# ASSESSMENT VARIABILITY OF ANNUAL DAILY MAXIMUM RAINFALL OF JOHOR, MALAYSIA 

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# ASSESSMENT VARIABILITY OF ANNUAL DAILY MAXIMUM RAINFALL OF JOHOR, MALAYSIA 

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Thesis submitted in partial fulfilment of the requirements for award of the degree of Bachelor of Civil Engineering (Hons)

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## DEDICATION

My humble efforts are dedicated to my parents

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#### Abstract

Floods generally occur in the main settlements in Johor. Flood happened in Johor generally is characterised by the yearly alternation of Southwest and Northeast monsoons. Floods have caused roads and connection between towns cut off. This problem makes it harder for emergency teams to deliver aids quickly. This paper deals with the assessment variability of annual daily maximum rainfall of Johor area. Daily rainfall data were collected from daily satellite image, Tropical Rainfall Measuring Mission (TRMM) for 16 years (1998-2013). Descriptive statistical analysis was conducted for the three types of data i) annual rainfall ii) annual monthly maximum rainfall and iii) annual daily maximum rainfall. Gumbel distribution function was applied to estimate extreme rainfall events' return period and found that annual daily maximum for Kluang, the city with the highest rainfall equal or greater than 535 mm had a return period of 100 years. The outcomes of this paper can be used to know the estimated rainfall depth of maximum rainfall in Johor Bahru and can be used in understanding rainfall patterns in different parts of cities in Johor. On top of that, we can have better planning of infrastructures for mitigation to cater the predicted high rainfall intensity.


#### Abstract

ABSTRAK

Banjir biasanya berlaku di kawasan penempatan utama di Johor. Banjir berlaku di Johor umumnya adalah semasa peralihan antara monsun Barat Daya dan Timur Laut. Banjir telah menyebabkan jalan raya dan hubungan antara bandar-bandar terputus. Masalah ini menyukarkan pasukan kecemasan untuk menyampaikan bantuan dengan segera ke kawasan-kawasan tersebut. Objektif kajian adalah untuk menilai kepelbagaian curahan hujan maksimum tahunan harian di Johor. Data curahan hujan harian imej satelit Tropical Rainfall Measuring Mission (TRMM) bagi tempoh selama 16 tahun (19982013) dimuat turun dari pangkalan data domain awam. Analisis statistik deskriptif telah dijalankan untuk tiga jenis data i) hujan tahunan ii) hujan tahunan maksimum bulanan dan iii) hujan maksimum harian tahunan. Fungsi taburan Gumbel digunakan untuk menganggarkan tempoh masa peristiwa hujan luar biasa dan mendapati bahawa maksimum harian tahunan bagi Kluang, bandar dengan hujan yang paling tinggi mempunyai tempoh ulangan 100 tahun untuk kedalaman hujan yang sama atau lebih daripada 535 mm . Hasil kajian ini boleh digunakan untuk mengetahui anggaran kedalaman hujan maksimum di Johor dan boleh digunakan untuk memahami corak taburan hujan pada bahagian yang berlainan di bandar-bandar sekitar Johor. Selain itu, perancangan yang lebih baik untuk infrastruktur boleh diaplikasikan untuk tujuan mitigasi bagi menampung keamatan hujan yang tinggi pada masa akan datang.


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## LIST OF SYMBOLS

Annual daily maximum rainfall
Mean of observed annual daily maximum rainfall

Standard deviation of observed annual daily maximum rainfall

## LIST OF ABBREVIATIONS

| TRMM | Tropical Rainfall Measuring Mission |
| :--- | :--- |
| DID | Department of Irrigation and Drainage Malaysia |
| FRMP | Flood Risk Management Planning |
| NFRA | National Food Reserve Agency |
| IPCC | Intergovernmental Panel on Climate Change |
| MMD | Malaysian Meteorological Department |
| ENSO | Southern Oscillation phenomenon |
| GIS | Geographical Information System |
| RS | Remote sensing |

## CHAPTER 1

## INTRODUCTION

### 1.1 INTRODUCTION

Malaysia has experienced series of floods since 1920s and one of the severest is the December 2006 and January 2007 floods (Tompkins, Lemos, \& Boyd, 2008). Most floods that occur are as natural result of cyclical monsoons as Malaysia is located in the South East Asia with seasonal monsoons of Southwest and Northeast Monsoons. In December 2006 and January 2007, the Northeast Monsoon had brings heavy rain through series of continuous extreme rainfall that caused destructive floods in the southern region of Peninsular Malaysia particularly to Johor. The storms had occurred in two separate phases in late December 2006 and early January 2007 with a total precipitation in four days exceeding twice of the monthly rainfall in which some places recorded a higher number. Extreme rainfall events are among the most disruptive natural phenomena occurred in Malaysia caused by climate change. In the case of extreme rainfall events, they adversely affect urban populations because the infrastructures are often inadequate to accommodate flooding.


Figure 1.1: Flood in Segamat

Source: abushahid.wordpress.com (2015)

Johor on the other hand has faced a number of severe floods over several past years and its vulnerability to these resulted from the rapid urban development of the Johor. The impacts of river flooding are even more damaging and interrupt economic activities and the livelihoods of people in the area. Severe flooding that generally occur in the main settlements in Johor had occurred in 2006 and 2007. Heavy rain and overflowing rivers have flooded hundreds of towns and villages in Southern Malaysia. The floods took many lives as well as destroyed crops and cut off roads, power lines and rail services. (The Star Archive, 2006).


Figure 1.2: Road cut off due to flooding

Source: media.straitstimes.com (2015)

In certain parts of the city, flooding due to excessive rainfall can be a severe problem as the water is inundated for several days due to drainage congestion and the pumping facilities to remove the stagnant water are insufficient. The roads that were cut off hardens the situation as this makes it difficult to deliver aids quickly to the flood areas The water depths in some areas are very high, which creates large infrastructure problems for the city and can bring damage to existing property and goods.

### 1.2 PROBLEM STATEMENT

In Johor, many infrastructures like roads and highways were submerged due to flooding even though the design of hydraulic structures has taken into account the extreme rainfall depth. The existing system of drainage and infrastructures were designed based on historical rainfall data, but the capacity of the drainage network will not be sufficient enough with high intensive short duration rainfall which is expected to change due to global climate alteration.

Thus, it is important that any drainage structure to be designed and constructed in Johor should be resilient to the latest extreme rainfall events happened to cater the predicted maximum rainfall intensity.

### 1.3 OBJECTIVES

The main objective of this study was to assess the variability of annual daily maximum rainfall of Johor, Malaysia. And the specific objectives are:
i. To obtain daily satellite-based rainfall data for Johor area.
ii. To analyse annual rainfall, annual monthly maximum, and annual daily maximum rainfall data

### 1.4 SCOPE OF STUDY

The scope of the work for this research are divided into four parts which are area of study, the study period, the source of data and the data analysis. The study area is Johor which located in the Southern part of Peninsular Malaysia. The specific study areas that being selected are major cities inside Johor state which are Johor Bahru, Pontian, Kota Tinggi, Mersing, Batu Pahat, Muar, Segamat, and Kluang.


Figure 1.3: Specific study areas in Johor

The study period for this research is 16 years (January 1998 - December 2013). The source of data being used in this study is collected from Tropical Rainfall Measuring Mission (TRMM) which is a research satellite to study rainfall for weather and climate research.

On top of that, the methods used for data analysis are descriptive statistics and Gumbel distribution function. Descriptive statistics is used to determine central tendency (mean, median, and mode) and variability (standard deviation) of rainfall data that were collected. Besides, Gumbel distribution function is used to analyse return period of annual daily maximum rainfall.

### 1.5 SIGNIFICANCE OF STUDY

Based on the statistical analysis that has been carried out on daily rainfall data, the maximum and minimum rainfall for every city can be determined. Thus, it can be used to have better understanding on rainfall patterns in different parts of cities in Johor.

The proposed return period of annual daily maximum rainfall in this study can be used to plan the infrastructures and drainage network. The outcomes of this paper can be used to upgrade the capacities of hydraulic structures in Johor area to cater the predicted high rainfall intensity. On top of that, the forecasted extreme rainfall events can also help in making early preparation for flood and determining future flood risk

### 1.6 THESIS STRUCTURE

This research comprises of five chapters. The first chapter consists of introduction section. It states the background, problem statement, objectives of study, scope of study and lastly the significant of study. For chapter two, the key terms inpurpose for this research are described and also the literature review that related and suitable for this research. Chapter three explains the research methodology for research data collected and the method of data analysis to be employed. For chapter four, the results obtained from study area and year of study were presented and the analysis from the result was discussed. Finally, chapter five comprises the conclusion from the overall chapter and relates some recommendations for future work on research field.

## CHAPTER 2

## LITERATURE REVIEW

### 2.1 INTRODUCTION

The most destructive natural disaster experienced in Malaysia is flood. Flooding is a natural disaster caused by climatological factors or climatic factors such as temperature, rainfall, evaporation, wind movement and the nature of the earth (Balek, 1977). Throughout Malaysia, including Sabah and Sarawak, there is total of 189 river basins with the main channels flowing directly to the South China Sea and 85 of them are prone to recurrent flooding (89 of the river basins are in Peninsula Malaysia, 78 in Sabah and 22 in Sarawak). The estimated area vulnerable to flood disaster is approximately $29,800 \mathrm{~km}^{2}$ or $9 \%$ of the total Malaysia area, and is affecting almost 4.82 million people which is around $22 \%$ of the total population of the country (DID, 2009). A flood can be defined as any high water flow that control over the natural or artificial banks in any part of the river system. Therefore, when a river bank is overflowing, it will generally become hazard to the society as the water extends over the flood plain (Ching et al., 2013).

### 2.1.1 Flood in Malaysia

In Malaysia, floods and flash floods happen especially in the East Coast during the monsoon season. Increased frequency of flooding in the country occur either naturally or due to changes in monsoon corresponding to the increase in the urban areas(Chan 1996; Rose \& Peters, 2001). Flooding is usually caused either by continuous rain by greater amounts than normal or overflow of river water to river banks or from both situations (Balkema et al. 1993; Schulz et al. 1972).Significant flood events that had happened in Malaysia occurred in 2006 and 2007. They had caused millions of lost and damages in four states namely Negeri Sembilan, Melaka, Pahang and Johor. Recurrent flooding that occurred will increase the shallowness of riverbed at downstream areas (Bradley \& Potter, 1992). Municipal buildings that were built on the clay that is impermeable, quickly saturated and less absorb water will cause water to spill over the banks of the river quickly in case of heavy rain (Smith \& Ward, 1998). Bank erosion which affects the thickness of sediment in the river also contributes to flooding (Ward \& Trimble, 2004). When floods occurred, it has terrible impacts on people as it disrupts their daily activities and the impacts can last for a week or a year, climate change is likely to make the situation even more challenging (NFRA, 2011). No matter how hard a government or society tried to minimize or to stop it completely, flooding is a natural event and it's more likely to occur naturally (FRMP 2012).

### 2.2 HYDROLOGICAL CYCLE

Hydrological cycle can be interpreted as a set of water fluxes (hydrological processes), which transfer water between reservoirs in the geosphere (hydrosphere proper - oceans, seas, lakes, rivers, wetlands, and marshes; cryosphere - ice and snow; lithosphere - groundwater, water in rocks, and Earth crust; and atmosphere - clouds) and biosphere (water contained in living organisms, plants and animals).

Water moves from one reservoir to another by processes like evaporation, condensation, precipitation, deposition, runoff, infiltration, sublimation, transpiration, melting, and groundwater flow. The oceans supply most of the evaporated water found in the atmosphere. Of this evaporated water, only $91 \%$ of it is returned to the ocean basins by way of precipitation


Figure 2.1: Hydrologic Cycle.

Adapted from: PhysicalGeography.net

Hydrologic cycle as the key external driver of the water cycle is accelerating due to climate change. Projected increases in global temperatures are associated with changes in the hydrologic cycle, including changes in precipitation patterns (frequency and intensity), increased atmospheric water vapour, as well as changes in groundwater and soil moisture. These changes are often referred to as an intensification and acceleration of the hydrologic cycle.

The next table summarizes the observed trends and projections for the $21^{\text {st }}$ century of key hydrologic variables. The result of hydrologic change and increased variability is shorter periods of more intense rainfall, and longer warmer dryer periods.

Table 2.1: Observed trends and projections for the 21st century of key hydrologic variables

| Key Variables | Observed Trends | Projections for 21st <br> Century |
| :--- | :--- | :--- |
| Obecipitation | Trend is unclear. General <br> increases in precipitation <br> over land from $30^{\circ}$ <br> N to $85^{\circ} \mathrm{N}$. Notable <br> decreases from $10^{\circ} \mathrm{S}$ to <br> $30^{\circ} \mathrm{N}$. | Increase (about 2\% $/{ }^{\circ} \mathrm{C}$ ) in <br> total precipitation. High <br> latitude areas generally <br> projected to increase. Many <br> low to mid- latitude areas <br> projected to decrease. |
| Atmospheric water vapour | Increasing in lower <br> atmosphere (lower <br> content | Increasing <br> $1 \% /$ troposphere; about in specific <br> humidity; little change in <br> relative humidity <br> Disproportionate |

Adapted from: IPCC, 2007a; National Centre for Atmospheric
Research. Personal Communication.

### 2.3 RAINFALL TYPE

Precipitation can be classified into three main types according to the air lifting mechanism which are convectional, orographic, and frontal or cyclonic precipitation


Figure 2.2: Illustration of convectional, orographic, and cyclonic rain

Source: www.nirmancare.com (2015)

### 2.3.1 Convectional rainfall

Convectional rain is caused by the rising of moist air following its contact with surface of the earth. It forms thunder clouds or cumulonimbus s it reaches the condensation level. This types of rain overcast skies and bring heavy downpour that last between one to two hours accompanied by strong winds and sometimes flash floods. Convectively driven storms like tropical cyclones will bring intense precipitation. Wet monsoons usually bring this convective rain which form continuous, heavy rain in the area affected while high intensities convectional rains happened during inter monsoon period.

### 2.3.2 Orographic Rainfall

Orographic rain falls mainly along the windward side of mountains, notably the Titiwangsa Range that forms the backbone of Peninsular Malaysia. Orographic rain also poured its fair share on the highlands in Sabah and Sarawak of which is spilled by water laden clouds as they rise above the condensation level in the attempt to cross over a mountain.

### 2.3.3 Cyclonic Rainfall

Cyclonic rainfall, which can pour continuously for days on end, is one of the major causes of floods in Malaysia. Most of it falls during the Northeast monsoon period and covers a wide area along the east coast of Peninsular Malaysia as well as coastal areas in Sarawak. It is caused by the collision between the easterly and the westerly trade winds that results in the ascension of moist air into the atmosphere and condenses into rain.

### 2.4 SPATIAL AND TEMPORAL RAINFALL VARIABILITY

Understanding the spatial and temporal of rainfall variability is a crucial element in gaining knowledge on water balance dynamics on various scales for water resources planning and management. Peninsular Malaysia lacks of detailed quantitative studies mostly because of the limited number of stations with long records and the problem of missing data (Moten, 1993). Most studies were conducted in the 1980s and 1990s. Nieuwolt (1982) who studied agro climatic study introduced a simple method to quantify rainfall variability over time and related the results to agriculture.

