GOVERNMENT OF MALAYSIA

VOLUME I - MAIN REPORT

REVIEWED AND UPDATED THE HYDROLOGICAL PROCEDURE NO. 1 (ESTIMATION OF DESIGN RAINSTORM IN PENINSULAR MALAYSIA)

Prepared for

DEPARTMENT OF IRRIGATION AND DRAINAGE MALAYSIA

DECEMBER 2010

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FINAL REPORT: REVIEWED AND UPDATED VERSION OF HYDROLOGICAL PROCEDURE NO.1

VOLUME I

ESTIMATION OF DESIGN RAINSTORM IN PENINSULAR MALAYSIA

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1 INTRODUCTION

1.1 Background and General Review

National Hydraulic Research Institute of Malaysia (NAHRIM) has been engaged by the Department of Irrigation and Drainage Malaysia (DID) to carry out the consultancy job for reviewing and updating **Hydrological Procedure No.1** (referred to as '**HP1'**) – ***Estimation of the Design Rainstorm in Peninsular Malaysia***. The procedure was revised using the current available rainfall data collected and managed by DID throughout the Peninsular Malaysia.

First edition of HP1 by Heiler (1973) was developed using 80 rainfall stations with available record length up to 1970. Second edition of HP1 authored by Mahmood, *et al*., (DID, 1982), on the other hand, use approximately 210 rainfall stations with data recorded to year 1979/80. It was affirmed that only 4 rainfall stations has data recorded for more than 20 years, 59 rainfall stations has less than 10 years and the remaining ranging from 10 to 20 years.

Due to restrictions of records length, the estimation of design rainstorm/rainfall intensity is only able to give an estimation utmost to 50 years return period. Adversely, there is a common practice to use 100-years return period as a level of protection for designing a major water resources or hydraulic structure in Malaysia. As for the methodology adopted, the reviewed and updated HP1 (1982) was still using similar methodology as per first edition (1972). This is purportedly acceptable while the annual maximum series of rainfall was considered as a model of the data series in frequency analysis. The Gumbel distribution maintained as the frequency distribution type and Gumbel paper has been used to estimate the 2-parameters Gumbel distribution. Cunnane (1989) expressed that the error of estimate increases with return period (T), population Coefficient of Variation (C_v) and Coefficient of Skewness (C_s) and is inversely proportional to sample size. This signifies larger error of estimate could occur from small sample size that produces large C_v and C_s, at a high return period and it could also be contributed by the choice of parent distribution and method of estimation.

Effect of rainfall spatial variability particularly for long-duration of rainfall (i.e. longer time of concentration) and large catchments, however, US Area Reduction Factor (ARF) as shown in Table 6 - Value of Areal Average Rainfall – Point Rainfall in existing HP1 (1982,Pg12) has been adopted. Since then, this spatial correction factor has been widely applied without notice of accuracy assurance.

As for the effect of rainfall temporal variability, it has optimized local data from historical rainfall records by means of the standardized storm profiles technique. The temporal storm profiles were sub-divided into two regions, which were recognized as the West Coast Region and the East Coast Region of Peninsular Malaysia.

Despite the disparity mentioned, HP1 (1982) has been widely used by the government agencies and the public sectors for determining the design rainstorm or rainfall intensity in water related project. This procedure was particularly used in conjunction with other DID procedures or associated with other approaches such as rainfall-runoff model with respect to water resources engineering either for planning, designing and operating of water related projects.

The estimation of design rainfall intensity based on the rainfall Intensity – Duration – Frequency - relationship (IDF relationship) has been used as standard practice for many decades for the design of water resources and hydraulic structures. The IDF-relationship gave an idea about the frequency or return period of a mean rainfall intensity or rainfall volume that can be expected within a certain period of storm duration.

For the past 30 years, the numbers of rainfall stations have tremendously increased. To date, there are about 294 and 952 of automatic and daily rainfall gauging stations respectively which has been registered and managed by DID throughout Peninsular Malaysia. The utilization of larger volume and longer record of available rainfall data could assure accurate quantiles estimation.

Therefore, the major aims of reviewing and updating this procedure are mainly to overcome the following issues:

- To enhance and improve the accuracy of quantiles estimation particularly at high return period;
- To improve the estimation of design rainstorm/rainfall intensity with respect to the temporal storm variability;
- To improve the estimation of design rainstorm/rainfall intensity with respect to the spatial storm variability;
- To facilitate the Urban Stormwater Management Manual (MSMA) with respect to the estimation of design rainstorm at low return period and to provide more at-site IDF relationship; and
- To provide the estimation of design rainstorm/rainfall intensity and IDF relationship at ungauged site.

1.2 Objective

The project objective is primarily to revise and update HP1 (1982) based on data available in the custodian of DID with extended data record up to 2004. In view of the users' ease of use, it is necessary to maintain the arrangement and presentation as per existing edition. An effort to apply the current, most appropriate and relevant techniques associated with the methodology was used. It is a guide to improve quantiles accuracy for the reviewed and updated edition.

1.3 Scope of Revision and Update

Key subjects in the proposed revision and updating of HP1 (1982) can be summarized as follows:

- Review existing techniques used in HP1;
- Review the method of estimation using Method of Moments (MOM) and *L*-Moments (LMOM));
- Review the frequency distribution by means of the Gumbel or Extreme Value Type 1 (EV1), Generalized Extreme Value (GEV) , Generalized Logistic (GLO) and Generalized Pareto (GPA) distribution;
- Derive quantiles estimate for high and low return period for long and short duration;
- Develop Intensity-Duration-Frequency (IDF) curves and relationship for gauged sites;
- Formulation of regional IDF relationship for ungauged sites;
- Develop new Areal reduction factor (ARF) for catchment rainfall;
- Develop temporal pattern or storm profiles.

1.4 Concerned Issues and Statements in the Proposed Revision and Update

1.4.1 Reviews on the Choice of Frequency Distribution

The choice of frequency distribution or accurately determination of parent distribution is subject to the type of data series used either Annual Maximum Series (AM) or Partial Duration Series (PD)/Plot over Threshold (POT). If AM series is chosen, the most appropriate parent distribution is likely to be either the Gumbel distribution/Extreme Value Type 1(EV1) or Generalized Extreme Value (GEV). As for the PD series, the Generalized Pareto (GPA) or Exponential distribution would be the most appropriate frequency type. Therefore, the review of parent distribution will involve AM and PD data series.

1.4.2 Short Duration Analysis

To facilitate shorter time of concentration particularly in urban areas, it was suggested that the derivation of design rainstorm or rainfall intensity should accommodate a one-minute temporal resolution. Nevertheless, due to errors in digitizing and processing of rainfall data; the minimum 15-minutes temporal resolution was adopted. Therefore, for short duration storm the data interval of 15min, 30min, 60min, 3-hour and 6-hour are selected for analysis, while 12-hour, 24-hour, 3-day, 5-day and 7-day were considered long-duration storm. Design rainstorm or rainfall intensity for the duration less than 15-minutes can however be estimated from the IDF relationship derivations.

1.4.3 Formulation of Regional IDF Relationship for Gauged and Ungauged Sites

An appropriate regional IDF relationship can be established if method of regional frequency analysis is chosen. It will produce a dimensionless regional growth curve (RGC) of the recognized homogeneous region. In this context, we can assume a few homogeneous regions within the entire Peninsular Malaysia can be produced, which is possibly dominated by the geographical factors and hydrologic characteristics such as location, altitude, average annual rainfall and annual maximum rainfall.

These factors will produce more than one regional growth curve of the IDF relationships. The analysis of regional growth curve can be conducted according to the index flood approach (Dalrymple, 1956) where it is representing the ratio of extreme rainfall of the return period concerned to an index rainfall $\left(R_T / \overline{R}_D\right)$. The development of a regional index-flood type approach to frequency analysis based on L-moments (Hosking and Wallis; 1993, 1997), termed the regional L-moments algorithm (RLMA) has many reported benefits, and has the potential of unifying current practices of regional design rainfall analysis as conducted by Smithers et al. (2000). Basically, regional rainfall frequency analysis with the index rainfall approach consists of two major components, namely the development of a dimensionless frequency curve or growth curve and the estimation of the value of the index rainfall. Further detailed description and showcase of the applicability and workability using the mentioned methodology can be explored in Amin (2002 & 2003).

Second option is to utilize the proposed procedure that will allow the constructed IDF relationships and the derived parameters at gauged sites possibly to be extended for the formulation of regional or ungauged IDF relationship. Under these circumstances, the parameters of the rigorous IDF relationship in the form of $i = \frac{\lambda T^k}{(d+\theta)^\eta}$ can be generalized for the entire specified area of interest. Koutsoyiannis (1998) has first motivated the idea of this approach, which explains deliberately on the mathematical expression of IDF relationship with respect to the probability distributions of annual maxima.

As expected to remain in the presentation of HP1 (1982), and to minimize the error of estimates and its simplicity in developing the IDF relationship for gauged and ungauged sites, the second approach was adopted. This means, Component II – Rainfall Depth-Duration Plotting Diagram and Component III – Rainfall Depth – Frequency Plotting Diagram is excluded from the analysis.

2 ORGANIZATION OF TASK

2.1 Brief Overview of the Task

The required revision and update of the procedure has been organized based on the designated tasks and can be simplified as per Figure 2.1 below.

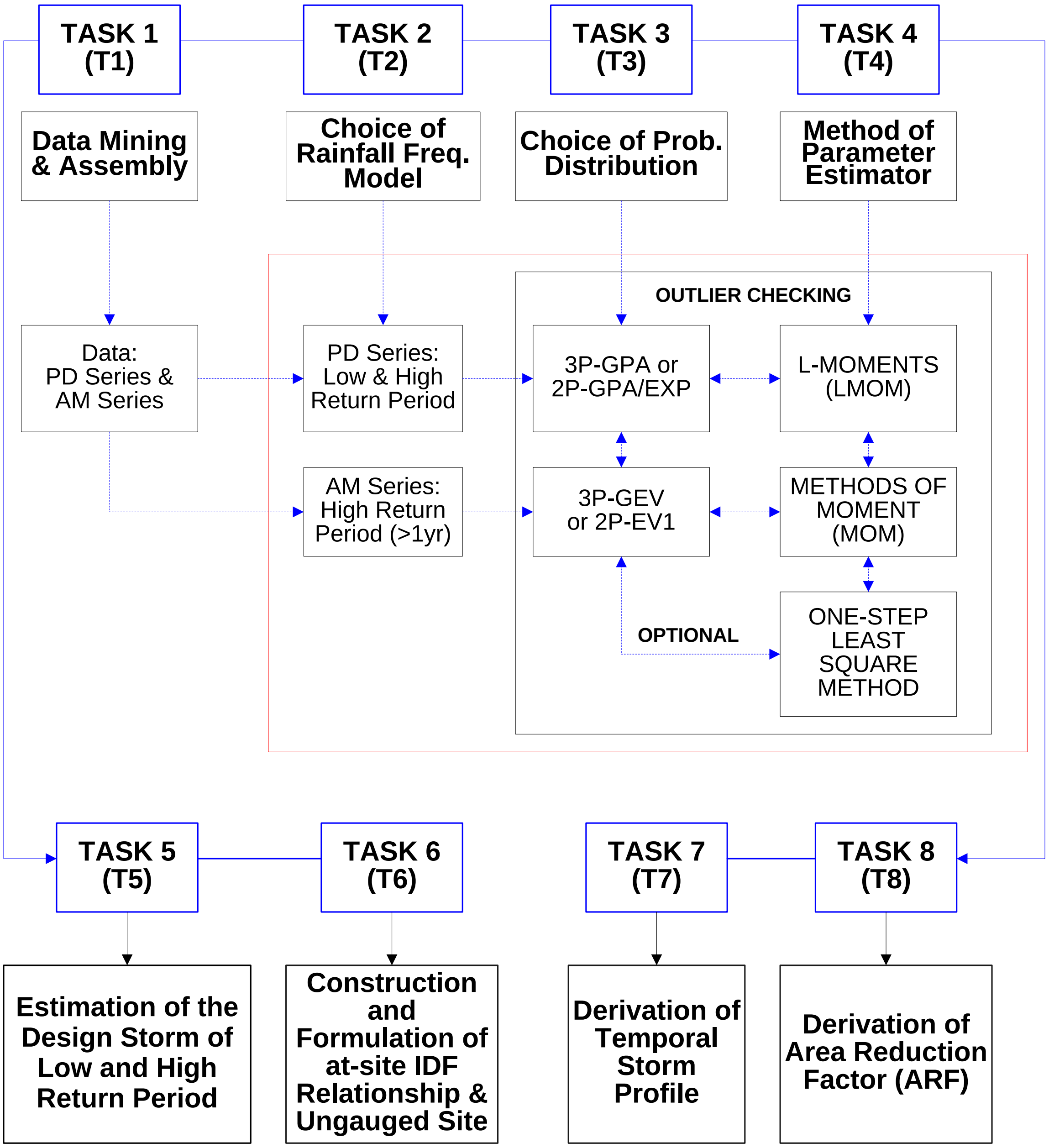


Figure 2:1: Flow chart of the designated tasks for the review and update process of Hydrological Procedure No.1 (HP1).

2.2 Objectives of the Designated Tasks

2.2.1 T1: Task 1 – Data Mining and Assembly

To collect, collate and screen the identified rainfall data provided by DID. Insufficient data set (quantity and quality) will trigger inaccuracy of estimation. Two types of possible data sets are identified as Annual Maximum series (AM) and Partial Duration series/Peak over Threshold (PD/POT). Assembly of data sets is much depending on the choice of estimation method. List of automatic rainfall stations used are summarized and shown in Figure 2.2.

Linkages: Provide information for the components of T2, T3, T4, T5, T6, T7, and T8.

2.2.2 T2: Task 2 – Choice of Rainfall Frequency Models

To determine the best type of data series that can be used in the analysis. Insufficient records length and missing records of data series will produce inaccuracy of estimation particularly at high return period.

The AM and POT model has been selected for the rainfall frequency models. Choice of the PD/POT data series will definitely lengthened the data sets and can assure and gain accuracy estimates. The series of AM rainfall can be extracted without difficulty from hydrometric records and it has been applied onto short and long duration storms.

However, the extraction of the PD/POT series of rainfall is less straightforward because of the occasional occurrence of rainfall events. The PD/POT model has been applied onto automatic recorded rainfall data for determining the design rainstorm/rainfall intensity of low (1 year and below) and high (2 years and above) return period.

Linkages: Provide information for the components of T3 and T4.

2.2.3 T3: Task 3 – Choice of Distribution to be Used in the Chosen Model (AM or PD/POT)

To identify the most appropriate parent distribution that can be analyzed using local data of AM series or PD/POT series.

Apparently, the most appropriate parent distribution for the PD/POT model is most likely the Generalized Pareto distribution (GPA) or Exponential Distribution.

The most likely parent distribution for am model is either the gumbel/extreme value type 1(ev1) or generalized extreme value distribution (gev). The task will be explained in detail in chapter 3-Approach and Methodology.

Linkages: Provide information for the components of T4, T5, T7, and T8.

2.2.4 T4: Task 4 – Method of Parameter Estimation

The most flexible, practical, robust and recent technique is the L-moments method, which has been flexibly used and plugged for the AM and PD/POT model. Its superior method that can be used is the at-site frequency analysis or regional frequency analysis whether by the 2-parameter or more parameter distribution. The application of L-moments approach (Hosking and Wallis, 1987 & 1997) has received widespread attention from researchers from all over the world. Maidment (1993) has expressed the advantage of L-moments as due to the sample estimators of L-moments which is in linear combination of the ranked observations, thus do not involve squaring or cubing the observations as the product-moment estimators.

These resulting L-moment estimators of the dimensionless coefficients of variation and skewness are almost unbiased. In a wide range of hydrologic applications, L-moments provide simple and reasonably efficient estimators of the characteristics of hydrologic data and of a distribution’s parameters.

Linkages: Provide information for the components of T5, T6, T7, and T8.

2.2.5 T5: Task 5 – Estimation of Design Storm for Low and High Return Period

The objective is to determine the magnitude of design rainstorm/rainfall intensity at gauged sites and ungauged sites. Direct estimation can be obtained for gauged sites; however, it is much complicated to estimate an ungauged site which is dominated by the choice of estimation techniques. If the choice is to maintain the existing technique currently in HP1, the depth-duration-plotting diagram and rainfall depth-frequency diagram shall be re-determined using new data sets. The mentioned technique is most likely inappropriate to be used onto the PD/POT data series. The only option is to follow what has been described in Chapter 1.4.3 which is based on the rigorous formulation of suggested IDF.

Linkages: Provide information for the components of T6, T7 and T8.

2.2.6 T6: Task 6 – Construction and Formulation of at-site IDF Curve

To formulate a mathematical relationship (duration, magnitude of design rainstorm/rainfall intensity and return period) of the established IDF curve particularly from gauged sites. This will make IDF relationships easier to use, and they are often estimated by regression curve. The polynomial formula and the modified Bernard and Koutsoyianis equation of IDF relationship has been constructed for low and high return period.

Linkages: Provide information to component T9 and the existing polynomial equation curves in MSMA, and possible to provide more information on other cities or identified urban areas that were not listed in the manual.

2.2.7 T7: Task 7 – Design Storm Profile (Temporal Pattern)

To derive temporal storm variability which is oftentimes in hydrologic modelling require design rainfall/rainstorm hyetographs. Design rainstorm/rainfall intensity that coupled with temporal storm variability (profile) provides input to hydrologic models, whereas the resulting flows and flow rates of the system are calculated using rainfall-runoff and flow routing procedure.

Linkages: Provide information to the MSMA procedure and the reviewed and updated HP1 particularly for updating existing storm profiles.

2.2.8 T8: Task 8 – Areal Reduction Factor (Spatial Correction)

Areal Reduction Factor (ARF) is defined as the ratio between the design values of areal average rainfall and point rainfall that is calculated for the same average recurrence interval (ARI). However, information from the IDF relationship is generally in the form of point design rainstorm/rainfall intensity. But the fact that larger catchments are less likely than smaller catchments to experience high intensity storms over the entire catchments area, the ARF is needed to reduce/convert point design rainfall to catchments design rainfall in order to estimate the areal average design rainfall intensity over the catchments. Due to the lack of adequate researches carried out in Malaysia that is probably due to data availability and station density, the ARF obtained from a study of a part in the United States were recommended for use in existing HP1 (1982).

Linkages: Provides information for the preparation of final report and the proposed procedure.

Table 2.1: List of Automatic Rainfall Gauging Stations throughout Peninsular Malaysia

State	No.	Station ID		Location	
				Long(^{o})	Lat (^{o})
Perak	1	4010001	JPS Teluk Intan	101.036	4.017
	2	4207048	JPS Setiawan	100.700	4.218
	3	4311001	Pejabat Daerah Kampar	101.156	4.306
	4	4409091	Rumah Pam Kubang Haji	100.901	4.461
	5	4511111	Politeknik Ungku Umar	101.125	4.589
	6	4807016	Bukit Larut Taiping	100.793	4.863
	7	4811075	Rancangan Belia Perlop	101.175	4.893
	8	5005003	Jln. Mtg. Buloh Bgn Serai	100.546	5.014
	9	5207001	Kolam Air JKR Selama	100.701	5.217
	10	5210069	Stesen Pem. Hutan Lawin	101.058	5.299
	11	5411066	Kuala Kenderong	101.154	5.417
	12	5710061	Dispensari Keroh	101.000	5.708
Selangor	13	2815001	JPS Sungai Manggis	101.542	2.826
	14	2913001	Pusat Kwln. JPS T Gong	101.393	2.931
	15	2917001	Setor JPS Kajang	101.797	2.992
	16	3117070	JPS Ampang	101.750	3.156
	17	3118102	SK Sungai Lui	101.872	3.174
	18	3314001	Rumah Pam JPS P Setia	101.413	3.369
	19	3411017	Setor JPS Tj. Karang	101.174	3.424
	20	3416002	Kg Kalong Tengah	101.664	3.436
	21	3516022	Loji Air Kuala Kubu Baru	101.668	3.576
	22	3710006	Rmh Pam Bagan Terap	101.082	3.729
Pahang	23	2630001	Sungai Pukim	103.057	2.603
	24	2634193	Sungai Anak Endau	103.458	2.617
	25	2828173	Kg Gambir	102.938	2.813
	26	3026156	Pos Iskandar	102.658	3.028
	27	3121143	Simpang Pelangai	102.197	3.175
	28	3134165	Dispensari Nenasi	103.442	3.138
	29	3231163	Kg Unchang	103.189	3.288
	30	3424081	JPS Temerloh	102.426	3.439
	31	3533102	Rumah Pam Pahang Tua	103.357	3.561
	32	3628001	Pintu Kaw. Pulau Kertam	102.856	3.633
	33	3818054	Setor JPS Raub	101.847	3.806
	34	3924072	Rmh Pam Paya Kangsar	102.433	3.904
	35	3930012	Sungai Lembing PCC Mill	103.036	3.917
	36	4023001	Kg Sungai Yap	102.325	4.032
	37	4127001	Hulu Tekai Kwsn."B"	102.753	4.106
	38	4219001	Bukit Bentong	101.940	4.233
	39	4223115	Kg Merting	102.383	4.243
	40	4513033	Gunung Brinchang	101.383	4.517

Table 2.1: List of Automatic Rainfall Gauging Stations throughout Peninsular Malaysia (Cont'd)

State	No.	Station ID		Location	
				Long(^{o})	Lat (^{o})
Terengganu	41	3933001	Hulu Jabor, Kemaman	103.308	3.918
	42	4131001	Kg, Ban Ho, Kemaman	103.175	4.133
	43	4234109	JPS Kemaman	103.422	4.232
	44	4332001	Jambatan Tebak, Kem.	103.263	4.378
	45	4529001	Rmh Pam Paya Kempian	102.979	4.561
	46	4529071	SK Pasir Raja	102.974	4.564
	47	4631001	Almuktafibillah Shah	103.199	4.139
	48	4734079	SM Sultan Omar, Dungun	103.419	4.763
	49	4832077	SK Jerangau	103.200	4.844
	50	4930038	Kg Menerong, Hulu Trg	103.061	4.939
	51	5029034	Kg Dura. Hulu Trg	102.942	5.067
	52	5128001	Sungai Gawi, Hulu Trg	102.844	5.143
	53	5226001	Sg Petualang, Hulu Trg	102.663	5.208
	54	5328044	Sungai Tong, Setiu	102.886	5.356
	55	5331048	Setor JPS K Terengganu	103.133	5.318
	56	5426001	Kg Seladang, Hulu Setiu	102.675	5.476
	57	5428001	Kg Bt. Hampar, Setiu	102.815	5.447
	58	5524002	SK Panchor, Setiu	102.489	5.540
	59	5725006	Klinik Kg Raja, Besut	102.565	5.797
Kelantan	60	4614001	Brook	101.485	4.676
	61	4726001	Gunung Gagau	102.656	4.757
	62	4819027	Gua Musang	101.969	4.879
	63	4915001	Chabai	101.579	5.000
	64	4923001	Kg Aring	102.353	4.938
	65	5120025	Balai Polis Bertam	102.049	5.146
	66	5216001	Gob	101.663	5.251
	67	5320038	Dabong	102.015	5.378
	68	5322044	Kg Lalok	102.275	5.308
	69	5522047	JPS Kuala Krai	102.203	5.532
	70	5718033	Kg Jeli, Tanah Merah	101.839	5.701
	71	5719001	Kg Durian Daun Lawang	101.867	5.701
	72	5722057	JPS Machang	102.219	5.788
	73	5824079	Sg Rasau Pasir Putih	102.417	5.871
	74	6019004	Rumah Kastam R Pjg	101.979	6.024
	75	6122064	Setor JPS Kota Bharu	102.257	6.217
N Sembilan	76	2719001	Setor JPS Sikamat	101.872	2.738
	77	2722202	Kg Sawah Lebar K Pilah	102.264	2.756
	78	2723002	Sungai Kepis	102.315	2.701
	79	2725083	Ladang New Rompin	102.513	2.719
	80	2920012	Petaling K Kelawang	102.065	2.944

Table 2.1: List of Automatic Rainfall Gauging Stations throughout Peninsular Malaysia (Cont'd)

State	No.	Station ID		Location	
				Long(^{o})	Lat (^{o})
Melaka	81	2222001	Bukit Sebukor	102.268	2.232
	82	2224038	Chin Chin Tepi Jalan	102.492	2.289
	83	2321006	Ladang Lendu	102.193	2.364
Pulau Pinang & Perlis	84	5204048	Sg Simpang Ampat	100.544	5.295
	85	5302001	Tangki Air Besar Sg Png	100.200	5.383
	86	5302003	Kolam Tkgn Air Hitam	100.250	5.383
	87	5303001	Rmh Kebajikan P Png	100.304	5.392
	88	5303053	Komplek Prai	100.392	6.382
	89	5402001	Klinik Bkt Bendera P Png	100.383	5.567
	90	5402002	Kolam Bersih P Pinang	100.383	5.500
	91	5404043	Ibu Bekalan Sg Kulim	100.481	5.433
	92	5504035	Lahar Ikan Mati K Batas	100.431	5.535
	93	6401002	Padang Katong, Kangar	100.188	6.446
Kedah	94	5507076	Bt. 27, Jalan Baling	100.736	5.583
	95	5704055	Kedah Peak	100.439	5.796
	96	5806066	Klinik Jeniang	101.067	3.717
	97	5808001	Bt. 61, Jalan Baling	100.894	5.881
	98	6103047	Setor JPS Alor Setar	100.361	6.113
	99	6108001	Komppleks Rumah Muda	100.847	6.106
	100	6206035	Kuala Nerang	100.613	6.254
	101	6207032	Ampang Padu	100.772	6.240
	102	6306031	Padang Sanai	100.690	6.343
Johor	103	1437116	Stor JPS Johor Baharu	103.458	1.471
	104	1534002	Pusat Kem. Pekan Nenas	103.494	1.515
	105	1541139	Johor Silica	104.185	1.526
	106	1636001	Balai Polis Kg Seelong	103.697	1.631
	107	1737001	SM Bukit Besar	103.719	1.764
	108	1829002	Setor JPS B Pahat	102.925	1.840
	109	1834124	Ladang Ulu Remis	103.468	1.849
	110	1839196	Simpang Masai K. Sedili	103.965	1.850
	111	1931003	Emp. Semberong	103.179	1.974
	112	2025001	Pintu Kaw. Tg. Agas	102.578	2.051
	113	2033001	JPS Kluang	103.319	2.022
	114	2231001	Ladang Chan Wing	103.147	2.250
	115	2232001	Ladang Kekayaan	103.422	2.251
	116	2235163	Ibu Bekalan Kahang	103.599	2.229
	117	2237164	Jalan Kluang-Mersing	103.736	2.257
	118	2330009	Ladang Labis	103.017	2.584
	119	2528012	Rmh. Tapis Segamat	102.814	2.517
	120	2534160	Kg Peta Hulu Sg Endau	103.419	2.539
	121	2636170	Setor JPS Endau	103.621	2.650

