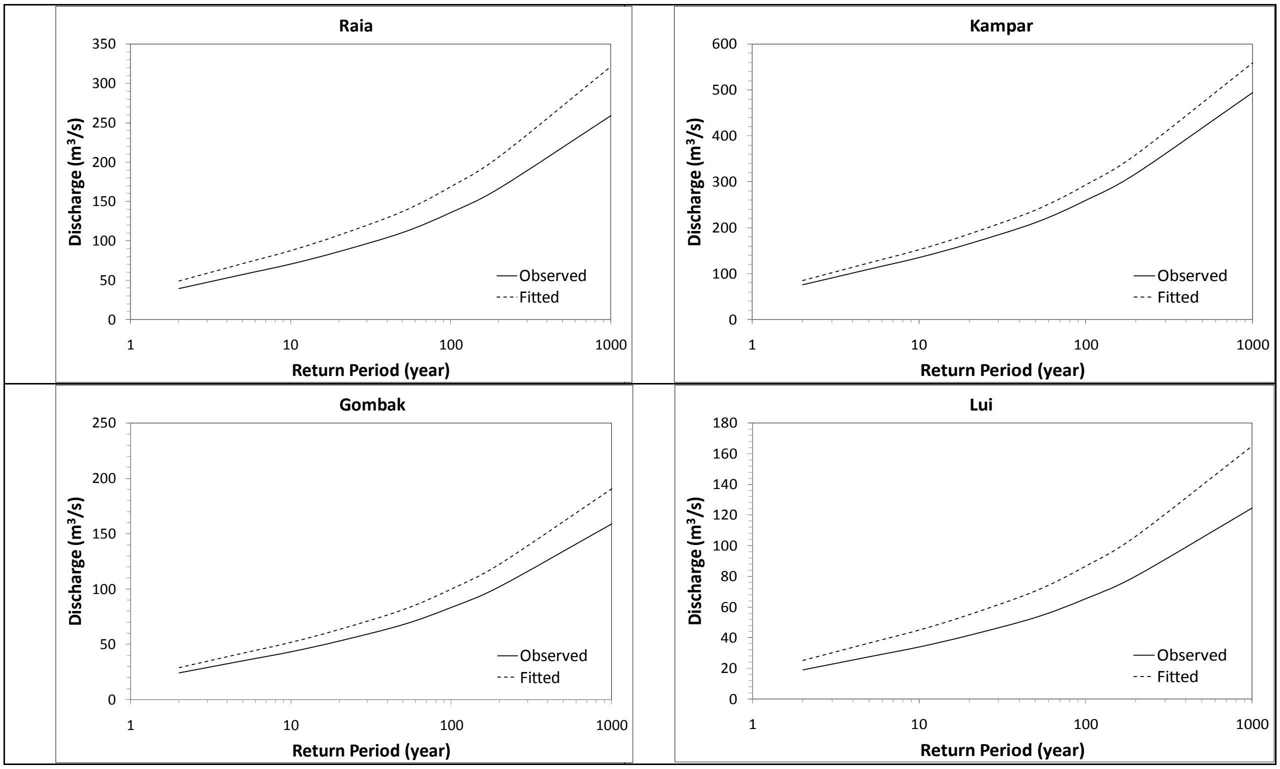

Figure 6: Comparison result of return periods for four testing sites between the observed and fitted values