The temporal and spatial characteristics of rainfall have been investigated, but often restricted to small catchments, e.g. an urbanized area (Desa and Niemczynowicz, 1996) and a forested catchment (Noguchi and Nik, 1996). Annual rainfall maps are derived by
the Economic Planning Unit (1999) from the data of monthly long-term records (19501990). These maps are only able to show us the spatial distribution of rainfall in the country instead of variable rainfall patterns over time. Some efforts have also been made during year 2000 to study the formation and occurrence of rainfall and extreme rainfall events in the region. For example, the synoptic scale disturbances over the South China Sea vicinity were investigated by (Chang, Harr, \& Chen, 2005), and the relation between Malaysian rainfall anomalies, sea surface temperature and El Nino-Southern Oscillation were studied by Tangang and Juneng on 2004, 2005 and 2007.

Seasonal periodicity of large-scale atmospheric circulation and the distribution of warm and cold sea currents determine the temporal variation of precipitation on large spatial scale. Trade winds and monsoons play an important role in this variation. For example, the zone of equatorial monsoons is distinguished by wet and dry seasons. In temperate zones, the cyclones that form over the oceans influenced the temporal variation of precipitation. Short-time variation of precipitation is mainly a result of diurnal changes in solar radiance and front passages or cyclonic storms.

### 2.4.1 Variability of Rainfall in Malaysia

Peninsular Malaysia is located between $1^{\circ}$ and $7^{\circ}$ north and $99^{\circ}$ to $105^{\circ}$ east, and comprises an area of 131587 km 2 . It is comprised of highland, floodplain and coastal zones. The Titiwangsa mountain range forms the backbone of the Peninsula, from15 southern Thailand running approximately south-southeast over a distance of 480 km and separating the eastern part from the western part (Suhaila \& Jemain, 2009). The precipitation climate is characterized by two rainy seasons which are the Southwest Monsoon (SWM) from May to September and the Northeast Monsoon (NEM) from November to March (Camerlengo \& Demmler, 1997; Suhaila \& Jemain, 2012; Tangang, 2001).

Significant rainfall also occurs in the transitional periods (usually in April and October) between the monsoon seasons (Suhaila \& Jemain, 2007).

Rainfall pattern of Peninsular Malaysia is highly variable in time and space (Dale, 1959; Ahmad et al, 2013). Thus, Dale(1959) divided Peninsular Malaysia into five rainfall regions with typical patterns of rainfall, which West Coast was divided into four region (North West Malaya, West Malaya, Port Dickson-Muar Coast and South West Malaya), and East Malaysia, Ahmad et al (2013). Johor has the longest coast of Peninsular Malaysia, with 400 km in the east and west coasts of the peninsula. This contributes to different the rainfall patterns from city to city according to their geographical condition. The cities that located near the coastal area will more likely to have more rainfall than others

### 2.5 CLIMATE CHANGE EFFECTS

Warming of the global climate system is undeniable (Solomon et al., 2007). Global warming is unquestionable and it happened very likely due to the increase in atmospheric greenhouse gas concentrations. This greenhouse effect has changed the climate mostly in global mean precipitation and evaporation but there is no statistically significant linear long-term trend in the time series of global precipitation in the period from 1900 to 2005 (Bengtsson, 2010). Thus, precipitation is the essential driver to control the effect of climate change on streamflow, lake levels and groundwater recharge.

Since water vapour is the dominant greenhouse gas which accounts for around $75 \%$ of the total greenhouse effect on Earth, it can contribute to the warming of the climate system by some $24^{\circ} \mathrm{C}$ (Kondratev 1972). As the amount of available water vapour is increasing in a warmer climate, latent-heat-driven weather systems such as tropical cyclones that are driven by organized convection will become more intensive as well.

So in general, the large increase in water vapour in a warmer climate might not only alter the structure of precipitation events but also the statistical distribution of weather systems driven by release of latent heat in most identical way.

### 2.5.1: Extreme Precipitation Events due to Climate Change

There was an overall increase in global mean land precipitation, until the 1950s, with peaks in 1950s and then in 1970s, a decline from 1970s until the early 1990s and a recovery subsequently. The large increase in extreme precipitation is likely to occur due to this climate change and it will lead to serious consequences. The change in the time distribution of precipitation intensity will reduce the probability of the return period of extreme events. Thus, the patterns of precipitation change will change drastically spatially and temporally over the globe.

Corresponding to rainfall variability, more intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. The frequency of heavy precipitation events has increased over most land areas (Solomon et al., 2007). As summarized by Bengtsson, long-term precipitation trends have been tracked in many large regions where data available is sufficient. Precipitation has generally increased over land in most areas of higher latitudes of Northern Hemisphere (north of $30^{\circ} \mathrm{N}$ ), and in the eastern part of North and South America. Then, it decreased from $30^{\circ} \mathrm{N}$ to $10^{\circ} \mathrm{S}$, mostly after 1977 , as well as in South Africa. The frequency of heavy precipitation and the maximum number of consecutive days without precipitation are projected to increase in the future (Parry, Canziani, Palutikof, van der Linden, \& Hanson, 2007). This would eventually happen for some regions where the mean precipitation is projected to decrease.

### 2.5.2 Extreme Rainfall Event in Johor

In the period of 19-31 December, 2006 and 12-17 January, 2007; Peninsular Malaysia has suffered by series of flood events with high rainfall recorded generated by Northeast Monsoon that caused severe floods in a few states located in the lower half of the Peninsular. In December 2006 and January 2007 flood events, more than 100,000 victims had been affected in two separate events. It is normal for the lower East Coast area to receive such heavy rains during the monsoon season, but the December 2006 and January 2007 storms brought extremely high rains to most Johor towns and districts especially Kota Tinggi. Kota Tinggi started to receive heavy, widespread rain from the period of five continuous days starting on the 17th to 21 st December 2006. Due to the low lying area of the Kota Tinggi town, the heavy, continuous rainfall had caused the water in the river to rise rapidly and started up to fill up the floodplain area. The inundation period lasted about 13 days and the number of victims in Kota Tinggi was approximately 5,243 people (Atikah S, 2009).

### 2.5.3 The Effects of Monsoon on Rainfall Variability

The origin of the expression monsoon is Arabic and means "season". This expression has been used by the sea men about several centuries ago to describe the semi-annual reversal in the winds over the Arabian Sea (Chao \& Chen, 2001).

Due to seasonal prevailing winds, the variability of rainfall in Peninsular Malaysia can be characterised by three seasons. From November to January, the east coast area will have maximum rainfall while June and July are the driest months of most areas. However, from May to August, the southwest coastal is much affected by early morning "Sumatras". Maximum rainfall occurs on October and November mostly while February is the month with minimum rainfall.

Table 2.2: Monsoon regimes in Malaysia

| monsoon | Period | Characteristics |
| :--- | :--- | :--- |
| Northeast | November - March | Winds 10-20 knots up to 30 <br> knots during cold surges <br> period affecting east coast <br> area. Heavy rainfall |
| Inter-monsoon | April - May <br> October - November <br> Southwest | Frequent period of <br> thunderstorm in afternoon <br> and evening hours with <br> heavy rainfall causing flash <br> flood |
|  | Winds below 15 knots <br> affecting west coast area. <br> Drier weather. |  |

Source: MMD

The rest of Peninsula has two distinct periods of maximum rainfall separated by two periods of minimum rainfall. The primary maximum rainfall usually occurs in October to November while the secondary maximum usually occurs in April to May. Over the northwest region, the primary minimum occurs in January to February with the secondary minimum in June to July. Elsewhere, the primary minimum occurs in June to July with the secondary minimum in February.(Chao \& Chen, 2001)


1
Low pressure area and cyclone vortex from Nov-Jan in Equator

2 High pressure air brings prevailing winds from Russia/China when the condition is favorable

Strong winds occurred
simultaneously in West
Pacific Ocean and South China Sea, both crossing path near the low pressure area in Peninsular Malaysia

4
Cumulonimbus clouds was formed with widespread heavy rainfall and rough seas occur usually in the East Coast

Figure 2.3: Heavy rains caused by monsoons

Source: MMD, 2007

The Northeast monsoon winds are much weaker than the Southwest monsoon winds in the Arabian Sea. The reverse is true in the South China Sea. Turbulence produced by strong winds mixes down the momentum input throughout the entire mixed layer (Niiler and Krauss, 1977). This is precisely what happens with the ocean mixed layer depth, at the western boundary during the North-east monsoon season (Saadon and Camerlengo, 1995). During the South-west monsoon season, cloudless skies cause an increase in both the salinity field and the temperature field patterns. A decrease of the mixed layer depth has also been recorded (Lokman et al., 1986).

### 2.5.4 El Nina and La Nina Effects on Rainfall Variability

The effects of El Nino and La Nina are stronger over East Malaysia than in Peninsular Malaysia. Nevertheless, El Nino and La Nina years did affect both the monsoons in our country. El Nino influence on monsoon rainfall is weaker in Peninsular Malaysia. There were only slight cases when both east and west coast states in peninsular were affected during the monsoons. In happened back then in 1986, both states in west and coast area were affected during the southwest monsoon and once again in 1982 during northeast monsoon (Cheang, 1993). La Nina had caused extreme precipitation during Northeast monsoon in only 2 out of 10 cases. Most of the remaining cases recorded normal rainfall during La Nina years.

### 2.5.5 El Nino

The El Nino - Southern Oscillation phenomenon (ENSO) is a well-known mode of climate variability that affects weather ad ecosystems in large parts of the world. It is referred as warm phase of ENSO. It is widely known that major ENSO episodes, like the one which occurred in 1982 and 1983, can lead to major displacement of rainfall regions in the tropics, bringing drought to broad areas and torrential rain to otherwise arid regions. E1 Nino phenomenon is believed associated with below normal rainfall over northern Australia, Indonesia and Philippines (Meehl, 1987; Ropelewski and Halpest, 1987). Since Malaysia is located near this region, there would be a probability that El Nino and Southern Oscillation give some effects on the rainfall of Malaysia. Out of the 12 El Nino years (1951, 1953, 1957, 1963, 1965, 1969, 1972, 1977, 1982, 1986, 1987 and 1991) seven of them did bring about extremely dry years to many stations over the whole country or Peninsular Malaysia or east Malaysia. However, 1951, 1953 and 1957 did not experience extremely dry conditions even though they are included in the El Nino years. The influence of El Nino on the west and east coast states in peninsular Malaysia was more complex. Both east and west were affected by very much below normal Northeast monsoon rainfall.

### 2.5.6 La Nina

La Nina is referred to cold phase of ENSO. The La Nina years are 1955, 1956, 1960, 1964, 1970, 1971, 1973, 1974, 1975 and 1988. Out of the 10 years, 8 of them recorded extremely wet conditions at many stations (Cheang, 1993). In 1960, 14 out of the 16 stations did not record any extreme condition. Only one recorded extremely dry and one recorded extremely wet year. In 1974 more stations recorded extremely dry than wet years.

In Peninsular Malaysia, the effect of La Nina is again more complex. During the southwest monsoon, there was no consistent trend. As regards to northeast monsoon, only 2 out of 10 La Nina years that the rainfall is above normal rainfalls.

### 2.6 RETURN PERIOD

Return period is the average time interval (expressed in years) between occurrences of a given or greater magnitude rainfall event. It denotes the recurrence interval of certain rainfall event. It can be expressed as a statistical measure of how frequently a rainfall event of certain magnitude is likely to occur. As for example, rainfall with a 10 -year return period would likely to happen every 10 years. A 100-year return period corresponds to such an extreme event that we expect it to occur only every 100 years (Mélice \& Reason, 2007)

### 2.7 GEOGRAPHICAL INFORMATION SYSTEM

For this research purpose, Geographical Information System (GIS) technique was used to process all the raw data collected from public domain. Conventional hydrological model that being used to estimate rainfall intensity is very costly and timeconsuming.

Thus, in order to solve the problem, remote sensing is used where this technology can also provide input data information economically and also offer largeland coverage. It is also a viable alternative. For about two decades, satellite or remote sensing (RS) data in the form of multi-spectral air photography, ground based weather radar as well as geostationary and polar orbiting satellite has been available to be used in hydrology field. Remotely sensed data provide relatively consistent spatial and temporal coverage of rainfall information.

Data available from satellite is suitable to enter GIS (Geographical Information System). Thus, various data can be stored as different layer by GIS. A lot of hydrological variables' measurements can be provided by satellite-based data which is generally used in hydrology and environmental model application, either as direct measurements comparable to traditional forms, as surrogates of traditional forms, or as entirely new data set (A.M.Melesse, S.F. Shih, 2002). Satellite-based data is very useful to obtain input data for distributed hydrological model

### 2.8 SUMMARY

It can be said that flood happened in Malaysia is characterised by the yearly alternation of Southwest and Northeast monsoons besides other climatic changes and urbanization occurred in the affected area. El Nina and La Nina contributes slightly in the extreme rainfall precipitation occurred throughout the country.

## CHAPTER 3

## METHODOLOGY

### 3.0 METHODOLOGY

The next figure will visualize the flow chart of methodology implemented for this research. The first step was to collect daily data from TRMM and determined the location of every major city in Johor. Secondly, the daily rainfall data was converted to GIS-ready forms and retrieved using GIS technique. The next step was to process the data by using descriptive statistical analysis for daily, monthly, and annual maximum rainfall. Then, Gumbel distribution function was applied to estimate the return period of extreme rainfall events. Lastly, result was organized in the form of rainfall characteristics, extreme rainfall events, and return period of annual daily maximum rainfall.


Figure 3.1: Summarized flow chart for research methodology

### 3.1 Study Area

The selected study area comprises of eight major cities in Johor which are Johor Bahru, Pontian, Kota Tinggi, Mersing, Batu Pahat, Muar, Segamat, and Kluang. Johor is the second most populous state with $19,210 \mathrm{~km}^{2}$ and situated in the southern part of Peninsular Malaysia. This contributes to the state's rapid development as an industrial hub. Johor has the second largest population in Malaysia at 3,230,440 as of 2010. Johor has a tropical rainforest climate with monsoon rain from November until February blowing from the South China Sea. The next table shows the population and area of eight major cities in Johor related in this study.

Table 3.1: Population and area of major cities in Johor

| Cities | Population (as of 2010) | Area (sq. miles) |
| :---: | :---: | :---: |
| Johor Bahru | $1,334,188$ | 722 |
| Pontian | 149,938 | 350 |
| Kota Tinggi | 193,210 | $1,346.99$ |
| Mersing | 69,028 | $1,346.99$ |
| Batu Pahat | 401,902 | 723.00 |
| Muar | 239,027 | 531 |
| Segamat | 182,985 | $1,090.9$ |
| Kluang | 288,364 | 1101.00 |

### 3.2 DATA COLLECTING

### 3.2.1 Satellite Data

In recent years, satellite-based precipitation estimates have been developed on sub daily time resolution over the globe by combining information from microwave (MW) and infrared (IR) observation (Hong, Hsu, Sorooshian, \& Gao, 2004; Hsu \& Gao, 1997; Huffman et al., 2007; Joyce, Janowiak, Arkin, \& Xie, 2004; Kidd, Kniveton, Todd, \& Bellerby, 2003; Sorooshian et al., 2000). Operational quasi-global satellite rainfall products used in this study is the Tropical Rainfall Measuring Mission (TRMM).

The TRMM data was used to generate daily, monthly and yearly satellite-based rainfall information. They were downloaded from http://disc.sci.gsfc.nasa.gov/site for 16 years period of time (January 1998- December 20013).The TRMM products are available 3-hourly at 0.25830 .258 spatial resolution at $508 \mathrm{~S}-\mathrm{N}$ latitude covering the globe. The real-time product, 3B42RT, uses the TRMM Combined Instrument (TCI; TRMM precipitation radar and TRMM Microwave Imager) dataset to calibrate precipitation estimates derived from available low-Earth-orbiting passive microwave radiometers and then merges all these estimates at 3-h intervals.