Table 2.1: List of Automatic Rainfall Gauging Stations throughout Peninsular Malaysia (Cont'd)

State	No.	Station ID		Location	
				Long(°)	Lat (°)
W. Persekutuan	122	3015001	Puchong Drop,K Lumpur	101.597	3.019
	123	3116003	Ibu Pejabat JPS	102.358	6.006
	124	3116004	Ibu Pejabat JPS1	101.682	3.156
	125	3116005	SK Taman Maluri	101.636	3.197
	126	3116006	Ladang Edinburgh	102.417	2.133
	127	3216001	Kg. Sungai Tua	101.686	3.272
	128	3216004	SK Jenis Keb. Kepong	102.217	2.683
	129	3217001	Ibu Bek. KM16, Gombak	101.729	3.268
	130	3217002	Emp. Genting Kelang	101.753	3.236
	131	3217003	Ibu Bek. KM11, Gombak	101.714	3.236
	132	3217004	Kg. Kuala Seleh, H. Klg	101.768	3.258
	133	3217005	Kg. Kerdas, Gombak	101.713	3.238
	134	3317001	Air Terjun Sg. Batu	101.704	3.335
	135	3317004	Genting Sempah	101.771	3.368

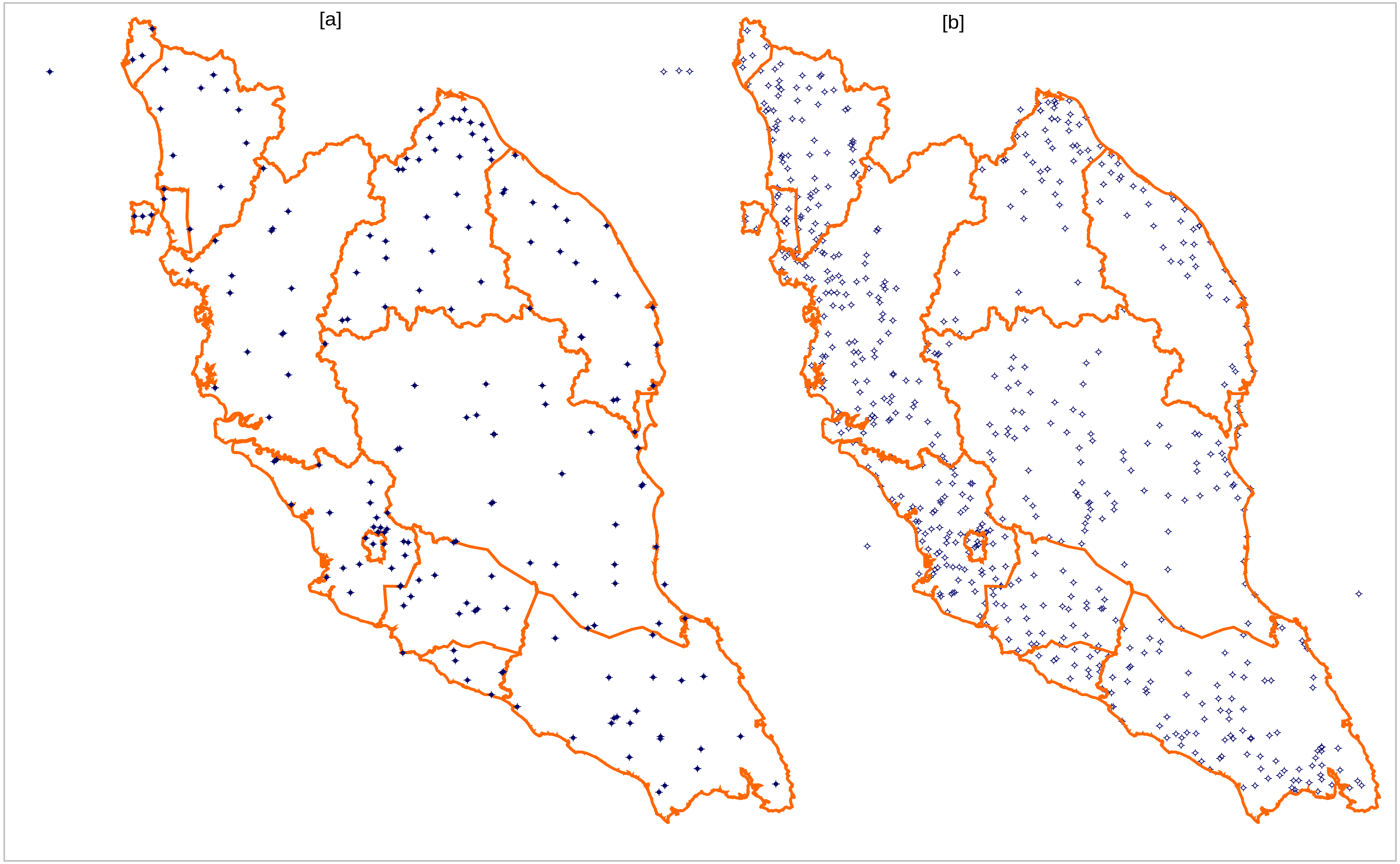


Figure 2.2: Location map of [a] automatic and [b] daily raingauges station throughout Peninsular Malaysia

3 APPROACH AND METHODOLOGY

3.1 Data Mining and Assembly

Error in rainfall data can be introduced at several stages: [1] at the rain gauge; problems can be caused by a poorly sites gauge, splashing of rainfall in and out, or losses due to high winds and vandalism, [2] human error or technical failure is always possible, both in reading the gauge and in archiving the results. Data mining that focuses on data checking and screening aimed to identify and investigate suspicious annual maximum series (AM) or partial duration series (PD) of rainfall.

AM or PD series abstracted from continuously hourly data will be checked against nearby daily totals. The hourly data will be compared to the totals for the day on which the maximum was recorded, from the nearest daily gauges. Any suspicious large hourly totals will be investigated further by inspecting the continuous data from which the AM or PD is abstracted. The most suspicious data either from the AM or PD will be statistically tested for the outlier. Thus, the identified outlier (low or high outlier) will be excluded from the analysis. The PD series will focus on independency of the data retrieved or abstracted, in order to ensure no overlapping of each maxima data.

3.2 Choice of Rainfall Frequency Model

Two general approaches are available for modelling flood, rainfall, and many other hydrologic series. One option is recognized as an annual maximum series (AM) that considers the largest event in each year; and second option is using a partial duration series (PD) or peak-over-threshold (POT) approach that performs analysis on all peaks above a truncation or threshold level.

An objection to using AM series is that it employs only the largest events in each year, regardless of whether the second largest event in a year exceeds the largest events of other years. Moreover, the largest annual maxima in a dry year and calling them storms are misleading. Furthermore, if hydrometric records are of insufficient records length, it will reflect the accuracy of estimation particularly at high return period. As reported by Cunnane (1989), the AM series has received widespread attention not due to objective manner but argued in general manner such as widely accepted, simple and convenient to apply.

The PD series analysis avoids such problems by considering all dependent peaks, which exceed a specified threshold. Stedinger *et. al*.,

(1993) cited that arguments in favour of PDS are that relatively long and reliable PDS records are often available, and if the arrival rate for peaks over threshold is large enough (1.65 events/year for the Poisson arrival with exponential exceedance model), PDS analyses should yield more accurate estimates of extreme quantiles than the corresponding annual-maximum frequency analysis. Still, the drawback of PDS analyses is that one must have criteria to identify only independent peaks (and not multiple peaks corresponding to the same event). However, to avoid counting any multiple peaks in the same event, an independency criterion has to be incorporated to distinguish dependant rainfall events that lead to the same effect. Vaes (2000) has specified that a rainfall volume is independent if in a certain period antecedent and posterior to the considered rainfall volume no larger than or equal rainfall volume occurs. For this period the maximum between 12-hours and the aggregation period is assumed.

Statistically if we denote the estimate of R_T obtained by the AM series as $\overline{R}_T$ and that obtained from the same hydrometric record by the PD method as $\overline{R}_T^*$, it is usually observed that these two estimates are unequal. Furthermore the sampling variance of $\overline{R}_T$ is not equal to that of $\overline{R}_T^*$, i.e. var ($\overline{R}_T$) $\neq$ var ($\overline{R}_T^*$). From a statistical point of view that method which has the smallest sampling variance enjoys an advantage. Cunnane (1973) examined the relative values of var ($\overline{R}_T$) and var ($\overline{R}_T^*$) and found that var ($\overline{R}_T$) $<$ var ($\overline{R}_T^*$) provided $\lambda<1.65$ where λ is the mean number of peaks per year included in the PD series. If $\lambda>1.65$ the opposite was true. This to show that the AM method is statistically efficient when λ is small and is less efficient when λ is large. These results have been re-examined by Yevjevich and Taesombut (1978) that suggested a value of $\lambda > 1.8$ or 1.9 may be required to ensure greater efficiency of PD estimates of $\overline{R}_T$.

3.3 Choice of Distribution to be Used in the Chosen Model (AM or PD/POT)

[1] Candidates of the AM model – the Generalized Extreme Value Distribution (GEV)

This is a general mathematical form which incorporates the Gumbel's type I, II and III of extreme value distributions for maxima. The GEV distribution's cdf can be written as:

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

The Gumbel distribution is obtained when $\kappa = 0$. For $|\kappa| < 0.3$, the general shape of the GEV distribution is similar to the Gumbel distribution, though the right-hand tail is thicker for $\kappa < 0$ and thinner for $\kappa > 0$. Here ξ is a location parameter, α is a scale parameter, and κ is the important shape parameter. For $\kappa > 0$ the distribution has a finite upper bound at $\xi + \alpha/\kappa$ and corresponds to the EV type III distribution for maxima that are bounded above; for $\kappa < 0$, the distribution has a thicker right-hand tail and corresponds to the EV type II distribution for maxima from thick-tailed distribution like the Generalized Pareto distribution with $\kappa < 0$. The parameters of the GEV distribution in term L-moments are:

$$\kappa = 7.8590c + 2.9554c^2 \qquad [2]$$

$$\alpha = \frac{\kappa\lambda_2}{\Gamma(1+\kappa)\left(1-2^{-\kappa}\right)} \qquad [3]$$

$$\xi = \lambda_1 + \frac{\alpha}{\kappa[\Gamma(1+\kappa)-1]} \qquad [4]$$

where

$$c = \frac{2\lambda_2}{(\lambda_3 + 3\lambda_2)} - \frac{\ln(2)}{\ln(3)} = \frac{2\beta_1 - \beta_o}{3\beta_2 - \beta_o} - \frac{\ln(2)}{\ln(3)} \qquad [5]$$

The quantiles of the GEV distribution can be calculated from:

$$X_T = \xi + \frac{\alpha}{\kappa}\left\{1 - [-\ln(F)]^{\kappa}\right\} \qquad [6]$$

where $F = 1 - 1/T$ is the cumulative probability of interest. When data are drawn from a Gumbel distribution ($\kappa = 0$), using the biased estimator b_r^* in equation [16] to calculate the L-moments estimators in equation [17] to [20] the resultant estimator of κ has a mean of 0 and variance $Var(\kappa) = 0.563/n$. Comparison of the statistic $Z = \hat{\kappa}\sqrt{n/0.563}$ with standard normal quantiles allows construction of a powerful test of whether $\kappa = 0$ or not when fitting with a GEV distribution.

[2] Candidate Distribution of the PD/POT Model – the Generalized Pareto Distribution (GPA)

The GPA distribution's cdf is given by:

$$F(x) = 1 - \left[1 - \kappa\left(\frac{x - X_o}{\alpha}\right)\right]^{1/\kappa} \qquad \text{for } \kappa \neq 0 \qquad [7]$$

where X_o is the threshold value, α and κ are scale and shape parameter respectively. For positive κ this cdf has upper bound $x_{\max} = X_o + \alpha/\kappa$; for $\kappa < 0$, an unbounded and thick-tailed distribution results; $\kappa = 0$ yields a two-parameter exponential distribution in the form of $F(x) = 1 - \exp\left[-\frac{1}{\xi}(x - X_o)\right]$. The parameters of the GEV distribution in term L-moments are:

[2.1] The threshold (X_o) is known

$$\kappa = \frac{4\beta_1 - 3\beta_o + X_o}{\beta_o - 2\beta_1} \qquad [8]$$

$$\alpha = (\beta_o - X_o)(1 + \kappa) \qquad [9]$$

[2.2] The threshold (X_o) to be estimated

$$\kappa = \frac{9\beta_2 - 10\beta_1 + 2\beta_o}{(2\beta_1 - 3\beta_2)} \qquad [10]$$

$$\alpha = (2\beta_1 - \beta_o)(1 + \kappa)(2 + \kappa) \qquad [11]$$

$$X_o = \beta_o - \frac{\alpha}{(1+\kappa)} \qquad [12]$$

The quantiles of the GPA distribution can be calculated from:

$$X_T = X_o + \frac{\alpha}{\kappa}\left[1 - \exp(-\kappa Y_T)\right] \quad \text{or} \qquad [13]$$

$$X_T = X_o + \frac{\alpha}{\kappa}\left[1 - (1-F)^{\kappa}\right] \qquad [14]$$

where $Y_T = -\ln(1-F)$ and $F = 1 - {}^{1}\!/_{\lambda T}$, while λ is the average number of events per year larger than a threshold X_o.

3.4 Methods of Parameter Estimation Using L-Moments

Just as the variance, or coefficient of skewness, of a random variable are functions of the moments *E(X), E(X^2)*, and *E(X^3)*, L-moments can be written as functions of probability-weighted moments (PWMs), which can be defined as:

$$\beta_r = E\left\{X[F(X)]^r\right\} \qquad [15]$$

where F(X) is the cdf for X. Probability-weighted moments are the expectation of X times powers of F(X). For r=0, β_o is the population mean μ_X. Estimators of L-moments are mostly simply written as linear function of estimators of PWMs. The first PWM estimator b_o of β_o is the sample mean $\bar{X}$. To estimate other PWMs, one employs the ordered observations, or the order statistics $X_{(n)} \leq \ldots\ldots \leq X_{(1)}$, corresponding to the sorted or ranked observation in a sample $\left(X_i \middle| i = 1, \ldots., n\right)$. A simple estimator of β_r for $r \geq 1$ is:

$$b_r^* = \frac{1}{n}\sum_{j=1}^{n} X_{(j)}\left[1 - \frac{(j-0.35)}{n}\right]^r \qquad [16]$$

where $1-\frac{(j-0.35)}{n}$ are estimators of $F\left(X_{(j)}\right)$. b_r^* is suggested for use when estimating quantiles and fitting a distribution at a single site. Although it is biased, it generally yields smaller mean square error quantiles estimators than the unbiased estimators as in equation below. When unbiasedness is important, one can employ unbiased PWM estimators as:

$$b_o = \overline{X} \qquad [17]$$

$$b_1 = \sum_{j=1}^{n-1} \frac{(n-j)X_{(j)}}{n(n-1)} \qquad [18]$$

$$b_2 = \sum_{j=1}^{n-2} \frac{(n-j)(n-j-1)X_{(j)}}{n(n-1)(n-2)} \qquad [19]$$

$$b_3 = \sum_{j=1}^{n-3} \frac{(n-j)(n-j-1)(n-j-2)X_{(j)}}{n(n-1)(n-2)(n-3)} \qquad [20]$$

These are examples of the general formula:

$$\hat{\beta}_r = b_r = \frac{1}{n}\sum_{j=1}^{n-r} \frac{\binom{n-j}{r}X_{(j)}}{\binom{n-r}{r}} = \frac{1}{(r+1)}\sum_{j=1}^{n-r} \frac{\binom{n-j}{r}X_{(j)}}{\binom{n}{r+1}} \qquad [21]$$

for $r = 1, ..., n-1$ (which defines PWMs in terms of powers of *(1-F)*; this formula can be derived using the fact that $(r+1)\beta_r$ is the expected value of the largest observation in a sample of size $(r+1)$. The unbiased estimators are recommended for calculating L-moments diagrams and for use with regionalization procedures where unbiasedness is important. For any distribution, L-moments are easily calculated in term of PWMs from:

$$\lambda_1 = \beta_o \qquad [22]$$

$$\lambda_2 = 2\beta_1 - \beta_o \qquad [23]$$

$$\lambda_3 = 6\beta_2 - 6\beta_1 + \beta_o \qquad [24]$$

$$\lambda_4 = 20\beta_3 - 30\beta_2 + 12\beta_1 - \beta_o \qquad [25]$$

3.5 Estimation of Design Storm/Rainfall Intensity of Low and High Return Period

The estimated parameters of the chosen probability distributions as to be carried out in Task 5 (T5), will lead to the possibility of calculating quantile estimation of design storm/rainfall intensity for low and high return period. It can be calculated from the proposed equations of (11), (12) and (13) associated with return period, *T*; and duration, *D*. The calculated quantiles estimation at low return period of *T*=1-month, 2-month, 3-month and 6-month (less than one-year) at specified durations is intentionally calculated to accommodate the construction of IDF relationship at specified urban/city areas in the urban stormwater/sewer design. It is also purposely carried out to supplement the existing discrepancies in MASMA (JPS, 2000). The calculated quantiles estimation at high return period (with respect to *T*=2, 5, 10, 20, 50 and 100-year return period) is definitely to enhance and improve the rainfall intensity design values of the existing HP1 and integral for the construction of IDF relationship/curves for the entire gauged and ungauged sites of Peninsular Malaysia.

3.6 Construction and Formulation of At-Site IDF Curve

The formulation of a mathematical expression on the at-site IDF relationships is definitely for the benefit of the users and it will assist them to calculate the quantiles estimation easily and quickly. The polynomial equations have been introduced in the Urban Storm Water Management Manual, MSMA (JPS, 2000), however, the equations is limited to the duration of an hour to 1000 minutes. Possible reasons are due to the proposed polynomial equation that has failed to fit the small storm duration (less than 1-hour) and larger storm duration for more than 24-hours. For duration less than one hour, a relationship of the required duration and the factor of 2-years return period 24-hours rainfall that explicitly showed in the manual as in Chapter 13- equation [13.3](13.3) has been introduced. But no explanation has been proposed or introduced on how to perform estimation for more than 1000 minutes duration in particular.

Consequently, as quoted in the procedure, the error of estimation is likely to be up ± 20% particularly for the shorter duration of 30-minutes and longer duration of 15-hours. To give a more precise estimation and for minimizing the error of estimates due to the chosen mathematical expression, we proposed general equation [26] and the identical equation[27] to be adopted as general mathematical formulation of the IDF relationship. Under these circumstances, for the specified formulation of the GEV distribution, the Gumbel distribution and the GPA distribution can be explicitly performed using equation [35], [36] and [37] respectively.

3.6.1 An Overview on the Mathematical Expression of an IDF relationship

IDF relationship is a mathematical relationship between the rainfall intensity *i*, the duration *d*, and the return period *T* (or, equivalently, the annual frequency of exceedance, typically referred to as 'frequency' only) (Koutsoyiannis, Kozonis and Manetas; 1998).

The typical IDF relationship for a specific return period is a special case of the generalized formula as given in equation [25] where ω,ν, θ and η are non-negative coefficients with $\nu\eta \leq 1$. This expression is an empirical formula that encapsulates the experience from several studies. A numerical study shows if assumed $\nu=1$, the corresponding error are much less than the typical estimation errors which results equation [26].

$$i = \frac{\omega}{\left(d^{\nu} + \theta\right)^{\eta}} \qquad [25]$$

$$i = \frac{\omega}{(d + \theta)^{\eta}} \qquad [26]$$

For any two return periods T_1 and T_2 where $T_2<T_1$ yields the set of restriction in equation [26] which $\theta_1 = \theta_2 = \theta \geq 0$, $0 < \eta_1 = \eta_2 = \eta < 1$, and $\omega_1 > \omega_2 > 0$. With these restrictions, ω is considered as a (increasing) function of the return period *T*. This leads to a general IDF relationship shows in equation [27], which has the advantage of a separable functional dependence of *i* on *T* and *d*. The function of *b(d)* is $b(d) = (d + \theta)^{\eta}$ where θ and η is parameter to be estimated ($\theta>0$, $0<\eta<1$).

$$i = \frac{a(T)}{b(d)} \qquad [27]$$

The function of *a(T)*; however, completely could be determined from the probability distribution function of the maximum rainfall intensities *I(d)*. Therefore, if the intensity *I(d)* of a certain duration *d* has a particular distribution $F_{I(d)}(i;d)$, yields the distribution of variable $X \approx I(d)b(d)$, which is no more than the intensity rescaled by *b(d)*. Mathematically, this can be expressed by $F_{I(d)}(I;d) = F_X(x_T) = 1 - 1/T$ (non-exceedance probability), which can be shown in the form of equation [28]; therefore proved that *a(T)* can completely be determined from the distribution function of maximum intensity.

$$X_T \equiv a(T) = F_Y^{-1}\left(1 - 1/T\right) \qquad [28]$$

The distribution function of the proposed GEV, the Gumbel and the GPA distribution respectively can be written in the form of equation [29], [30] and [31] where κ>0, α>0, and ξ are shape, scale and location parameters respectively. Subsequently, X_T for the GEV, the Gumbel and the GPA distribution can be directly obtained from equation [29], [30] and [31], which in turns into equation [32], [33] and [34] respectively. Finally, general formula for *idf* relationship is shown in equation [27] can be written in specific form of the GEV, the Gumbel and the GPA distribution respectively in the form of equation [35], [36] and [37].

$$F(x) = \exp\left\{-\left[1 + \kappa\left(\frac{x}{\alpha} - \xi\right)\right]^{-1/\kappa}\right\} \qquad [29]$$

$$F(x) = \exp\left\{-\exp\left(-x/\alpha + \xi\right)\right\} \qquad [30]$$

$$F(x) = 1 - \left[1 + \kappa\left(\frac{x}{\alpha} - \xi\right)\right]^{-1/\kappa} \qquad [31]$$

$$X_T \equiv a(T) = \alpha\left\{\xi + \frac{\left[-\ln\left(1 - 1/T\right)\right]^{-\kappa} - 1}{\kappa}\right\} \qquad [32]$$

$$X_T \equiv a(T) = \alpha\left\{\xi - \ln\left[-\ln\left(1 - 1/T\right)\right]\right\} \qquad [33]$$

$$X_T \equiv a(T) = \alpha\left[\xi + \frac{T^{\kappa} - 1}{\kappa}\right] \qquad [34]$$

$$i = \frac{\alpha\left\{\xi + \frac{\left[-\ln\left(1 - \frac{1}{T}\right)\right]^{-\kappa}}{\kappa}\right\}}{(d+\theta)^{\eta}} \qquad [35]$$

$$i = \frac{\alpha\{\xi - \ln[-\ln(1 - 1/T)]\}}{(d+\theta)^{\eta}} \qquad [36]$$

$$i = \frac{\alpha\left[\xi + \frac{T^{k} - 1}{\kappa}\right]}{(d+\theta)^{\eta}} \qquad [37]$$

For the case of the GEV, the Gumbel and the GPA distribution, the parameters of the function of *a(T)* (i.e. κ, α and ξ) and *b(d)* (i.e θ and η) could be separately determined either function a(T) or b(d), or simultaneously solving for function *a(T)* and *b(d)* .

The function of *a(T*), however, as for simplicity used, can be expressed in Bernard equation (1932) in the form of:

$$a(T) = \lambda T^{k} \qquad [38]$$

and finally equation [37](13) can be transformed in general term as follow:

$$i = \frac{\lambda T^{k}}{(d+\theta)^{\eta}} \qquad [39]$$

Equation [39] has been used to formulate the gauged IDF relationship and the derived parameters of λ, κ, θ and η has been generalized for the construction of ungauged IDF relationship. As for the MSMA polynomial equation, it has been reviewed and updated using new quantile estimation derivations.

3.6.2 One-Step Least Square Method of the IDF Relationships

For solving equation [39], one-step least square method is chosen due to its ability solving function $a(T)$, and $b(d)$ simultaneously. To this aim, an empirical return period can be assigned using the Gringorten plotting formula $T_{jl} = \frac{n_j + 0.12}{l - 0.44}$ to each data value i_{jl} (j refer to a particular duration d, $j = 1,....k$; l denoting the rank, $l = 1,.....n_j$ where n_j is the length of the group j). Each data will have a triplet of numbers $\left(i_{lj}, T_{ij}, d_j\right)$ and resulted in the intensity model as $\hat{i}_{jl} = \frac{a\left(T_{jl}\right)}{b\left(d_j\right)}$. The corresponding error could be measured as $e_{jl} = \ln i_{jl} - \ln \hat{i}_{jl} = \ln\left(i_{jl} \big/ \hat{i}_{jl} \right)$. The overall mean square error is $e^2 = \frac{1}{k} \sum_{j=1}^{k} \frac{1}{n_j} \sum_{l=1}^{n} e_{jl}^2$ which leads into an optimization procedure defined as $e = f_2(\eta, \theta, \lambda, \kappa)$. Simultaneous solution to perform the optimization as defined can be executed using the embedded solver tools of common spreadsheet package.

4 ASSESSMENT OF THE PROPOSED METHODOLOGY

4.1 Assessment Procedure

Assessment procedure of the proposed methodology has been conducted as per Figure 4.1. The objectives of this procedure are:

1. Data mining and assembly which are among others to identify and investigate suspicious annual maximum series (AM) or partial duration series (PD) of rainfall data; identification data independency for PD/POT data series in order to avoid any overlapping each of maxima data; and to ensure clean data set (quantity and quality) for the AM and PD/POT model analysis;
3. To determine the best type of data series that can be used in analysis. Two models are identified as Annual Maximum model (AM) and Partial Duration series/Peaks over Threshold model (PD/POT);
4. To identify the most appropriate parent distribution that can be used in analysis of AM series or PD/POT data series;
5. To determine the best method of parameter estimator between the Method of Moment (MOM) and L-Moments (LMOM) approach;
6. To determine the best fit or appropriate distribution-estimates (D/E) model; which can be carried out by robustness study in which includes determination of good performance (bias) and accuracy of estimation (rmse) of the model;
7. To estimate the magnitude of design rainstorm in corresponds with return period (low and high) which includes developing design raindepth-duration and rainfall intensity-duration relationship;
8. To construct and formulate the Intensity-Duration-Frequency relationship for gauged sites.

In order to perform assessment of the proposed methodology, annual maximum data series (AM) and partial duration data series are collected from eight (8) selected rainfall stations as listed below:

1. Site 2033001 at Pekan Nenas, Johor;
2. Site 3428081 at Temerloh, Pahang;
3. Site 3613004 at Ibu Bekalan Sg Bernam, Selangor;
4. Site 5005003 at Bagan Serai, Perak;
5. Site 5328044 at Sungai Tong, Terengganu;
6. Site 6019004 at Kastam Rantau Panjang, Kelantan;
7. Site 6103047 at Hospital Alor Setar, Kedah; and
8. Site 6401002 at Padang Katong, Perlis

4.2 Choice of Rainfall Frequency Model

There are two choices for the rainfall frequency model; Annual Maximum Series (AM) model and the Partial Duration Series/Peak Over Threshold (PD/POT) model. One-hour duration historical data records have been extracted from eight (8) rainfall stations as listed above. All selected rainfall stations has been assumed to have similar statistical characteristics and has been tested using the models proposed.