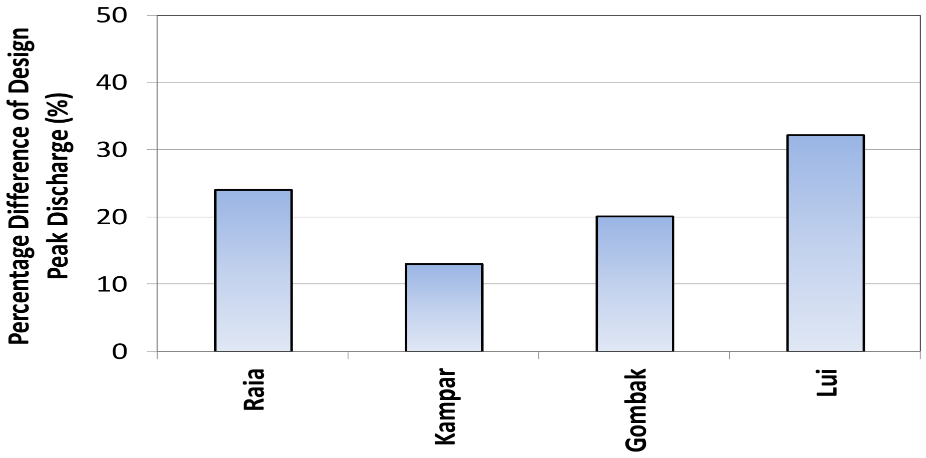

Figure 7: Percentage difference of design peak discharge for four testing sites.

Table 7: Observed and fitted design peak discharge for Raia, Kampar, Gombak, and Lui

Return Period	**Raia**		**Kampar**		**Gombak**		**Lui**	
	Observed	**Fitted**	**Observed**	**Fitted**	**Observed**	**Fitted**	**Observed**	**Fitted**
2	39.23	48.67	74.87	84.69	24.04	28.88	18.89	24.99
5	57.02	70.75	108.83	123.09	34.95	41.98	27.46	36.32
10	70.37	87.31	134.30	151.90	43.13	51.80	33.89	44.82
20	86.20	106.95	164.52	186.08	52.83	63.46	41.51	54.90
50	110.40	136.97	210.70	238.31	67.66	81.27	53.16	70.31
100	135.80	168.49	259.17	293.14	83.22	99.96	65.40	86.49
200	166.40	206.45	317.57	359.20	101.98	122.49	80.13	105.98
1000	258.78	321.08	493.89	558.62	158.60	190.50	124.62	164.82

The HP4 method had been developed using similar method with this study which is adopted the regional analysis using discharges data [22]. Currently, HP4 widely used by the goverment and designer to estimate the design flow for ungauged catchments. Table 8 shows the comparison results between L-Moment method and HP4 method for flow 50 ARI. It can be seen the percentage differences for Raia and Kampar catchment almost similar between L-Moment and HP4 method however for Gombak and Lui catchment the HP4 values slightly higher about 6 % to 8%. It shows the L-Moment method is the reliable method to be further use in determination the design flow for ungauged catchments. Although, this method rarely used in tropical climate since the variability of rainfall pattern and catchment characteristics, the accuracy shall be improved by increase the numbers of calibration sites and performing the cluster analysis.

Table 8: Comparison flows using L-Moment and HP4 method for 50 ARI

SITE	**L-MOMENT**	**HP4**	**Difference (%)**
RAIA	136.97	135.59	1.01
KAMPAR	238.31	236.93	0.58
GOMBAK	81.27	86.82	-6.83
LUI	70.31	75.64	-7.58

6 Conclusion

In this work, the L-moments approach has been successfully used to estimate the regional floods for the catchments in the west coast of Peninsular Malaysia, where streamflow records are available. Discordancy measure test results showed that the peak flow data for all of the 18 sites are suitable for regional flood frequency analysis. However, homogeneity test showed that the 14 sites formed the homogeneous region for the study area, and were thus adopted for further analysis. Using the L-moment ratio diagram and the Z_i^{dist} goodness of fit test, the GLO has been found to be the best distribution, which fits the data of the study area. This is, followed by GEV. Other distributions, such as PE3, GNO, and GPA, did not pass the goodness of fit test. This finding revealed that GLO and GEV are the best regional flood frequency distributions in the west coast region of Peninsular Malaysia. The results are comparably equal with the findings of Lim and Lye for the Sarawak catchments [13]. This study also successfully developed the regional relationships for flood estimation in gauged and ungauged catchments. In addition, the reliability test results showed that three of four sites produced good design peak discharges estimation with a percentage of error of less than 30%. In order to improve the findings, further study should be carried out, including a more streamflow data, especially for sites influenced by urbanization activities. The study area could be widened to include the entire area of Peninsular Malaysia to see the effect of monsoon seasons that influence the climate of the region.

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