### 3.2.2 RAINFALL DATA



Figure 3.2: Maps of districts in every state in Malaysia

Corresponding maps and location data for representative districts within Peninsular Malaysia were obtained from the Jabatan Ukur dan Pemetaan Malaysia (JUPEM).

Right after the map has been inserted into ArcGis 9 software, coordinates for major cities in Johor were marked on the available map by simply inserting the coordinates (latitude, longitude) of Johor Bahru, Pontian, Kota Tinggi, Batu Pahat, Kluang, Muar, Segamat, and Mersing to get the daily rainfall data for each city. The location for every major cities in Johor, together with Latitude and longitude, are presented in Table 5

Table 3.2: Latitude and longitude for major cities in Johor

| No | Cities | Latitude | Longitude |
| :--- | :--- | :--- | :--- |
| 1 | Johor Bahru | $102.78^{\circ} \mathrm{E}$ | $1.48^{\circ} \mathrm{N}$ |
| 2 | Batu Pahat | $102.93^{\circ} \mathrm{E}$ | $1.85^{\circ} \mathrm{N}$ |
| 3 | Kluang | $103.32^{\circ} \mathrm{E}$ | $2.03^{\circ} \mathrm{N}$ |
| 4 | Muar | $102.57^{\circ} \mathrm{E}$ | $2.05^{\circ} \mathrm{N}$ |
| 5 | Kota Tinggi | $103.98^{\circ} \mathrm{E}$ | $1.74^{\circ} \mathrm{N}$ |
| 6 | Pontian | $103.40^{\circ} \mathrm{E}$ | $1.51^{\circ} \mathrm{N}$ |
| 7 | Segamat | $102.82^{\circ} \mathrm{E}$ | $2.52^{\circ} \mathrm{N}$ |
| 8 | Mersing | $103.81^{\circ} \mathrm{E}$ | $2.42^{\circ} \mathrm{N}$ |

### 3.3 PRE - PROCESSING

### 3.3.1 Data Transformation

Firstly, the data processing required data transformation in order to make sure the interoperability with ArcGis environment. The satellite precipitation products downloaded from public domain do not fit easily into the traditional Geographical Information System (GIS) standards (raster or vector). Another application was used to transform the satellite rain products into accessible Geotiff format. The application used is the Global Mapper v11.00. It transformed the datasets by exporting the raster and elevation data to GeoTiff and selected the 32-bit floating point samples for the elevation file type.


Figure 3.3: Global Mapper platform


Figure 3.4: Rainfall data exported to GeoTIFF format


Figure 3.5: GeoTIFF export option

### 3.3.2 Conversion and Clipping of Dataset

This dataset was ready to open in the ArcGIS after being transformed to tiff format previously. For the next step, the dataset was opened in ArcGis. All the transformed data were then exported as raster data and TIFF format. The location where the data was saved was separated into different folders according to their respective year and month.

After the data had been exported, the data then extracted to a portion of a raster dataset based on a template extent. The clip output shall include any pixels that intersect the template extent. The clipped area in this study was specified by a rectangular envelope using minimum and maximum x and y -coordinates as in the table below

Table 3.3: Coordinates for data clipping

|  | X-coordinates | Y-coordinates |
| :--- | :--- | :--- |
| Minimum | 99.500000 | 1.000000 |
| Maximum | 104.000000 | 7.000000 |



Figure 3.6: Data exportation in ArcGis


Figure 3.7: Raster data exportation in ArcGis


Figure 3.8: Clipping data in ArcGis


Figure 3.9: Execution of clipping data

### 3.3.3 Data Extraction

The next step involved the extraction of rainfall data according to the places mapped on the available peninsular map. Before the data can be extracted, there were a few steps need to be accomplished first. The map of peninsular Malaysia was opened in ArcCatalog and new shapefile for major cities in Johor was created. It was then marked on the map according to the longitude and latitude for each city.

The map of peninsular Malaysia was added as a new layer as well as the shapefile for major cities in Johor. Next, the previous clipped data was added to the layers. Then, a spatial analyst tool was used to extract values to point. The input point features defined the location from which you want to extract the raster cell values and in this study it was the cities in Johor. The input raster dataset whose values will be extracted was selected from the clipped data added to the layer earlier on.The output point feature dataset then would contain the extracted raster values.

By opening the attributes of the extract for the new extracted data added on the layer, the rainfall depth for every city that has been marked on map would be generated. The extracted data was saved in the form of text file so that it can be opened later in Microsoft Excel.


Figure 3.10: Malaysia map in ArcGis


Figure 3.11: Adding new layer of major cities in Johor on map


Figure 3.12: Extract values to points in ArcGis


Figure 3.13: Rainfall depth extracted


Figure 3.14: Saving attributes of extracted data

### 3.4 PROCESSING

### 3.4.1 Descriptive Statistics

After all the data has been extracted to text file, the data was opened in excel to be organized in the form of tables and graphs. Descriptive statistics was conducted for the three types of data i) annual rainfall ii) annual daily maximum rainfall and iii) annual monthly maximum rainfall. It was applied to the rainfall data to examine its central tendency and variability. The statistical moments used in this study are given as:

First moment (mean):

$$
\bar{y}=\frac{\sum y_{i}}{n}
$$

Second moment (variance):
$s^{2}=\frac{\sum\left(y_{i}-\bar{y}\right)}{n-1}$

### 3.4.2 Gumbel Distribution Function

The famous statistician Emil Julius Gumbel (1941) was probably, the first person who dealt extreme values of hydro-logical data in organized way for conducting flood frequency analysis. Traditionally three extreme value distributions: Fréchet, Weibull and Gumbel are commonly used for analysing return periods of annual daily maximum rainfall.

Nadarajah and Choi (2007) and Carvalho et al. (2003) expressed the cumulative distribution function of the Generalized Extreme Value (GEV) distribution as:

$$
\begin{equation*}
\mathrm{F}(\mathrm{x})=\exp \left\{-\left(1+\xi \cdot \frac{\mathrm{x}-\mu}{\sigma}\right)^{-\frac{1}{\xi}}\right\} \tag{3.1}
\end{equation*}
$$

For $1+\xi(\mathrm{x}-\mu) / \sigma>0$, where $\xi, \mu$, and $\sigma$ are referred as shape, location and scale parameters respectively. The Eq. (1) is referred as Gumbel distribution for the cases of $\xi \rightarrow 0$. The GEV distribution can be expressed as Eq. (2). The probability and return periods of annual daily maximum rainfall were estimated using Eqs. (3) and (4) respectively.

$$
\begin{equation*}
\mathrm{F}(\mathrm{x})=\exp \left[-\exp \left\{-\left(\frac{x-\mu}{\sigma}\right)\right\}\right] \tag{3.2}
\end{equation*}
$$

$\mathrm{P}(\mathrm{x})=1-\mathrm{F}(\mathrm{x})$

$$
\begin{equation*}
\mathrm{N}=\frac{1}{P(x)} \tag{3.4}
\end{equation*}
$$

$\mathrm{x} \quad$ annual daily maximum rainfall
$\mu \quad$ mean of observed annual daily maximum rainfall
$\sigma \quad$ standard deviation of observed annual daily maximum rainfall
$\mathrm{F}(\mathrm{x}) \quad$ cumulative probability distribution
$\mathrm{P}(\mathrm{x}) \quad$ probability distribution
$\mathrm{N} \quad$ return periods of annual daily maximum rainfall

### 3.5 SUMMARY

This chapter explained the methodology to conduct this research. It started off with data collecting and then pre-processing, processing and the result is later discussed in the next chapter.

## CHAPTER 4

## RESULT AND DISCUSSION

### 4.1 RAINFALL CHARACTERISTICS

Table 4.1: Monthly rainfall for major cities in Johor

| Cities | Monthly rainfall (mm) |  |
| :---: | :---: | :---: |
|  | Maximum | Minimum |
| Johor Bahru | 874.23992 | 25.35092 |
|  | (December) | (January) |
| Pontian | 823.25245 | 25.36777 |
|  | (December) | (February) |
| Kota Tinggi | 840.75315 | 22.67447 |
|  | (December) | (February) |
| Mersing | 774.92299 | 10.30848 |
|  | (January) | (February) |
| Batu Pahat | 534.82471 | 36.08092 |
|  | (December) | (February) |
| Muar | 488.21803 | 33.77532 |
|  | (December) | (July) |
| Segamat | 641.65745 | 12.6418 |
|  | (December) | (February) |
| Kluang | 745.11556 | 46.60511 |
|  | (December) | (February) |

It can be seen that most of cities experienced highest rainfall intensity on December. The highest amount of rainfall was recorded in Johor Bahru with 874.24 mm followed by Kota Tinggi, 840.75 mm and Pontian, 823.25 mm .

Johor Bahru serves as its capital state in highly urbanized setting. It is also known as port of entry and an international business hub. Pluvial flooding which usually occur in town and modern cities can be said to be a contributing factor to high rainfall intensity on monthly basis. Flooding in urban areas is majorly caused by intense and prolonged rainfall which overwhelms the capacity of the drainage system. This is due to the high proportion of paved surfaces, which limits water infiltration and increase the speed of water as well as the amount surface run off to the ground surface.

The same situation also affects Kota Tinggi as urbanization in this area is growing rapidly focusing in housing development and agricultural activities. The close distance of Kota Tinggi to Johor Bahru which is approximately $42-\mathrm{km}$ north-east of Johor Bahru also contributes to its rapid development as a part of Johor Bahru corridor and affects the rainfall events happened in the area.

On the other hand, it can be said that geographical position contributes to higher intensity of rainfall in some places. Based on geographical location of these three cities, they are all located near coastal area. The coastal areas are closer to water and closer to the sea. Thus, it can be said that the climate will be wetter. So, it contributes to more rainfall monthly compared to the other places in Johor

The minimum rainfall on the other hand was recorded in Mersing with 10.31 mm , followed by Segamat, 12.65 mm and Kota Tinggi, 22.67 mm .

All three cities recorded minimum rainfall on February. This may be due to the fact that even though North-east monsoon occurs from November till March, it generally brings heavy rain around November to January. It usually stops at the end of January. Thus, the inland areas which are sheltered by mountain ranges are relatively free from North-east monsoon during this period. Due to this, it contributes to the lowest rainfall downpour in most part of Johor.

Table 4.2: Annual rainfall for major cities in Johor

| Cities | Annual rainfall (mm) |  |
| :---: | :---: | :---: |
|  | Maximum | Minimum |
| Johor Bahru | $\begin{aligned} & 221.2035 \\ & (\mathbf{2 0 0 6}, \mathbf{2 0 0 7}) \end{aligned}$ | $\begin{gathered} 49.66177 \\ (\mathbf{2 0 0 9}) \end{gathered}$ |
| Pontian | $\begin{gathered} 231.4471 \\ (\mathbf{2 0 0 1 , 2 0 0 7}) \end{gathered}$ | $\begin{gathered} 45.36311 \\ (\mathbf{2 0 1 1}) \\ \hline \end{gathered}$ |
| Kota Tinggi | $\begin{gathered} 211.4133 \\ (\mathbf{2 0 0 6}) \\ \hline \end{gathered}$ | $\begin{gathered} 74.63789 \\ \mathbf{( 2 0 0 0 )} \\ \hline \end{gathered}$ |
| Mersing | $\begin{gathered} 265.1129 \\ (\mathbf{2 0 0 6}) \\ \hline \end{gathered}$ | $\begin{gathered} 59.51974 \\ (\mathbf{2 0 0 9}) \\ \hline \end{gathered}$ |
| Batu Pahat | $\begin{gathered} 184.5667 \\ (\mathbf{2 0 0 4}) \\ \hline \end{gathered}$ | $\begin{gathered} 62.27600 \\ (\mathbf{1 9 9 9}) \\ \hline \end{gathered}$ |
| Muar | $\begin{gathered} 153.9978 \\ (\mathbf{2 0 0 4}) \\ \hline \end{gathered}$ | $\begin{gathered} 49.66177 \\ \mathbf{( 2 0 1 1 )} \\ \hline \end{gathered}$ |
| Segamat | $\begin{gathered} 265.1129 \\ (\mathbf{2 0 0 1}) \\ \hline \end{gathered}$ | $\begin{gathered} 62.27600 \\ \mathbf{( 2 0 0 6}) \\ \hline \end{gathered}$ |
| Kluang | $\begin{gathered} 347.8475 \\ \mathbf{( 2 0 0 6}) \\ \hline \end{gathered}$ | $\begin{gathered} 65.15989 \\ \mathbf{( 2 0 0 9 )} \\ \hline \end{gathered}$ |

On the contrary, the highest amount of rainfall annually brought different result in places compared to monthly rainfall. It can be seen that Kluang recorded the highest amount of rainfall with 347.85 mm followed by Segamat and Mersing with 265.11 mm respectively. All three cases recorded highest amount of rainfall in 2006.

2006 and 2007 flood events are among the worst in century. Geographical characteristics and inadequate drainage facilities are the factors that trigger this heavy rain. Kluang situated just slightly outside Titiwangsa range which make it opens to both North-east and South-west monsoons over the year. Thus, it can be said that maximum annual rainfall would likely to occur here. Segamat which is located in lowland area was affected by continuous rainfall that happened during 2006.

Water from Segamat river spilled over to the right and left banks of the river and submerged some areas there. Mersing located on east part of Johor. It opens to Northeast monsoon which brings heavy rainfall to the east coast of Peninsular Malaysia. Minimum rainfall recorded was recorded on Pontian in 2011, followed by Muar which also happened to be in 2011 and Johor Bahru on 2009.

### 4.2 EXTREME RAINFALL EVENTS

Table 4.3: Historical extreme rainfall events of major cities in Johor

| Cities | Dates | Daily rainfall <br> $(\mathrm{mm})$ |
| :---: | :---: | :---: |
| Johor Bahru | December 19,2006 <br> January 12,2007 | 221.20 |
| Pontian | January 12, 20072 | 231.45 |
| Kota Tinggi | December 19,2006 | 211.41 |
| Mersing | December 19,2006 | 265.11 |
| Batu Pahat | March 9,2004 | 184.57 |
| Muar | October 27,2004 | 154.00 |
| Segamat | January 18, 2001 | 265.11 |
| Kluang | December 19, 2006 | 347.85 |

### 4.3 RETURN PERIOD OF ANNUAL DAILY MAXIMUM RAINFALL

The daily rainfall equal or greater than 221 mm has return period of 9 years for Johor Bahru. While, daily rainfall equal or greater than 303 mm will have return period of 25 years, 353 mm for 50 years of return period and 402 mm for 100 years of return period.


Figure 4.1: Return period graph of Johor Bahru

The daily rainfall equal or greater than 231 mm has return period of 7 years for Pontian. While, daily rainfall equal or greater than 360 mm will have return period of 25 years, 412 mm for 50 years of return period and 473 mm for 100 years of return period.


Figure 4.2: Return period graph of Pontian

The daily rainfall equal or greater than 202 mm has return period of 9 years for Kota Tinggi. While, daily rainfall equal or greater than 260 mm will have return period of 25 years, 297 mm for 50 years of return period and 333 mm for 100 years of return period.


Figure 4.3: Return period graph of Kota Tinggi

The daily rainfall equal or greater than 265 mm has return period of 8 years for Mersing. While, daily rainfall equal or greater than 379 mm will have return period of 25 years, 439 mm for 50 years of return period and 498 mm for 100 years of return period.


Figure 4.4: Return period graph of Mersing

The daily rainfall equal or greater than 185 mm has return period of 8 years for Batu Pahat. While, daily rainfall equal or greater than 264 mm will have return period of 25 years, 305 mm for 50 years of return period and 346 mm for 100 years of return period.