For the record, PD/POT model was tested for high and low return period while AM model was only tested for high return period. Quantile estimates of low return period calculates for T= 0.5, 1, 3 and 6-months meanwhile high return period refers to T= 2, 5, 10, 20, 25, 50 and 100 years. Comparatively, the PD/POT model has advantage against the AM model as the later could not derived quantile estimates for low return period.

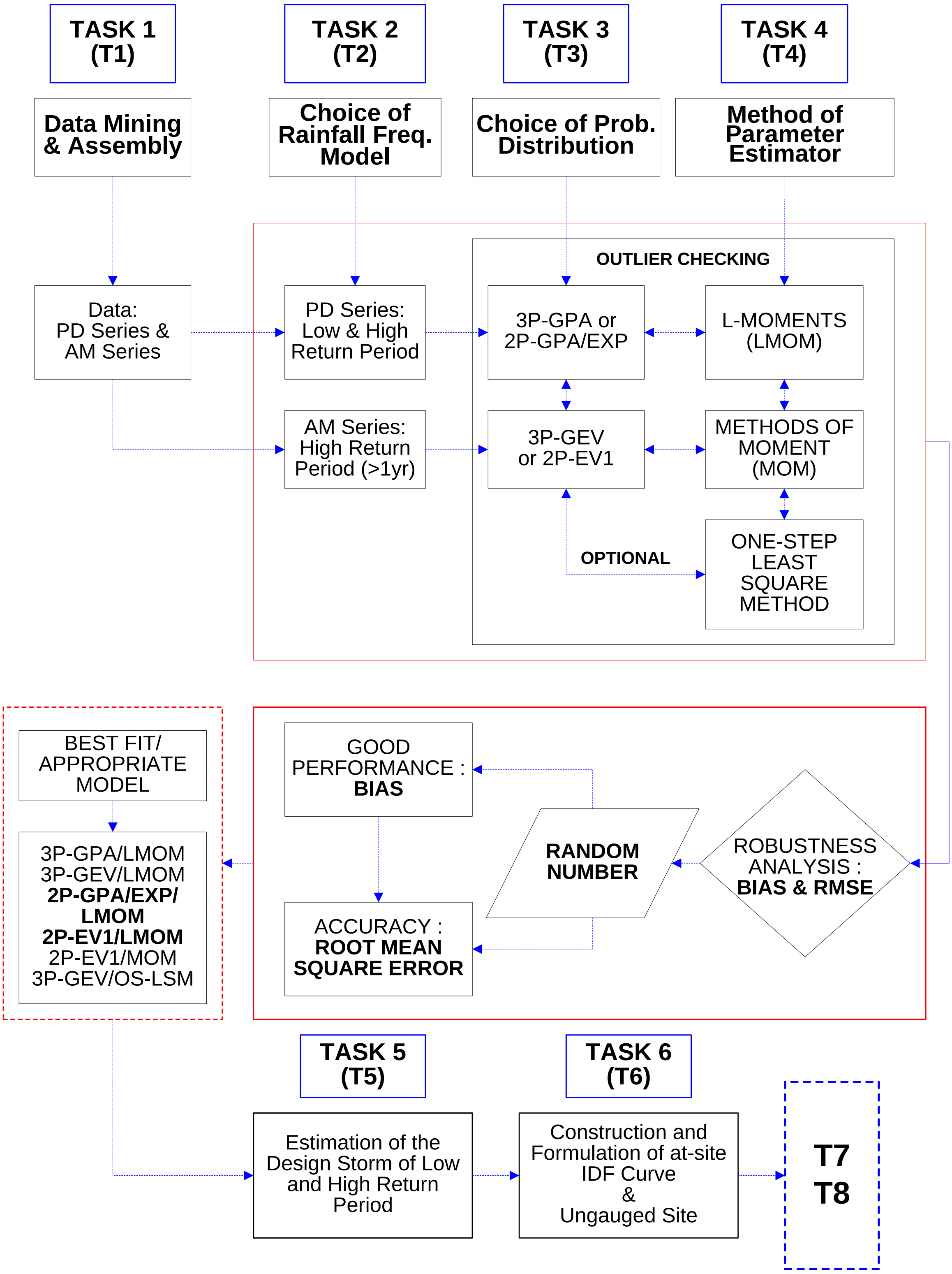
Comparatively, this analysis yields quantiles estimation of the PD/POT constantly greater than the AM model. In addition, the analysis using the PD/POT model subsequently produced the quantile estimation of low return period with respect to T=0.5, 1, 3 and 6-months, which definitely could not derived from the AM model. Therefore, based on this findings, the PD/POT model quite certain can be the most appropriate rainfall model, which it has capability and ability to derive the quantiles estimation of low and high return period simultaneously.

4.3 Robustness Study and Efficiency Procedure

Objective quantile estimation is based on methods developed for use with random samples from stationary populations. Such random samples have the characteristics that different samples, when treated in the same way, generally yield numerically different values of quantile estimates.

A procedure for estimating R_T is robust if it yields estimates of R_T which are good estimations (low bias, high efficiency) even if the procedure is based on an assumptions which is not true. A procedure is not robust if it yields poor estimates of R_T when the procedure's assumption departs even slightly from what is true.

Figure 4:1: Flow Chart in Assessment Procedure of the Proposed Methodology



Since we do not know how the distribution of AM series or PD series behaves naturally, we have to seek out and find a distribution and an estimation procedure which are robust and able to be used with distributions that gives random samples of a storm-like behaviour. It should be emphasized that split samples test based on historical rainstorm records are inadequate for testing the robustness of any distribution and estimation (D/E) procedure (Cunnane, 1989).

A suitable method of testing a D/E procedure involves simulating random samples from a parent distribution in which the *R-T* relationships is exactly known (Hosking et. al., 1985a). To be authentic, in this context, the parent distribution must produce random samples which are rainstorms-like in their behaviour. Such a parent distribution would be a GEV and EV1 of the AM model and a GPA and EXP of the PDS/POT model. Then the D/E under test is applied to each sample and $\hat{R}_T$ is obtained from each sample for a selection of *T* values. This is repeated for M samples (M large) and the equations [40] to [44] are used to calculate bias and rmse from the M values of $\hat{R}_T$:

$$mean = \hat{R}_T = \sum_{i=1}^{M} \frac{\left(\hat{R}_T\right)}{M} \qquad [40]$$

$$St.Dev = S\hat{R}_T = \left[\frac{\sum \left[\left(\hat{R}_T\right)_i - \bar{\hat{R}}_T \right]^2}{M} \right]^{1/2} \qquad [41]$$

$$Bias = b_T = \hat{R}_T - R_T \qquad [43]$$

$$RMSE = r_T = \left[\frac{\sum \left[\left(\hat{R}_T\right)_i - R_T \right]^2}{M} \right]^{1/2} \qquad [44]$$

In these expressions $\hat{R}_T$ is known population value. The sampling distribution of $\hat{R}_T$ is also examined and frequently this can be approximated by a Normal distribution so that 5% and 95% quantiles of the sampling distribution, denoted lower and upper confidence levels, LCL and UCL, can be obtained as:

$$LCL = \overline{\hat{R}_T} - 1.645 S\hat{R}_T \quad [46]$$

$$UCL = \overline{\hat{R}_T} + 1.645 S\hat{R}_T \quad [47]$$

All these quantiles can be made dimensionless by division of population value R_T . This practice is usually done to enable inter-comparison of D/E procedures. Based on the procedures mentioned, the D/E was tested by means of the following combinations (1) 3P-GPA/LMOM, (2) 3P-GEV/LMOM, (3) 2P-GPA/EXP/LMOM; (4) 2P-EV1/LMOM, and (5) 2p-EV1/MOM. The D/E technique as explained above is referred to as predictive ability procedure, but it is also guided with descriptive ability which is based on visual inspection of the probability plot of *R*-*T* relationship.

4.4 Results of the Assessment for the Choice of Rainfall Model, Parent Distribution and Parameter Estimation

The AM and PD/POT model has been tested for determining quantile estimation at high return period (*T*) which are corresponding with *T*=2, 5, 10, 20, 25, 50 and 100 years. Meanwhile, the quantile estimation of PD/POT model was tested for low return period (less than *T*=1 year) that corresponds with *T*=0.5, 1, 3, and 6-month return period. The assessment of PD/POT model was highly motivated due to insufficient at-site information in MSMA (2000) particularly for quantiles estimation of low return period.

The assessment have been carried out to obtain the most efficient model of the PD/POT model that represented by 3P-Generalized Pareto (GPA) and 2P-GPA/Exponential distribution (EXP) to the AM model of 3P-Generalized Extreme Value (GEV) and 2P-Extreme Value Type 1 (EV1/Gumbel) distribution.

Parameters of probable distribution of the proposed model were estimated by a robust approach of the *L*-Moment (LMOM) and conventional technique of the Method of Moments (MOM). The analysis results the following conclusions:

a. For less than 6-hr rainfall duration, the D/E test showed that the best options are represented by the 2P-EV1/LMOM and 2P-GPA-EXP/LMOM. However, for 6-hr rainfall duration and greater, the 3P-GPA/LMOM and 3P-GEV/LMOM is pretty well fitted particularly in Johor, Kelantan and Terengganu;

b. Robustness study shows the 2P-EV1/LMOM and 2P-GPA-EXP/LMOM produced small root mean square error (*rmse)*; however, the 2P-GPA-EXP/LMOM has been chosen due to the major advantage of this model which is its ability for determining quantile estimates at high and low return period;

c. Method of parameter estimation study showed that *L*-Moments was selected instead MOM where the former has advantages as follows; (1) the method was accepted worldwide; (2) flexible and easy to use with other types of distribution; and (3) recommended method for the regionalization approach as it will accommodate important tool in Task 8 (T8);

d. Hypothesis for determining *k*=0 or not when fitting with GEV has been carried out for the AM model of 3P-GEV/LMOM by means of comparing the statistic $Z = \kappa\sqrt{n/0.563}$) with standard normal quantiles level which is found that for all stations-duration shows not significantly large at 5% significant level. Hence the hypothesis that *k*=0 is not rejected;

e. This conclude that the 2P-EV1/LMOM distribution/estimation is accepted for representing the AM model of daily rainfall data series;

f. The 2P-GPA/EXP distribution is considered the best option for the PDS/POT model as 2P-EV1 and 2P-GPA/EXP is special case of the 3P-GEV and 3P-GPA distribution when the shape parameter *k*=0;

In summary, the quantile estimate of design rainstorm throughout Peninsular Malaysia was derived based on [1] 188 nos. of automatic rain gauged stations throughout Peninsular Malaysia analysed using PDS/POT model of 2P-GPA/EXP distribution; [2] 827 nos. of daily rain gauged stations in the entire of Peninsular Malaysia were modelled with the AM model of 2P-EV1/LMOM; and [3] 135 nos. of IDF curves have been produced for high and low return period. As for the location of automatic and daily raingauges station in Peninsular Malaysia, it can be seen at Figure 2.2 in Chapter 2.

5 DEVELOPING THE INTENSITY-DURATION FREQUENCY (IDF) RELATIONSHIP – GAUGED SITES

5.1 Choice of Mathematical Formulation for IDF Relationship

As explained in Chapter 3.6.1, the formulation of IDF relationship was constructed based on equation [39]. This equation has been formulated based on formula derived by Koutsoyiannis (1998) and Bernard (1932) as shown in equation [26] and [38] respectively.

General term of the IDF relationship or recognized as an empirical formula is finally in the form of $i = \frac{\lambda T^k}{(d+\theta)^\eta}$. The required IDF model parameters of λ, κ; θ and η were derived using simultaneous solution of the embedded MS Excel SOLVER by means of One-Step Least Square (OSLS) method.

As for accommodating the MSMA polynomial equation (2000) as stated in Table 13.A1 (Volume 4, Chapter13), new polynomial parameters of *a, b, c* and *d* were reviewed and updated using new quantile estimates derived. The new polynomial formula was derived particularly for accommodating longer time period for the duration of 15 to 4320-minutes (72-hrs) which is in contrast to the current MSMA polynomial formula that is valid only for the duration of 30 to 1000 minutes.

The formulated equations of empirical and polynomial formula has been established onto 135 nos. of selected rainfall gauging stations throughout Peninsular Malaysia and it has been applied to quantiles estimates of high (more than or equal to 2-year) and low (less than or equal to 1-year) return period.

5.2 Comparison of New Polynomial Equation and MSMA (2000)

For comparison purposes, Site 3117070 at DID Ampang is selected where the site IDF curve was regular and widely used for determining design rainstorm/intensity in Kuala Lumpur area. The polynomial parameters of *a, b, c* and *d* that derived from the recent exercise and based on current MSMA are summarized in Table 5.1 while Table 5.2 shows quantiles estimate from the two fitted equations. As was mentioned previously, the new formula has an advantage and ability to accommodate longer period of time; 15 to 4320 minutes. This makes its unnecessary to have additional tool for quantiles estimate for the duration of less than 30 minutes and beyond 1000 minutes. According to Table 5.2, significant different in the estimated design rainstorm can be seen. For instance, say quantile estimate for short duration of one-hour corresponding with 100-year ARI is found to be 114.2mm and 110.2mm which represents new fitted parameters and current parameters respectively or about 3.6% increase.

Table 5.1: Polynomial Equation Parameters of Site 3117070

Parameter	Value of derived parameters (new) associated with return period (ARI)					
	2	5	10	20	50	100
a	4.1889	4.3678	4.4705	4.5603	4.6658	4.7382
b	-0.7113	-0.7153	-0.7174	-0.7190	-0.7207	-0.7217
c	-0.0929	-0.0817	-0.0763	-0.0721	-0.0676	-0.0648
d	0.0165	0.0142	0.0131	0.0122	0.0113	0.0108
Parameter	Value of present parameters(MSMA, 2000) associated with return period (ARI)					
a	5.3255	5.1086	4.9696	4.9781	4.8047	5.0064
b	0.1806	0.5037	0.6796	0.7533	0.9399	0.8709
c	-0.1322	-0.2155	-0.2584	-0.2796	-0.3218	-0.3070
d	0.0047	0.0112	0.0147	0.0166	0.0197	0.0186

Table 5.2: Polynomial Equation Parameters of Site 3117070

Duration (hr.)	Quantiles estimate associated with new parameters (mm)					
	2	5	10	20	50	100
0.25	141.5	175.0	197.1	218.3	245.9	266.5
0.5	**102.7**	**123.9**	**137.9**	**151.4**	**168.9**	**182.0**
1	**65.9**	**78.9**	**87.4**	**95.6**	**106.3**	**114.2**
3	**27.6**	**33.2**	**36.9**	**40.4**	**45.0**	**48.5**
6	**15.0**	**18.3**	**20.4**	**22.4**	**25.1**	**27.1**
12	**8.2**	**10.0**	**11.2**	**12.4**	**13.9**	**15.0**
24	4.6	5.6	6.3	7.0	7.8	8.5
Duration (hr.)	Quantiles estimate associated with current parameters (mm) (MSMA, 2000)					
0.5	99.0	117.9	130.4	142.4	156.6	172.2
1	64.8	75.7	83.9	91.3	100.5	110.2
3	28.7	32.5	36.2	39.4	43.2	47.2
6	15.9	18.0	20.4	22.4	24.7	26.8
12	8.4	9.8	11.5	12.9	14.4	15.6

5.3 Comparison of New Polynomial and Empirical Equation

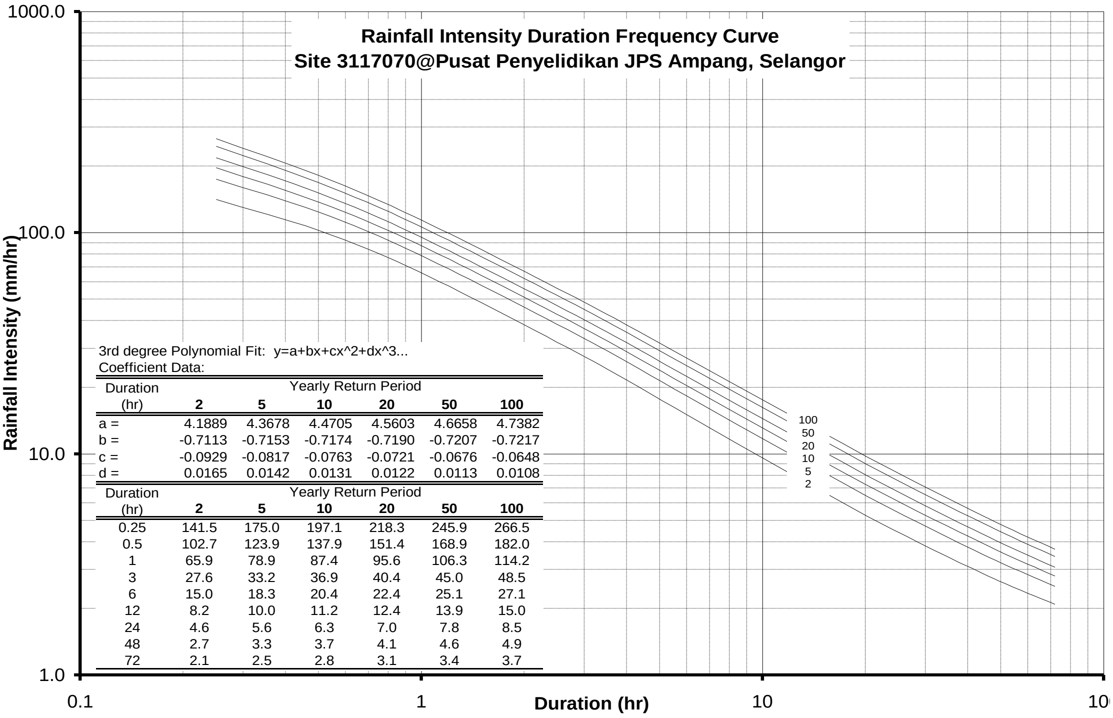
As for assessing the variation of quantiles estimates from the new fitted polynomial equation and new derived empirical equation, previous site which is Site 3117070 has been adopted.

Figure 5:1 and Figure 5:2 depicts the IDF curves that were fitted by means of polynomial and empirical equation respectively. Table 5.3 shows quantiles estimate of the former and latter, respectively.

Table 5.3: Design Rainfall Intensity for Site 3117070 at DID Ampang

Duration (hr.)	Quantiles estimate of rainfall intensity by Polynomial (mm)					
	2	5	10	20	50	100
0.25	141.5	175.0	197.1	218.3	245.9	266.5
0.5	102.7	123.9	137.9	151.4	168.9	182.0
1	65.9	78.9	87.4	95.6	106.3	114.2
3	27.6	33.2	36.9	40.4	45.0	48.5
6	15.0	18.3	20.4	22.4	25.1	27.1
12	8.2	10.0	11.2	12.4	13.9	15.0
24	4.6	5.6	6.3	7.0	7.8	8.5
48	2.7	3.3	3.7	4.1	4.6	4.9
72	2.1	2.5	2.8	3.1	3.4	3.7
Duration (hr.)	Quantiles estimate of rainfall intensity by Empirical (mm)					
0.25	155.1	177.7	196.9	218.2	249.9	276.9
0.5	103.8	118.9	131.8	146.0	167.2	185.3
1	64.6	74.0	82.0	90.8	104.1	115.3
3	27.9	31.9	35.4	39.2	44.9	49.7
6	15.9	18.2	20.2	22.4	25.7	28.4
12	9.0	10.3	11.4	12.7	14.5	16.1
24	5.1	5.8	6.4	7.1	8.2	9.0
48	2.8	3.3	3.6	4.0	4.6	5.1
72	2.0	2.3	2.6	2.9	3.3	3.6
Duration (hr)	Difference (%) of quantiles estimate					
0.25	9.61	1.55	-0.08	-0.06	1.65	3.91
0.5	1.08	-4.06	-4.48	-3.57	-0.98	1.84
1	-2.05	-6.20	-6.20	-4.99	-2.07	0.94
3	1.00	-3.84	-4.12	-3.10	-0.36	2.56
6	5.85	-0.18	-0.93	-0.22	2.21	4.96
12	10.26	3.10	1.91	2.30	4.45	7.03
24	11.02	3.51	2.17	2.45	4.47	6.97
48	4.85	-1.55	-2.49	-1.97	0.24	2.82
72	-2.81	-7.76	-8.18	-7.31	-4.82	-2.13

Figure 5:1: Site 3117070 IDF curve fitted by Polynomial Equation

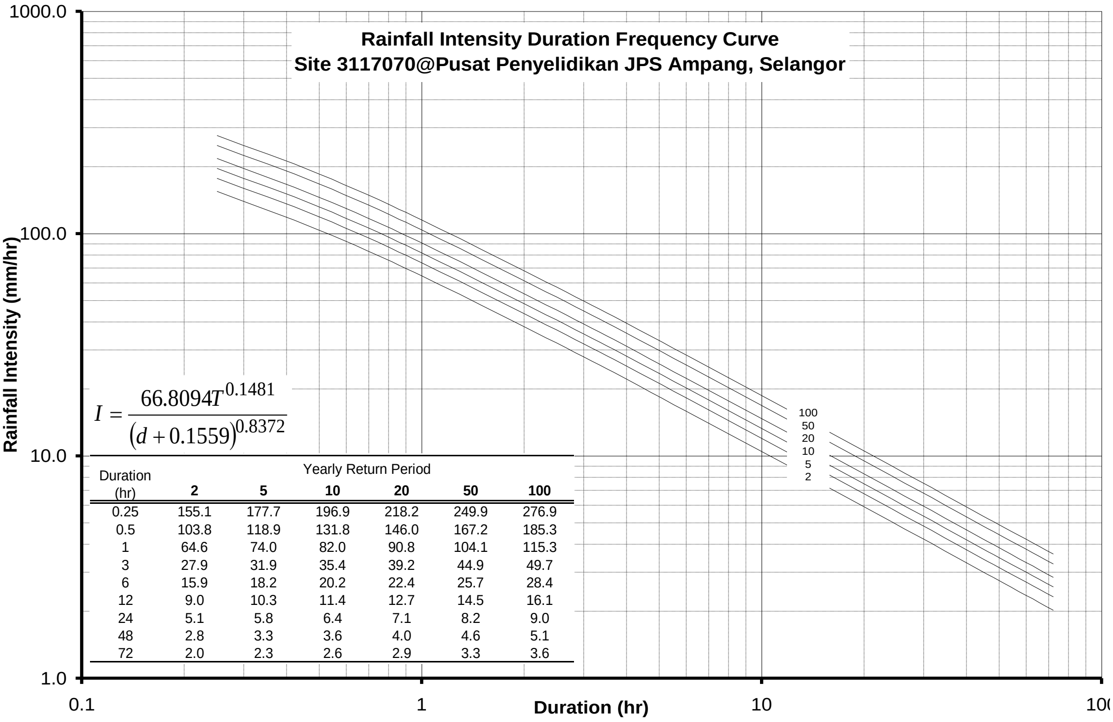


3rd degree Polynomial Fit: y=a+bx+cx^2+dx^3...
Coefficient Data:

Duration (hr)	Yearly Return Period 2	5	10	20	50	100
a =	4.1889	4.3678	4.4705	4.5603	4.6658	4.7382
b =	-0.7113	-0.7153	-0.7174	-0.7190	-0.7207	-0.7217
c =	-0.0929	-0.0817	-0.0763	-0.0721	-0.0676	-0.0648
d =	0.0165	0.0142	0.0131	0.0122	0.0113	0.0108

Duration (hr)	Yearly Return Period 2	5	10	20	50	100
0.25	141.5	175.0	197.1	218.3	245.9	266.5
0.5	102.7	123.9	137.9	151.4	168.9	182.0
1	65.9	78.9	87.4	95.6	106.3	114.2
3	27.6	33.2	36.9	40.4	45.0	48.5
6	15.0	18.3	20.4	22.4	25.1	27.1
12	8.2	10.0	11.2	12.4	13.9	15.0
24	4.6	5.6	6.3	7.0	7.8	8.5
48	2.7	3.3	3.7	4.1	4.6	4.9
72	2.1	2.5	2.8	3.1	3.4	3.7

Figure 5:2: Site 3117070 IDF curve fitted by Empirical Equation



$$I = \frac{66.8094T^{0.1481}}{(d + 0.1559)^{0.8372}}$$

Duration (hr)	Yearly Return Period 2	5	10	20	50	100
0.25	155.1	177.7	196.9	218.2	249.9	276.9
0.5	103.8	118.9	131.8	146.0	167.2	185.3
1	64.6	74.0	82.0	90.8	104.1	115.3
3	27.9	31.9	35.4	39.2	44.9	49.7
6	15.9	18.2	20.2	22.4	25.7	28.4
12	9.0	10.3	11.4	12.7	14.5	16.1
24	5.1	5.8	6.4	7.1	8.2	9.0
48	2.8	3.3	3.6	4.0	4.6	5.1
72	2.0	2.3	2.6	2.9	3.3	3.6

6 DEVELOPING THE INTENSITY-DURATION FREQUENCY (IDF) RELATIONSHIP – UNGAUGED SITES

6.1 Brief Description

As for determining quantiles estimation at ungauged sites from the current HP1 (1982), the so called Component II – Rainfall Depth-Duration Plotting Diagram and Component III – Rainfall Depth – Frequency Plotting Diagram has been used in association with the isopleths maps of 0.5hr, 3hr, 24hr and 72hr which is in correspond with 2 and 20 years return period.

The required quantiles estimation in correspond with return period acquires information to be retrieved from the isopleths map mentioned and it has to be transformed onto the rainfall depth–duration plotting diagram and rainfall depth–frequency (return period) plotting diagram. As shown in Appendix C of the HP1 (1982), the error of estimates contributed by this approach for 2 and 20 years return period are ranging from -30% to +18% and -58% and +53% respectively. Apparently, it clearly demonstrates that the worst performances are contributed at shorter duration of 0.25hr and higher return period while also demonstrating good performance for longer duration.

Large error of estimates could be contributed particularly from [1] the isopleths map developed using less and shorter rainfall data, and [2] flaws from the rainfall depth-duration and frequency plotting diagram developed.

As the analysis was performed and derived at 2 and 20 years return period, the required quantiles estimate particularly at higher return period which was produced by means of extrapolation, in turn could lead to larger error. Eventually, the method described only has the ability for determining quantiles estimate but it would not be able to establish the IDF curve and IDF relationship of ungauged sites required.

As to anticipate and minimize the error of estimates and its simplicity in developing the IDF curve and IDF relationship at ungauged sites, eventually the constructed IDF relationship of gauged sites can be extended in the formulation of ungauged IDF relationship. In turn, the component II and III of rainfall depth-duration and rainfall depth-frequency plotting diagrams were excluded in the analysis.