Figure 4.5: Return period graph of Batu Pahat

The daily rainfall equal or greater than 154 mm has return period of 8 years for Muar. While, daily rainfall equal or greater than 213 mm will have return period of 25 years, 246 mm for 50 years of return period and 279 mm for 100 years of return period.


Figure 4.6: Return period graph of Muar

The daily rainfall equal or greater than 265 mm has return period of 16 years for Segamat.While, daily rainfall equal or greater than 311 mm will have return period of 25 years, 363 mm for 50 years of return period and 415 mm for 100 years of return period.


Figure 4.7: Return period graph of Segamat

The daily rainfall equal or greater than 348 mm has return period of 18 years for Kluang. While, daily rainfall equal or greater than 398 mm will have return period of 25 years, 467 mm for 50 years of return period and 535 mm for 100 years of return period.


Figure 4.8: Return period graph of Kluang

All the return period for all areas is summarized in the form of table on the next page. The gradient, m and y -intercept, c are provided in the table as well as the estimated rainfall depth for return period of 25,50 and 100 years.

Table 4.4: Equation of return period for major cities in Johor

| cities | equation |  | m |  | c | R2 | N |  |
| :--- | :--- | :---: | :---: | :---: | ---: | ---: | ---: | :---: |
|  |  |  |  |  |  |  | 100 |  |
| Johor Bahru | $71.248 \ln (\mathrm{x})+73.98$ | 71.248 | 73.98 | 0.9928 | 303.34 | 352.73 | 402.11 |  |
| pontian | $88.005 \ln (\mathrm{x})+67.224$ | 88.005 | 67.22 | 0.9962 | 350.5 | 411.5 | 472.5 |  |
| Kota Tinggi | $52.414 \ln (\mathrm{x})+92.13$ | 52.414 | 92.13 | 0.9919 | 260.55 | 296.86 | 333.16 |  |
| Mersing | $85.652 \ln (\mathrm{x})+103.76$ | 85.652 | 103.76 | 0.9837 | 379.46 | 438.83 | 498.2 |  |
| Batu Pahat | $58.862 \ln (\mathrm{x})+74.541$ | 58.862 | 74.54 | 0.9935 | 264.01 | 304.81 | 345.61 |  |
| Muar | $47.558 \ln (\mathrm{x})+59.76$ | 47.558 | 59.76 | 0.9934 | 212.84 | 245.81 | 278.77 |  |
| Segamat | $75.579 \ln (\mathrm{x})+67.283$ | 75.579 | 67.28 | 0.9959 | 310.56 | 362.95 | 415.34 |  |
| Kluang | $99.038 \ln (\mathrm{x})+79.14$ | 99.038 | 79.14 | 0.9934 | 397.93 | 466.58 | 535.23 |  |

Besides that, return period can also be calculated by inserting the known mean and standard deviation of major cities in Johor.

Table 4.5: Mean and standard deviation for all major cities in Johor

| Cities | Mean | Std.deviation |
| :---: | :---: | :---: |
| Johor Bahru | 116.3704 | 49.86982 |
| Pontian | 119.8029 | 60.75221 |
| Kota Tinggi | 123.2674 | 37.45545 |
| Mersing | 156.0576 | 52.6296 |
| Batu Pahat | 110.4826 | 36.90276 |
| Muar | 88.18795 | 32.77969 |
| Segamat | 115.0536 | 55.91696 |
| Kluang | 138.9674 | 71.9062 |

Putting those values in equation (3.2); we developed equation (4.1) for the estimation of return period. Take Johor Bahru for example, the extreme rainfall events as

$$
\begin{equation*}
N=\left[1-\exp \left[-\exp \left\{-\left(\frac{x-116.37}{49.87}\right)\right\}\right]\right]^{-1} \tag{4.1}
\end{equation*}
$$

### 4.4 SUMMARY

It can be concluded that the highest amount of rainfall was recorded in Johor Bahru for annual monthly maximum rainfall. Whereas, Kluang recorded the highest amount of rainfall for annual maximum rainfall. Most of the cities experienced highest amount of rainfall in year 2006 and 2007. Lastly, the return period of annual daily maximum rainfall was calculated for each city using Gumbel distribution function

## CHAPTER 5

## CONCLUSION AND RECOMMENDATIONS

### 5.1 CONCLUSION

The highest numbers of very wet days and extremely wet days occur during the North-east season for every major city in Johor. As for annual daily maximum, it can be seen that Kluang recorded the highest rainfall. But the result is different for annual monthly maximum rainfall. Johor Bahru recorded the highest rainfall for the monthly maximum downpour. This may be due to Kluang's geographical factor that situated just outside Titiwangsa range and opens to both monsoon seasons over the year. Both places share almost identical characteristics in terms extreme rainfall intensity. These findings can be related to the location of these both places. They are heavily populated areas with intensive urbanization. The increase in the frequency of flash floods in these two areas in recent years may be partly due to climate change and this contributes to high intensity of rainfall monthly and annually.

The annual pattern of extreme rainfall in Johor is highly influenced by the North-east monsoon. It can be clearly seen through the historical extreme rainfall events in major cities in Johor. Highest rainfall recorded during North-east monsoon for major part of the cities.

The highest amount of rainfall recorded during December 2006 and January 2007 where Malaysia had been stroked down by the most destructive flood events during 19-31 December, 2006 and 12-17 January, 2007 period

The statistical analysis was carried out based on daily rainfall data. Data collected was organized to get its central tendency and variability It was then compared to get daily maximum, monthly maximum as well as annual maximum Any drainage structure to be designed and constructed in Johor should be resilient to extreme rainfall event. The existing system was designed based on historical rainfall data, but the capacity of the drainage network will not be sufficient enough with high intensive short duration as the variability rainfall is expected to alter due to global climate change. The proposed return periods of annual daily maximum rainfall of this study can be used for upgrading the capacities of hydraulic structures for Johor. This outcome can be used in many ways; it can help to understand future flash flooding risk. This paper also describes the overall rainfall pattern of Johor. The research outcome can be made as guideline in the planning of infrastructures to be built in the future.

### 5.2 Recommendations for future research

To further this research, there are some action plans that can be taken in order to get better results. Some recommendations that can be implemented to further research are:

1. 16 years of data was collected for this research (1998-2013). Generally, 30 years of data is considered essential to estimate the desired flood based upon the available flow data of catchment. The results of the frequency analysis depend upon the length of data. Frequency analysis should not be adopted if the length of records is less than 10 years. Thus, it would be more practical and the result would be more reliable if longer years are used to estimate the variability of rainfall.
2. Data collected for this research was downloaded from TRMM satellite. The result of data should be compared with rain-gauge station in order to get more precise result and compare both data to calibrate the data.
3. Instead of using only one method to get return period, one can also use different approach of probability distributions to get return period of extreme rainfall events like using lognormal, Weibull function or Log-Person type III to compare the results.

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## APPENDIX A

Annual Daily Maximum for Johor Bahru, Pontian, and Kota Tinggi

| JOHOR BAHRU |  |  |
| :---: | :---: | :---: |
| year | date | depth |
| 1998 | 15-Oct | 78.094245 |
| 1999 | 1-Jan | 74.637893 |
| 2000 | 23-Nov | 93.59613 |
| 2001 | 17-Jan | 147.182037 |
| 2002 | 26-Jan | 97.930412 |
| 2003 | 1-Feb | 122.805023 |
| 2004 | 9-Mar | 184.566696 |
| 2005 | 3-Jan | 112.175132 |
| 2006 | 19-Dec | 221.203506 |
| 2007 | 12-Jan | 221.203506 |
| 2008 | 12-Nov | 97.930412 |
| 2009 | 1-Mar | 49.661773 |
| 2010 | 24-Jun | 107.210395 |
| 2011 | 26-Sep | 74.637893 |
| 2012 | 15-Apr | 85.494575 |
| 2013 | 8-Feb | 93.59613 |
| total |  | 1861.925758 |
| max |  | 221.203506 |
| min |  | 49.661773 |
| mean |  | 116.3703599 |
| std.dev |  | 49.86982379 |


| PONTIAN |  |  |
| :---: | :---: | :---: |
| year | date | depth |
| 1998 | 12-Oct | 102.4654 |
| 1999 | 1-Jan | 81.710693 |
| 2000 | 5-Jan | 81.710693 |
| 2001 | 28-Dec | 231.447067 |
| 2002 | 18-Nov | 107.210395 |
| 2003 | 1-Feb | 102.4654 |
| 2004 | 9-Mar | 211.413314 |
| 2005 | 5-Oct | 71.33451 |
| 2006 | 19-Dec | 211.413314 |
| 2007 | 12-Jan | 231.447067 |
| 2008 | 8-Jan | 93.59613 |
| 2009 | 17-Mar | 107.210395 |
| 2010 | 3-Mar | 81.710693 |
| 2011 | 22-Oct | 45.363109 |
| 2012 | 14-Dec | 81.710693 |
| 2013 | 8-Feb | 74.637893 |
| total |  | 1916.846766 |
| max |  | 231.447067 |
| min |  | 45.363109 |
| mean |  | 119.8029229 |
| std.dev |  | 60.75221243 |


| KOTA TINGGI |  |  |
| :---: | :---: | :---: |
| year | date | depth |
| 1998 | 30-Dec | 122.805023 |
| 1999 | 1-Jan | 97.930412 |
| 2000 | 1-May | 74.637893 |
| 2001 | 17-Jan | 202.056427 |
| 2002 | 25-Jan | 153.997787 |
| 2003 | 6-Jan | 107.210395 |
| 2004 | 9-Mar | 140.667938 |
| 2005 | 19-Aug | 89.453681 |
| 2006 | 19-Dec | 211.413314 |
| 2007 | 5-Dec | 140.667938 |
| 2008 | 12-Nov | 122.805023 |
| 2009 | 13-Mar | 102.4654 |
| 2010 | 24-Jun | 97.930412 |
| 2011 | 8-Oct | 102.4654 |
| 2012 | 24-Apr | 93.59613 |
| 2013 | 20-Jan | 112.175132 |
|  | otal | 1972.278305 |
|  | max | 211.413314 |
|  | min | 74.637893 |
|  | mean | 123.2673941 |
|  | d.dev | 37.45545154 |

## APPENDIX B

Annual daily maximum for Mersing, Batu Pahat, and Muar

| BATU PAHAT |  |  |  |
| ---: | ---: | ---: | ---: |
| year | date | depth |  |
| 1998 | 13-May | 93.59613 |  |
| 1999 | 1-Jan | 62.275997 |  |
| 2000 | 5-Jan | 78.094245 |  |
| 2001 | 18-Jan | 140.667938 |  |
| 2002 | 26-Jan | 65.159889 |  |
| 2003 | 3-Jan | 153.997787 |  |
| 2004 | 9-Mar | 184.566696 |  |
| 2005 | 15-Jul | 81.710693 |  |
| 2006 | 19-Dec | 140.667938 |  |
| 2007 | 11-Jan | 161.12915 |  |
| 2008 | 5-Dec | 81.710693 |  |
| 2009 | 17-Mar | 140.667938 |  |
| 2010 | 24-Jun | 112.175132 |  |
| 2011 | 23-Apr | 89.453681 |  |
| 2012 | 14-Jul | 74.637893 |  |
| 2013 | 3-Dec | 107.210395 |  |
| total |  | 1767.722195 |  |
| max |  | 184.566696 |  |
| min |  | 62.275997 |  |
| mean | 110.4826372 |  |  |
| mtd.dev | 36.90276118 |  |  |


| MUAR |  |  |
| :---: | :---: | :---: |
| year | date | depth |
| 1998 | 13-May | 85.494575 |
| 1999 | 16-Jul | 78.094245 |
| 2000 | 17-Jan | 85.494575 |
| 2001 | 18-Jan | 147.182037 |
| 2002 | 28-Apr | 74.637893 |
| 2003 | 1-Feb | 65.159889 |
| 2004 | 27-Oct | 153.997787 |
| 2005 | 31-Oct | 68.177337 |
| 2006 | 19-Dec | 147.182037 |
| 2007 | 12-Jan | 107.210395 |
| 2008 | 27-Jan | 68.177337 |
| 2009 | 17-Mar | 78.094245 |
| 2010 | 24-Oct | 51.961528 |
| 2011 | 17-May | 49.661773 |
| 2012 | 25-Apr | 56.885471 |
| 2013 | 2-Dec | 93.59613 |
| total |  | 1411.007254 |
| max |  | 153.997787 |
| min |  | 49.661773 |
| mean |  | 88.18795338 |
| std.dev |  | 32.77968638 |

## APPENDIX C

Annual daily maximum for Segamat and Kluang

| SEGAMAT |  |  |
| :---: | :---: | :---: |
| year | date | depth |
| 1998 | 30-Jan | 74.637893 |
| 1999 | 1-Jan | 78.094245 |
| 2000 | 23-Dec | 134.442153 |
| 2001 | 18-Jan | 265.112915 |
| 2002 | $24-\mathrm{Nov}$ | 62.275997 |
| 2003 | 19-Jan | 78.094245 |
| 2004 | 30-Jan | 97.930412 |
| 2005 | 5-Dec | 117.369766 |
| 2006 | 19-Dec | 168.590774 |
| 2007 | 10-Dec | 122.805023 |
| 2008 | 18-Dec | 71.33451 |
| 2009 | 17-Mar | 93.59613 |
| 2010 | 8-Jun | 68.177337 |
| 2011 | 11-Dec | 93.59613 |
| 2012 | 25-Dec | 93.59613 |
| 2013 | 2-Dec | 221.203506 |
| total |  | 1840.857166 |
| max |  | 265.112915 |
| min |  | 62.275997 |
| mean |  | 115.0535729 |
| std.dev |  | 55.91696009 |


| year | date | depth |
| :---: | :---: | :---: |
| 1998 | 22-Feb | 85.494575 |
| 1999 | 1-Jan | 122.805023 |
| 2000 | 22-Dec | 89.453681 |
| 2001 | 18-Jan | 253.379226 |
| 2002 | 25-Jan | 140.667938 |
| 2003 | 1-Feb | 102.4654 |
| 2004 | 9-Mar | 134.442153 |
| 2005 | 21-Nov | 102.4654 |
| 2006 | 19-Dec | 347.847503 |
| 2007 | 12-Nov | 221.203506 |
| 2008 | 8-Dec | 112.175132 |
| 2009 | 17-Mar | 65.159889 |
| 2010 | 20-Jun | 107.210395 |
| 2011 | 5-Apr | 97.930412 |
| 2012 | 6-Mar | 93.59613 |
| 2013 | 2-Dec | 147.182037 |
| total |  | 2223.4784 |
| max |  | 347.847503 |
| min |  | 65.159889 |
| mean |  | 138.9674 |
| std.dev |  | 71.90619951 |

## APPENDIX D

Gumbel distribution function analysis for Johor Bahru and Pontian

| JOHOR BAHRU |  |  |  |  |  |  | PONTIAN |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| date | year | depth | x | $F(x)$ | $\mathrm{P}(\mathrm{x})$ | N | date | year | depth | x | $F(x)$ | $\mathrm{P}(\mathrm{x})$ | N |
| 15-Oct | 1998 | 78.094245 | -0.76752056 | 0.115970681 | 0.884029 | 1.131184 | 12-Oct | 1998 | 102.4654 | -0.28538093 | 0.264406214 | 0.735594 | 1.359446 |
| 1-Jan | 1999 | 74.637893 | -0.83682804 | 0.099357463 | 0.900643 | 1.110318 | 1-Jan | 1999 | 81.710693 | -0.62700976 | 0.153815038 | 0.846185 | 1.181775 |
| 23-Nov | 2000 | 93.59613 | -0.45667356 | 0.206219651 | 0.79378 | 1.259794 | 5-Jan | 2000 | 81.710693 | -0.62700976 | 0.153815038 | 0.846185 | 1.181775 |
| 17-Jan | 2001 | 147.182037 | 0.617842109 | 0.583269161 | 0.416731 | 2.39963 | 28-Dec | 2001 | 231.447067 | 1.837696763 | 0.852839728 | 0.14716 | 6.795312 |
| 26-Jan | 2002 | 97.930412 | -0.36976164 | 0.235183416 | 0.764817 | 1.307503 | 18-Nov | 2002 | 107.210395 | -0.20727686 | 0.292198138 | 0.707802 | 1.412825 |
| 1-Feb | 2003 | 122.805023 | 0.129029193 | 0.415219366 | 0.584781 | 1.710043 | 1-Feb | 2003 | 102.4654 | -0.28538093 | 0.264406214 | 0.735594 | 1.359446 |
| 9-Mar | 2004 | 184.566696 | 1.367487008 | 0.775113095 | 0.224887 | 4.44668 | 9-Mar | 2004 | 211.413314 | 1.507935061 | 0.801422813 | 0.198577 | 5.035825 |
| 3-Jan | 2005 | 112.175132 | -0.08412358 | 0.336969349 | 0.663031 | 1.508226 | 5-Oct | 2005 | 71.33451 | -0.7978049 | 0.108537341 | 0.891463 | 1.121752 |
| 19-Dec | 2006 | 221.203506 | 2.102135884 | 0.884975645 | 0.115024 | 8.693811 | 19-Dec | 2006 | 211.413314 | 1.507935061 | 0.801422813 | 0.198577 | 5.035825 |
| 12-Jan | 2007 | 221.203506 | 2.102135884 | 0.884975645 | 0.115024 | 8.693811 | 12-Jan | 2007 | 231.447067 | 1.837696763 | 0.852839728 | 0.14716 | 6.795312 |
| 12-Nov | 2008 | 97.930412 | -0.36976164 | 0.235183416 | 0.764817 | 1.307503 | 8-Jan | 2008 | 93.59613 | -0.43137183 | 0.214516671 | 0.785483 | 1.273101 |
| 1-Mar | 2009 | 49.661773 | -1.33765435 | 0.022146056 | 0.977854 | 1.022648 | 17-Mar | 2009 | 107.210395 | -0.20727686 | 0.292198138 | 0.707802 | 1.412825 |
| 24-Jun | 2010 | 107.210395 | -0.18367751 | 0.300704194 | 0.699296 | 1.43001 | 3-Mar | 2010 | 81.710693 | -0.62700976 | 0.153815038 | 0.846185 | 1.181775 |
| 26-Sep | 2011 | 74.637893 | -0.83682804 | 0.099357463 | 0.900643 | 1.110318 | 22-Oct | 2011 | 45.363109 | -1.22530211 | 0.033200357 | 0.9668 | 1.03434 |
| 15-Apr | 2012 | 85.494575 | -0.61912761 | 0.156092415 | 0.843908 | 1.184964 | 14-Dec | 2012 | 81.710693 | -0.62700976 | 0.153815038 | 0.846185 | 1.181775 |
| 8-Feb | 2013 | 93.59613 | -0.45667356 | 0.206219651 | 0.79378 | 1.259794 | 8-Feb | 2013 | 74.637893 | -0.74343021 | 0.122072841 | 0.877927 | 1.139047 |
|  | total | 1861.925758 |  |  |  |  |  | total | 1916.846766 |  |  |  |  |
|  | max | 221.203506 |  |  |  |  |  | max | 231.447067 |  |  |  |  |
|  | mean | 116.3703599 |  |  |  |  |  | mean | 119.8029229 |  |  |  |  |
|  | std.dev | 49.86982379 |  |  |  |  |  | std.dev | 60.75221243 |  |  |  |  |

## APPENDIX E

Gumbel distribution function analysis for Mersing and Kota Tinggi

| MERSING |  |  |  |  |  |  | KOTA TINGGI |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| date | year | depth | x | $\mathrm{F}(\mathrm{x})$ | $\mathrm{P}(\mathrm{x})$ | N | date | year | depth | x | F(x) | $\mathrm{P}(\mathrm{x})$ | N |
| 10-May | 1998 | 122.805023 | -0.63182202 | 0.152432297 | 0.847568 | 1.179847 | 30-Dec | 1998 | 122.805023 | -0.01234456 | 0.363338247 | 0.636662 | 1.570693 |
| 1-Jan | 1999 | 231.447067 | 1.43245453 | 0.787633616 | 0.212366 | 4.708843 | 1-Jan | 1999 | 97.930412 | -0.67645646 | 0.13989046 | 0.86011 | 1.162643 |
| 23-Dec | 2000 | 140.667938 | -0.29241386 | 0.261935411 | 0.738065 | 1.354895 | 1-May | 2000 | 74.637893 | -1.29832906 | 0.025651054 | 0.974349 | 1.026326 |
| 18-Jan | 2001 | 202.056427 | 0.874011346 | 0.658840139 | 0.34116 | 2.931177 | 17-Jan | 2001 | 202.056427 | 2.103539797 | 0.88512737 | 0.114873 | 8.705294 |
| 25-Jan | 2002 | 93.59613 | -1.18681188 | 0.03775572 | 0.962244 | 1.039237 | $25-\mathrm{Jan}$ | 2002 | 153.997787 | 0.820451808 | 0.643886566 | 0.356113 | 2.808094 |
| 9-Dec | 2003 | 202.056427 | 0.874011346 | 0.658840139 | 0.34116 | 2.931177 | 6-Jan | 2003 | 107.210395 | -0.42869591 | 0.215400948 | 0.784599 | 1.274536 |
| 9-Mar | 2004 | 147.182037 | $-0.16864132$ | 0.306145289 | 0.693855 | 1.441224 | 9-Mar | 2004 | 140.667938 | 0.464566391 | 0.533440613 | 0.466559 | 2.14335 |
| 8 -Jan | 2005 | 128.491912 | -0.52376706 | 0.184819446 | 0.815181 | 1.226722 | 19-Aug | 2005 | 89.453681 | -0.90277147 | 0.084887427 | 0.915113 | 1.092762 |
| 19-Dec | 2006 | 265.112915 | 2.072129723 | 0.881687736 | 0.118312 | 8.452209 | 19-Dec | 2006 | 211.413314 | 2.353353552 | 0.909327583 | 0.090672 | 11.02871 |
| 13-Jan | 2007 | 193.113662 | 0.704092415 | 0.609840871 | 0.390159 | 2.563057 | 5-Dec | 2007 | 140.667938 | 0.464566391 | 0.533440613 | 0.466559 | 2.14335 |
| 8-Jan | 2008 | 147.182037 | $-0.16864132$ | 0.306145289 | 0.693855 | 1.441224 | 12-Nov | 2008 | 122.805023 | -0.01234456 | 0.363338247 | 0.636662 | 1.570693 |
| 15-Mar | 2009 | 59.519737 | $-1.83428772$ | 0.00190996 | 0.99809 | 1.001914 | 13-Mar | 2009 | 102.4654 | -0.55537961 | 0.175064226 | 0.824936 | 1.212216 |
| 20-Mar | 2010 | 161.12915 | 0.096363808 | 0.403276209 | 0.596724 | 1.675817 | 24-Jun | 2010 | 97.930412 | -0.67645646 | 0.13989046 | 0.86011 | 1.162643 |
| 11-Jan | 2011 | 85.494575 | $-1.34074722$ | 0.021886216 | 0.978114 | 1.022376 | 8-Oct | 2011 | 102.4654 | -0.55537961 | 0.175064226 | 0.824936 | 1.212216 |
| 25-Dec | 2012 | 140.667938 | $-0.29241386$ | 0.261935411 | 0.738065 | 1.354895 | 24-Apr | 2012 | 93.59613 | -0.79217478 | 0.109898997 | 0.890101 | 1.123468 |
| 4-Dec | 2013 | 176.39801 | 0.38648307 | 0.506899648 | 0.4931 | 2.027985 | 20-Jan | 2013 | 112.175132 | -0.29614546 | 0.26062681 | 0.739373 | 1.352497 |
|  | total | 2496.920985 |  |  |  |  |  | total | 1972.278305 |  |  |  |  |
|  | max | 265.112915 |  |  |  |  |  | max | 211.413314 |  |  |  |  |
|  | mean | 156.0575616 |  |  |  |  |  | mean | 123.2673941 |  |  |  |  |
|  | std.dev | 52.62959757 |  |  |  |  |  | std.dev | 37.45545154 |  |  |  |  |

## APPENDIX F

Gumbel distribution function analysis for Batu Pahat and Muar

| BATU PAHAT |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| date | year | depth | x | F(x) | $\mathrm{P}(\mathrm{x})$ | N |
| 13-May | 1998 | 93.59613 | -0.45759468 | 0.20591983 | 0.79408 | 1.259319 |
| 1-Jan | 1999 | 62.275997 | -1.30631526 | 0.02490859 | 0.975091 | 1.025545 |
| 5-Jan | 2000 | 78.094245 | -0.87766853 | 0.090239745 | 0.90976 | 1.099191 |
| 18-Jan | 2001 | 140.667938 | 0.817968625 | 0.643182193 | 0.356818 | 2.802551 |
| 26-Jan | 2002 | 65.159889 | $-1.22816686$ | 0.032877601 | 0.967122 | 1.033995 |
| 3-Jan | 2003 | 153.997787 | 1.179184116 | 0.735261144 | 0.264739 | 3.777307 |
| 9-Mar | 2004 | 184.566696 | 2.007547849 | 0.874312305 | 0.125688 | 7.956228 |
| 15-Jul | 2005 | 81.710693 | -0.77966914 | 0.11295671 | 0.887043 | 1.127341 |
| 19-Dec | 2006 | 140.667938 | 0.817968625 | 0.643182193 | 0.356818 | 2.802551 |
| 11-Jan | 2007 | 161.12915 | 1.372431525 | 0.776087628 | 0.223912 | 4.466033 |
| 5-Dec | 2008 | 81.710693 | -0.77966914 | 0.11295671 | 0.887043 | 1.127341 |
| 17-Mar | 2009 | 140.667938 | 0.817968625 | 0.643182193 | 0.356818 | 2.802551 |
| 24-Jun | 2010 | 112.175132 | 0.045863636 | 0.384745884 | 0.615254 | 1.625345 |
| 23-Apr | 2011 | 89.453681 | -0.56984777 | 0.170674356 | 0.829326 | 1.205799 |
| 14-Jul | 2012 | 74.637893 | -0.9713296 | 0.071257572 | 0.928742 | 1.076725 |
| 3-Dec | 2013 | 107.210395 | -0.08867201 | 0.335302489 | 0.664698 | 1.504444 |
|  | total | 1767.722195 |  |  |  |  |
|  | max | 184.566696 |  |  |  |  |
|  | mean | 110.4826372 |  |  |  |  |
|  | std.dev | 36.90276118 |  |  |  |  |


| MUAR |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| date | year | depth | x | F(x) | $\mathrm{P}(\mathrm{x})$ | N |
| 13-May | 1998 | 85.494575 | -0.08216608 | 0.337686915 | 0.662313 | 1.50986 |
| 16 -Jul | 1999 | 78.094245 | -0.30792572 | 0.256506849 | 0.743493 | 1.345002 |
| 17-Jan | 2000 | 85.494575 | -0.08216608 | 0.337686915 | 0.662313 | 1.50986 |
| 18-Jan | 2001 | 147.182037 | 1.799714705 | 0.847600338 | 0.1524 | 6.561694 |
| 28-Apr | 2002 | 74.637893 | -0.4133676 | 0.220490493 | 0.77951 | 1.282858 |
| 1-Feb | 2003 | 65.159889 | $-0.70251021$ | 0.132812888 | 0.867187 | 1.153154 |
| 27-0ct | 2004 | 153.997787 | 2.007640734 | 0.874323213 | 0.125677 | 7.956919 |
| 31-Oct | 2005 | 68.177337 | -0.61045783 | 0.158615189 | 0.841385 | 1.188517 |
| 19-Dec | 2006 | 147.182037 | 1.799714705 | 0.847600338 | 0.1524 | 6.561694 |
| 12-Jan | 2007 | 107.210395 | 0.580311886 | 0.571366871 | 0.428633 | 2.332997 |
| 27-Jan | 2008 | 68.177337 | -0.61045783 | 0.158615189 | 0.841385 | 1.188517 |
| 17-Mar | 2009 | 78.094245 | $-0.30792572$ | 0.256506849 | 0.743493 | 1.345002 |
| 24-Oct | 2010 | 51.961528 | -1.10514863 | 0.048817167 | 0.951183 | 1.051323 |
| 17-May | 2011 | 49.661773 | -1.17530656 | 0.039197756 | 0.960802 | 1.040797 |
| 25-Apr | 2012 | 56.885471 | -0.95493538 | 0.074384874 | 0.925615 | 1.080363 |
| 2-Dec | 2013 | 93.59613 | 0.164985612 | 0.428310918 | 0.571689 | 1.749203 |
|  | total | 1411.007254 |  |  |  |  |
|  | max | 153.997787 |  |  |  |  |
|  | mean | 88.18795338 |  |  |  |  |
|  | std.dev | 32.77968638 |  |  |  |  |