6.2 Mathematical Formulation for the IDF Relationship of Ungauged Sites

As described in Chapter 3.6.1 and it has also discussed in Chapter 1, the formulation of IDF curve and IDF relationship at ungauged site was extended from the rigorous general term of IDF relationship used for gauged site in the form of $i = \frac{\lambda T^{k}}{(d+\theta)^{\eta}}$. The four parameters or coefficients derived from gauged sites which are λ, κ, θ and η can be separately generalized in order to produce the isopleths map of each parameters. Advantages for using this approach are gained from [1] the ungauged parameters are directly transformed from gauged sites, [2] ungauged IDF relationship can directly be formulated at any point from the four parameters isopleths maps, [3] IDF curve can easily be generated at any point of interest, and [4] the required design rainstorm can easily be derived in correspond with any return period (low and high return period) and duration (15minutes to 72hrs)

6.3 Summary of Findings

The four parameters derived from 135 nos. of raingauge stations are tabulated in Table 6.1a-6.1d and Table 6.2a - 6.2d for the IDF relationship with corresponding to high return period and low return period respectively. The high and low return periods are associated with T=2, 5, 10, 20, 50, 100-years and T=1, 2, 3, 6 and 12-month respectively. Figure 11.1 to 11.4 in Appendix 1, depicts the generalized isopleths map of λ, κ, θ and η.

Table 6.1a: Derived IDF parameters of high ARI for Peninsular Malaysia

State	No.	Station ID	Station Name	Derived Parameters			
				λ	κ	θ	η
Perak	1	4010001	JPS Teluk Intan	54.017	0.198	0.084	0.790
	2	4207048	JPS Setiawan	56.121	0.174	0.211	0.854
	3	4311001	Pejabat Daerah Kampar	69.926	0.148	0.149	0.813
	4	4409091	Rumah Pam Kubang Haji	52.343	0.164	0.177	0.840
	5	4511111	Politeknik Ungku Umar	70.238	0.164	0.288	0.872
	6	4807016	Bukit Larut Taiping	87.236	0.165	0.258	0.842
	7	4811075	Rancangan Belia Perlop	58.234	0.198	0.247	0.856
	8	5005003	Jln. Mtg. Buloh Bgn Serai	52.752	0.163	0.179	0.795
	9	5207001	Kolam Air JKR Selama	59.567	0.176	0.062	0.807
	10	5210069	Stesen Pem. Hutan Lawin	52.803	0.169	0.219	0.838
	11	5411066	Kuala Kenderong	85.943	0.223	0.248	0.909
	12	5710061	Dispensari Keroh	53.116	0.168	0.112	0.820
Selangor	1	2815001	JPS Sungai Manggis	56.052	0.152	0.194	0.857
	2	2913001	Pusat Kwln. JPS T Gong	63.493	0.170	0.254	0.872
	3	2917001	Setor JPS Kajang	59.153	0.161	0.118	0.812
	4	3117070	JPS Ampang	65.809	0.148	0.156	0.837
	5	3118102	SK Sungai Lui	63.155	0.177	0.122	0.842
	6	3314001	Rumah Pam JPS P Setia	62.273	0.175	0.205	0.841
	7	3411017	Setor JPS Tj. Karang	68.290	0.175	0.243	0.894
	8	3416002	Kg Kalong Tengah	61.811	0.161	0.188	0.816
	9	3516022	Loji Air Kuala Kubu Baru	67.793	0.176	0.278	0.854
	10	3710006	Rmh Pam Bagan Terap	60.793	0.173	0.185	0.884
Pahang	1	2630001	Sungai Pukim	46.577	0.232	0.169	0.687
	2	2634193	Sungai Anak Endau	66.179	0.182	0.081	0.589
	3	2828173	Kg Gambir	47.701	0.182	0.096	0.715
	4	3026156	Pos Iskandar	47.452	0.184	0.071	0.780
	5	3121143	Simpang Pelangai	57.109	0.165	0.190	0.867
	6	3134165	Dispensari Nenasi	61.697	0.152	0.120	0.593
	7	3231163	Kg Unchang	55.568	0.179	0.096	0.649
	8	3424081	JPS Temerloh	73.141	0.173	0.577	0.896
	9	3533102	Rumah Pam Pahang Tua	58.483	0.212	0.197	0.586
	10	3628001	Pintu Kaw. Pulau Kertam	50.024	0.211	0.089	0.716
	11	3818054	Setor JPS Raub	53.115	0.168	0.191	0.833
	12	3924072	Rmh Pam Paya Kangsar	62.301	0.167	0.363	0.868
	13	3930012	Sungai Lembing PCC Mill	45.999	0.210	0.074	0.590
	14	4023001	Kg Sungai Yap	65.914	0.195	0.252	0.817
	15	4127001	Hulu Tekai Kwsn."B"	59.861	0.226	0.213	0.762
	16	4219001	Bukit Bentong	73.676	0.165	0.384	0.879
	17	4223115	Kg Merting	52.731	0.184	0.096	0.805
	18	4513033	Gunung Brinchang	42.004	0.164	0.046	0.802

Table 6.1b: Derived IDF parameters of high ARI for Peninsular Malaysia (cont'd)

State	No.	Station ID	Station Name	Derived Parameters			
				λ	κ	θ	η
Tereng-ganu	1	3933001	Hulu Jabor, Kemaman	103.519	0.228	0.756	0.707
	2	4131001	Kg, Ban Ho, Kemaman	65.158	0.164	0.092	0.660
	3	4234109	JPS Kemaman	55.899	0.201	0.000	0.580
	4	4332001	Jambatan Tebak, Kem.	61.703	0.185	0.088	0.637
	5	4529001	Rmh Pam Paya Kempian	53.693	0.194	0.000	0.607
	6	4631001	Almuktafibillah Shah	66.029	0.199	0.165	0.629
	7	4734079	SM Sultan Omar, Dungun	51.935	0.213	0.020	0.587
	8	4832077	SK Jerangau	54.947	0.212	0.026	0.555
	9	4930038	Kg Menerong, Hulu Trg	60.436	0.204	0.063	0.588
	10	5029034	Kg Dura. Hulu Trg	60.510	0.220	0.087	0.617
	11	5128001	Sungai Gawi, Hulu Trg	48.101	0.215	0.027	0.566
	12	5226001	Sg Petualang, Hulu Trg	48.527	0.228	0.000	0.547
	13	5328044	Sungai Tong, Setiu	52.377	0.188	0.003	0.558
	14	5331048	Setor JPS K Terengganu	58.307	0.210	0.123	0.555
	15	5426001	Kg Seladang, Hulu Setiu	57.695	0.197	0.000	0.544
	16	5428001	Kg Bt. Hampar, Setiu	55.452	0.186	0.000	0.545
	17	5524002	SK Panchor, Setiu	53.430	0.206	0.000	0.524
	18	5725006	Klinik Kg Raja, Besut	52.521	0.225	0.041	0.560
Kelantan	1	4614001	Brook	49.623	0.159	0.242	0.795
	2	4726001	Gunung Gagau	43.024	0.220	0.004	0.527
	3	4819027	Gua Musang	57.132	0.155	0.119	0.795
	4	4915001	Chabai	47.932	0.169	0.108	0.794
	5	4923001	Kg Aring	47.620	0.187	0.020	0.637
	6	5120025	Balai Polis Bertam	61.338	0.168	0.193	0.811
	7	5216001	Gob	41.783	0.175	0.122	0.720
	8	5320038	Dabong	51.442	0.189	0.077	0.710
	9	5322044	Kg Lalok	53.766	0.197	0.121	0.705
	10	5522047	JPS Kuala Krai	39.669	0.231	0.000	0.563
	11	5718033	Kg Jeli, Tanah Merah	72.173	0.196	0.360	0.703
	12	5719001	Kg Durian Daun Lawang	51.161	0.193	0.063	0.745
	13	5722057	JPS Machang	48.433	0.219	0.000	0.601
	14	5824079	Sg Rasau Pasir Putih	51.919	0.216	0.062	0.560
	15	6019004	Rumah Kastam R Pjg	49.315	0.228	0.000	0.609
	16	6122064	Setor JPS Kota Bharu	60.988	0.214	0.148	0.616
Negeri Sembilan	1	2719001	Setor JPS Sikamat	52.823	0.167	0.159	0.811
	2	2722202	Kg Sawah Lebar K Pilah	44.811	0.181	0.137	0.811
	3	2723002	Sungai Kepis	54.400	0.176	0.134	0.842
	4	2725083	Ladang New Rompin	57.616	0.191	0.224	0.817
	5	2920012	Petaling K Kelawang	50.749	0.173	0.235	0.854

Table 6.1c: Derived IDF parameters of high ARI for Peninsular Malaysia (cont'd)

State	No.	Station ID	Station Name	Derived Parameters			
				λ	κ	θ	η
Melaka	1	2222001	Bukit Sebukor	95.823	0.169	0.660	0.947
	2	2224038	Chin Chin Tepi Jalan	54.241	0.161	0.114	0.846
	3	2321006	Ladang Lendu	72.163	0.184	0.376	0.900
Pulau Pinang & Perlis	1	5204048	Sg Simpang Ampat	62.089	0.220	0.402	0.785
	2	5302001	Tangki Air Besar Sg Png	67.949	0.181	0.299	0.736
	3	5302003	Kolam Tkgn Air Hitam	52.459	0.191	0.106	0.729
	4	5303001	Rmh Kebajikan P Png	57.326	0.203	0.325	0.791
	5	5303053	Komplek Prai	52.771	0.203	0.095	0.717
	6	5402001	Klinik Bkt Bendera P Png	64.504	0.196	0.149	0.723
	7	5402002	Kolam Bersih P Pinang	53.785	0.181	0.125	0.706
	8	5404043	Ibu Bekalan Sg Kulim	57.832	0.188	0.245	0.751
	9	5504035	Lahar Ikan Mati K Batas	48.415	0.221	0.068	0.692
	10	6401002	Padang Katong, Kangar	57.645	0.179	0.254	0.826
Kedah	1	5507076	Bt. 27, Jalan Baling	52.398	0.172	0.104	0.788
	2	5704055	Kedah Peak	81.579	0.200	0.437	0.719
	3	5806066	Klinik Jeniang	59.786	0.165	0.203	0.791
	4	5808001	Bt. 61, Jalan Baling	47.496	0.183	0.079	0.752
	5	6103047	Setor JPS Alor Setar	64.832	0.168	0.346	0.800
	6	6108001	Komppleks Rumah Muda	52.341	0.173	0.120	0.792
	7	6206035	Kuala Nerang	54.849	0.174	0.250	0.810
	8	6207032	Ampang Padu	66.103	0.177	0.284	0.842
	9	6306031	Padang Sanai	60.331	0.193	0.249	0.829
Johor	1	1437116	Stor JPS Johor Baharu	59.972	0.163	0.121	0.793
	2	1534002	Pusat Kem. Pekan Nenas	54.265	0.179	0.100	0.756
	3	1541139	Johor Silica	59.060	0.202	0.128	0.660
	4	1636001	Balai Polis Kg Seelong	50.115	0.191	0.099	0.763
	5	1737001	SM Bukit Besar	50.554	0.193	0.117	0.722
	6	1829002	Setor JPS B Pahat	64.099	0.174	0.201	0.826
	7	1834124	Ladang Ulu Remis	55.864	0.166	0.174	0.810
	8	1839196	Simpang Masai K. Sedili	61.562	0.191	0.103	0.701
	9	1931003	Emp. Semberong	60.568	0.163	0.159	0.821
	10	2025001	Pintu Kaw. Tg. Agas	80.936	0.187	0.258	0.890
	11	2033001	JPS Kluang	54.428	0.192	0.108	0.740
	12	2231001	Ladang Chan Wing	57.188	0.186	0.093	0.777
	13	2232001	Ladang Kekayaan	53.457	0.180	0.094	0.735
	14	2235163	Ibu Bekalan Kahang	**52.177**	0.186	0.055	0.652
	15	2237164	Jalan Kluang-Mersing	56.966	0.190	0.144	0.637
	16	2330009	Ladang Labis	45.808	0.222	0.012	0.713
	17	2528012	Rmh. Tapis Segamat	45.212	0.224	0.039	0.711
	18	2534160	Kg Peta Hulu Sg Endau	59.500	0.185	0.129	0.623
	19	2636170	Setor JPS Endau	62.040	0.215	0.103	0.592

Table 6.1d: Derived IDF parameters of high ARI for Peninsular Malaysia (cont'd)

State	No.	Station ID	Station Name	Derived Parameters			
				λ	κ	θ	η
W. Persekutuan	1	3015001	Puchong Drop,K Lumpur	69.650	0.151	0.223	0.880
	2	3116003	Ibu Pejabat JPS	61.976	0.145	0.122	0.818
	3	3116004	Ibu Pejabat JPS1	64.689	0.149	0.174	0.837
	4	3116005	SK Taman Maluri	62.765	0.132	0.147	0.820
	5	3116006	Ladang Edinburgh	63.483	0.146	0.210	0.830
	6	3216001	Kg. Sungai Tua	64.203	0.152	0.250	0.844
	7	3216004	SK Jenis Keb. Kepong	73.602	0.164	0.330	0.874
	8	3217001	Ibu Bek. KM16, Gombak	66.328	0.144	0.230	0.859
	9	3217002	Emp. Genting Kelang	70.200	0.165	0.290	0.854
	10	3217003	Ibu Bek. KM11, Gombak	62.609	0.152	0.221	0.804
	11	3217004	Kg. Kuala Seleh, H. Klg	61.516	0.139	0.183	0.837
	12	3217005	Kg. Kerdas, Gombak	63.241	0.162	0.137	0.856
	13	3317001	Air Terjun Sg. Batu	72.992	0.162	0.171	0.871
	14	3317004	Genting Sempah	61.335	0.157	0.292	0.868

Table 6.2a: Derived IDF parameters of low ARI for Peninsular Malaysia

State	No.	Station ID	Station Name	Derived Parameters			
				λ	κ	θ	η
Perak	1	4010001	JPS Teluk Intan	65.185	0.368	0.255	0.846
	2	4207048	JPS Setiawan	56.270	0.343	0.206	0.847
	3	4311001	Pejabat Daerah Kampar	79.271	0.183	0.305	0.853
	4	4409091	Rumah Pam Kubang Haji	47.832	0.353	0.104	0.802
	5	4511111	Politeknik Ungku Umar	62.932	0.344	0.170	0.823
	6	4807016	Bukit Larut Taiping	83.396	0.319	0.177	0.817
	7	4811075	Rancangan Belia Perlop	57.491	0.320	0.203	0.870
	8	5005003	Jln. Mtg. Buloh Bgn Serai	63.236	0.318	0.333	0.846
	9	5207001	Kolam Air JKR Selama	67.050	0.316	0.226	0.808
	10	5210069	Stesen Pem. Hutan Lawin	53.731	0.337	0.224	0.835
	11	5411066	Kuala Kenderong	68.536	0.420	0.156	0.838
	12	5710061	Dispensari Keroh	59.220	0.327	0.162	0.852
Selangor	1	2815001	JPS Sungai Manggis	57.350	0.276	0.169	0.867
	2	2913001	Pusat Kwln. JPS T Gong	65.356	0.328	0.345	0.863
	3	2917001	Setor JPS Kajang	62.956	0.329	0.130	0.827
	4	3117070	JPS Ampang	69.173	0.249	0.192	0.837
	5	3118102	SK Sungai Lui	68.459	0.304	0.204	0.873
	6	3314001	Rumah Pam JPS P Setia	65.186	0.282	0.218	0.870
	7	3411017	Setor JPS Tj. Karang	70.991	0.300	0.293	0.906
	8	3416002	Kg Kalong Tengah	59.975	0.244	0.164	0.807
	9	3516022	Loji Air Kuala Kubu Baru	66.888	0.280	0.349	0.833
	10	3710006	Rmh Pam Bagan Terap	62.264	0.317	0.280	0.867

Table 6.2b: Derived IDF parameters of low ARI for Peninsular Malaysia

State	No.	Station ID	Station Name	Derived Parameters			
				λ	κ	θ	η
Pahang	1	2630001	Sungai Pukim	63.978	0.391	0.256	0.872
	2	2634193	Sungai Anak Endau	79.431	0.364	0.143	0.705
	3	2828173	Kg Gambir	61.193	0.386	0.188	0.824
	4	3026156	Pos Iskandar	59.990	0.349	0.226	0.877
	5	3121143	Simpang Pelangai	64.965	0.323	0.300	0.900
	6	3134165	Dispensari Nenasi	88.648	0.383	0.404	0.761
	7	3231163	Kg Unchang	71.647	0.352	0.181	0.789
	8	3424081	JPS Temerloh	62.208	0.353	0.351	0.837
	9	3533102	Rumah Pam Pahang Tua	80.889	0.361	0.480	0.758
	10	3628001	Pintu Kaw. Pulau Kertam	63.507	0.383	0.288	0.820
	11	3818054	Setor JPS Raub	61.343	0.369	0.393	0.845
	12	3924072	Rmh Pam Paya Kangsar	58.376	0.333	0.242	0.843
	13	3930012	Sungai Lembing PCC Mill	77.000	0.453	0.570	0.813
	14	4023001	Kg Sungai Yap	77.149	0.373	0.344	0.881
	15	4127001	Hulu Tekai Kwsn."B"	60.224	0.465	0.124	0.802
	16	4219001	Bukit Bentong	67.613	0.271	0.246	0.866
	17	4223115	Kg Merting	62.751	0.284	0.363	0.902
	18	4513033	Gunung Brinchang	42.176	0.283	0.147	0.785
Terengganu	1	3933001	Hulu Jabor, Kemaman	74.805	0.217	0.253	0.728
	2	4131001	Kg, Ban Ho, Kemaman	68.666	0.316	0.116	0.697
	3	4234109	JPS Kemaman	75.826	0.239	0.381	0.730
	4	4332001	Jambatan Tebak, Kem.	77.283	0.346	0.304	0.730
	5	4529001	Rmh Pam Paya Kempian	65.279	0.364	0.148	0.667
	6	4631001	Almuktafibillah Shah	81.886	0.340	0.260	0.746
	7	4734079	SM Sultan Omar, Dungun	66.426	0.329	0.215	0.702
	8	4832077	SK Jerangau	81.498	0.374	0.423	0.759
	9	4930038	Kg Menerong, Hulu Trg	80.965	0.378	0.256	0.716
	10	5029034	Kg Dura. Hulu Trg	62.786	0.350	0.110	0.664
	11	5128001	Sungai Gawi, Hulu Trg	59.306	0.400	0.131	0.680
	12	5226001	Sg Petualang, Hulu Trg	51.786	0.297	0.070	0.659
	13	5328044	Sungai Tong, Setiu	63.414	0.386	0.100	0.654
	14	5331048	Setor JPS K Terengganu	67.027	0.284	0.263	0.669
	15	5426001	Kg Seladang, Hulu Setiu	76.909	0.451	0.164	0.683
	16	5428001	Kg Bt. Hampar, Setiu	57.946	0.249	0.038	0.600
	17	5524002	SK Panchor, Setiu	75.149	0.415	0.258	0.676

Table 6.2c: Derived IDF parameters of low ARI for Peninsular Malaysia (cont'd)

State	No.	Station ID	Station Name	Derived Parameters			
				λ	κ	θ	η
Kelantan	1	4614001	Brook	49.731	0.316	0.198	0.792
	2	4915001	Chabai	56.296	0.299	0.197	0.838
	3	4923001	Kg Aring	70.265	0.381	0.242	0.819
	4	5120025	Balai Polis Bertam	67.720	0.327	0.243	0.842
	5	5216001	Gob	47.465	0.283	0.153	0.785
	6	5320038	Dabong	67.791	0.378	0.274	0.812
	7	5322044	Kg Lalok	67.766	0.329	0.237	0.819
	8	5522047	JPS Kuala Krai	63.069	0.468	0.310	0.783
	9	5718033	Kg Jeli, Tanah Merah	73.814	0.388	0.116	0.760
	10	5719001	Kg Durian Daun Lawang	67.240	0.365	0.182	0.753
	11	5722057	JPS Machang	57.376	0.344	0.174	0.709
	12	5824079	Sg Rasau Pasir Putih	68.508	0.408	0.202	0.700
	13	6019004	Rumah Kastam R Pjg	65.365	0.443	0.158	0.753
Negeri Sembilan	1	2719001	Setor JPS Sikamat	60.423	0.279	0.269	0.854
	2	2722202	Kg Sawah Lebar K Pilah	49.323	0.272	0.216	0.850
	3	2723002	Sungai Kepis	61.334	0.254	0.329	0.872
	4	2725083	Ladang New Rompin	65.025	0.358	0.355	0.875
	5	2920012	Petaling K Kelawang	51.734	0.292	0.264	0.863
Melaka	1	2222001	Bukit Sebukor	78.148	0.269	0.368	0.897
	2	2224038	Chin Chin Tepi Jalan	66.059	0.336	0.330	0.891
	3	2321006	Ladang Lendu	64.759	0.298	0.290	0.879
Pulau Pinang & Perlis	1	5204048	Sg Simpang Ampat	59.312	0.339	0.335	0.809
	2	5302001	Tangki Air Besar Sg Png	71.748	0.293	0.293	0.778
	3	5302003	Kolam Tkgn Air Hitam	56.115	0.298	0.178	0.763
	4	5303001	Rmh Kebajikan P Png	60.108	0.358	0.275	0.830
	5	5303053	Kompleks Prai P Pinang	49.486	0.331	0.052	0.712
	6	5402001	Klinik Bkt Bendera P Png	68.100	0.311	0.190	0.766
	7	5402002	Kolam Bersih P Pinang	62.753	0.269	0.249	0.776
	8	5504035	Lahar Ikan Mati K Batas	60.860	0.337	0.232	0.798
	9	6401002	Padang Katong, Kangar	52.151	0.357	0.158	0.786
Kedah	1	5507076	Bt. 27, Jalan Baling	62.761	0.258	0.304	0.835
	2	5704055	Kedah Peak	58.596	0.339	0.064	0.661
	3	5806066	Klinik Jeniang	67.120	0.382	0.238	0.823
	4	5808001	Bt. 61, Jalan Baling	56.399	0.388	0.252	0.803
	5	6103047	Setor JPS Alor Setar	67.641	0.334	0.274	0.828
	6	6108001	Komppleks Rumah Muda	58.404	0.278	0.234	0.829
	7	6206035	Kuala Nerang	62.960	0.308	0.359	0.859
	8	6207032	Ampang Padu	70.997	0.293	0.382	0.863
	9	6306031	Padang Sanai	63.615	0.313	0.309	0.852

Table 6.2d: Derived IDF parameters of low ARI for Peninsular Malaysia (cont'd)

State	No.	Station ID	Station Name	Derived Parameters			
				λ	κ	θ	η
Pulau Pinang & Perlis	1	5204048	Sg Simpang Ampat	59.312	0.339	0.335	0.809
	2	5302001	Tangki Air Besar Sg Png	71.748	0.293	0.293	0.778
	3	5302003	Kolam Tkgn Air Hitam	56.115	0.298	0.178	0.763
	4	5303001	Rmh Kebajikan P Png	60.108	0.358	0.275	0.830
	5	5303053	Kompleks Prai P Pinang	49.486	0.331	0.052	0.712
	6	5402001	Klinik Bkt Bendera P Png	68.100	0.311	0.190	0.766
	7	5402002	Kolam Bersih P Pinang	62.753	0.269	0.249	0.776
	8	5504035	Lahar Ikan Mati K Batas	60.860	0.337	0.232	0.798
	9	6401002	Padang Katong, Kangar	52.151	0.357	0.158	0.786
Johor	1	1437116	Stor JPS Johor Baharu	73.679	0.277	0.293	0.862
	2	1534002	Pusat Kem. Pekan Nenas	62.651	0.323	0.156	0.821
	3	1541139	Johor Silica	79.536	0.336	0.295	0.810
	4	1636001	Balai Polis Kg Seelong	61.212	0.337	0.238	0.843
	5	1737001	SM Bukit Besar	61.351	0.303	0.203	0.824
	6	1829002	Setor Daerah JPS B Pahat	62.158	0.306	0.142	0.825
	7	1834124	Ladang Ulu Remis	59.171	0.294	0.185	0.838
	8	1839196	Simpang Masai K. Sedili	71.795	0.268	0.186	0.807
	9	1931003	Emp. Semberong	66.885	0.355	0.211	0.838
	10	2025001	Pintu Kaw. Tg. Agas	77.772	0.310	0.281	0.879
	11	2033001	JPS Kluang	-	-	-	-
	12	2231001	Ladang Chan Wing	66.144	0.324	0.178	0.849
	13	2232001	Ladang Kekayaan	66.754	0.308	0.227	0.838
	14	2235163	Ibu Bekalan Kahang	62.339	0.279	0.163	0.739
	15	2237164	Jalan Kluang-Mersing	73.236	0.343	0.220	0.773
	16	2330009	Ladang Labis	65.222	0.395	0.235	0.846
	17	2528012	Rmh. Tapis Segamat	63.689	0.382	0.259	0.871
	18	2534160	Kg Peta Hulu Sg Endau	69.958	0.350	0.181	0.706
	19	2636170	Setor JPS Endau	77.630	0.399	0.250	0.693
W. Persekutuan	1	3015001	Puchong Drop,K Lumpur	68.587	0.352	0.170	0.849
	2	3116004	Ibu Pejabat JPS	65.992	0.286	0.160	0.834
	3	3116005	SK Taman Maluri	74.451	0.266	0.312	0.861
	4	3116006	Ladang Edinburgh	64.503	0.275	0.181	0.833
	5	3216001	Kg. Sungai Tua	62.940	0.258	0.199	0.837
	6	3216004	SK Jenis Keb. Kepong	69.788	0.296	0.167	0.851
	7	3217001	Ibu Bek. KM16, Gombak	66.069	0.257	0.229	0.840
	8	3217002	Emp. Genting Kelang	66.258	0.262	0.242	0.845
	9	3217003	Ibu Bek. KM11, Gombak	73.954	0.298	0.324	0.824
	10	3217004	Kg. Kuala Seleh, H. Klg	64.318	0.234	0.182	0.865
	11	3217005	Kg. Kerdas, Gombak	68.853	0.298	0.202	0.882
	12	3317001	Air Terjun Sg. Batu	75.935	0.248	0.266	0.867
	13	3317004	Genting Sempah	55.393	0.282	0.184	0.835

7 DEVELOPING THE REGION OF TEMPORAL STORM PROFILES BY MEANS OF CLUSTERING ANALYSIS

7.1 Introduction

Cluster analysis is a multivariate analysis technique or procedure in order to organize information of variables to form relatively homogeneous groups, or “cluster”. There are several types of cluster analysis such as K-Means Cluster Analysis and Hierarchical Cluster Analysis.