## APPENDIX G

Gumbel distribution function analysis for Segamat and Kluang

| SEGAMAT |  |  |  |  |  |  | KLUANG |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| date | year | depth | x | $\mathrm{F}(\mathrm{x})$ | $\mathrm{P}(\mathrm{x})$ | N | date | year | depth | x | F(x) | $\mathrm{P}(\mathrm{x})$ | N |
| 30-Jan | 1998 | 74.637893 | -0.64926019 | 0.14747093 | 0.852529 | 1.172981 | 22-Feb | 1998 | 85.494575 | -0.69776558 | 0.13408811 | 0.865912 | 1.154852 |
| 1-Jan | 1999 | 78.094245 | -0.588077 | 0.165212514 | 0.834787 | 1.19791 | 1-Jan | 1999 | 122.805023 | -0.19163597 | 0.297830866 | 0.702169 | 1.424158 |
| 23-Dec | 2000 | 74.637893 | -0.64926019 | 0.14747093 | 0.852529 | 1.172981 | 22-Dec | 2000 | 56.885471 | -1.08585833 | 0.051716361 | 0.948284 | 1.054537 |
| 18-Jan | 2001 | 265.112915 | 2.722465084 | 0.936399977 | 0.0636 | 15.72326 | 18-Jan | 2001 | 253.379226 | 1.579649905 | 0.813794647 | 0.186205 | 5.370415 |
| 24-Nov | 2002 | 62.275997 | -0.86808634 | 0.09233357 | 0.907666 | 1.101726 | 25-Jan | 2002 | 140.667938 | 0.050680873 | 0.386516014 | 0.613484 | 1.630034 |
| 19-Jan | 2003 | 78.094245 | -0.588077 | 0.165212514 | 0.834787 | 1.19791 | 1-Feb | 2003 | 102.4654 | -0.46755025 | 0.202689626 | 0.79731 | 1.254217 |
| 30-Jan | 2004 | 97.930412 | -0.23694379 | 0.281571216 | 0.718429 | 1.391926 | 9-Mar | 2004 | 134.442153 | -0.03377413 | 0.355457014 | 0.644543 | 1.551487 |
| 5-Dec | 2005 | 117.369766 | 0.107165168 | 0.407229945 | 0.59277 | 1.686995 | 21-Nov | 2005 | 102.4654 | -0.46755025 | 0.202689626 | 0.79731 | 1.254217 |
| 19-Dec | 2006 | 168.590774 | 1.013862358 | 0.695715165 | 0.304285 | 3.286394 | 19-Dec | 2006 | 347.847503 | 2.861145952 | 0.944402175 | 0.055598 | 17.98632 |
| 10-Dec | 2007 | 122.805023 | 0.203378274 | 0.442210386 | 0.55779 | 1.792791 | 12-Nov | 2007 | 221.203506 | 1.143174727 | 0.72701709 | 0.272983 | 3.663233 |
| 18-Dec | 2008 | 71.33451 | -0.70773557 | 0.131415576 | 0.868584 | 1.151299 | 8 -Dec | 2008 | 112.175132 | $-0.33583426$ | 0.246817246 | 0.753183 | 1.327699 |
| 17-Mar | 2009 | 93.59613 | -0.3136678 | 0.254504931 | 0.745495 | 1.34139 | 17-Mar | 2009 | 65.159889 | $-0.97361288$ | 0.070828609 | 0.929171 | 1.076228 |
| 8-Jun | 2010 | 68.177337 | -0.76362279 | 0.116946724 | 0.883053 | 1.132435 | 20-Jun | 2010 | 107.210395 | $-0.40318269$ | 0.223894509 | 0.776105 | 1.288485 |
| 11-Dec | 2011 | 93.59613 | -0.3136678 | 0.254504931 | 0.745495 | 1.34139 | 5-Apr | 2011 | 97.930412 | -0.52906899 | 0.183168035 | 0.816832 | 1.224242 |
| 25-Dec | 2012 | 93.59613 | -0.3136678 | 0.254504931 | 0.745495 | 1.34139 | 6-Mar | 2012 | 93.59613 | -0.58786508 | 0.165275558 | 0.834724 | 1.198 |
| 2-Dec | 2013 | 221.203506 | 1.945195381 | 0.866789356 | 0.133211 | 7.506908 | 2-Dec | 2013 | 147.182037 | 0.139046961 | 0.418873145 | 0.581127 | 1.720795 |
|  | total | 1781.052906 |  |  |  |  |  | total | 2190.91019 |  |  |  |  |
|  | max | 265.112915 |  |  |  |  |  | max | 347.847503 |  |  |  |  |
|  | mean | 111.3158066 |  |  |  |  |  | mean | 136.9318869 |  |  |  |  |
|  | std.dev | 56.49185705 |  |  |  |  |  | std.dev | 73.71718174 |  |  |  |  |

## APPENDIX H

## Annual monthly maximum rainfall analysis for Johor Bahru

| JOHOR BAHRU |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| month/year | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
| january | 242.0058 | 295.6137 | 374.364 | 459.6951 | 236.3947 | 228.557 | 329.0083 | 189.6584 | 463.1458 | 575.1183 | 253.1151 | 174.4056 | 25.35092 | 119.0505 | 152.2737 | 213.264 |
| february | 88.14951 | 64.47587 | 193.3251 | 65.5475 | 128.522 | 262.5394 | 89.39768 | 33.03383 | 132.4381 | 156.0444 | 125.5278 | 163.3816 | 45.57721 | 33.89126 | 97.64344 | 456.5677 |
| march | 86.72752 | 384.9528 | 365.4607 | 232.3495 | 164.3162 | 172.3663 | 422.4018 | 123.946 | 104.2934 | 173.4262 | 409.1135 | 213.0633 | 267.2727 | 270.0201 | 298.0301 | 167.248 |
| april | 173.5177 | 163.5563 | 286.2367 | 235.7661 | 265.9668 | 286.8825 | 169.6801 | 187.0169 | 303.1541 | 331.0537 | 241.6471 | 176.7542 | 211.5566 | 231.5574 | 303.9688 | 248.5146 |
| may | 304.6331 | 179.1338 | 141.3706 | 176.3942 | 235.479 | 122.2809 | 101.8674 | 318.8883 | 218.1397 | 231.2399 | 118.3508 | 163.4116 | 166.0827 | 134.2711 | 286.4419 | 243.6913 |
| june | 176.728 | 105.7543 | 134.0661 | 135.7085 | 100.9643 | 204.2071 | 92.92539 | 109.1761 | 224.9235 | 196.9941 | 117.033 | 163.4016 | 245.7638 | 186.4022 | 89.671 | 143.7259 |
| july | 193.156 | 168.5008 | 147.1599 | 102.4683 | 258.8188 | 133.927 | 243.6283 | 189.0024 | 127.1196 | 144.4116 | 140.7688 | 172.4046 | 299.0381 | 85.77171 | 126.0923 | 168.6978 |
| august | 228.6163 | 201.6317 | 175.7931 | 129.3513 | 162.846 | 175.1807 | 167.6967 | 180.6617 | 118.7531 | 189.7972 | 134.5243 | 177.263 | 281.9906 | 161.8073 | 101.8348 | 204.3001 |
| september | 145.4887 | 121.243 | 147.8925 | 189.0483 | 162.4124 | 240.6802 | 214.9561 | 286.3064 | 247.6396 | 181.41 | 173.8387 | 182.8475 | 184.2361 | 197.0708 | 124.0545 | 263.964 |
| October | 223.5594 | 251.0143 | 140.4288 | 224.3357 | 135.4408 | 345.1335 | 212.2432 | 317.9019 | 153.0725 | 190.3564 | 183.1362 | 163.4016 | 154.2337 | 249.2809 | 159.3839 | 267.0771 |
| november | 110.3907 | 231.1664 | 281.1997 | 171.8513 | 342.6981 | 226.2476 | 424.778 | 281.1251 | 323.7809 | 255.8362 | 275.4273 | 161.4716 | 272.847 | 395.0176 | 277.6316 | 350.9739 |
| december | 363.5307 | 245.3639 | 311.5371 | 355.8033 | 307.7493 | 219.9995 | 150.517 | 189.2223 | 874.2399 | 439.2265 | 191.9198 | 161.4816 | 144.1032 | 395.0276 | 296.5157 | 300.3203 |
| max | 363.5307 | 384.9528 | 374.364 | 459.6951 | 342.6981 | 345.1335 | 424.778 | 318.8883 | 874.2399 | 575.1183 | 409.1135 | 213.0633 | 299.0381 | 395.0276 | 303.9688 | 456.5677 |
| min | 86.72752 | 64.47587 | 134.0661 | 65.5475 | 100.9643 | 122.2809 | 89.39768 | 33.03383 | 104.2934 | 144.4116 | 117.033 | 161.4716 | 25.35092 | 33.89126 | 89.671 | 143.7259 |
| mean | 194.7086 | 201.0339 | 224.9029 | 206.5266 | 208.4674 | 218.1668 | 218.2583 | 200.4949 | 274.225 | 255.4095 | 197.0335 | 172.774 | 191.5044 | 204.9307 | 192.7951 | 252.3621 |
| variance | 6510.418 | 7098.208 | 7856.676 | 11025.59 | 5388.216 | 3660.466 | 12720.56 | 7071.659 | 42896.19 | 15720.76 | 6816.131 | 197.5267 | 7390.974 | 11439.06 | 7504.493 | 7004.158 |
| std.deviation | 80.68716 | 84.25086 | 88.63789 | 105.0028 | 73.40447 | 60.50178 | 112.7855 | 84.09315 | 207.114 | 125.3825 | 82.55986 | 14.05442 | 85.97078 | 106.9535 | 86.62848 | 83.69085 |

## APPENDIX I

Annual monthly maximum rainfall analysis for Pontian

| PONTIAN |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| month/year | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
| january | 218.32 | 322.4464 | 285.7146 | 490.0643 | 216.337 | 233.6161 | 327.2812 | 162.0002 | 429.0338 | 611.0434 | 293.8089 | 339.7176 | 55.20952 | 131.899 | 155.0778 | 175.8813 |
| february | 82.64342 | 78.87115 | 193.8841 | 78.62653 | 102.7042 | 227.1831 | 71.04084 | 47.27677 | 115.2137 | 174.5292 | 131.9531 | 301.5369 | 68.80781 | 25.36777 | 136.3326 | 385.2304 |
| march | 103.9671 | 436.6159 | 327.8443 | 209.1507 | 194.3644 | 170.9628 | 396.339 | 164.6442 | 120.3827 | 202.3971 | 426.0026 | 323.5429 | 304.0138 | 252.0973 | 244.481 | 169.7631 |
| april | 159.0684 | 195.1347 | 342.7642 | 276.1824 | 315.6054 | 289.7226 | 169.2422 | 169.1628 | 319.4322 | 376.5428 | 227.0611 | 310.4379 | 285.0826 | 193.8005 | 331.032 | 220.3056 |
| may | 329.5117 | 177.7873 | 172.1354 | 175.2961 | 255.3493 | 149.6893 | 106.3005 | 303.8922 | 201.1558 | 250.4324 | 171.0295 | 303.553 | 215.428 | 158.2249 | 274.1887 | 233.4469 |
| june | 158.0538 | 98.94897 | 147.0852 | 160.517 | 107.7278 | 240.6502 | 86.83296 | 116.7368 | 221.5495 | 215.2345 | 300.617 | 301.5569 | 201.6522 | 199.3949 | 94.1067 | 143.5204 |
| july | 198.4614 | 139.016 | 154.9992 | 104.2245 | 246.5677 | 141.9746 | 259.6565 | 185.3733 | 126.769 | 151.6122 | 253.6179 | 344.1979 | 261.7659 | 63.9562 | 139.1687 | 147.8278 |
| august | 251.7254 | 170.1724 | 204.9579 | 138.752 | 183.334 | 208.7316 | 168.902 | 213.4037 | 122.7051 | 209.0249 | 236.3702 | 316.9144 | 261.3972 | 137.099 | 202.839 | 222.2057 |
| september | 134.0357 | 125.9199 | 142.8427 | 166.4856 | 209.7622 | 234.5945 | 248.3733 | 300.399 | 228.4967 | 194.45 | 249.6074 | 291.3032 | 206.0849 | 230.0804 | 154.4155 | 213.3603 |
| october | 206.1764 | 297.7724 | 191.2778 | 195.3652 | 168.4396 | 329.9766 | 235.9191 | 348.6201 | 239.9735 | 212.5127 | 247.9323 | 301.5569 | 194.6983 | 291.8999 | 195.6853 | 286.9637 |
| november | 103.7499 | 206.0874 | 281.0061 | 173.9082 | 361.6095 | 213.1915 | 382.0778 | 307.1984 | 339.8318 | 266.0062 | 246.879 | 277.2524 | 270.4189 | 354.8337 | 311.6473 | 314.7435 |
| december | 327.2618 | 185.216 | 313.376 | 338.375 | 278.1471 | 190.8 | 125.0268 | 191.434 | 823.2525 | 437.9741 | 234.0383 | 273.8547 | 163.0298 | 354.8437 | 307.0068 | 310.8255 |
| max | 329.5117 | 436.6159 | 342.7642 | 490.0643 | 361.6095 | 329.9766 | 396.339 | 348.6201 | 823.2525 | 611.0434 | 426.0026 | 344.1979 | 304.0138 | 354.8437 | 331.032 | 385.2304 |
| min | 82.64342 | 78.87115 | 142.8427 | 78.62653 | 102.7042 | 141.9746 | 71.04084 | 47.27677 | 115.2137 | 151.6122 | 131.9531 | 273.8547 | 55.20952 | 25.36777 | 94.1067 | 143.5204 |
| mean | 189.4146 | 202.8324 | 229.824 | 208.9123 | 219.9957 | 219.2577 | 214.7493 | 209.1785 | 273.983 | 275.1466 | 251.5764 | 307.1187 | 207.2991 | 199.4581 | 212.1651 | 235.3395 |
| variance | 6226.753 | 9683.013 | 5151.812 | 11655.81 | 5472.647 | 2690.673 | 11519.28 | 7317.594 | 36397.99 | 16615.71 | 4716.15 | 430.7202 | 5817.535 | 9949.468 | 5823.468 | 5162.104 |
| std.deviation | 78.90978 | 98.4023 | 71.77612 | 107.9621 | 73.97734 | 51.8717 | 107.3279 | 85.54294 | 190.7826 | 128.902 | 68.67423 | 20.7538 | 76.27277 | 99.74702 | 76.31165 | 71.84778 |

## APPENDIX J

Annual monthly maximum rainfall analysis for Kota Tinggi

| KOTA TINGGI |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| month/year | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
| january | 205.6829 | 344.3235 | 323.0777 | 475.5408 | 205.2975 | 355.6226 | 400.6846 | 196.6791 | 403.4044 | 642.4673 | 323.562 | 306.8623 | 54.05652 | 154.8345 | 93.23566 | 292.1452 |
| february | 29.31159 | 50.53843 | 130.0676 | 69.29076 | 85.79699 | 205.0229 | 123.4653 | 33.92867 | 116.0531 | 171.5079 | 207.4032 | 303.975 | 29.28858 | 22.67447 | 124.1935 | 417.4262 |
| march | 64.22378 | 353.1655 | 215.0098 | 310.9673 | 105.4512 | 107.7919 | 409.9193 | 132.9359 | 129.4882 | 192.5739 | 395.4072 | 309.6491 | 223.4143 | 319.3076 | 302.7614 | 120.1116 |
| april | 195.4317 | 146.1201 | 173.7442 | 241.6794 | 231.796 | 255.581 | 153.0124 | 178.333 | 323.2295 | 299.0544 | 236.0014 | 303.995 | 265.2867 | 182.2641 | 307.1235 | 261.1977 |
| may | 238.9911 | 177.7478 | 189.5013 | 186.4235 | 253.1562 | 104.7237 | 161.9284 | 355.854 | 224.5766 | 244.3382 | 131.3228 | 306.0836 | 245.5513 | 224.1335 | 268.6832 | 237.9925 |
| june | 221.1993 | 102.7552 | 149.1884 | 138.0438 | 116.08 | 225.7097 | 110.7267 | 138.1954 | 234.3565 | 208.7966 | 108.1975 | 303.995 | 264.3522 | 169.931 | 113.3359 | 138.806 |
| july | 203.2248 | 167.5537 | 142.1941 | 110.9667 | 241.2781 | 162.0446 | 279.4991 | 198.4247 | 144.9364 | 200.1635 | 213.0697 | 307.9313 | 302.4243 | 94.93123 | 149.4243 | 163.5157 |
| august | 229.4691 | 189.5966 | 184.9249 | 153.8477 | 133.8636 | 201.5056 | 187.1434 | 189.5763 | 153.5436 | 211.7677 | 227.7344 | 309.829 | 191.1639 | 150.2821 | 183.4403 | 238.4302 |
| september | 152.1124 | 94.90828 | 145.3186 | 165.2982 | 173.9517 | 250.0399 | 234.6677 | 383.5894 | 205.9896 | 123.0842 | 231.1481 | 310.3225 | 193.1484 | 186.5259 | 175.3543 | 240.0646 |
| october | 190.8276 | 254.8606 | 167.328 | 272.6746 | 156.5381 | 325.8055 | 223.0301 | 323.1193 | 134.2042 | 209.4101 | 265.4847 | 303.995 | 189.4642 | 335.0805 | 156.2141 | 228.8853 |
| november | 110.071 | 200.4291 | 260.5081 | 198.6961 | 334.0327 | 284.0021 | 417.5352 | 358.247 | 295.3413 | 274.97 | 274.2928 | 307.9213 | 300.3819 | 303.3395 | 300.8164 | 307.3689 |
| december | 435.2018 | 215.8208 | 326.8666 | 453.7355 | 267.7315 | 301.7849 | 177.1 | 207.316 | 840.7531 | 441.8957 | 256.4409 | 307.9313 | 211.7662 | 303.3495 | 313.2989 | 365.5333 |
| max | 435.2018 | 353.1655 | 326.8666 | 475.5408 | 334.0327 | 355.6226 | 417.5352 | 383.5894 | 840.7531 | 642.4673 | 395.4072 | 310.3225 | 302.4243 | 335.0805 | 313.2989 | 417.4262 |
| min | 29.31159 | 50.53843 | 130.0676 | 69.29076 | 85.79699 | 104.7237 | 110.7267 | 33.92867 | 116.0531 | 123.0842 | 108.1975 | 303.975 | 29.28858 | 22.67447 | 93.23566 | 120.1116 |
| mean | 189.6456 | 191.485 | 200.6441 | 231.4304 | 192.0811 | 231.6362 | 239.8927 | 224.6832 | 267.1564 | 268.3358 | 239.1721 | 306.8742 | 205.8582 | 203.8878 | 207.3234 | 250.9564 |
| variance | 9580.777 | 7839.821 | 4251.919 | 15012.77 | 5277.849 | 5896.164 | 11565.96 | 10618.93 | 37121.02 | 18561.59 | 5369.731 | 5.462631 | 6833.209 | 8553.175 | 6593.533 | 7008.208 |
| std.deviation | 97.88145 | 88.54276 | 65.20674 | 122.5266 | 72.64881 | 76.78648 | 107.5451 | 103.0482 | 192.6682 | 136.2409 | 73.27845 | 2.337227 | 82.66323 | 92.48338 | 81.20057 | 83.71504 |