In this study, regions were formed by K-Means Cluster Analysis method to identify homogeneous groups of cases that based on selected of site characteristics by using an algorithm that can handle large numbers of cases. A data vector is associated with each site, and sites are partitioned into groups according to the similarity of their data vectors that can include at-site statistics, site characteristics or combination of two. But, in this clustering analysis, site characteristics only selected, and did not involve any at-site statistics measuring the shape of the frequency distribution of rainfall. When cluster analysis is based on site characteristics, the at-site statistics are available for use as the basis of an independent test of the homogeneity of the final regions.

Most clustering algorithms measure similarity by the reciprocal of Euclidean distance in a space of site characteristics. This distance measure is affected by the scale of measurement or rescale of the site characteristics in order to have same amount of variability, as measured by their range or standard deviation across all of the sites in the data set. In determining clusters, it may not be appropriate when the rescaling gives equal weight to each site characteristics that have greater influence on the form of the frequency distribution and it should be given greater weight in the clustering. There is no assumption that there are distinct clusters of sites that satisfy the homogeneity condition and no ‘correct’ number of clusters, instead a balance must be sought between using regions that are too small or too large. The output from the cluster analysis need not be final because some subjective adjustment can be done in order to improve the physical coherence of the regions and to reduce the heterogeneity of the regions that measured by the heterogeneity test, H.

The clustering analysis is aimed to form relatively homogenous ‘groups’ or ‘regions’ that are able to accommodate and creates new regions for the storm profiles or storm temporal pattern as in existence HP1 (1982) divided into the region of East Coast and West Coast.

7.2 Data Availability and Acquisition

The numerical analysis was performed using 1-day duration rainfall of 56 selected automatic recording rainfall stations maintained by DID. Pertinent details on the rainfall station ID and length of records for each 56 automatic rainfall stations throughout Peninsular Malaysia is tabulated in Table 7.1. While in the environmental application study, five variables of site characteristics were chosen such as latitude, longitude, elevation, mean annual rainfall and the ratio of the minimum average two-month rainfall to maximum average two-month rainfall. The available data for the site characteristics that used for clustering analysis is tabulated in Table 7.2.

7.3 Data Screening

Data screening represents an important step in all statistical computations. The first important step of any statistical data analysis is to check that the data are appropriate for the analysis. Before carrying out the frequency analysis, the data integrity check was carried out where there should not be too long gaps in the data records in each year.

In this study, we stated that more than 10% yearly gaps are discarded from the analysis. Perhaps, a check of each site's data separately is needed in order to identify outlying values and repeated value, which may be due to error of recording data.

7.4 Formation of Region by Clustering Analysis

Identifying clusters in a space of site characteristics formed regions. At-site statistics are used to assess the homogeneity of the regions that are formed in the clustering procedure, and the validity of this assessment is compromised if the same data are used both to form regions and to test their homogeneity.

In this study, five variables of site characteristics were chosen such as site latitude, site longitude, site elevation, mean annual rainfall and the ratio of the minimum average two-month rainfall to maximum average two-month rainfall. The variables need to be transformed in order to get comparable ranges because the standard methods of cluster analysis are very sensitive to such scale differences. All the variables were rescaled so that their values lay between 0 and 1. Table 7.3 shows the transformations from the five site characteristics to the variables used in cluster analysis. For this study, some combinations of this site characteristics or variables as shown in Table 7.4 would be done in order to see the impact through the result of clustering process.

Table 7.1: Summary of selected 56 automatic rainfall stations for Peninsular Malaysia

No	Station ID	Station Name	Data Period		No. of Years	No	Station ID	Station Name	Data Period		No. of Years
			Record	Selected					Record	Selected	
1	6401002	Padang Katong at Kangar Perlis	741103-1010104	750101-1001231	25	15	4409091	Rumah Pam Kubang Haji, Perak	700627-1010414	710101-1001231	29
2	6402008	Ngolang at Perlis	830220-1010103	840101-1001231	16	16	4209093	JPS Telok Sena, Perak	700703-1010414	710101-1001231	29
3	6306031	Padang Sanai, Kedah	700701-1010107	710101-1001231	29	17	4010001	JPS Telok Intan, Perak	700701-1010417	710101-1001231	29
4	6207032	Ampang Pedu, Kedah	700629-1010107	710101-1001231	29	18	3516022	Logi Air Kuala Kubu Baru, Selangor	700629-1010102	710101-1001231	29
5	6206035	Kuala Nerang at Kedah	700627-1010107	710101-1001231	29	19	3416002	Kg. Kalong Tengah (AB), Selangor	780830-1010102	790101-1001231	21
6	6108001	Kompleks Rumah Muda, Kedah	741215-1010102	710101-1001231	29	20	3411017	Stor JPS Tanjung Karang, Selangor	700629-1010103	710101-1001231	29
7	5808001	Bt 61 Jalan Baling, Kedah	740929-1010103	750101-1001231	25	21	3317004	Genting Sempah, Wilayah Persekutuan	741001-1010116	750101-1001231	25
8	5704055	Kedah Peak, Kedah	750102-1010101	750101-1001231	25	22	3314001	Rumah Pam Paya Setia, Selangor	740102-1010103	740101-1001231	26
9	5504035	Lahar Ikan Mati at Pulau Pinang	700701-1010115	710101-1001231	29	23	3118102	Sek. Keb. Sg Lui at Selangor	700723-1010404	710101-1001231	29
10	5710061	Dispensari Kroh, Perak	400101-1010503	700101-1001231	30	24	2917001	Stor JPS Kajang, Selangor	750402-1010102	760101-1001231	24
11	5210069	Stesen Pemeriksaan Hutan Lawin, Perak	700629-1010619	710101-1001231	29	25	2723002	Sg Kepis at Masjid site 2, Negeri Sembilan	770529-1010605	780101-1001231	22
12	5005003	Jalan Matang Buloh Bagan Serai, Perak	740401-1010601	750101-1001231	25	26	2719001	Stor JPS Sikamat Seremban, Negeri Sembilan	700626-1010606	710101-1001231	29
13	4708084	Ibu Bekalan Talang, Kuala Kangsar, Perak	700704-1010619	710101-1001231	29	27	2321006	Ladang Lendu, Melaka	740511-1010507	750101-1001231	25
14	4511111	Politeknik Ungku Omar, Ipoh Perak	720501-1010418	730101-1001231	27	28	2224038	Chin Chin (Tepi Jalan), Melaka	700702-1010419	710101-1001231	29

Table 7.1: Summary of selected 56 automatic rainfall stations for Peninsular Malaysia (cont'd)

No	Station ID	Station Name	Data Period		No. of Years	No	Station ID	Station Name	Data Period		No. of Years
			Record	Selected					Record	Selected	
29	2330009	Ladang Sg. Labis at Labis, Johor	700629-1010101	710101-1001231	29	43	5331048	Stor JPS Kuala Terengganu	700629-1010528	710101-1001231	29
30	2033001	Stor Baru JPS Kluang, Johor	761205-1000703	770101-991231	22	44	5029034	Kg Dura Terengganu	710704-1010528	720101-1001231	28
31	2025001	Pintu Kawalan Tg. Agas, Muar Johor	740810-1010101	750101-1001231	25	45	4930038	Kg menerong Terengganu	710811-1010527	700101-1001231	30
32	1839196	Simpang Mawai, Kuala Sedeli, Johor	700630-1010102	710101-1001231	29	46	4929001	Kg Embong Sekayu Ulu Terengganu	750411-1010526	760101-1001231	24
33	1737001	Sek. Men. Bukit Besar at Kota Tinggi, Johor	740727-1010101	750101-1001231	25	47	4234109	JPS Kemaman Terengganu	700628-1010605	710101-1001231	29
34	1732004	Parit Madirono at Site 4, Johor	781011-1010101	790101-1001231	21	48	4513033	Gunung Berinchang, Cameron Highland, Phg	750701-1010202	760101-1001231	24
35	1534002	Pusat Kemajuan Perikanan, Pkn Nanas, Jhr	781030-1010101	790101-1001231	21	49	4023001	Kg Sungai Yap, Pahang	731108-1010119	740101-1001231	26
36	5824079	Sg. Rasau Pasir Puteh, Kelantan	700629-970225	710101-961231	25	50	4019001	JKR Benta, Benta, Pahang	770103-1010207	780101-1001231	22
37	5718002	Air Lanas, Kelantan	800714-1010101	810101-1001231	19	51	3924072	Rumah Pam Paya Kangsar, Pahang	700629-1010104	710101-1001231	29
38	5320038	Dabong at Kelantan	710913-1010109	720101-991231	27	52	3818054	Stor JPS Raub, Pahang	700701-1010109	710101-1001231	29
39	4923001	Kg Aring at Kelantan	741116-1000901	750101-991231	24	53	3717001	Bukit Peninjau at Pahang	751014-1010104	760101-1001231	24
40	5725006	Klinik Kg Raja, Besut Terengganu	700704-1010524	720101-1001231	28	54	3533102	Rumah Pam Pahang Tua, Pekan Pahang	700704-1010402	730101-1001231	27
41	5428002	Klinik Chalok Barat S1 Terengganu	780202-1010527	790101-1001231	21	55	3519125	Kuala Marong, Benta, Pahang	700629-1010109	710101-1001231	29
42	5428001	Kg Batu Hampar At Chalok Site 1 Terengganu	780202-1000529	790101-1001231	21	56	3231163	Kg. Unchang at Pahang	740306-1010207	750101-1001231	25

Table 7.2: Available Data of Site Characteristics

No	Station ID	Long (Deg)	Lat (Deg)	Elev (M)	Mean (Mm)	Ratio	No	Station ID	Long (Deg)	Lat (Deg)	Elev (M)	Mean (Mm)	Ratio
1	6401002	100.19	6.45	2.6	2012	0.1238	29	2330009	103.02	2.38	32.0	1975	0.6000
2	6402008	100.25	6.48	7.0	1405	0.1885	30	2033001	103.33	2.01	40.0	2050	0.5723
3	6306031	100.77	6.24	34.8	1614	0.119	31	2025001	102.58	2.02	3.0	1991	0.4033
4	6207032	100.69	6.34	61.0	1946	0.1416	32	1839196	103.97	1.85	14.0	2612	0.5253
5	6206035	100.61	6.25	78.3	1701	0.1397	33	1737001	103.72	1.76	45.1	2127	0.5539
6	6108001	100.85	6.11	152.4	2084	0.1313	34	1732004	103.27	1.71	40.0	2167	0.6253
7	5808001	100.89	5.88	128.9	2406	0.1406	35	1534002	103.49	1.52	40.0	2376	0.7473
8	5704055	100.44	5.8	1063.8	3193	0.1347	36	5824079	102.42	5.83	3.0	2694	0.1324
9	5504035	100.43	5.53	3.7	1973	0.2344	37	5718002	101.89	5.85	74.1	3857	0.2653
10	5710061	101.00	5.71	313.0	2168	0.2162	38	5320038	102.02	5.38	76.2	2182	0.2482
11	5210069	101.06	5.3	103.0	1686	0.2811	39	4923001	102.31	5.83	91.1	2714	0.2655
12	5005003	100.55	5.01	2.0	2037	0.5159	40	5725006	102.57	5.8	5.1	2705	0.1242
13	4708084	100.89	4.78	50.1	1491	0.5861	41	5428002	102.82	5.41	33.0	3682	0.2095
14	4511111	101.13	4.59	61.0	2327	0.4813	42	5428001	102.82	5.45	10.0	3211	0.1745
15	4409091	100.90	4.46	23.2	1731	0.5267	43	5331048	103.13	5.32	87.0	2834	0.1541
16	4209093	100.9	4.26	12.8	2098	0.59	44	5029034	102.94	5.07	55.0	3187	0.2228
17	4010001	101.04	4.02	14.9	2442	0.4466	45	4930038	103.06	4.94	15.0	3509	0.2268
18	3516022	101.45	3.58	143.9	2488	0.4450	46	4929001	102.97	4.95	70.0	4646	0.2743
19	3416002	101.66	3.44	70.1	2595	0.3621	47	4234109	103.42	4.23	5.5	2783	0.245
20	3411017	101.17	3.42	2.4	1690	0.5105	48	4513033	101.38	4.52	2031.2	2398	0.4636
21	3317004	101.77	3.37	818.1	2242	0.4016	49	4023001	101.33	4.03	76.2	1636	0.4903
22	3314001	101.41	3.37	17.1	2029	0.5603	50	4019001	102.00	4.03	121.9	2033	0.5597
23	3118102	101.94	3.16	85.0	2492	0.4684	51	3924072	102.43	3.90	45.7	1656	0.4074
24	2917001	101.80	2.99	39.0	2353	0.5313	52	3818054	101.85	3.81	228.6	1942	0.5718
25	2723002	102.32	2.70	121.9	1709	0.5468	53	3717001	101.80	3.72	1323.1	2243	0.4213
26	2719001	101.96	2.74	121.9	1933	0.4754	54	3533102	103.36	3.57	7.0	2519	0.2585
27	2321006	102.19	2.36	33.0	1762	0.458	55	3519125	101.92	3.51	91.5	1876	0.4833
28	2224038	102.49	2.29	8.6	1628	0.4807	56	3231163	103.20	3.30	40.0	2114	0.3669

Table 7.3: Transformation of Site Characteristics

Site Characteristic, X	Cluster Variable, Y
Latitude (deg)	Y= X / 90
Longitude (deg)	Y= X / 150
Elevation (deg)	Y= X / 10000
Mean Annual Rainfall (mm)	Y = X / 100
Ratio of minimum average two-month rainfall to maximum average two-month rainfall	Y= X

Table 7.4: Site Characteristics Combinations of Cluster Analysis

Site Characteristics Combinations	Combination Code
Latitude + Longitude + Elevation	A1
Latitude + Longitude + Mean of Rain	A2
Latitude + Longitude + Ratio	A3
Latitude + Longitude + Elevation + Mean of Rain	A4
Latitude + Longitude + Elevation + Mean of Rain + Ratio	A5

Clustering analysis was performed by Ward's method where the distance between two clusters is the sum of squares between the two clusters summed over all the variables. This is an "agglomerative hierarchical" clustering procedure.

The method tends to join clusters that contains a small number of sites and strongly biased in favour of producing clusters containing approximately equal number of sites.

This method is based on the Euclidean distances and also sensitive to redundant information that may be contained in the variables as well as to the scale of the variables being clustered (Fovell and Fovell, 1993). Initially each site is a cluster by itself, and clusters are then merged one by one until all sites belong to a single cluster.

The assignment of sites to clusters can be determined for any number of clusters and there is no formal measure of an "optimal" number of clusters where the choice is subjective.

7.5 Results of Clustering Analysis

In this study, for Peninsular Malaysia that consists of 56 selected automatic rainfall stations, it is decided that four clusters would be an appropriate number.

The clusters obtained by Ward's method were adjusted by K-means algorithm of Hartigan and Wong (1979), which yield clusters that were little more compact in the space of cluster variables. The result of heterogeneity measures showed that the best combination of site characteristics is found to be group A5 where cluster no.1, 2, 3 and 4 were classified as acceptably homogeneous (H=0.72), possibly heterogeneous (H=2.13b), acceptably homogeneous (H=-1.23a) and possibly heterogeneous (H=1.48b) respectively.

Summary of cluster membership for group A5 is given in Table 7.5 and summary of cluster centre is tabulated in Table 7.6. Figure 7:1 shows final region created and region no.4 was a distinct region as it is located and represents mountainous area; meanwhile Region No.5 was specifically created for accommodating an urban area.

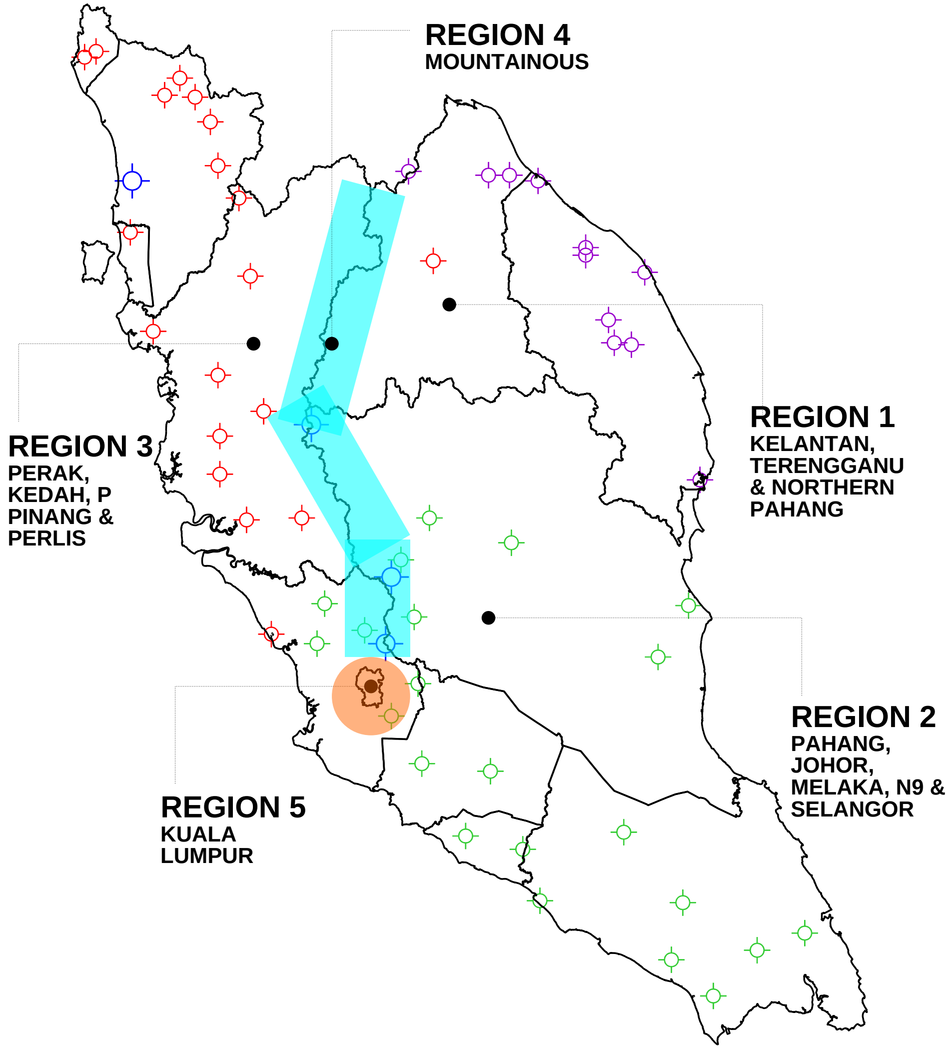
Table 7.5: Summary of Clustering Analysis of A5 Combination

Cluster	Total Members	Station No.
1	11	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 38
2	29	12, 13, 14, 15, 16, 17, 18, 19, 20, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 49, 50, 51, 52, 55, 56
3	12	36, 37, 39, 40, 41, 42, 43, 44, 45, 46, 47, 54
4	4	8, 21, 48, 53

Table 7.6: Summary of Cluster Centres of A5 Combination

Cluster	Latitude	Longitude	Elevation	Mean	Ratio
1	100.76	5.97	65.47	1914.66	0.18
2	102.07	3.21	45.3	2035.24	0.51
3	102.81	5.19	29.36	3168.66	0.21
4	101.35	4.35	1272.02	2504.65	0.36

Figure 7:1: The “region” created by means of the clustering analysis approach



8 DEVELOPING THE DESIGN STORM PROFILES (TEMPORAL STORM)

8.1 Introduction

A variety of methods to generate design storm hyetograph exist in the literature, but as cited by Veneziano and Villani (1999) suggested that the most practical methods can be divided into three categories:

[1] Specification of simple geometrical shapes anchored to a single point of the IDF curve/relationships – the traditional approach uses a rectangular design hyetograph with duration equal to the concentration time of the basin and rainfall rate derived from the IDF relationship (i.e. frequently used in a combination of the rational method as shown in Hydrological Procedure No. 5)

[2] Use of the entire IDF curves to specify a rainfall profile that reflects the entire IDF relationship and not only the IDF value at a single duration.

[3] Use of standardized profiles obtained directly from historic rainfall records which is able to reduce a rainfall event to a dimensionless curve by dividing time by the total duration of the event and cumulative rainfall by the total rainfall volume (i.e. as appeared in the existing procedure and has directly been adopted in the MSMA).

Based on the categories mentioned, the last two methods are recognized as the best choice to adopt, but to continue as in the existing HP1 (1982), the method of standardized profiles is selected.

Use of standardized rainfall profiles is quite common in the hydrology literature. Prodanovic and Simonovic (2004) cited that the most popular are those of Huff (1967) and SCS (1986). Standardized profiles, also known as mass curve, transform a precipitation event to a dimensionless curve with cumulative fraction of storm time on the horizontal and cumulative fraction of total rainfall on the vertical axis. Since rainfall records are highly variable because of the uncertainty of what actually constitutes a rainfall event, as well as randomness of the rainfall phenomena itself, the standardized profiles method must use some sort of temporal smoothing, or assemble averaging.

In the Soil Conservation System (SCS) hypothetical storm method uses standardized rainfall intensities arranged to maximize the peak runoff at a given storm depth. Although primarily has been used for the design of small dams, it has been applied in many rural and urban areas. The required input parameters are distribution type and total storm depth.

The Huff method has features similar to the SCS method, except that it gives the user more flexibility – restrictions are not placed on storm duration. The required input parameters are quantile distribution, storm duration, *d* and total storm depth, *D*.

The main appeal of this category of methods of design rainstorm/rainfall intensity hyetographs is that the resulting output is based on the actual data of intense regional rainfall. Furthermore, as the methods do not rely on IDF data, rainfall exceeding return period of 100-years can be easily used, if available. In the context of available records of rainfall data managed by DID in Peninsular Malaysia, however, it apparently shows that the maximum length of historic rainfall records are mostly found to be about 30-40 years. Under these circumstances, the mentioned methodology probably has limited ability for producing design hyetograph at high return period for more than 50 year. This method also requires large sample data sets for the construction of regional profiles, which in turn generates large uncertainties. Therefore, temporal smoothing needs to be performed and this might overlook some of the important features of rainfall at the locality interest.

8.2 Derivation of Storm Profiles (Temporal Pattern)

About 441 number of storms was considered in the analysis, with durations ranging from 0.25-hr to 72-hrs. Generally, the storms were selected and identified from 5 nos. of annual maximum rainfall intensity at each state. However, due to lack of station density, Melaka and Negeri Sembilan, and Pulau Pinang and Perlis were grouped as two distinct areas. The required input parameters are storm duration and total storm depth where the mass curves of selected duration were constructed and temporal smoothing has been carried out by means of mass curve averaging. As reported in Chapter 0, the clustering analysis has produced 4 distinct regions throughout Peninsular Malaysia and in addition, Federal Territory of Kuala Lumpur region was specifically created. Therefore, the regional storm profiles basically refer to:

1. Northeast Region – Kelantan, Terengganu and Northen Pahang
2. Central and Southern Region – Pahang (except Northern Pahang), Selangor, Negeri Sembilan, Melaka and Johor;
3. Northwest Region – Perak, Kedah, Pulau Pinang and Perlis;
4. Mountainous Region – covers an area of high altitude which is no longer recognized by administrative boundary;
5. Urban Region – specifically for Federal Territory of Kuala Lumpur

Thus, final regional storm profiles were obtained by means of averaging the mass curves from the stated states in each derived region. With the newly created regions as stated above, the current East and West Coast region of HP1 (1982) is no longer usable and appropriate. Figure 7:1 depicts the derived region.

8.3 Summary of Results

Based on the final regions created, actual storm profiles for each region are summarized in Table 8.1 **-** Table 8.5. However, the normalization (standardization) of actual storm profile is produced by generating accurate peak discharge or runoff volumes estimation. Table 8.6 – Table 8.10 show normalized temporal storm profile for the region of 1 to 5. Example of storm profile block diagrams is illustrated in Figure 8:1 - Figure 8:2 associated with storm duration.