## APPENDIX K

Annual monthly maximum rainfall analysis for Mersing

| MERSING |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| month/year | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
| anuary | 115.534 | 624.7799 | 397.6733 | 542.9534 | 202.6584 | 498.8982 | 106.0451 | 199.21 | 280.5461 | 774.923 | 365.5284 | 244.8873 | 80.1691 | 195.6851 | 146.8876 | 394.7278 |
| february | 19.0599 | 60.5193 | 143.058 | 331.3337 | 96.88038 | 238.22 | 67.8758 | 10.30848 | 194.8561 | 61.5833 | 249.9593 | 206.3674 | 20.43489 | 20.04061 | 215.94 | 434.5818 |
| march | 71.30756 | 256.0091 | 200.3458 | 187.7545 | 120.094 | 112.0464 | 339.2891 | 54.83689 | 67.40621 | 159.9802 | 313.8391 | 207.6568 | 233.9536 | 266.9502 | 222.1101 | 83.77818 |
| april | 78.96055 | 186.6459 | 158.8336 | 154.8027 | 134.8029 | 163.8548 | 126.9623 | 175.3421 | 188.0514 | 167.3369 | 125.3351 | 206.3874 | 144.5167 | 94.78993 | 236.9728 | 203.5428 |
| may | 213.1339 | 154.2076 | 138.676 | 184.0087 | 209.7059 | 140.2892 | 99.55594 | 213.0122 | 173.3133 | 197.2631 | 167.7905 | 206.3974 | 174.6278 | 141.7819 | 195.321 | 173.6406 |
| june | 120.5155 | 133.1131 | 196.7519 | 104.2086 | 72.72547 | 114.5363 | 120.8897 | 163.6802 | 207.5351 | 174.3699 | 157.1189 | 206.3874 | 198.8199 | 181.5486 | 107.0325 | 86.51974 |
| july | 180.818 | 117.3178 | 83.89829 | 133.8518 | 250.5947 | 145.8267 | 223.4546 | 153.4077 | 170.0758 | 253.7017 | 197.7169 | 210.3237 | 253.6357 | 107.3858 | 106.1317 | 170.3252 |
| august | 176.3831 | 98.66296 | 220.7456 | 118.8498 | 112.4515 | 170.1969 | 100.8043 | 217.7377 | 168.4648 | 224.0896 | 184.8721 | 206.3974 | 165.2087 | 114.5797 | 111.7507 | 174.9104 |
| september | 68.96458 | 118.5889 | 116.005 | 117.0966 | 206.2863 | 249.1687 | 141.8719 | 221.9783 | 124.8173 | 168.261 | 171.7719 | 212.7816 | 165.742 | 147.863 | 214.1602 | 206.3515 |
| october | 199.1678 | 240.8063 | 153.5801 | 288.0382 | 114.4275 | 317.0833 | 371.7621 | 191.668 | 108.1104 | 141.3036 | 160.4956 | 211.3135 | 190.5569 | 314.721 | 216.4006 | 237.6397 |
| november | 126.1729 | 178.9706 | 309.426 | 267.3725 | 248.7133 | 345.9492 | 279.3684 | 425.9321 | 246.8796 | 283.1216 | 113.1238 | 202.4612 | 291.0383 | 340.2453 | 248.467 | 244.6988 |
| december | 376.419 | 295.2297 | 416.9317 | 438.4472 | 349.1417 | 447.889 | 335.1347 | 311.2899 | 611.7917 | 610.2974 | 423.9816 | 211.764 | 364.388 | 342.0686 | 461.0001 | 743.5255 |
| max | 376.419 | 624.7799 | 416.9317 | 542.9534 | 349.1417 | 498.8982 | 371.7621 | 425.9321 | 611.7917 | 774.923 | 423.9816 | 244.8873 | 364.388 | 342.0686 | 461.0001 | 743.5255 |
| min | 19.0599 | 60.5193 | 83.89829 | 104.2086 | 72.72547 | 112.0464 | 67.8758 | 10.30848 | 67.40621 | 61.5833 | 113.1238 | 202.4612 | 20.43489 | 20.04061 | 106.1317 | 83.77818 |
| mean | 145.5364 | 205.4043 | 211.3271 | 239.0598 | 176.5402 | 245.3299 | 192.7512 | 194.867 | 211.8207 | 268.0193 | 219.2944 | 211.0938 | 190.2576 | 188.9716 | 206.8479 | 262.8535 |
| variance | 8054.313 | 20361.49 | 10699.74 | 17930.24 | 6097.331 | 15729.51 | 11214.08 | 10442.07 | 17590.53 | 40056.58 | 8928.787 | 111.9185 | 7583.489 | 10152.6 | 8380.984 | 31084.88 |
| std.deviation | 89.74583 | 142.6937 | 103.4395 | 133.9038 | 78.08541 | 125.4174 | 105.8965 | 102.1864 | 132.6293 | 200.1414 | 94.49226 | 10.57915 | 87.08323 | 100.7601 | 91.54771 | 176.3091 |

## APPENDIX L

Annual monthly maximum rainfall analysis for Batu Pahat

| BATU PAHAT |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| month/year | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
| january | 175.5611 | 309.8053 | 247.361 | 347.8696 | 153.8279 | 247.6203 | 185.1501 | 104.2348 | 205.3716 | 467.2977 | 174.4248 | 280.4927 | 78.71048 | 63.68983 | 155.3063 | 130.1935 |
| february | 65.52262 | 68.36132 | 155.5141 | 41.64869 | 56.32271 | 186.3655 | 57.45456 | 54.63203 | 130.141 | 156.7713 | 103.1494 | 260.4363 | 104.3296 | 36.08092 | 198.5618 | 304.7834 |
| march | 121.1582 | 264.7403 | 254.8325 | 141.2837 | 106.9345 | 179.787 | 339.4197 | 119.3164 | 124.4471 | 189.5228 | 313.7279 | 278.801 | 172.0699 | 154.3146 | 197.2123 | 134.7865 |
| april | 137.5856 | 193.4937 | 330.9977 | 286.0098 | 325.186 | 301.2752 | 204.6896 | 189.9172 | 235.3172 | 335.5766 | 173.7377 | 260.4563 | 146.9973 | 178.7598 | 185.9912 | 186.6057 |
| may | 317.2791 | 164.7398 | 110.6513 | 218.4857 | 251.942 | 171.9495 | 88.41408 | 217.887 | 159.9831 | 198.9461 | 151.9514 | 260.4663 | 130.8917 | 163.1926 | 198.9021 | 135.1272 |
| june | 151.2662 | 121.097 | 186.1888 | 167.6927 | 91.48779 | 170.7528 | 78.04514 | 114.0185 | 204.2768 | 171.0202 | 99.13887 | 260.4563 | 276.8804 | 175.5854 | 72.56369 | 80.04991 |
| july | 204.0382 | 176.261 | 154.265 | 84.11161 | 295.3313 | 128.0179 | 168.374 | 230.4085 | 192.2489 | 186.4275 | 210.5547 | 265.3924 | 198.1404 | 56.40788 | 146.7255 | 106.8638 |
| august | 262.2058 | 178.674 | 225.6103 | 168.9205 | 174.8417 | 139.4364 | 165.0669 | 239.6657 | 141.5407 | 197.1444 | 174.2673 | 278.4163 | 177.8506 | 119.5154 | 137.9371 | 137.3423 |
| september | 173.4603 | 181.6158 | 174.5085 | 174.9378 | 201.4329 | 178.1996 | 176.1318 | 229.522 | 164.8963 | 182.7297 | 153.6497 | 309.7586 | 188.3661 | 211.7714 | 147.0268 | 212.0305 |
| october | 151.393 | 300.1517 | 188.6281 | 407.2993 | 109.5951 | 233.6694 | 271.7968 | 246.5493 | 176.3285 | 232.2382 | 151.9984 | 260.4563 | 137.4011 | 270.9279 | 211.2804 | 196.8476 |
| november | 131.8739 | 244.8572 | 273.3785 | 157.5222 | 321.6637 | 177.3421 | 277.9789 | 259.7501 | 320.7474 | 239.9648 | 113.4955 | 261.1743 | 222.2293 | 263.76 | 282.1979 | 228.5735 |
| december | 223.1792 | 149.8293 | 370.1964 | 190.0442 | 272.0433 | 189.7991 | 87.6822 | 166.6432 | 534.8247 | 372.2688 | 241.1194 | 255.5403 | 146.6653 | 263.77 | 237.7531 | 296.5853 |
| max | 317.2791 | 309.8053 | 370.1964 | 407.2993 | 325.186 | 301.2752 | 339.4197 | 259.7501 | 534.8247 | 467.2977 | 313.7279 | 309.7586 | 276.8804 | 270.9279 | 282.1979 | 304.7834 |
| min | 65.52262 | 68.36132 | 110.6513 | 41.64869 | 56.32271 | 128.0179 | 57.45456 | 54.63203 | 124.4471 | 156.7713 | 99.13887 | 255.5403 | 78.71048 | 36.08092 | 72.56369 | 80.04991 |
| mean | 176.2103 | 196.1355 | 222.6777 | 198.8188 | 196.7174 | 192.0179 | 175.017 | 181.0454 | 215.8436 | 244.159 | 171.7679 | 269.3206 | 165.0444 | 163.148 | 180.9549 | 179.1491 |
| variance | 4188.523 | 4735.44 | 5355.802 | 9921.268 | 8278.309 | 2089.349 | 7206.263 | 4211.246 | 11869.15 | 8504.329 | 3414.571 | 216.4496 | 2613.658 | 6169.999 | 2658.116 | 4713.689 |
| std.deviation | 64.7188 | 68.81453 | 73.18334 | 99.60556 | 90.98521 | 45.7094 | 84.88971 | 64.89411 | 108.9456 | 92.21892 | 58.43433 | 14.71223 | 51.12395 | 78.54934 | 51.55692 | 68.65631 |

## APPENDIX M

Annual monthly maximum rainfall analysis for Muar

| MUAR |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| month/year | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
| january | 133.3451 | 233.0799 | 272.8241 | 284.1331 | 104.0764 | 191.1255 | 157.6188 | 81.79741 | 190.1308 | 369.8342 | 158.4229 | 175.1745 | 69.10098 | 56.88231 | 174.1753 | 164.3871 |
| february | 49.03451 | 75.90344 | 156.7498 | 77.42095 | 46.3227 | 197.6901 | 44.64643 | 52.29324 | 147.4055 | 121.6004 | 102.2933 | 162.9843 | 138.2606 | 40.10713 | 164.1351 | 227.1025 |
| march | 106.8928 | 218.2478 | 239.6942 | 115.041 | 108.3129 | 190.828 | 278.6936 | 127.1995 | 120.7061 | 161.6578 | 300.838 | 166.5998 | 151.5019 | 173.2069 | 117.0765 | 106.5051 |
| april | 80.86464 | 141.213 | 206.8917 | 296.5695 | 313.4237 | 276.9592 | 207.043 | 175.6539 | 208.1754 | 274.7717 | 186.2458 | 163.0043 | 190.7898 | 158.7041 | 183.9889 | 197.7369 |
| may | 302.41 | 161.9176 | 109.0452 | 218.5058 | 185.8791 | 171.9495 | 106.1663 | 174.5158 | 165.1691 | 183.8449 | 96.69944 | 163.0143 | 119.9546 | 165.2651 | 155.6842 | 122.8845 |
| june | 124.047 | 112.9147 | 168.4035 | 120.7347 | 81.28975 | 108.1918 | 69.08001 | 82.40002 | 143.6063 | 158.7595 | 145.5321 | 167.5031 | 232.1377 | 150.2165 | 46.77971 | 54.39468 |
| july | 178.5842 | 177.1927 | 131.5759 | 60.96444 | 305.2857 | 150.4591 | 115.9839 | 197.7052 | 159.6953 | 167.1788 | 151.808 | 168.4081 | 171.7482 | 33.77532 | 118.7213 | 108.0396 |
| august | 270.2155 | 172.6076 | 227.2222 | 173.5602 | 176.9454 | 100.425 | 125.1222 | 280.5786 | 141.0791 | 185.4828 | 118.5059 | 164.8811 | 172.2917 | 104.3557 | 110.2222 | 61.99152 |
| september | 157.0682 | 171.5926 | 152.3309 | 161.2529 | 161.6576 | 142.7415 | 157.5677 | 146.8692 | 135.4544 | 161.2455 | 118.052 | 165.1181 | 136.8638 | 156.6838 | 141.6905 | 127.3569 |
| october | 143.0939 | 258.2998 | 139.8834 | 298.2868 | 108.5958 | 205.8735 | 282.3518 | 216.0298 | 178.9259 | 247.4531 | 146.013 | 163.0043 | 137.3357 | 249.8842 | 221.2594 | 168.3442 |
| november | 149.4713 | 232.8923 | 179.3977 | 183.5244 | 272.6224 | 172.4502 | 242.2759 | 267.8123 | 271.5645 | 186.7267 | 133.6983 | 159.5967 | 230.9906 | 223.2864 | 286.4376 | 271.8846 |
| december | 223.4916 | 150.2121 | 344.1299 | 161.9539 | 196.9524 | 167.9828 | 100.1679 | 171.7976 | 488.218 | 387.4107 | 227.7845 | 182.7947 | 173.2557 | 223.2964 | 222.5974 | 300.2239 |
| max | 302.41 | 258.2998 | 344.1299 | 298.2868 | 313.4237 | 276.9592 | 282.3518 | 280.5786 | 488.218 | 387.4107 | 300.838 | 182.7947 | 232.1377 | 249.8842 | 286.4376 | 300.2239 |
| min | 49.03451 | 75.90344 | 109.0452 | 60.96444 | 46.3227 | 100.425 | 44.64643 | 52.29324 | 120.7061 | 121.6004 | 96.69944 | 159.5967 | 69.10098 | 33.77532 | 46.77971 | 54.39468 |
| mean | 159.8766 | 175.5061 | 194.0124 | 179.329 | 171.7803 | 173.0564 | 157.2265 | 164.5544 | 195.8442 | 217.1638 | 157.1578 | 166.8403 | 160.3526 | 144.6387 | 161.8974 | 159.2376 |
| variance | 5050.743 | 2596.246 | 4178.757 | 6088.015 | 7129.133 | 2005.132 | 5763.709 | 4671.349 | 9275.137 | 6734.861 | 3083.894 | 37.09718 | 1926.241 | 4800.516 | 3633.734 | 5579.376 |
| std.deviation | 71.06858 | 50.95337 | 64.64331 | 78.02573 | 84.4342 | 44.7787 | 75.9191 | 68.34727 | 96.30751 | 82.0662 | 55.53282 | 6.090746 | 43.88896 | 69.28576 | 60.28046 | 74.69522 |

## APPENDIX N

Annual monthly maximum rainfall analysis for Segamat

| SEGAMAT |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| month/year | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
| january | 205.3095 | 305.4779 | 243.1918 | 376.1426 | 99.08137 | 351.061 | 233.1913 | 116.0663 | 258.3886 | 422.8961 | 218.0796 | 285.4453 | 115.5685 | 80.96258 | 184.8326 | 227.0097 |
| february | 50.82663 | 89.6333 | 173.6576 | 174.0082 | 73.94601 | 187.7774 | 67.49705 | 50.83481 | 223.6338 | 85.20476 | 155.6013 | 212.4607 | 96.03658 | 12.64718 | 173.1777 | 409.987 |
| march | 50.18869 | 222.9342 | 206.73 | 165.238 | 117.7727 | 167.0158 | 260.8298 | 114.2485 | 101.3351 | 153.1938 | 308.4788 | 213.4054 | 104.4293 | 286.9969 | 198.1911 | 27.7014 |
| april | 79.97997 | 153.3055 | 162.7831 | 221.3026 | 189.101 | 249.5437 | 203.1262 | 151.963 | 215.6972 | 191.1926 | 195.2035 | 215.2111 | 170.164 | 135.3949 | 202.541 | 148.9909 |
| may | 232.612 | 178.744 | 133.4189 | 195.4781 | 179.9446 | 171.9495 | 137.2274 | 178.5531 | 199.6771 | 222.0035 | 96.31006 | 216.9895 | 228.3387 | 172.2912 | 183.6187 | 165.9029 |
| june | 102.066 | 127.0674 | 137.8581 | 98.06848 | 99.10947 | 102.2274 | 87.35951 | 100.3007 | 141.8555 | 170.0781 | 114.3851 | 212.4807 | 202.1522 | 140.7603 | 53.94151 | 61.23566 |
| july | 181.534 | 161.2042 | 123.6016 | 67.0003 | 271.6117 | 157.5543 | 154.2856 | 146.4575 | 181.8056 | 186.3586 | 140.0118 | 240.5739 | 136.2951 | 41.4327 | 112.1539 | 121.4165 |
| august | 269.0725 | 165.7724 | 232.0171 | 149.3403 | 174.4541 | 130.372 | 122.4493 | 179.3795 | 144.8678 | 212.0176 | 160.1942 | 212.4907 | 152.913 | 114.6415 | 185.8779 | 136.8905 |
| september | 135.9338 | 111.4552 | 149.386 | 144.3906 | 159.3488 | 129.9024 | 188.4479 | 177.5196 | 120.1801 | 155.0084 | 167.8757 | 201.5709 | 165.9015 | 188.779 | 122.8968 | 189.14 |
| october | 193.506 | 240.8411 | 166.3312 | 290.1428 | 115.6298 | 219.8751 | 341.269 | 222.7967 | 168.5495 | 257.4705 | 208.5163 | 212.4807 | 124.1419 | 262.7723 | 241.7571 | 181.954 |
| november | 164.8638 | 176.8407 | 162.2494 | 242.4713 | 238.4115 | 197.8794 | 208.6818 | 339.5436 | 247.7494 | 184.8343 | 119.5005 | 221.651 | 265.3331 | 241.864 | 247.7643 | 175.4142 |
| december | 313.0999 | 238.3543 | 391.0737 | 265.7315 | 286.3549 | 251.6247 | 193.5701 | 297.169 | 591.6764 | 641.6575 | 202.5318 | 208.2345 | 284.7121 | 242.9231 | 303.7994 | 514.4687 |
| max | 313.0999 | 305.4779 | 391.0737 | 376.1426 | 286.3549 | 351.061 | 341.269 | 339.5436 | 591.6764 | 641.6575 | 308.4788 | 285.4453 | 284.7121 | 286.9969 | 303.7994 | 514.4687 |
| min | 50.18869 | 89.6333 | 123.6016 | 67.0003 | 73.94601 | 102.2274 | 67.49705 | 50.83481 | 101.3351 | 85.20476 | 96.31006 | 201.5709 | 96.03658 | 12.64718 | 53.94151 | 61.23566 |
| mean | 164.9161 | 180.9692 | 190.1915 | 199.1096 | 167.0638 | 193.0652 | 183.1612 | 172.9027 | 216.2847 | 240.1596 | 173.8907 | 221.0829 | 170.4988 | 160.1221 | 184.2127 | 205.0094 |
| variance | 6524.827 | 3469.158 | 4968.455 | 6780.238 | 4500.184 | 4242.38 | 5325.458 | 6148.003 | 15047.41 | 20675.32 | 3063.677 | 456.2395 | 3580.177 | 7191.532 | 4019.205 | 15238.91 |
| std.deviation | 80.7764 | 58.89956 | 70.48727 | 82.3422 | 67.08341 | 65.13356 | 72.97573 | 78.4092 | 122.6679 | 143.7892 | 55.35049 | 21.35976 | 59.83458 | 84.8029 | 63.3972 | 123.446 |

## APPENDIX 0

Annual monthly maximum rainfall analysis for Kluang

| KLUANG |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| month/year | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
| january | 257.8937 | 427.5674 | 346.8163 | 509.8405 | 206.8698 | 353.2434 | 299.9235 | 195.6996 | 331.1264 | 736.1472 | 339.8303 | 388.9679 | 189.531 | 151.5805 | 240.8549 | 264.6948 |
| february | 114.6853 | 89.2862 | 151.9018 | 117.3481 | 98.49441 | 257.8858 | 91.58085 | 60.59899 | 178.4978 | 112.0457 | 202.218 | 316.1154 | 63.78426 | 46.60511 | 223.0241 | 303.1197 |
| march | 118.9999 | 270.7964 | 217.9881 | 156.5297 | 105.1598 | 137.0182 | 343.3308 | 128.8711 | 111.432 | 158.8851 | 378.3033 | 316.1454 | 274.1855 | 281.8987 | 239.6061 | 137.1013 |
| april | 132.4147 | 232.9629 | 305.0316 | 249.3207 | 254.0233 | 203.4779 | 228.1226 | 208.1306 | 267.7055 | 249.8943 | 258.3881 | 319.7209 | 240.3157 | 249.3296 | 272.6361 | 262.0951 |
| may | 234.0298 | 166.1776 | 174.4364 | 195.8587 | 210.8824 | 171.9495 | 103.438 | 198.4297 | 213.2137 | 237.6841 | 143.0415 | 332.1505 | 224.0486 | 178.7958 | 232.2724 | 237.683 |
| june | 143.0584 | 136.9854 | 218.9936 | 114.6617 | 134.878 | 147.8158 | 78.07461 | 165.2419 | 213.5625 | 213.6075 | 229.0699 | 316.1354 | 243.0365 | 192.8459 | 100.3486 | 101.171 |
| july | 191.0011 | 128.3776 | 109.9829 | 116.1441 | 208.3866 | 198.6834 | 257.7148 | 192.605 | 159.3569 | 232.1418 | 279.3827 | 361.4985 | 261.2671 | 85.59411 | 139.5058 | 149.1262 |
| august | 218.4547 | 170.4604 | 237.1998 | 138.8088 | 159.9478 | 148.8997 | 108.1663 | 191.1987 | 177.5109 | 213.0244 | 193.0952 | 316.1454 | 214.9069 | 151.1924 | 163.6411 | 210.6535 |
| september | 112.3653 | 133.0419 | 165.9673 | 188.4837 | 210.8625 | 242.1504 | 223.3352 | 246.9775 | 161.5303 | 141.5006 | 252.7166 | 317.5958 | 234.9667 | 260.9737 | 203.8253 | 186.4123 |
| october | 209.647 | 278.5081 | 202.1529 | 282.9888 | 160.2427 | 341.4952 | 361.9322 | 276.2313 | 220.4953 | 188.4814 | 342.1181 | 316.1354 | 164.5317 | 333.6599 | 213.0657 | 250.1371 |
| november | 144.3964 | 196.9728 | 242.8617 | 250.6874 | 303.3928 | 309.0443 | 322.8767 | 362.3632 | 303.3491 | 276.3194 | 246.0663 | 271.2856 | 292.4184 | 324.4831 | 334.0759 | 298.508 |
| december | 389.4592 | 257.8935 | 456.897 | 323.65 | 308.7271 | 277.386 | 236.9355 | 337.927 | 745.1156 | 590.034 | 362.4743 | 302.3632 | 314.3998 | 324.4931 | 341.8067 | 465.9526 |
| max | 389.4592 | 427.5674 | 456.897 | 509.8405 | 308.7271 | 353.2434 | 361.9322 | 362.3632 | 745.1156 | 736.1472 | 378.3033 | 388.9679 | 314.3998 | 333.6599 | 341.8067 | 465.9526 |
| min | 112.3653 | 89.2862 | 109.9829 | 114.6617 | 98.49441 | 137.0182 | 78.07461 | 60.59899 | 111.432 | 112.0457 | 143.0415 | 271.2856 | 63.78426 | 46.60511 | 100.3486 | 101.171 |
| mean | 188.8671 | 207.4192 | 235.8524 | 220.3602 | 196.8223 | 232.4208 | 221.2859 | 213.6895 | 256.908 | 279.1471 | 268.892 | 322.8549 | 226.4494 | 215.121 | 225.3886 | 238.8879 |
| variance | 5987.762 | 7883.958 | 8274.673 | 12094.54 | 4365.558 | 5333.299 | 9735.073 | 6422.851 | 25289.22 | 32376.04 | 4978.381 | 774.4341 | 3992.821 | 8401.709 | 4627.765 | 8458.808 |
| std.deviation | 77.38063 | 88.79166 | 90.96523 | 109.9752 | 66.07237 | 73.02944 | 98.66647 | 80.14269 | 159.0259 | 179.9334 | 70.55764 | 27.82866 | 63.18877 | 91.66084 | 68.02768 | 91.97178 |

## APPENDIX P

Annual maximum rainfall analysis for Johor Bahru, Pontian, Kota Tinggi, Mersing, Batu Pahat, Muar, Segamat, and Kluang

| year | depth (mm) |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | JOHOR BAHRU | PONTIAN | KOTA TINGGI | MERSING | BATUPAHAT | MUAR | SEGAMAT | KLUANG |  |
| 1998 | 2336.50328 | 2272.975101 | 2275.747076 | 1746.436621 | 6362.230602 | 1918.518847 | 1978.992641 | 2266.405556 |  |
| 1999 | 2412.406914 | 2433.988396 | 2297.819527 | 2464.85112 | 6826.967956 | 2106.073445 | 2171.630123 | 2489.030039 |  |
| 2000 | 2698.834305 | 2757.887458 | 2407.729279 | 2535.925191 | 7742.753945 | 2328.148506 | 2282.298433 | 2830.229327 |  |
| 2001 | 235.766053 | 2506.947581 | 2777.164462 | 2868.717739 | 12138.04871 | 2151.947686 | 2389.314859 | 2644.322309 |  |
| 2002 | 2501.608266 | 2639.948204 | 2304.973683 | 2118.482143 | 10574.87278 | 2061.36389 | 2004.766115 | 2361.867093 |  |
| 2003 | 204.207138 | 2631.092878 | 2779.63451 | 2943.958762 | 4099.827152 | 2076.676267 | 2316.782623 | 2789.049626 |  |
| 2004 | 2619.100008 | 2576.992127 | 2878.712195 | 2313.013827 | 9091.644533 | 1886.71761 | 2197.934869 | 2655.431156 |  |
| 2005 | 2405.939178 | 2510.141511 | 2696.198584 | 2338.40357 | 6411.117738 | 1974.652585 | 2074.832308 | 2564.274397 |  |
| 2006 | 3290.700175 | 3287.796133 | 3205.876487 | 2541.847875 | 14639.1119 | 2350.130429 | 2595.416073 | 3082.89609 |  |
| 2007 | 190.356418 | 3301.759421 | 3220.029522 | 3216.231164 | 11153.29689 | 2605.966196 | 2881.915642 | 3349.765508 |  |
| 2008 | 2364.402414 | 3018.917286 | 2870.064783 | 2631.53315 | 5295.380778 | 1885.893333 | 2086.688524 | 3226.704348 |  |
| 2009 | 2073.28758 | 3685.424591 | 3682.490395 | 2533.125244 | 3202.730008 | 2002.083475 | 2652.994476 | 302.36321 |  |
| 2010 | 2298.052678 | 2487.588925 | 2470.298553 | 2283.091437 | 4612.718197 | 1924.231323 | 2045.985962 | 2717.392264 |  |
| 2011 | 2459.168697 | 2393.497176 | 2446.653771 | 2267.659768 | 8165.085865 | 1735.663962 | 1921.465638 | 2581.451745 |  |
| 2012 | 2313.541746 | 2545.981426 | 2487.881199 | 2482.17443 | 4628.219002 | 1942.768252 | 2210.552071 | 2704.662774 |  |
| 2013 | 3028.344826 | 2824.074209 | 3011.477216 | 3154.242011 | 6671.091776 | 1910.851576 | 2460.112853 | 2866.654632 |  |
| mean | $\mathbf{2 0 8 9 . 5 1 3 7 3}$ | $\mathbf{2 7 4 2 . 1 8 8 2 7 6}$ | $\mathbf{2 7 3 8 . 2 9 6 9 5 3}$ | $\mathbf{2 5 2 7 . 4 8 0 8 7 8}$ | $\mathbf{7 6 0 0 . 9 4 3 6 1 5}$ | $\mathbf{2 0 5 3 . 8 5 5 4 6 1}$ | $\mathbf{2 2 6 6 . 9 8 0 2 0 1}$ | $\mathbf{2 5 8 9 . 5 3 1 2 5 5}$ |  |
| variance | $\mathbf{8 4 2 0 5 3 . 2 6 5 6}$ | $\mathbf{1 3 4 3 1 4 . 9 2 6 2}$ | $\mathbf{1 4 0 2 0 5 . 8 9 9 1}$ | $\mathbf{1 3 5 0 3 1 . 5 0 9 9}$ | $\mathbf{9 5 7 7 7 0 1 . 2 7 5}$ | $\mathbf{4 4 6 8 8 . 8 9 1 2 6}$ | $\mathbf{6 8 5 2 4 . 0 2 6 0 9}$ | $\mathbf{4 2 7 3 1 4 . 1 3 3 5}$ |  |
| std.dev | $\mathbf{9 4 5 . 8 7 6 0 9 9}$ | $\mathbf{3 7 7 . 7 6 9 2 5 3 7}$ | $\mathbf{3 8 5 . 9 6 4 7 2 3 5}$ | $\mathbf{3 6 7 . 4 6 6 3 3 8 5}$ | $\mathbf{3 0 9 4 . 7 8 6 1 4 4}$ | $\mathbf{2 1 1 . 3 9 7 4 7 2 2}$ | $\mathbf{2 6 1 . 7 7 0 9 4 2}$ | $\mathbf{6 5 3 . 6 9 2 6 9 0 4}$ |  |