Table 8.1: Derived Temporal Pattern for Region 1 – Terengganu, Kelantan and Northern Pahang

No. of Block	**Duration**								
	15-min	**30-min**	**60-min**	**180-min**	**6-hr**	**12-hr**	**24-hr**	**48-hr**	**72-hr**
1	0.316	0.202	0.091	0.071	0.057	0.064	0.025	0.029	0.022
2	0.368	0.193	0.060	0.060	0.063	0.070	0.027	0.046	0.020
3	0.316	0.161	0.062	0.059	0.071	0.073	0.050	0.049	0.021
4		0.100	0.054	0.060	0.069	0.084	0.048	0.058	0.029
5		0.133	0.061	0.061	0.059	0.084	0.058	0.054	0.030
6		0.211	0.115	0.080	0.073	0.097	0.058	0.028	0.033
7			0.082	0.078	0.086	0.086	0.036	0.019	0.052
8			0.087	0.100	0.067	0.070	0.046	0.029	0.053
9			0.087	0.120	0.082	0.099	0.044	0.028	0.048
10			0.097	0.110	0.119	0.083	0.039	0.060	0.038
11			0.120	0.132	0.130	0.106	0.057	0.053	0.036
12			0.084	0.069	0.123	0.083	0.049	0.055	0.041
13							0.056	0.038	0.042
14							0.050	0.037	0.047
15							0.043	0.040	0.059
16							0.068	0.044	0.053
17							0.048	0.027	0.038
18							0.050	0.033	0.037
19							0.042	0.030	0.033
20							0.028	0.046	0.067
21							0.019	0.048	0.056
22							0.016	0.065	0.058
23							0.022	0.048	0.055
24							0.022	0.034	0.030

Table 8.2: Derived Temporal Pattern for Region 2 - Johor, Negeri Sembilan, Melaka, Selangor and Pahang

No. of Block	**Duration**								
	15-min	**30-min**	**60-min**	**180-min**	**6-hr**	**12-hr**	**24-hr**	**48-hr**	**72-hr**
1	0.255	0.103	0.103	0.042	0.044	0.041	0.024	0.026	0.023
2	0.376	0.124	0.110	0.080	0.090	0.045	0.040	0.022	0.035
3	0.370	0.126	0.046	0.097	0.081	0.048	0.031	0.013	0.016
4		0.130	0.063	0.129	0.083	0.056	0.032	0.012	0.016
5		0.152	0.059	0.151	0.090	0.046	0.022	0.025	0.033
6		0.365	0.088	0.128	0.081	0.106	0.020	0.045	0.024
7			0.069	0.079	0.115	0.146	0.024	0.036	0.022
8			0.053	0.062	0.114	0.124	0.039	0.041	0.049
9			0.087	0.061	0.106	0.116	0.033	0.059	0.038
10			0.057	0.053	0.085	0.127	0.054	0.058	0.027
11			0.060	0.054	0.074	0.081	0.050	0.066	0.047
12			0.153	0.063	0.037	0.064	0.047	0.068	0.067
13							0.031	0.062	0.057
14							0.029	0.059	0.051
15							0.029	0.051	0.036
16							0.039	0.022	0.049
17							0.042	0.026	0.048
18							0.093	0.022	0.049
19							0.052	0.026	0.068
20							0.035	0.056	0.043
21							0.083	0.040	0.079
22							0.065	0.093	0.050
23							0.057	0.039	0.043
24							0.028	0.032	0.030

Table 8.3: Derived Temporal for Region 3 - Perak, Kedah, P Pinang and Perlis

No. of Block	**Duration**								
	15-min	**30-min**	**60-min**	**180-min**	**6-hr**	**12-hr**	**24-hr**	**48-hr**	**72-hr**
1	0.215	0.141	0.077	0.085	0.047	0.040	0.048	0.021	0.044
2	0.395	0.173	0.064	0.100	0.041	0.046	0.033	0.045	0.026
3	0.390	0.158	0.098	0.086	0.070	0.036	0.034	0.060	0.063
4		0.161	0.087	0.087	0.099	0.066	0.033	0.086	0.074
5		0.210	0.068	0.087	0.081	0.066	0.034	0.039	0.021
6		0.158	0.074	0.088	0.113	0.060	0.036	0.028	0.050
7			0.078	0.100	0.121	0.081	0.031	0.020	0.058
8			0.072	0.100	0.099	0.092	0.044	0.026	0.049
9			0.075	0.085	0.078	0.119	0.036	0.015	0.008
10			0.104	0.063	0.076	0.114	0.027	0.014	0.031
11			0.106	0.060	0.129	0.113	0.023	0.028	0.030
12			0.099	0.059	0.045	0.166	0.035	0.017	0.044
13							0.041	0.057	0.025
14							0.053	0.039	0.022
15							0.039	0.044	0.044
16							0.055	0.035	0.024
17							0.032	0.038	0.024
18							0.031	0.052	0.025
19							0.039	0.069	0.023
20							0.080	0.046	0.070
21							0.076	0.056	0.078
22							0.044	0.046	0.081
23							0.042	0.045	0.028
24							0.056	0.073	0.058

Table 8.4: Derived Temporal Pattern for Region 4 - Mountainous Area

No. of Block	**Duration**								
	15-min	**30-min**	**60-min**	**180-min**	**6-hr**	**12-hr**	**24-hr**	**48-hr**	**72-hr**
1	0.146	0.117	0.028	0.055	0.054	0.120	0.026	0.018	0.116
2	0.177	0.121	0.028	0.098	0.040	0.041	0.007	0.057	0.011
3	0.677	0.374	0.066	0.132	0.041	0.065	0.023	0.037	0.005
4		0.107	0.079	0.164	0.062	0.052	0.050	0.033	0.006
5		0.130	0.073	0.197	0.020	0.056	0.055	0.047	0.011
6		0.152	0.064	0.169	0.019	0.048	0.048	0.081	0.000
7			0.106	0.095	0.045	0.052	0.023	0.018	0.014
8			0.058	0.027	0.016	0.157	0.142	0.027	0.018
9			0.280	0.019	0.060	0.058	0.049	0.024	0.096
10			0.042	0.019	0.171	0.059	0.060	0.007	0.035
11			0.052	0.019	0.390	0.038	0.009	0.003	0.060
12			0.119	0.006	0.082	0.253	0.112	0.000	0.039
13							0.034	0.002	0.028
14							0.040	0.080	0.016
15							0.001	0.066	0.005
16							0.002	0.007	0.009
17							0.000	0.031	0.065
18							0.026	0.036	0.028
19							0.008	0.026	0.023
20							0.007	0.204	0.034
21							0.000	0.037	0.127
22							0.027	0.062	0.027
23							0.227	0.053	0.056
24							0.027	0.043	0.171

Table 8.5: Derived Temporal Pattern for Region 5 - Urban Area (Kuala Lumpur)

No. of Block	**Duration**								
	15-min	**30-min**	**60-min**	**180-min**	**6-hr**	**12-hr**	**24-hr**	**48-hr**	**72-hr**
1	0.184	0.072	0.058	0.095	0.023	0.007	0.080	0.017	0.047
2	0.448	0.097	0.050	0.175	0.161	0.003	0.054	0.012	0.031
3	0.368	0.106	0.061	0.116	0.118	0.003	0.011	0.001	0.006
4		0.161	0.108	0.096	0.096	0.051	0.023	0.001	0.027
5		0.164	0.096	0.093	0.107	0.074	0.025	0.033	0.060
6		0.400	0.103	0.097	0.102	0.086	0.017	0.026	0.049
7			0.106	0.078	0.092	0.206	0.015	0.020	0.022
8			0.065	0.050	0.096	0.081	0.047	0.027	0.009
9			0.065	0.060	0.091	0.140	0.021	0.053	0.067
10			0.056	0.048	0.045	0.180	0.012	0.041	0.023
11			0.068	0.062	0.037	0.107	0.035	0.068	0.019
12			0.164	0.030	0.033	0.064	0.032	0.096	0.014
13							0.009	0.132	0.050
14							0.002	0.015	0.040
15							0.003	0.018	0.014
16							0.075	0.011	0.025
17							0.055	0.031	0.003
18							0.087	0.030	0.072
19							0.076	0.004	0.110
20							0.052	0.024	0.054
21							0.103	0.036	0.087
22							0.048	0.142	0.052
23							0.027	0.033	0.050
24							0.091	0.129	0.070

Table 8.6: Normalized Temporal Pattern For Region 1 - Terengganu & Kelantan

No. of Block	**Duration**								
	15-min	**30-min**	**60-min**	**180-min**	**6-hr**	**12-hr**	**24-hr**	**48-hr**	**72-hr**
1	0.316	0.133	0.060	0.060	0.059	0.070	0.019	0.027	0.021
2	0.368	0.193	0.062	0.061	0.067	0.073	0.022	0.028	0.029
3	0.316	0.211	0.084	0.071	0.071	0.083	0.027	0.029	0.030
4		0.202	0.087	0.080	0.082	0.084	0.036	0.033	0.033
5		0.161	0.097	0.110	0.119	0.097	0.042	0.037	0.037
6		0.100	0.120	0.132	0.130	0.106	0.044	0.040	0.038
7			0.115	0.120	0.123	0.099	0.048	0.046	0.042
8			0.091	0.100	0.086	0.086	0.049	0.048	0.048
9			0.087	0.078	0.073	0.084	0.050	0.049	0.053
10			0.082	0.069	0.069	0.083	0.056	0.054	0.055
11			0.061	0.060	0.063	0.070	0.058	0.058	0.058
12			0.054	0.059	0.057	0.064	0.068	0.065	0.067
13							0.058	0.060	0.059
14							0.057	0.055	0.056
15							0.050	0.053	0.053
16							0.050	0.048	0.052
17							0.048	0.046	0.047
18							0.046	0.044	0.041
19							0.043	0.038	0.038
20							0.039	0.034	0.036
21							0.028	0.030	0.033
22							0.025	0.029	0.030
23							0.022	0.028	0.022
24							0.016	0.019	0.020

Table 8.7: Normalized Temporal Pattern for Region 2 - Johor, Negeri Sembilan, Melaka, Selangor and Pahang

No. of Block	**Duration**								
	15-min	**30-min**	**60-min**	**180-min**	**6-hr**	**12-hr**	**24-hr**	**48-hr**	**72-hr**
1	0.255	0.124	0.053	0.053	0.044	0.045	0.022	0.027	0.016
2	0.376	0.130	0.059	0.061	0.081	0.048	0.024	0.028	0.023
3	0.370	0.365	0.063	0.063	0.083	0.064	0.029	0.029	0.027
4		0.152	0.087	0.080	0.090	0.106	0.031	0.033	0.033
5		0.126	0.103	0.128	0.106	0.124	0.032	0.037	0.036
6		0.103	0.153	0.151	0.115	0.146	0.035	0.040	0.043
7			0.110	0.129	0.114	0.127	0.039	0.046	0.047
8			0.088	0.097	0.090	0.116	0.042	0.048	0.049
9			0.069	0.079	0.085	0.081	0.050	0.049	0.049
10			0.060	0.062	0.081	0.056	0.054	0.054	0.051
11			0.057	0.054	0.074	0.046	0.065	0.058	0.067
12			0.046	0.042	0.037	0.041	0.093	0.065	0.079
13							0.083	0.060	0.068
14							0.057	0.055	0.057
15							0.052	0.053	0.050
16							0.047	0.048	0.049
17							0.040	0.046	0.048
18							0.039	0.044	0.043
19							0.033	0.038	0.038
20							0.031	0.034	0.035
21							0.029	0.030	0.030
22							0.028	0.029	0.024
23							0.024	0.028	0.022
24							0.020	0.019	0.016

Table 8.8: Normalized Temporal Pattern for Region 3 - Perak, Kedah, P Pinang & Perlis

No. of Block	**Duration**								
	15-min	**30-min**	**60-min**	**180-min**	**6-hr**	**12-hr**	**24-hr**	**48-hr**	**72-hr**
1	0.215	0.158	0.068	0.060	0.045	0.040	0.027	0.015	0.021
2	0.395	0.161	0.074	0.085	0.070	0.060	0.031	0.020	0.023
3	0.390	0.210	0.077	0.086	0.078	0.066	0.033	0.026	0.024
4		0.173	0.087	0.087	0.099	0.092	0.034	0.028	0.025
5		0.158	0.099	0.100	0.113	0.114	0.035	0.038	0.028
6		0.141	0.106	0.100	0.129	0.166	0.036	0.039	0.031
7			0.104	0.100	0.121	0.119	0.039	0.045	0.044
8			0.098	0.088	0.099	0.113	0.042	0.046	0.049
9			0.078	0.087	0.081	0.081	0.044	0.052	0.058
10			0.075	0.085	0.076	0.066	0.053	0.057	0.063
11			0.072	0.063	0.047	0.046	0.056	0.069	0.074
12			0.064	0.059	0.041	0.036	0.080	0.086	0.081
13							0.076	0.073	0.078
14							0.055	0.060	0.070
15							0.048	0.056	0.058
16							0.044	0.046	0.050
17							0.041	0.045	0.044
18							0.039	0.044	0.044
19							0.036	0.039	0.030
20							0.034	0.035	0.026
21							0.033	0.028	0.025
22							0.032	0.021	0.024
23							0.031	0.017	0.022
24							0.023	0.014	0.008

Table 8.9: Normalized Temporal Pattern for Region 4 - Mountainous Area

No. of Block	**Duration**								
	15-min	**30-min**	**60-min**	**180-min**	**6-hr**	**12-hr**	**24-hr**	**48-hr**	**72-hr**
1	0.146	0.117	0.028	0.019	0.019	0.041	0.000	0.002	0.005
2	0.677	0.130	0.052	0.019	0.040	0.052	0.002	0.007	0.006
3	0.177	0.374	0.064	0.055	0.045	0.056	0.007	0.018	0.011
4		0.152	0.073	0.098	0.060	0.059	0.009	0.024	0.014
5		0.121	0.106	0.164	0.082	0.120	0.023	0.027	0.018
6		0.107	0.280	0.197	0.390	0.253	0.026	0.033	0.027
7			0.119	0.169	0.171	0.157	0.027	0.037	0.028
8			0.079	0.132	0.062	0.065	0.040	0.043	0.035
9			0.066	0.095	0.054	0.058	0.049	0.053	0.056
10			0.058	0.027	0.041	0.052	0.055	0.062	0.065
11			0.042	0.019	0.020	0.048	0.112	0.080	0.116
12			0.028	0.006	0.016	0.038	0.227	0.204	0.171
13							0.142	0.081	0.127
14							0.060	0.066	0.096
15							0.050	0.057	0.060
16							0.048	0.047	0.039
17							0.034	0.037	0.034
18							0.027	0.036	0.028
19							0.026	0.031	0.023
20							0.023	0.026	0.016
21							0.008	0.018	0.011
22							0.007	0.007	0.009
23							0.001	0.003	0.005
24							0.000	0.000	0.000

Table 8.10: Normalized Temporal Pattern for Region 5 - Urban Area (Kuala Lumpur)

No. of Block	Duration								
	15-min	30-min	60-min	180-min	6-hr	12-hr	24-hr	48-hr	72-hr
1	0.184	0.097	0.056	0.048	0.033	0.003	0.003	0.001	0.006
2	0.448	0.161	0.061	0.060	0.045	0.051	0.011	0.011	0.014
3	0.368	0.400	0.065	0.078	0.092	0.074	0.015	0.015	0.019
4		0.164	0.096	0.095	0.096	0.086	0.021	0.018	0.023
5		0.106	0.106	0.097	0.107	0.140	0.025	0.024	0.027
6		0.072	0.164	0.175	0.161	0.206	0.032	0.027	0.040
7			0.108	0.116	0.118	0.180	0.047	0.031	0.049
8			0.103	0.096	0.102	0.107	0.052	0.033	0.050
9			0.068	0.093	0.096	0.081	0.055	0.041	0.054
10			0.065	0.062	0.091	0.064	0.076	0.068	0.067
11			0.058	0.050	0.037	0.007	0.087	0.129	0.072
12			0.050	0.030	0.023	0.003	0.103	0.142	0.110
13							0.091	0.132	0.087
14							0.080	0.096	0.070
15							0.075	0.053	0.060
16							0.054	0.036	0.052
17							0.048	0.033	0.050
18							0.035	0.030	0.047
19							0.027	0.026	0.031
20							0.023	0.020	0.025
21							0.017	0.017	0.022
22							0.012	0.012	0.014
23							0.009	0.004	0.009
24							0.002	0.001	0.003

Figure 8:1: Block diagrams of temporal storm profile corresponding with storm duration (0.25 to 12-hr) for Region 1

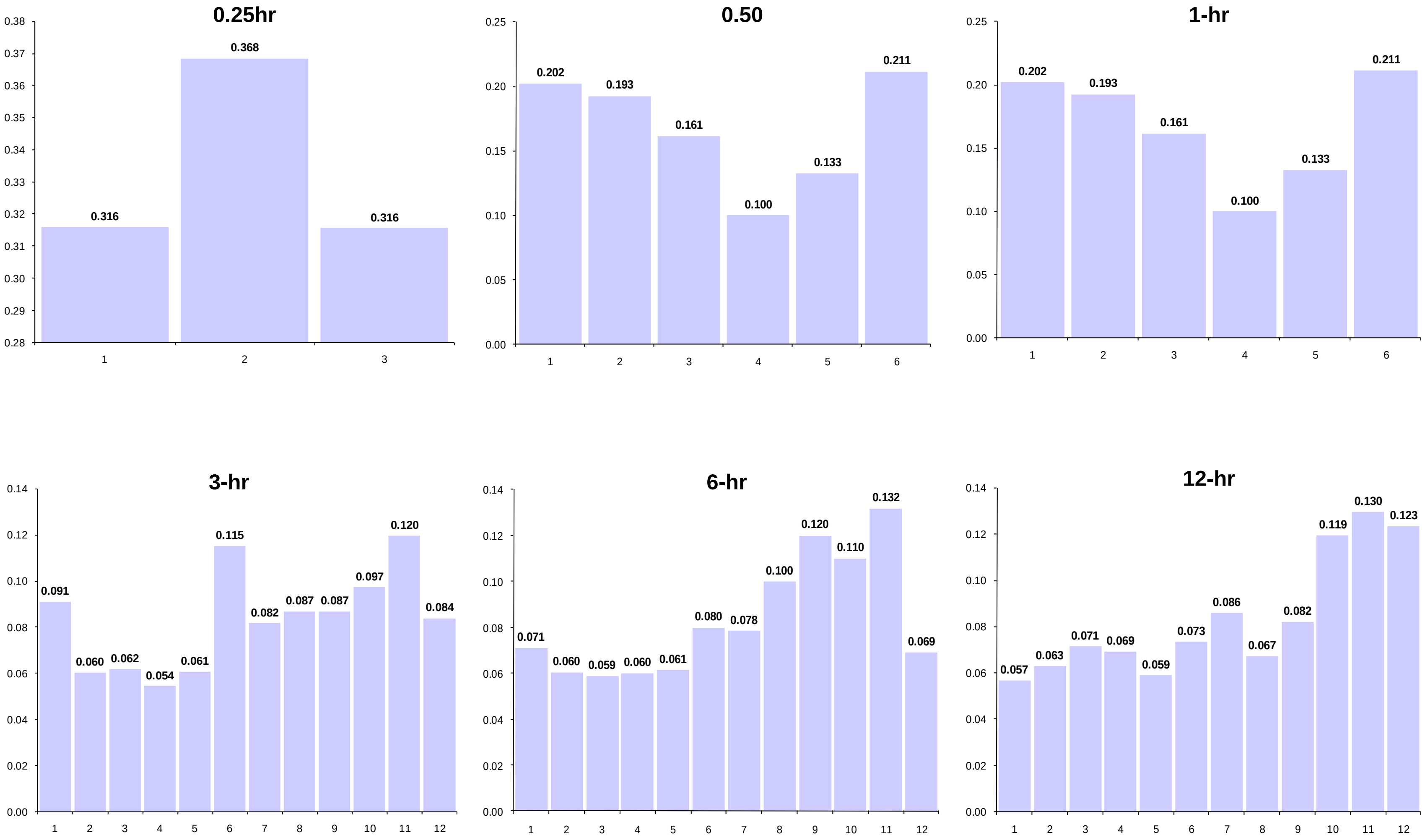
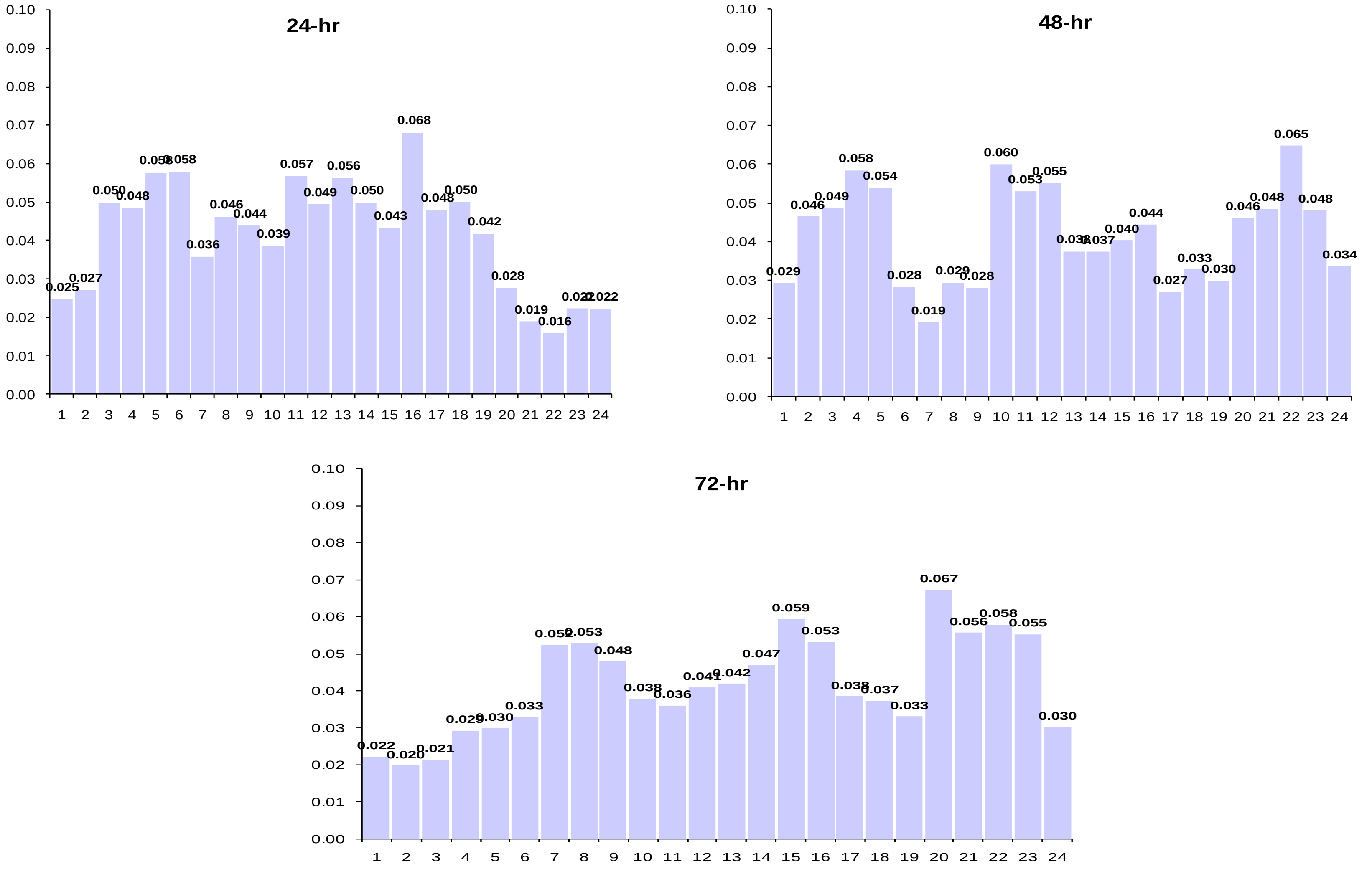


Figure 8:2: Block diagrams of temporal storm profile corresponding with storm duration (24, 48 and 72-hr) for Region 1



9 DEVELOPING THE AREAL REDUCTION FACTOR (SPATIAL CORRECTION FACTOR)

9.1 Introduction

Sriwardena and Weinmann (1996) described the available methods for deriving fixed-area areal reduction factors can be generally classified into three categories, namely empirical, analytical and analytical-empirical methods. These three categories can be briefly explained as follow:

9.1.1 Empirical Method

In this category, recorded rainfall depths at a number of stations within a ‘catchments’ were used to derive the Area Reduction Factors (ARF) empirically. Three methods were grouped under this category. They are [1] US Weather Bureau method, [2] UK method and [3] Bell’s method.

The first two methods derived a single value of ARF for a given area and duration, but Bell’s method derives the ARF as a function of annual exceedance probability.

9.1.2 Analytical Method

With this category, a mathematical model is fitted to characterize the space-time variation of rainfall with simplifying assumptions. The ARF is then derived analytically from properties of the fitted model. Four models are under this category; [1] Roche method, [2] Rodriguez-Iturbe and Mejia, [3] Meynink and Brady and [4] statistical derivation of ARF.

9.1.3 Analytical-Empirical Method

In analytical-empirical category, the Myers and Zehr is the only one model identified and has been recommended for use in Australia (Australia Rainfall and Runoff, 1987).

As reviewed by Sriwardena and Weinmann (1996), out of three categories mentioned, only Bell’s method allows the variation in the magnitude of ARFs with annual exceedance probability (AEP). Bell fitted an exponential distribution in the partial series of point and areal rainfall in the derivation of ARFs. Since the different distributions may result in different ARF estimates, particularly for lower AEPs, the best fit distribution needs to be used to obtain the most accurate ARF estimates for a particular region.

The concept introduced by Bell (1976), however reviewed by Stewart (1989) with some modification. Point and areal rainfall frequency curves were derived from annual maximum series, standardized by mean of annual maxima. The modified Bell's has introduced a single areal rainfall growth curve for each 'catchment' size. At a specified average recurrence interval (ARI), *T*, the ARF can be defined as:

$$ARF(T) = \frac{RC(T)}{RP(T)} \qquad [48]$$

where *RC* and *RP* denote areal and point rainfall respectively. If *RC*s and *RP*s are used to denote standardized areal and point rainfall, and $\overline{RC}$ and $\overline{RP}$ are used to denote the means of annual maximum areal and point rainfalls respectively, and the ARF can be defined as:

$$RC_S(T) = \frac{RC(T)}{\overline{RC}} \qquad [49]$$

$$RP_S(T) = \frac{RP(T)}{\overline{RP}} \qquad [50]$$

and the final ARF can be expressed as:

$$ARF(T) = \left[\frac{RCs(T)}{RPs(T)}\right]\left[\frac{\overline{RC}}{\overline{RP}}\right] \qquad [51]$$

9.2 Derivation Procedure of Areal Reduction Factor (ARF)

Figure 9:1 shows the basic steps in the derivation of ARFs for each sample/hypothetical catchment.

However, for point rainfall, a frequency curve condensing information from all point rainfall series within the sample/hypothetical catchment is required. To accommodate this, a regional procedure of fitting a GEV distribution using L-moments was performed; here the sample/hypothetical catchment or the region refers to the circular catchment under study. In brief, the procedure for regional analysis involves the following steps shown in Figure 9:2.

Since the calculation involves many stations and '*regions*', a Fortran program was applied to facilitate the computation. The '*regions*' are referring to hypothetical catchments of 300km^2 and 2000km^2.

9.3 Summary of Results

Main outcomes of these tasks are as follows:

1. The result of this analysis can be tabularized by the relationship of areal reduction factor (ARF) as a function of [a] rainfall duration (hour) and catchment area (km^2) for varies average recurrence interval (ARI); and [b] catchment area against average recurrence interval (ARI) for a specific duration;

The relationship of ARF in association with rainfall duration and ARI is expressed in the form of $ARF = a\ln(d) + b$ where d=rainfall duration in hour, while *a* and *b* are ARF coefficients. The derived ARF coefficient corresponding with ARI, *T*=100, 50, 25, 20, 10, 5 and 2 years return period are given in

2. Table 9.1 to Table 9.7;
3. The relationship of ARF in association with catchment area and rainfall duration is expressed in the form of $ARF_d = aA^b$ where d=rainfall duration (hour), *a* and *b* are ARF coefficients and A=catchment area (km^2). The derived ARF coefficient corresponding with rainfall duration, d=0.25, 0.5, 1, 3, 6, 12, 24, 48, and 72-hours are given in Table 9.8 to 9.16;;
4. The ARF relationship mentioned, for example, can be seen in the respective Figure 9.4 and 9.5 that shows the plot of ARF and duration (hr.) corresponding with *T*=100 years return period; and the plot of ARF and catchment area (km^2) associated with rainfall duration (hr);
5. It is recommended that the adopted ARF values of US Weather Bureau (1957) as per Table 6 in existing HP1 (1982) should be replaced by the derived ARF values from this present study for the rainfall duration of 0.25 hour to 72 hours.

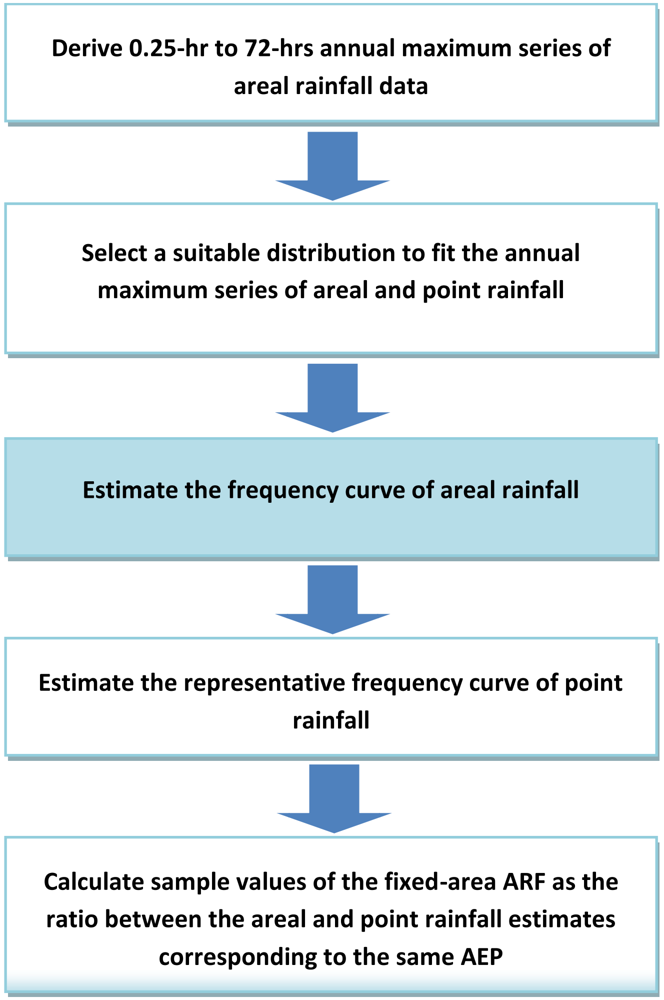


Figure 9:1: Basic steps in the derivation of ARFs for each sample/hypothetical catchment

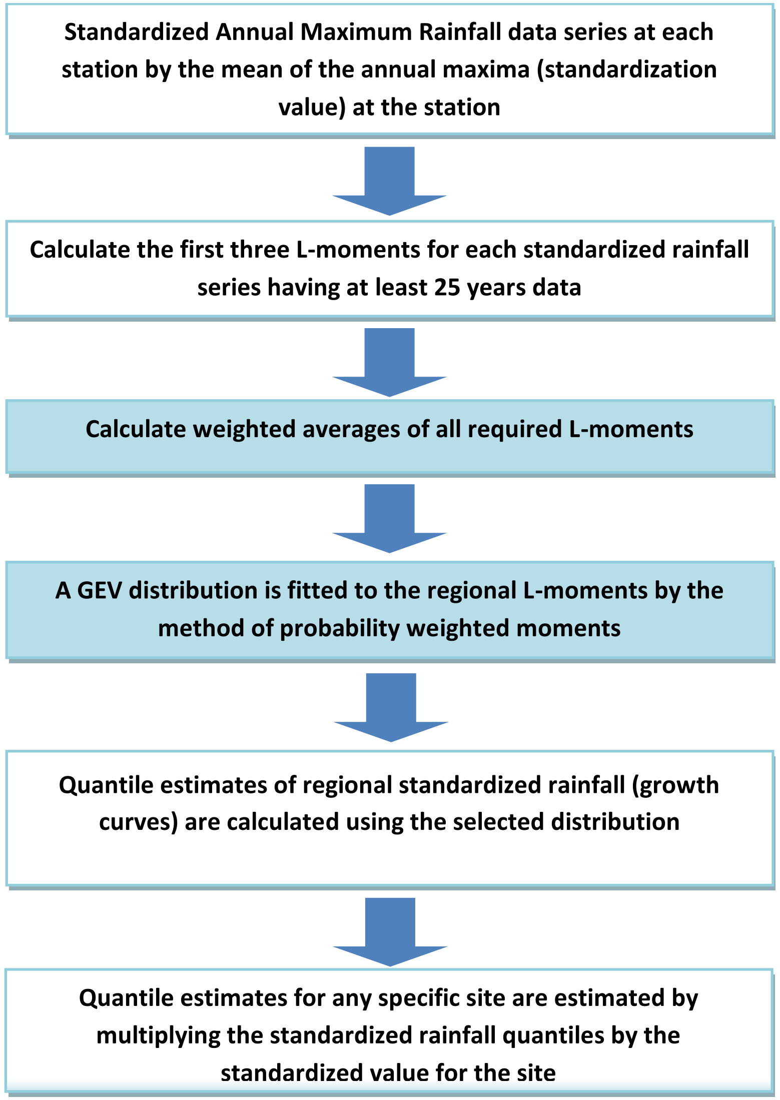


Figure 9:2: Regional procedure of fitting a GEV distribution using L-moments

Figure 9:3: Location of the 'Hypothetical Region' created for the entire Peninsular Malaysia

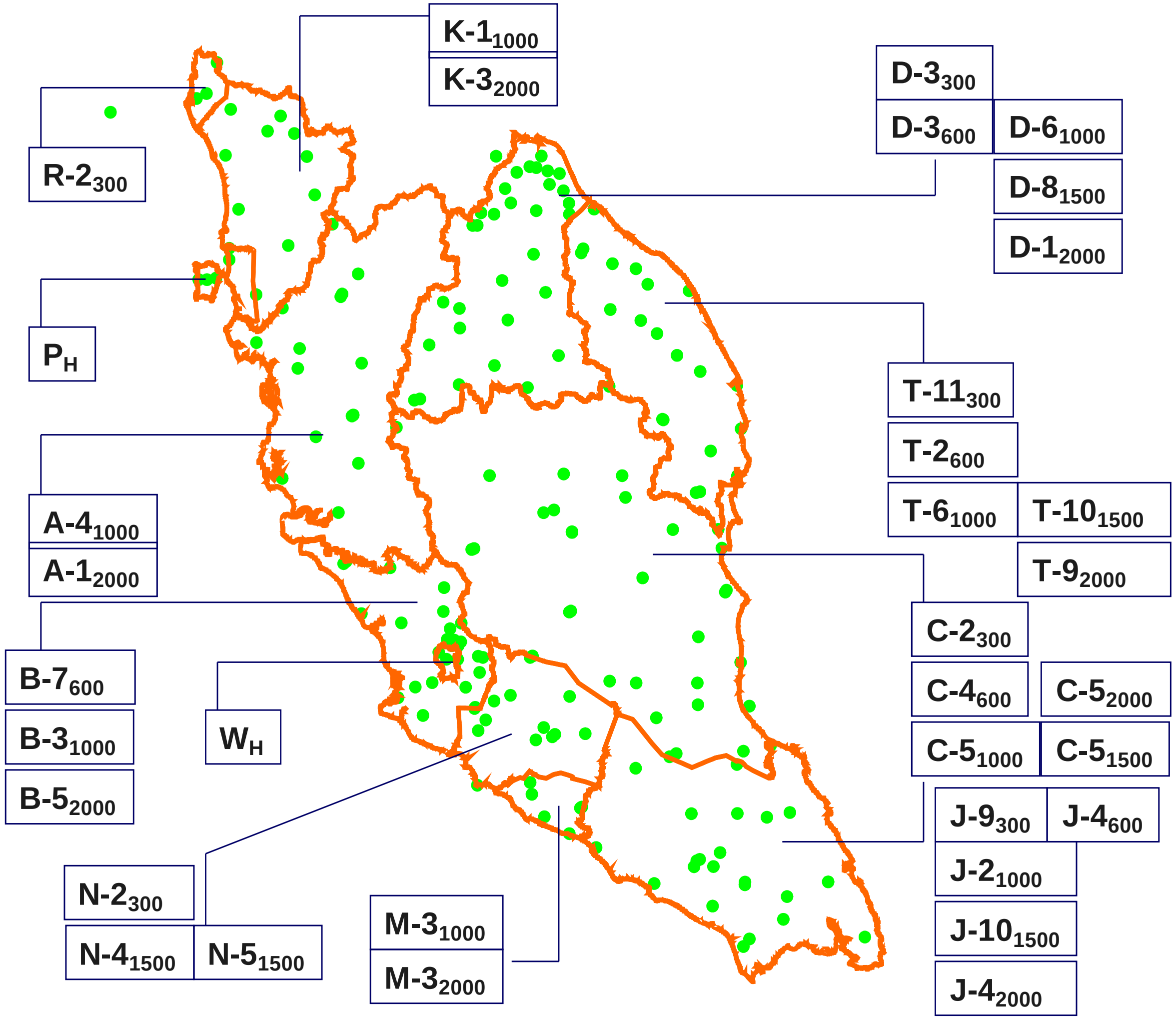


Table 9.1: The ARF values derived as a function of rainfall duration and catchment area corresponding with T=100 years return period

ARF = a*[ln(D)]+**b**	**Coefficient "a" and "b" corresponding with catchment area**				
a	-0.0070	-0.0170	-0.0170	-0.0180	-0.0160
b	0.8228	0.7401	0.7077	0.6884	0.6588
Duration (D=hr.)	**ARF corresponding with catchment area (km2)**				
	300km^2	**600km^2**	**1000km^2**	**1500km^2**	**2000km^2**
0.25	0.833	0.764	0.731	0.713	0.681
0.50	0.828	0.752	0.719	0.701	0.670
1	0.823	0.740	0.708	0.688	0.659
3	0.815	0.721	0.689	0.669	0.641
6	0.810	0.710	0.677	0.656	0.630
12	0.805	0.698	0.665	0.644	0.619
24	0.801	0.686	0.654	0.631	0.608
48	0.796	0.674	0.642	0.619	0.597
72	0.793	0.667	0.635	0.611	0.590

Table 9.2: The ARF values derived as a function of rainfall duration and catchment area corresponding with *T*=50 years return period

ARF = a*[ln(D)]+**b**	**Coefficient "a" and "b" corresponding with catchment area**				
a	-0.0050	-0.0150	-0.0170	-0.0140	-0.0180
b	0.8509	0.7896	0.7617	0.7330	0.7084
Duration (D=hr.)	**ARF corresponding with catchment area (km2)**				
	300km^2	**600km^2**	**1000km^2**	**1500km^2**	**2000km^2**
0.25	0.858	0.810	0.785	0.752	0.733
0.50	0.854	0.800	0.773	0.743	0.721
1	0.851	0.790	0.762	0.733	0.708
3	0.845	0.773	0.743	0.718	0.689
6	0.842	0.763	0.731	0.708	0.676
12	0.838	0.752	0.719	0.698	0.664
24	0.835	0.742	0.708	0.689	0.651
48	0.832	0.732	0.696	0.679	0.639
72	0.830	0.725	0.689	0.673	0.631

Table 9.3: The ARF values derived as a function of rainfall duration and catchment area corresponding with T=25 years return period

ARF = a*[ln(D)]+**b**	**Coefficient "a" and "b" corresponding with catchment area**				
a	-0.0030	-0.0210	-0.0210	-0.0150	-0.0140
b	0.8806	0.8279	0.8073	0.7681	0.7370
Duration (D=hr.)	**ARF corresponding with catchment area (km2)**				
	300km^2	**600km^2**	**1000km^2**	**1500km^2**	**2000km^2**
0.25	0.885	0.857	0.836	0.789	0.756
0.50	0.883	0.842	0.822	0.778	0.747
1	0.881	0.828	0.807	0.768	0.737
3	0.877	0.805	0.784	0.752	0.722
6	0.875	0.790	0.770	0.741	0.712
12	0.873	0.776	0.755	0.731	0.702
24	0.871	0.761	0.741	0.720	0.693
48	0.869	0.747	0.726	0.710	0.683
72	0.868	0.738	0.717	0.704	0.677

Table 9.4: The ARF values derived as a function of rainfall duration and catchment area corresponding with T=20 years return period

ARF = a*[ln(D)]+**b**	**Coefficient "a" and "b" corresponding with catchment area**				
a	-0.0030	-0.0140	-0.0150	-0.0140	-0.0160
b	0.8896	0.8313	0.8120	0.7846	0.7517
Duration (D=hr.)	**ARF corresponding with catchment area (km2)**				
	300km^2	**600km^2**	**1000km^2**	**1500km^2**	**2000km^2**
0.25	0.894	0.851	0.833	0.804	0.774
0.50	0.892	0.841	0.822	0.794	0.763
1	0.890	0.831	0.812	0.785	0.752
3	0.886	0.816	0.796	0.769	0.734
6	0.884	0.806	0.785	0.760	0.723
12	0.882	0.797	0.775	0.750	0.712
24	0.880	0.787	0.764	0.740	0.701
48	0.878	0.777	0.754	0.730	0.690
72	0.877	0.771	0.748	0.725	0.683

Table 9.5: The ARF values derived as a function of rainfall duration and catchment area corresponding with *T*=10 years return period

ARF = a*[ln(D)]+b	**Coefficient “a” and “b” corresponding with catchment area**				
a	-0.0010	-0.0150	-0.0150	-0.0130	-0.0160
b	0.9197	0.8739	0.8522	0.8214	0.7874
Duration (D=hr.)	**ARF corresponding with catchment area (km2)**				
	300km^2	**600km^2**	**1000km^2**	**1500km^2**	**2000km^2**
0.25	0.921	0.895	0.873	0.839	0.810
0.50	0.920	0.884	0.863	0.830	0.798
1	0.920	0.874	0.852	0.821	0.787
3	0.919	0.857	0.836	0.807	0.770
6	0.918	0.847	0.825	0.798	0.759
12	0.917	0.837	0.815	0.789	0.748
24	0.917	0.826	0.805	0.780	0.737
48	0.916	0.816	0.794	0.771	0.725
72	0.915	0.810	0.788	0.766	0.719

Table 9.6: The ARF values derived as a function of rainfall duration and catchment area corresponding with *T*=5 years return period

ARF = a*[ln(D)]+b	**Coefficient “a” and “b” corresponding with catchment area**				
a	-0.0020	-0.0130	-0.0140	-0.0170	-0.0210
b	0.9490	0.9222	0.9120	0.8851	0.8639
Duration (D=hr.)	**ARF corresponding with catchment area (km2)**				
	300km^2	**600km^2**	**1000km^2**	**1500km^2**	**2000km^2**
0.25	0.952	0.940	0.931	0.909	0.893
0.50	0.950	0.931	0.922	0.897	0.878
1	0.949	0.922	0.912	0.885	0.864
3	0.947	0.908	0.897	0.866	0.841
6	0.945	0.899	0.887	0.855	0.826
12	0.944	0.890	0.877	0.843	0.812
24	0.943	0.881	0.868	0.831	0.797
48	0.941	0.872	0.858	0.819	0.783
72	0.940	0.867	0.852	0.812	0.774

Table 9.7: The ARF values derived as a function of rainfall duration and catchment area corresponding with T=2 years return period

ARF = a*[ln(D)]+**b**	**Coefficient "a" and "b" corresponding with catchment area**				
a	-0.0060	-0.0060	-0.0070	-0.0070	-0.0070
b	0.9709	0.9663	0.9634	0.9602	0.9553
Duration (D=hr.)	**ARF corresponding with catchment area (km2)**				
	300km^2	**600km^2**	**1000km^2**	**1500km^2**	**2000km^2**
0.25	0.979	0.975	0.973	0.970	0.965
0.50	0.975	0.970	0.968	0.965	0.960
1	0.971	0.966	0.963	0.960	0.955
3	0.964	0.960	0.956	0.953	0.948
6	0.960	0.956	0.951	0.948	0.943
12	0.956	0.951	0.946	0.943	0.938
24	0.952	0.947	0.941	0.938	0.933
48	0.948	0.943	0.936	0.933	0.928
72	0.945	0.941	0.933	0.930	0.925

Table 9.8: The ARF values derived as a function of catchment area and return period for rainfall duration of 0.25 hour

$ARF_{0.25}=aA^b$	**Coefficient "a" and "b" corresponding with ARI**						
a	1.0196	1.1542	1.3257	1.3487	1.3366	1.3691	1.4647
b	-0.007	-0.033	-0.063	-0.072	-0.073	-0.082	-0.100
Catchment Areas, A (km^2)	**Return Period, T (ARI)**						
	2	**5**	**10**	**20**	**25**	**50**	**100**
200	0.982	0.969	0.949	0.921	0.908	0.887	0.862
300	0.980	0.956	0.926	0.894	0.881	0.858	0.828
600	0.975	0.935	0.886	0.851	0.838	0.810	0.773
1000	0.971	0.919	0.858	0.820	0.807	0.777	0.734
1500	0.969	0.907	0.836	0.797	0.784	0.752	0.705
2000	0.967	0.898	0.821	0.780	0.767	0.734	0.685

Table 9.9: The ARF values derived as a function of catchment area and return period for rainfall duration of 0.50 hour

$ARF_{0.5}=aA^b$	Coefficient "a" and "b" corresponding with ARI						
a	1.0182	1.1993	1.3935	1.3653	1.3600	1.4070	1.4981
b	-0.007	-0.040	-0.071	-0.074	-0.077	-0.088	-0.106
Catchment Areas, A (km^2)	**Return Period, T (ARI)**						
	2	**5**	**10**	**20**	**25**	**50**	**100**
200	0.981	0.970	0.957	0.922	0.904	0.883	0.854
300	0.978	0.955	0.929	0.895	0.877	0.852	0.818
600	0.974	0.929	0.885	0.850	0.831	0.801	0.760
1000	0.970	0.910	0.853	0.819	0.799	0.766	0.720
1500	0.967	0.895	0.829	0.795	0.774	0.739	0.690
2000	0.965	0.885	0.812	0.778	0.757	0.721	0.669

Table 9.10: The ARF values derived as a function of catchment area and return period for rainfall duration of 1-hour

$ARF_{1.0}=aA^b$	Coefficient "a" and "b" corresponding with ARI						
a	1.0168	1.2470	1.4354	1.4256	1.4150	1.4469	1.5332
b	-0.008	-0.047	-0.077	-0.083	-0.084	-0.094	-0.111
Catchment Areas, A (km^2)	**Return Period, T (ARI)**						
	2	**5**	**10**	**20**	**25**	**50**	**100**
200	0.975	0.972	0.955	0.918	0.907	0.879	0.851
300	0.971	0.954	0.925	0.888	0.876	0.846	0.814
600	0.966	0.923	0.877	0.838	0.827	0.793	0.754
1000	0.962	0.901	0.843	0.804	0.792	0.756	0.712
1500	0.959	0.884	0.817	0.777	0.766	0.728	0.681
2000	0.957	0.872	0.799	0.759	0.747	0.708	0.659

Table 9.11: The ARF values derived as a function of catchment area and return period for rainfall duration of 3-hour

$ARF_3=aA^b$	**Coefficient "a" and "b" corresponding with ARI**						
a	1.0146	1.3287	1.5058	1.4919	1.5206	1.5146	1.5928
b	-0.009	-0.059	-0.087	-0.092	-0.097	-0.103	-0.120
Catchment Areas, A (km^2)	**Return Period, T (ARI)**						
	2	**5**	**10**	**20**	**25**	**50**	**100**
200	0.967	0.972	0.950	0.916	0.910	0.878	0.843
300	0.964	0.949	0.917	0.883	0.874	0.842	0.803
600	0.958	0.911	0.863	0.828	0.818	0.784	0.739
1000	0.953	0.884	0.826	0.790	0.778	0.744	0.695
1500	0.950	0.863	0.797	0.761	0.748	0.713	0.662
2000	0.948	0.849	0.777	0.741	0.727	0.692	0.640

Table 9.12: The ARF values derived as a function of catchment area and return period for rainfall duration of 6-hour

$ARF_6=aA^b$	**Coefficient "a" and "b" corresponding with ARI**						
a	1.0133	1.3844	1.5528	1.5363	1.5508	1.5603	1.6331
b	-0.009	-0.067	-0.093	-0.098	-0.102	-0.110	-0.126
Catchment Areas, A (km^2)	**Return Period, T (ARI)**						
	2	**5**	**10**	**20**	**25**	**50**	**100**
200	0.966	0.971	0.949	0.914	0.903	0.871	0.838
300	0.963	0.945	0.914	0.878	0.867	0.833	0.796
600	0.957	0.902	0.857	0.821	0.808	0.772	0.729
1000	0.952	0.871	0.817	0.781	0.767	0.730	0.684
1500	0.949	0.848	0.787	0.750	0.736	0.698	0.650
2000	0.946	0.832	0.766	0.729	0.714	0.676	0.627

Table 9.13: The ARF values derived as a function of catchment area and return period for rainfall duration of 12-hour

$ARF_{12}=aA^b$	**Coefficient “a” and “b” corresponding with ARI**						
a	1.0120	1.4436	1.6021	1.5830	1.5819	1.6087	1.6750
b	-0.010	-0.074	-0.099	-0.104	-0.107	-0.116	-0.132
Catchment Areas, A (km^2)	**Return Period, T (ARI)**						
	2	**5**	**10**	**20**	**25**	**50**	**100**
200	0.960	0.975	0.948	0.912	0.897	0.870	0.832
300	0.956	0.947	0.911	0.875	0.859	0.830	0.789
600	0.949	0.899	0.850	0.814	0.798	0.766	0.720
1000	0.944	0.866	0.809	0.772	0.755	0.722	0.673
1500	0.941	0.840	0.777	0.740	0.723	0.689	0.638
2000	0.938	0.823	0.755	0.718	0.701	0.666	0.614

Table 9.14: The ARF values derived as a function of catchment area and return period for rainfall duration of 24-hour

$ARF_{24}=aA^b$	**Coefficient “a” and “b” corresponding with ARI**						
a	1.0106	1.5067	1.6538	1.6320	1.6142	1.6599	1.7206
b	-0.010	-0.082	-0.105	-0.110	-0.112	-0.123	-0.138
Catchment Areas, A (km^2)	**Return Period, T (ARI)**						
	2	**5**	**10**	**20**	**25**	**50**	**100**
200	0.958	0.976	0.948	0.911	0.892	0.865	0.828
300	0.955	0.944	0.909	0.871	0.852	0.823	0.783
600	0.948	0.892	0.845	0.807	0.789	0.756	0.712
1000	0.943	0.855	0.801	0.763	0.745	0.710	0.663
1500	0.939	0.827	0.767	0.730	0.712	0.675	0.627
2000	0.937	0.808	0.745	0.707	0.689	0.652	0.603

Table 9.15: The ARF values derived as a function of catchment area and return period for rainfall duration of 48-hour

$ARF_{48}=aA^b$	**Coefficient “a” and “b” corresponding with ARI**						
a	1.0093	1.5739	1.7080	1.6836	1.6475	1.7141	1.7682
b	-0.011	-0.090	-0.111	-0.117	-0.117	-0.129	-0.145
Catchment Areas, A (km^2)	**Return Period, T (ARI)**						
	2	**5**	**10**	**20**	**25**	**50**	**100**
200	0.952	0.977	0.949	0.906	0.886	0.865	0.820
300	0.948	0.942	0.907	0.864	0.845	0.821	0.773
600	0.941	0.885	0.840	0.797	0.779	0.751	0.699
1000	0.935	0.845	0.793	0.750	0.734	0.703	0.649
1500	0.931	0.815	0.758	0.716	0.700	0.667	0.612
2000	0.928	0.794	0.735	0.692	0.677	0.643	0.587

Table 9.16: The ARF values derived as a function of catchment area and return period for rainfall duration of 72-hour

$ARF_{72}=aA^b$	**Coefficient “a” and “b” corresponding with ARI**						
a	1.0085	1.4984	1.7409	1.7150	1.6676	1.7472	1.7973
b	-0.011	-0.085	-0.115	-0.120	-0.120	-0.133	-0.149
Catchment Areas, A (km^2)	**Return Period, T (ARI)**						
	2	**5**	**10**	**20**	**25**	**50**	**100**
200	0.951	0.955	0.947	0.908	0.883	0.864	0.816
300	0.947	0.923	0.903	0.865	0.841	0.818	0.768
600	0.940	0.870	0.834	0.796	0.774	0.746	0.693
1000	0.935	0.833	0.787	0.749	0.728	0.697	0.642
1500	0.931	0.805	0.751	0.713	0.693	0.661	0.604
2000	0.928	0.785	0.726	0.689	0.670	0.636	0.579

Figure 9:4: The relationship graph of ARF values derived and rainfall duration associated with various catchment areas at 100 years return period

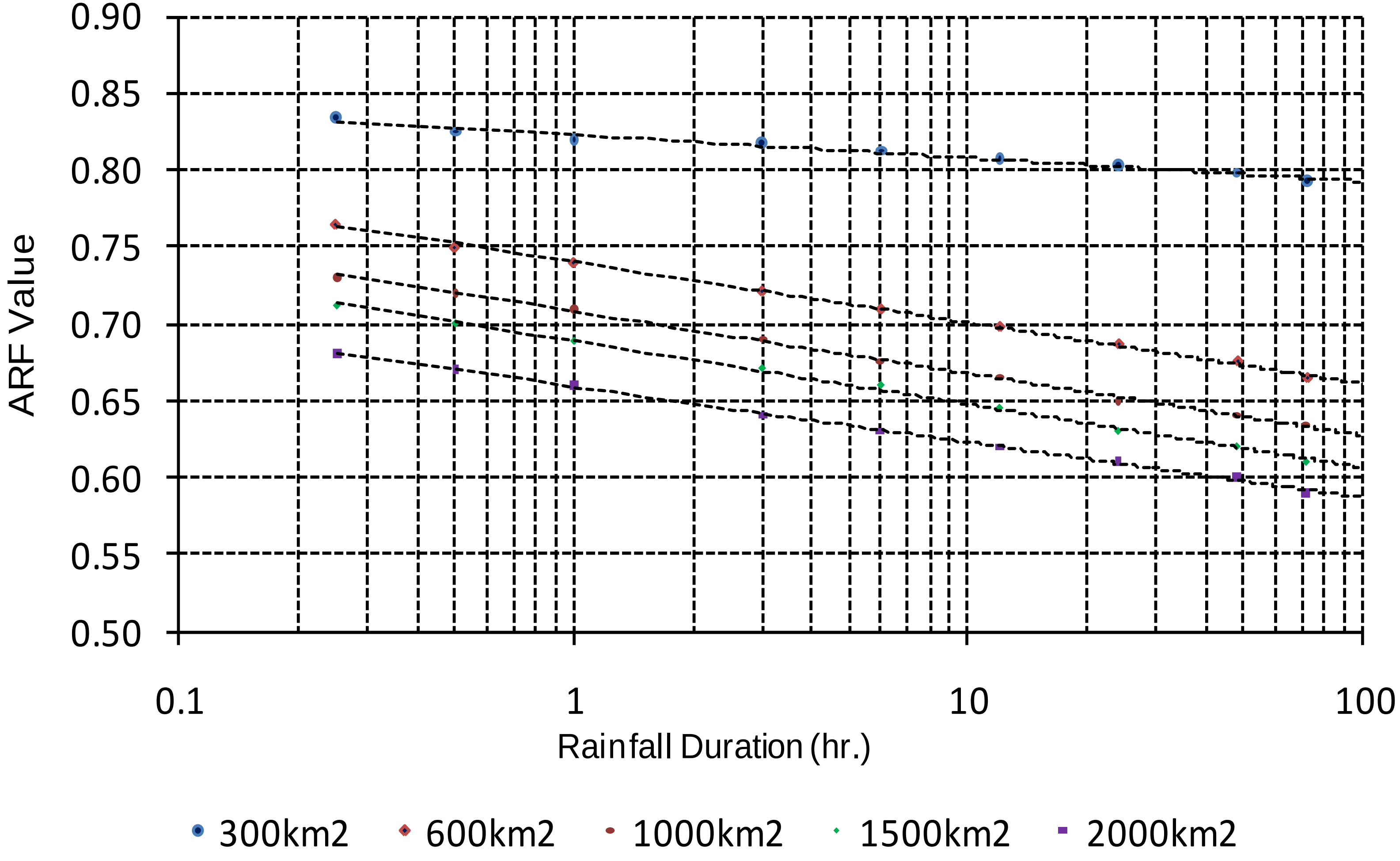
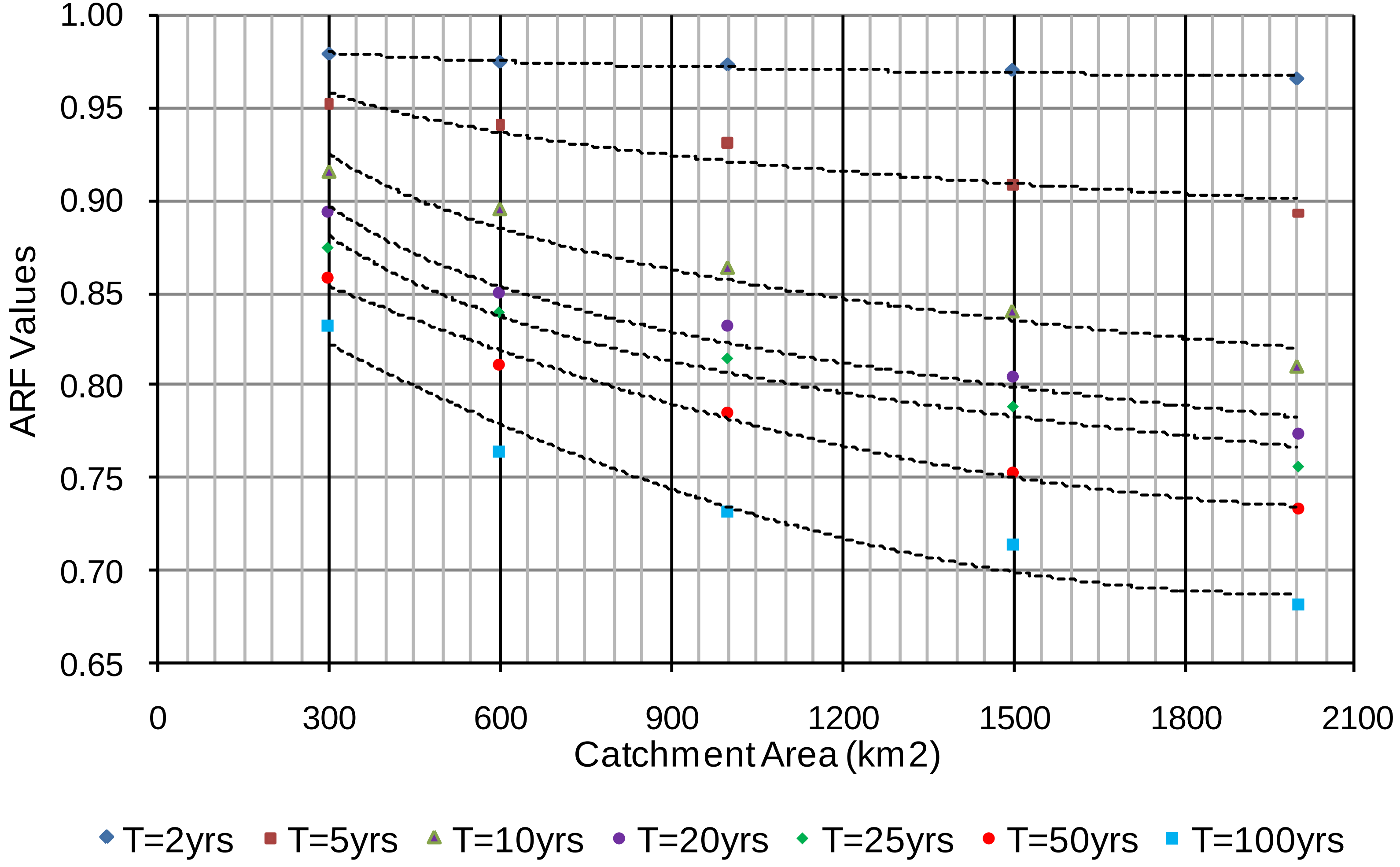


Figure 9:5: The relationship graph of ARF values derived and catchment area at various return periods for rainfall duration of 0.25 hour



10 SPECIAL CHAPTER: PRECIPITATION FACTOR IN DESIGN RAINSTORM IMPACTED BY CLIMATE CHANGE

10.1 Introduction: Climate Change Scenario

Climate change is already giving impact on water supplies and it will worsen in the future. As climates shifted and ocean temperatures warmed, precipitation patterns will become more seasonal and changed in both location and volume. Some areas that traditionally received predictable rainfall will see rain patterns shifts, altering runoff into rivers and reservoirs, and changing how or even if groundwater sources are recharged. In addition to these changes in water availability, climate change will impact water quality as key water-shaping ecosystems are lost or altered and the affects of pollution are amplified through both flood and drought cycles, and also cause sea level rise.

Concerning the attribution of the observed increase in global average temperatures since the mid-20th century, the AR4 states that this is “very likely due to observed increase in anthropogenic greenhouse gas concentrations” (IPCC, 2007). Most scientists expects the world will have warmer temperature and extreme rainfall.

The IPCC estimates that the global mean surface temperature has increased 0.74^{o}C (ranging from 0.56 to 0.92^{o}C) in between 1905 to 2005, and predicts an increase of 2 to 4.5^{o}C over the next 100 years. Temperature rise also affect the hydrologic cycle by directly increasing evaporation of available surface water and vegetation transpiration. Consequently, these changes can influence precipitation amounts, timings and intensity rates, and indirectly impact the flux and storage of water in surface and subsurface reservoirs (i.e., lakes, soil moisture and groundwater). In addition, there may be other associated impacts, such as sea water intrusion, water quality deterioration and potable water shortage.

These impacts will have profound consequences to the various sectors that act as income generators for the country. Changes in rainfall pattern will results in challenges related to water such as floods and drought, as has already been experienced, recently. As for Malaysia, we experienced more extreme weather events over the past few years.

For example, in December 2005, a widespread monsoon floods affect the northern states of Peninsular Malaysia, and in December 2006 and January 2007, an abnormal monsoonal rain resulted in massive unprecedented floods in Johor. The estimated total cost of these disasters is RM 1.5 billion, considered as the most costly flood in Malaysian history.

An analysis of temperature records in Malaysia shows the rate of mean surface temperature increase ranging from 0.6^oC to 1.2^oC per 50 years, consistent with global temperature trends [MMD, 2009]. Under the doubling of atmospheric CO_2, the mean temperature in Malaysia is projected to rise in the range of 1.5ºC to 2.0ºC, and rainfall is to change in the range of -6% to +11% [NAHRIM, 2006]. Data on sea level rise collected over a 20 year period (1986-2006) from an area at the southern tip of the Peninsular Malaysia showed an increase of 1.3 mm/year.

Rainfall intensity for year 2000 to 2007 which has been observed at DID Rainfall Station in Ampang showed that it exceeds the amount observed in year 1971 to 1980 which has been recorded as the previous highest record. An increase in annual maximum rainfall of 17 percent to 112mm/hour and 29 percent to 133mm/hour compared to the 1970s values has been recorded for 1 hour and 3 hour intensity respectively.

A study that has been carried out indicate a possible increase in inter-annual and intra-seasonal variability with increased hydrologic extremes (higher high flows and lower low flows) at various northern watersheds in the future (2025–2034 and 2041-2050).

Annual rainfall will also be affected with an increase in North East region and a small decrease over the Centre West Coast and Southern Regions of the peninsula. A uniform increase in air temperature will happen in 2050 by about 1.5ºC to 2.0^oC over all regions of Peninsular Malaysia, Sabah and Sarawak.

The probability of increase in rainfall would lead to a raise in river flow between 11 percent and 47 percent for Peninsular Malaysia with low flow reductions ranging from 31 percent to 93 percent for the central and southern regions [NAHRIM, 2006]. Parts of Malaysia may experience a decrease in return period for extreme precipitation events and the possibility of more frequent floods as well as drought.

10.2 Problem Statement

The design of infrastructure system and components is based upon conditions defined by historical climate data in addition to operation performance goals. Mounting evidence suggests that climate has changed, and will continue to change, creating situations where typical climate design ranges for a given location are no longer representative. Expanded climate ranges and increased frequency of extreme weather events have the potential to create vulnerability in the performance of engineered systems due to insufficient design capacity.

However, quite often practitioners and engineers have faced a difficult situation when giving consideration in the face of climate change uncertainty particularly for flood mitigation planning. A range of uncertainties implicate adaptation measures by planners. They are concerned that anticipating and adapting to a smaller change than one which actually occurs could result in costly impacts and endanger lives (e.g. bund overtopping or failure), yet adapting to too large a change could be financially wasteful.

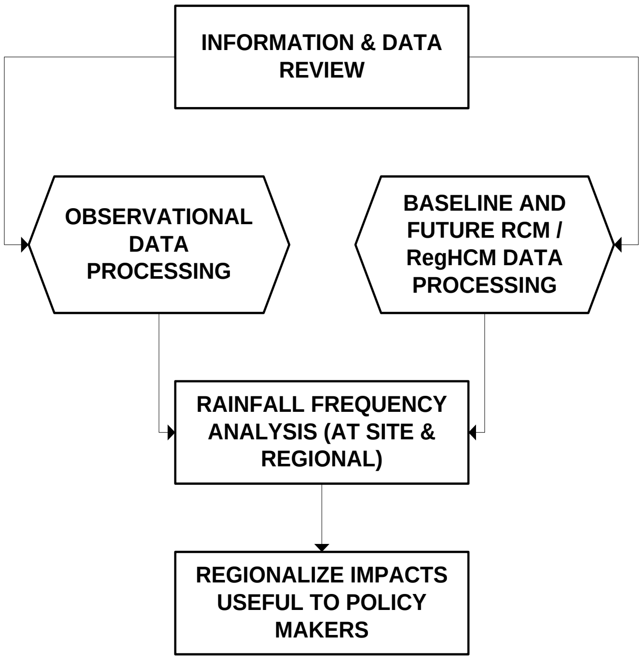


Figure 10:1: Approach to determination of climate change impacts on extreme rainfall

Therefore, in order to minimise the impact and to improve the design uncertainty, they may need to impose the so called climate change (precipitation) factor into design procedure particularly for updating intensity-duration-frequency (IDF) curve. As for an example of design rainstorm, an event which currently has a return period of 1 in 20 years might have a return period of 1 in 10 years by the 2050s.

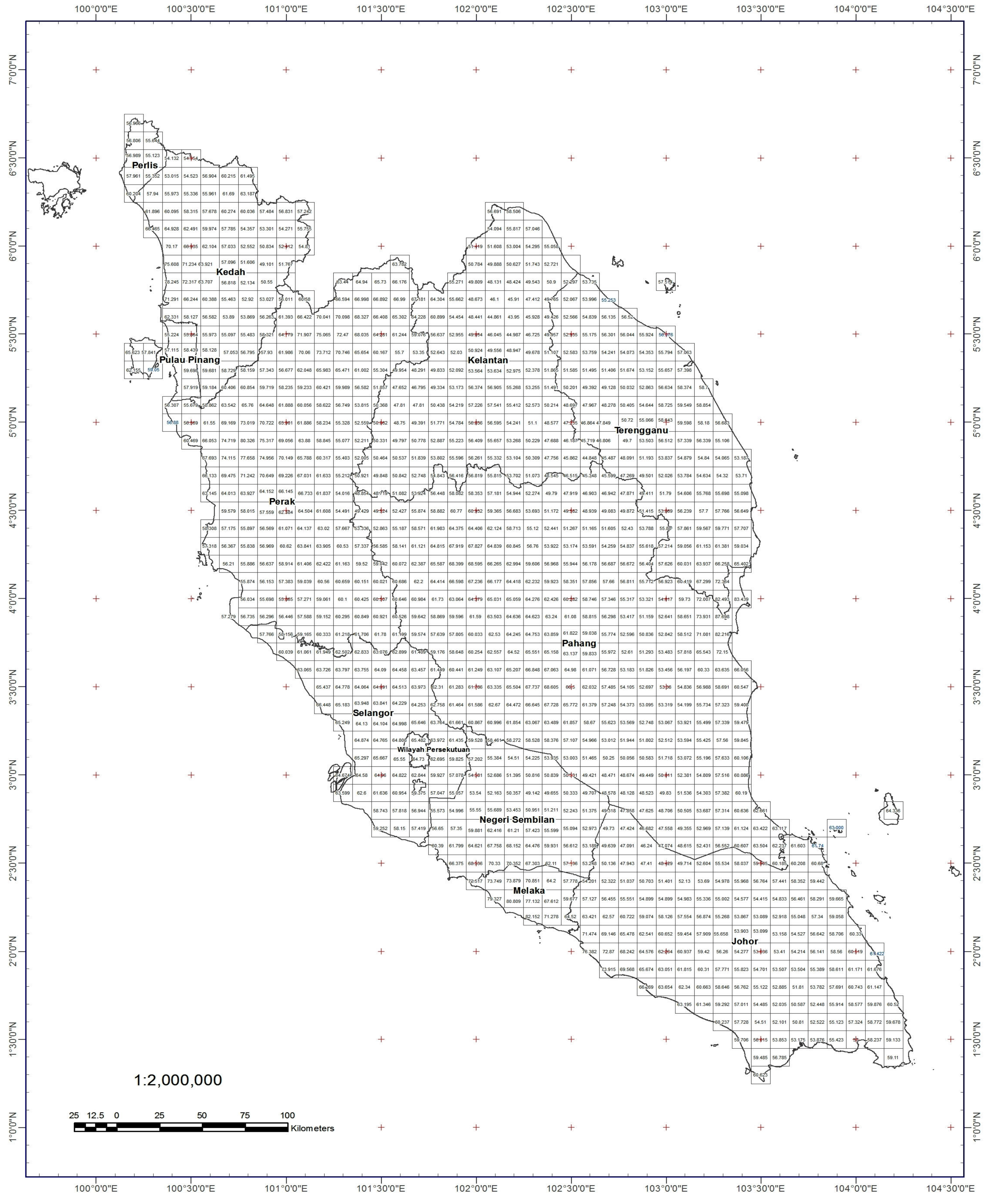
Due to this reason, it is recommended to use output based on Regional Climate Model (RCM) and Regional Hydroclimate Model (RegHCM) to update IDF curves under climate change to assist planners and engineers in better decision making. However, this process will need much time particularly for retrieving RCM and RegHCM data output. An overview of the suggested approach is provided in Figure 10:1.

10.3 Precipitation Factor: Interim Recommendation

As for interim solution, it is suggested that for each IDF curves or design rainstorm derived from raingauged station, an upper confidence level by means of a normal distribution of 5% and 95% quantiles of the sampling distribution which is denoted as UCL should be incorporated. Full explanation on this procedure can be obtained in Chapter 4.3. In summary, the design rainstorm of about 815 rainfall stations (188 nos. of automatic and 627 nos. of daily) has been equipped with the value of UCL, so that planners, practitioners and engineers can make a better decision making in their planning and design. The derived design UCL can be obtained in Volume II of the report.

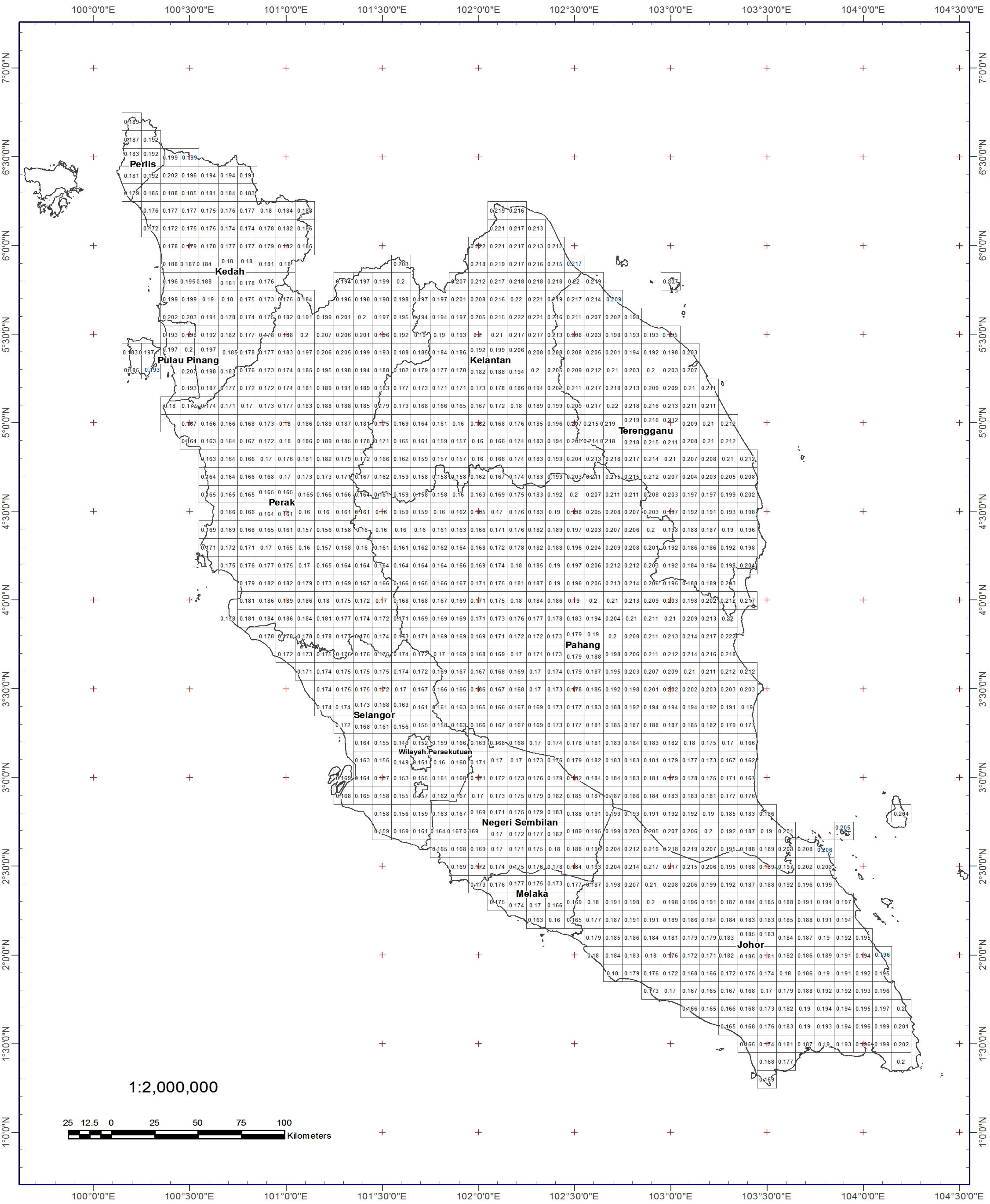
11 APPENDIX 1 – ISOPLETHS MAP OF IDF PARAMETER

FIGURE 11:1: IDF PARAMETER OF λ



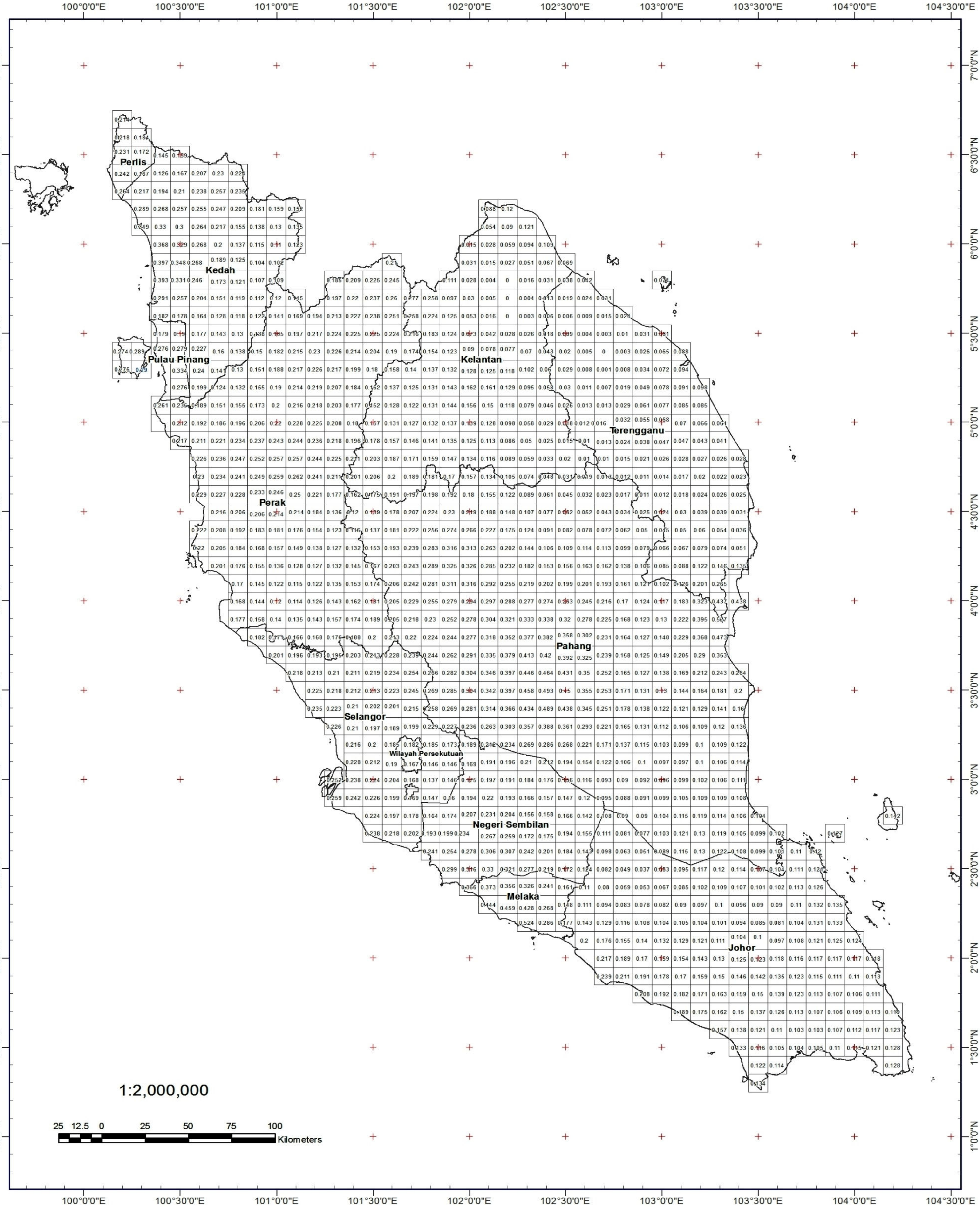
11 APPENDIX 1 - ISOPLETHS MAP OF IDF PARAMETER

FIGURE 11.2: IDF PARAMETER OF κ



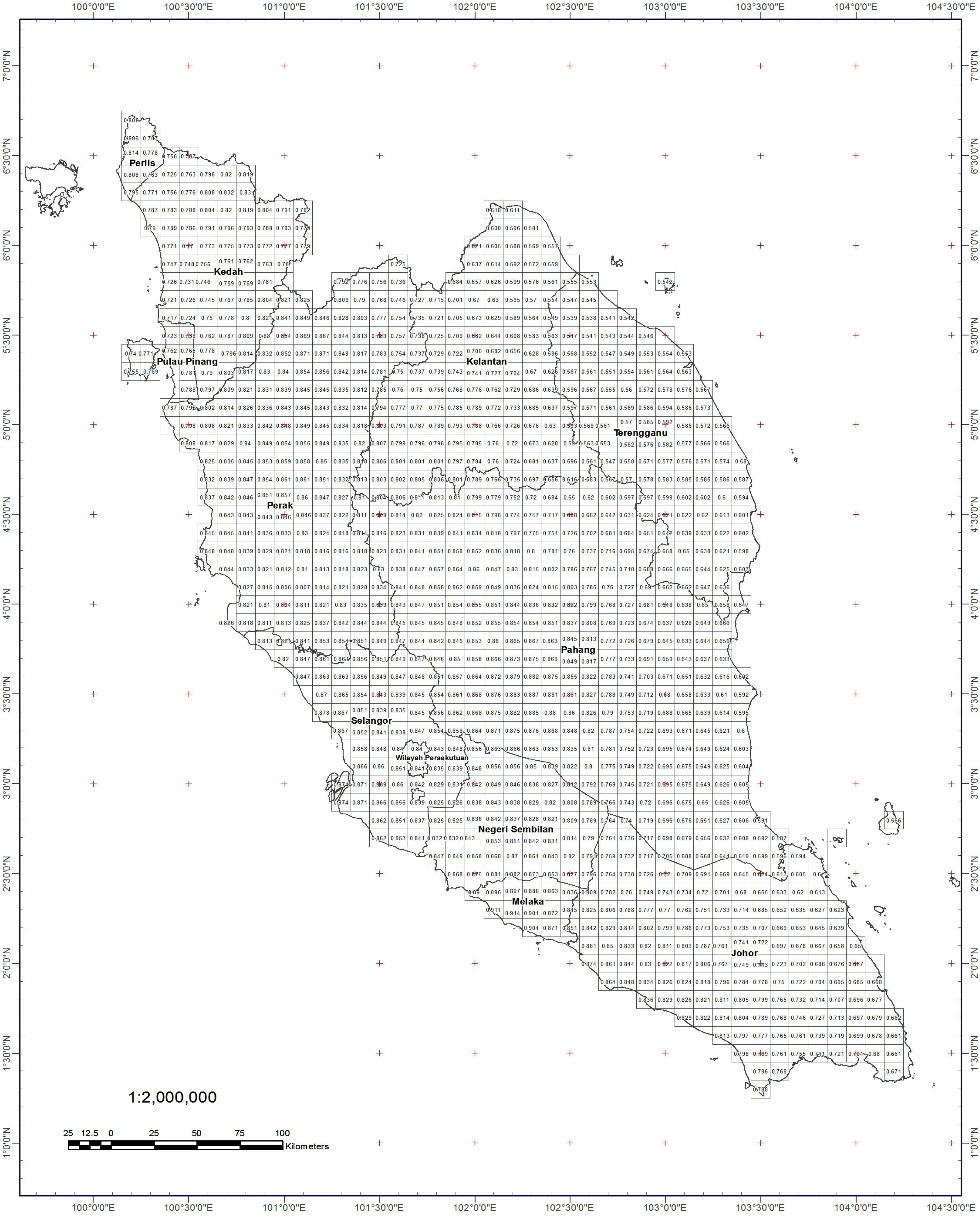
11 APPENDIX 1 - ISOPLETHS MAP OF IDF PARAMETER

FIGURE 11.3: IDF PARAMETER OF θ



11 APPENDIX 1 - ISOPLETHS MAP OF IDF PARAMETER

FIGURE 11.4: IDF PARAMETER OF η



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